Zoology

THE CENTURY BIOLOGICAL SERIES
Edited by Dwight E. Minnich

ZOOLOGY

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by

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NEW YORK
APPLETON
CENTURY
CROFTS, INC.

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PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

This book is the culmination of more than twenty years of teaching introductory zoology at the college and university level. During this period it has become increasingly evident to me that in order to understand the life sciences, students need, more than anything else, a broad underlying principle to cling to. In biology we have that in the story of organic evolution. Just as in the physical sciences, where the relationship of the elements in the periodic table provides a central core around which all other facts must revolve, so in biology evolution offers a great unifying principle to which all lesser principles can be related. This magnificent idea cannot be relegated to an isolated chapter; it must be the central theme, permeating the entire book, if it is to become a part of the student's thinking as it should. Thus organic evolution is the central theme of this work.

Every attempt has been made to integrate the seven parts of the book into what amounts to an historical narration of animal life. My aim has been to point out the salient points in zoology without diluting the subject matter; to present important, and often complex, material in a manner that will at the same time fascinate the general education student and challenge the embryo professional zoologist. How well this dual function has been accomplished, students of the future will decide.

After a brief discussion of the position zoology occupies as a science, there follows in Part I a discussion of the scientist and his methods. It is important to have the student understand the methods of science and recognize that zoology uses the same disciplines employed in other sciences.

The story of evolution begins to unfold in Part II, beginning with a survey of the early history of the earth and the nature of the physical world. It seems logical to start with the physical setting in which life took its inception. A possible explanation of the origin of the first living thing is offered, and its properties are examined.

In Part III we speculate upon the transition from single cells to many cells and discuss some of the problems arising out of organization into the more complex forms. The organized animal is considered in relation to its environment.

Built upon this foundation concerning the nature of animals and their environments, Part IV traces the long evolutionary sequence from one-celled forms to man. Here animals are described both morphologically and physiologically, with special emphasis upon their origins. The full weight of the evolutionary idea is given to the chordates in Chapter 13, concluding with a brief history of early man.

With this background the student is ready for a rather careful study of the organ systems of man, to which Part V is devoted. Each chapter is introduced by a brief résumé of the organ system under scrutiny as it appears in the various animal groups. This is done to fix firmly the origin of the various systems and to demonstrate that they are not peculiar to man. Because of the importance of the human species, considerable attention has been devoted to this section which, in some respects, will be the most valuable to students.

The continuity of life is taken up in Part VI, beginning with the reproduction of cells and carrying on through the continuity of the individual and of the race. Considerable attention is given to modern concepts in both embryology and genetics.

The book concludes in Part VII with a return to the discussion of organic evolution—its meaning, theories, and mechanisms. A word of speculation about the future of mankind seems a fitting finale for a work of this kind.

The material presented in these pages is derived from many sources, not only from published books and research papers but from first-hand observation in many instances. Wherever possible, living or preserved materials have been used in making the drawings.

I am indebted not only to those who have received specific recognition in the list of Acknowledgments in the back of the book, but also to former teachers and associates who have influenced my thinking regarding many topics contained in this book. I should like particularly to mention Professor D. E. Minnich, who has gone over the entire book critically and has given advice and suggestions of inestimable value. Professors Norman E. Kemp, Paul A. Wright, Drs. Frank Hooper, James F. Hogg, and Stanley P. Wyatt have examined several chapters and have made many helpful suggestions. The attractiveness of the drawings is due to the skill of Doris Stirratt Garlock, whose patience in interpreting my ideas knew no bounds. Some of the drawings, taken from my *Atlas in General Zoology,* were originally done by Olivia Jensen Ingersoll. The chapter headings and some of the plates were done by Raymond Jansma. Much of the beauty of the photographs is due to the expert ability and many hours of hard labor by Herbert Weinert, who gave unstintingly of his time to obtain the best possible pictures. To him and Fred Anderegg, director of the Photographic Services of the University of Michigan, I express my sincere appreciation.

Annette Van der Schalie and Ursula Freimarck together read and typed the entire manuscript.

Finally I wish to express my deep appreciation to members of my family, especially my wife, for not only helping in the preparation of the glossary and index but more particularly for their kind understanding during the inception and gestation of this book.

A. M. E.

Ann Arbor, Michigan

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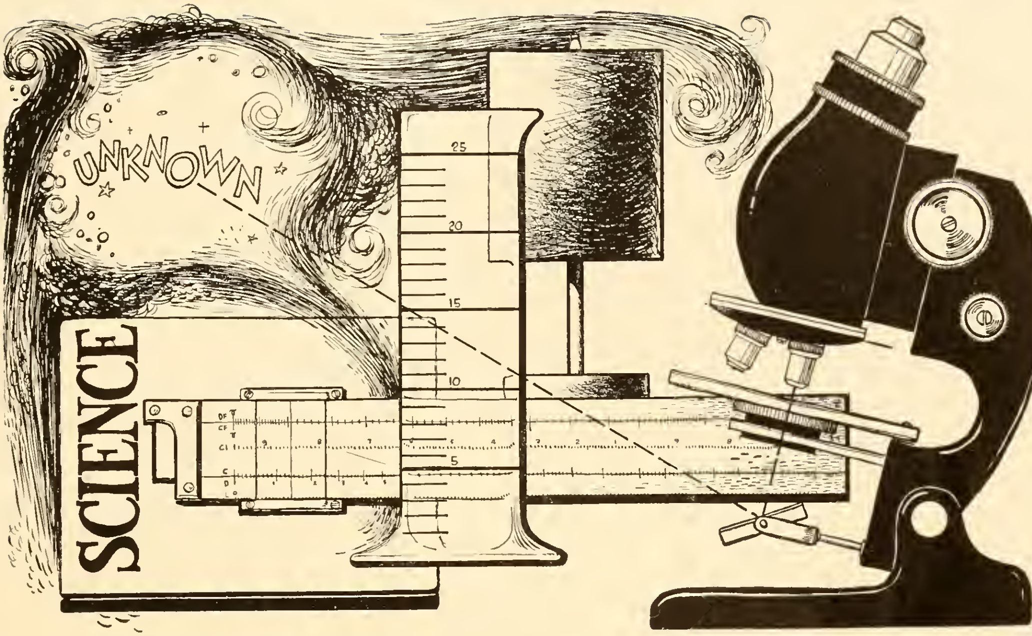
PART I

Zoology as a Science

CHAPTER 1



ZOOLOGY AS A SCIENCE

If values were placed on all the things that go to make up the universe, the greatest, undoubtedly, would be assigned to life and living things, particularly the life that resides in one special animal, man. It is difficult for us to interpret relative values in any other way because we are men, and nothing is more important to us than man himself. Since man is but one of many living things, the understanding of life itself becomes the pinnacle of all goals. No problems transcend this one, either in importance or in complexity. Life in all of its diversity poses so many fascinating problems that the scientist, grasping at one after the other, is only now beginning to see his way through this intricate maze of apparent confusion. Viewing the great profusion and variety of animal and plant life around him, it is small wonder he has been slow in bringing a semblance of order out of this chaos.

Little by little, bit by bit, he has been able to assemble innumerable facts about living things, until today these apparently unrelated fragments of knowledge are beginning to fall into an integrated picture of the story of life on the earth. So far, great gaps exist in this picture, but from a distance the basic pattern is discernible. It will be a long time before the entire panorama is completed, if it ever is, but in the meantime, it seems important that the over-all pattern be presented in such a manner that it can become a part of the philosophy of the non-scientist as well as that of the scientist. That is the purpose of this book.

Like all scientific knowledge, zoology has become more and more specialized into many compartments, such as anatomy (study of gross structure), physiology (study of function), embryology (study of early development), histology (study of tissues), and many others. In seeking a broad view of the entire field it is necessary to select only the salient parts of each of these segments and fit them into a unified whole. The task set before us, then, may be compared with a professor escorting a student down the long corridor of zoology, allowing him only a short stay before each portal of entrance to the specialized knowledge within (Fig. 1-1). From these bits of information and with the aid of the interpretation given by the professor, it is hoped that the student will be impressed with this unified picture, that he will absorb something of the spirit of science, and that he will take away with him something which may be integrated into his own philosophy of life.

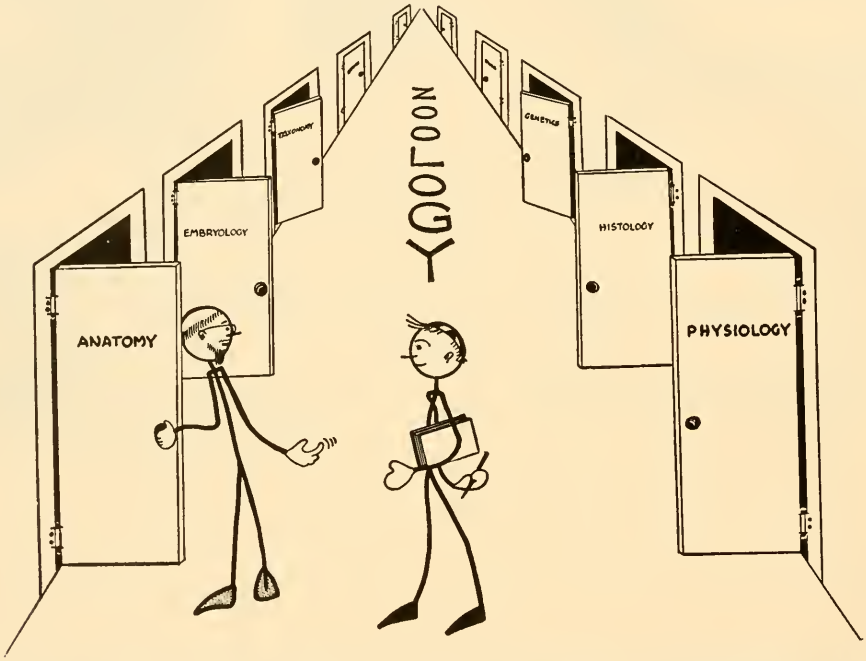


Fig. 1-1. A course in general zoology merely gives the beginning student a panoramic view of the field by taking brief glances at its separate disciplines.

WHAT IS SCIENCE?

Zoology is the **science** of **animal life.** Two words in this definition require further explanation before the definition can be understood. First a consideration must be given to the word *science,* and second to the word *life.* Of the two the latter is by far the more difficult to define, if indeed that is possible at all. Let us try to ascertain **what science is.**

Many attempts have been made to define science, and, in general, there is a certain amount of agreement among all of the definitions. Science is usually considered to be **organized knowledge,** either the knowledge itself or the **process** of gathering such knowledge. Obviously, there is a difference between the knowledge itself and the process which leads to its accumulation. The apparent discrepancy here disappears when the various sciences are considered. For example, the science of human anatomy is indeed organized knowledge, because over the past centuries all of the parts of the body have been described in ever greater detail and it is highly unlikely that a great deal new can be added to our present knowledge in this field. Therefore, the anatomist thinks of his science as organized knowledge per se. The physiologist, on the other hand, is working in a field of biology that is constantly changing; from one month to the next new facts are being brought to light, so that at no time can he say his is a nearly completed volume of knowledge. He is apt to think of his science as the **process** by which organized knowledge is assembled. His is a dynamic definition of science, whereas the anatomist's is a static one.

It is apparent, then, that as knowledge in a certain field of science comes to a point where there is very little left to be added, it can be considered as organized knowledge. During the process of gathering this knowledge, that is, during the early days of a new science, it must be considered as the process by which organized knowledge is assembled. It is a matter of time; some day perhaps all science will be the static type, although this is highly unlikely.

In general, people appreciate the static type of science because it is the certain science. They like to be certain of the answers with no guesswork. Today we are in the midst of many new sciences, all of them dynamic, all of them crying out for more and better answers to problems involved in the business of living. Very few of them are certain; most of them are solving problems that change almost from day to day. This makes many people very uneasy, even to the point of wishing the scientist would stop his headlong plunge into the world of the unknown. In our present state he will never stop, nor should he. Whether his efforts are good or bad are not for him to decide; it is not what he learns that is either good or bad, it is the use of that knowledge that determines ultimately its value to society. The scientist should not be curbed in his inquiry into the unknown; rather society should take stock of its own interrelationships, so that what is discovered by the scientist can always be put to ultimate good in alleviating the burdens of the workaday world, freeing man from pestilence and disease, and giving him a more enjoyable world in which to live. This is a real goal and one to which the scientist has contributed mightily in the past, and can contribute to in the future.

Just how did the scientific approach to the study of problems get underway, or has it always been a part of man's way of life? It is said that we live in a scientific age, a statement which would indicate that science is a recent thing. Just when did it have its inception and by whom and where? Perhaps a brief historical sketch would help answer some of these questions. From this history we may see how the scientist works.

HISTORICAL BACKGROUND OF ZOOLOGY

From the time man first organized into groups or societies he has had his problems either solved or greatly influenced by certain members of his group who were placed in a position of authority, and whose word was absolute, even to the point of life and death. Conclusions were based on emotions, hunches, and superstition, but rarely, if ever, on observed facts. This cannot be relegated entirely to ancient times, since even today there are countries in the world where similar policies are followed. In this modern world such tactics have led to much bloodshed and may continue to do so.

Historically, we need not go back any farther than **Aristotle** (384-322 B.C.) to find the faint beginnings of a new way of solving problems, indeed, a complete new way of life. Aristotle gave us the **inductive method** of reasoning, which means that generalizations are made from the facts observed. Many facts are collected on the topic in question and after these are all assembled, certain conclusions are drawn. The counterpart of this method is the **deductive method** of reasoning, wherein the generalization is made and the facts gathered to fit the generalization. Most of our great advances in science have come from the utilization of the inductive rather than the deductive method of reasoning. Even when the latter method is employed certain basic facts, frequently mathematical, are used as a starting point. While Aristotle was undoubtedly influential in introducing the inductive method of reasoning to the world, even he was dependent on considerable information that had accumulated during the centuries before his time. It cannot be emphasized too strongly that no man, however great, stands out entirely alone. He always depends to some extent at least on what preceded him.

Aristotle was a man of considerable influence in his day and his stature grew tremendously for centuries after his death; the student of today could hardly miss his name in almost any field of learning. His greatest contribution, perhaps, was his method of approaching problems. Not that he was right in all of his observations, for he made many mistakes, but it was his constant insistence on making careful observations, first hand, and recording them accurately that was important. To be sure, he did rely on accounts by his friends or earlier writers for the description of forms he had never seen. For example, he wrote that there were no neck bones in the lion but merely a fused mass extending from the thorax to the skull. It is obvious that he had not seen a lion's skeleton or he would never have written this account. However, where he made his own observations, such as his description of the development of the chick, he was meticulously accurate. The reader is impressed by his account of the breeding of sharks. On the other hand, his description of the internal human anatomy is inaccurate; one is certain that he was observing the viscera of some lower mammal when he wrote it. His ideas concerning the function of the various parts of the body are rather amusing to us today. For example, he thought that the brain produced mucus and was cold while the spinal cord was hot, that the heart was the seat of intelligence, and that food "cooked" in the digestive tract.

Aristotle was convinced that animals evolved from lower forms, culminating in man; thus he laid the foundation for the theory of evolution, which was to gain a foothold over 2,000 years later. He described 520 species of animals that have since been identified. He erected a crude method of classifying animals, although his system was not accepted by subsequent taxonomists.

Using Aristotle's contribution toward initiating the scientific method of approach to the solution of problems, some progress was made by his followers. But the road was difficult and progress was extremely slow. Of the many men who wrote during the first few hundred years following Aristotle, **Galen**, who lived in the second century A.D., was the most outstanding; he made some rather remarkable contributions to the anatomical studies of the human body (Fig. 1-2). Aristotle's influence probably stimulated Galen to make some accurate observations on the brain and heart particularly. He was denied the use of human bodies for dissection, and his writings indicate that he used the ape and goat for his studies.

Galen was a voluminous writer, having completed 256 treatises during his lifetime, most of which were medical in character. Of these his most outstanding were written on human anatomy. Galen lived at the close of the Age of Classical Culture, just before the Middle Ages, in which all learning was at a standstill. It was fortunate, for the hundreds of generations of medical men who followed, that Galen did produce work of such high grade, because it formed the ba-

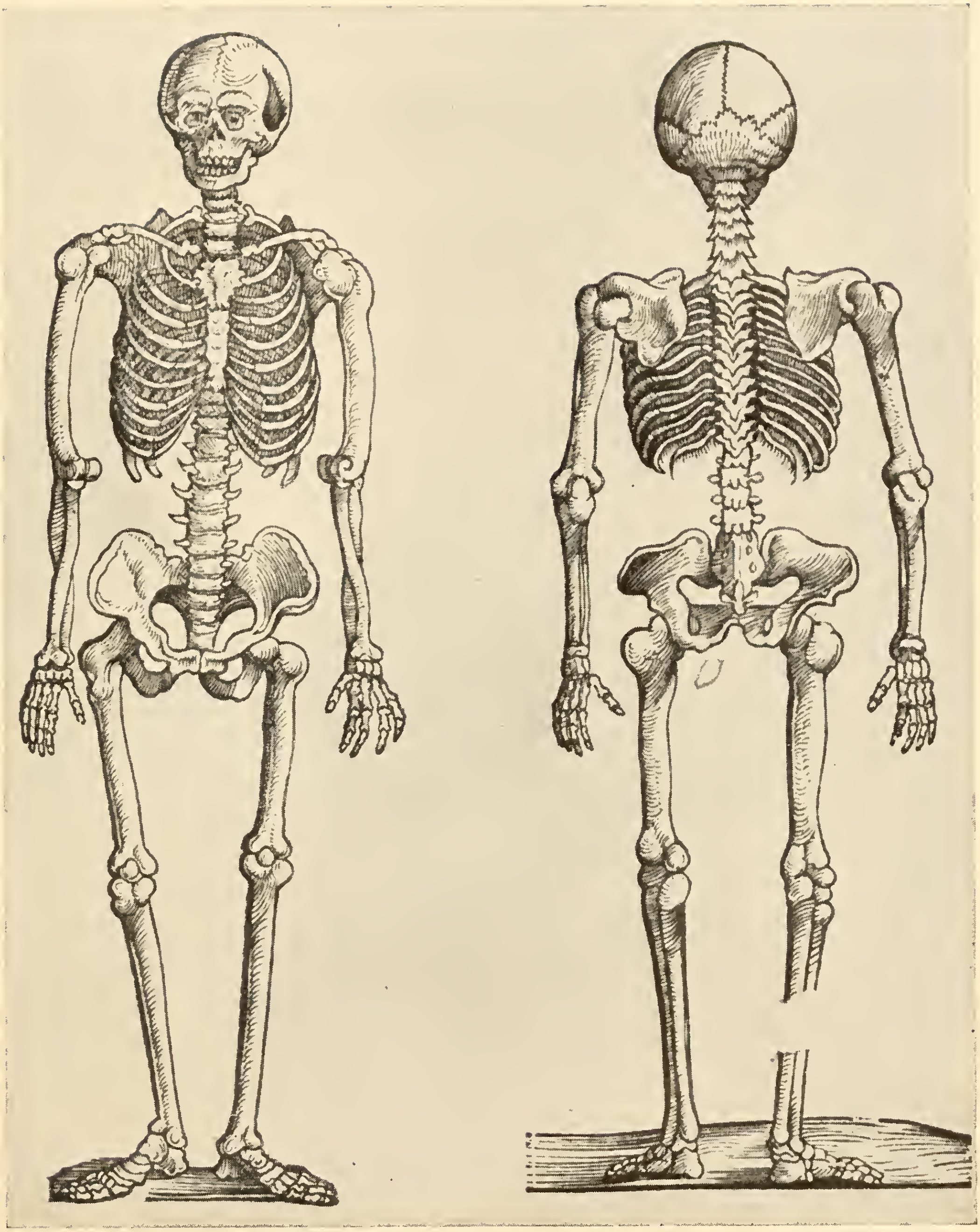


Fig. 1-2. This is a sketch of the human skeleton that appears in Galen's book, *On Anatomical Preparations*. By comparing it with a modern drawing some discrepancies will be noted. Note the shape of the neck vertebrae in the right-hand figure and observe that the coccyx (tailbone) is one piece and peculiarly shaped.

sis for medical knowledge for the next 1,200 years. His book, *On Anatomical Preparations,* was the standard medical text during this long period, perhaps the longest "run" any textbook has ever enjoyed.

In the next twelve centuries authority as a source of all information reached its peak. This was very well illustrated in the study of medicine. The professor of anatomy, for example, sat before his class with a large volume of Galen's text before him, and a human body, when it was available, displayed on the dissecting bench some distance below. A barber or two huddled over the body, exposing the various parts, as the professor read about them from the text. The students looked on and absorbed what they could from this crude demonstration. The unquestioning faith in authority of this period was revealed when some portion of the human body did not agree with the description in Galen; the body was always considered at fault, not the text. Such mistakes were common, since Galen's dissections were based on animals other than man. This was typical of the time, even in learned circles, and this profound respect for authority persisted until a few bold men dared strike out to see and learn for themselves some centuries later.

Among the many men who had the ability and courage to fight blind ignorance was **Vesalius**, who was born in Brussels (1514), trained for medicine in Paris, and finally became professor of medicine at Padua in Italy at 22 years of age. During his early medical school days he was a devoted follower of Galen's teachings. But Vesalius was able to secure human bodies for dissection, and as he probed more deeply into the details of human anatomy he discovered Galen's errors. Being an independent thinker, he soon decided that he must write down his own observations concerning human anatomy without reference to the work of anyone else. He secured the services of some of the best artists of his day to illustrate the book that he felt the urge to write. Some recently discovered wood-cuts made by Calcar, a student of Titian, were found to be as beautiful as when first used in Vesalius' book, *On the Structure of the Human Body* (Figs. 1-3 and 4). Because he was at variance with Galen, Vesalius soon became the subject of much adverse criticism, which finally forced him to leave his professorial post to become court physician for Emperor Charles V. In this position he apparently was not happy, because some years later he left on a pilgrimage to Jerusalem from which he never returned.

The greatest contribution this energetic man made to the world was his break away from authority and his reëstablishment of the old Aristotelian ideal of pursuing the answer to problems by direct observations. This revolt from authority was furthered by others after Vesalius, but it received its greatest impetus from William **Harvey** (1578), a British physician, who gave us the first experimental approach to biological problems. Educated at Padua, Vesalius' old school, Harvey became interested in the blood vascular system, and went to work eagerly after he left the university, to learn more about this perplexing problem. Up to his time the heart was thought to be purely passive and non-muscular; the blood was supposed to flow into the heart causing it to expand suddenly, which accounted for its audible beat against the thorax. The blood somehow picked up that intangible "spiritus vitalis" while in the heart, then passed to the liver where the food was changed into blood, thus nourishing the body.

Harvey demonstrated that the heart was a muscular organ and that its contractions were responsible for propelling the blood through the arteries. He experimented with animals and studied normal and abnormal humans for twenty years before he was certain that the blood flowed away from the heart in the arteries, and returned to the

Fig. 1-3. This is a woodcut taken from Vesalius' book, *The Structure of the Human Body*. It depicts Vesalius himself giving one of his public demonstrations of the internal anatomy of the human body.

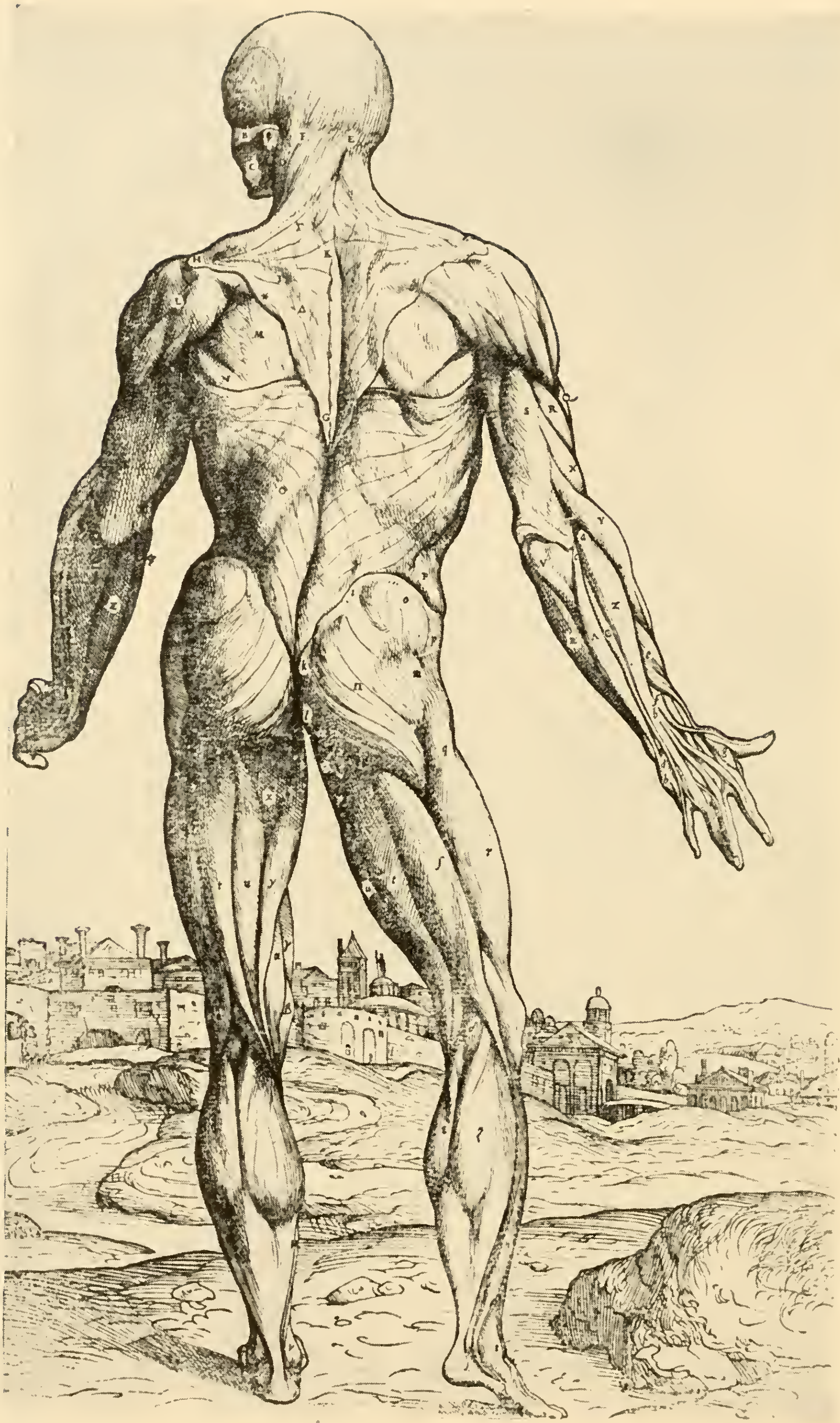


Fig. 1-4. This is another woodcut taken from Vesalius' book, showing the superficial muscles of the back. This is done with remarkable accuracy. Note the background, which undoubtedly was the contribution made by the artist Calcar.

heart in the veins (Fig. 1-5). His most important contribution was to prove mathematically that the blood must circulate through the body in this fashion. He went about demonstrating his theory, much the same as it would be done today in a modern research laboratory. He computed that at each beat, the human heart delivered about two ounces of blood; beating at 65 times per minute, in an hour it would force about 50 pounds of blood through itself. He reasoned that such a tremendous quantity of blood simply had to stay within the body and circulate from one part to the other. He was able to work out the pulmonary circulation quite satisfactorily, but he was forced to guess at the existence of body capillaries because, lacking a microscope, he never saw them. Truly Harvey was a great scientist, and his courage put physiology on its first step toward the profound science it is today. He brought experimentation based on mathematics into the study of biology for the first time, and has been looked upon as the founder of modern physiology.

The values of direct observation and experimentation gradually became obvious to the intelligent world in the years following Harvey's initial steps. All through the nineteenth century brilliant men added their influence to the growing infant science of physiology until it gained full stature at the turn of the twentieth century, and it has been growing steadily up to the present. During the nineteenth century most biological work was morphological, that is, the study of form and structure of animals; today physiological problems are receiving most of the attention. Biologists are primarily concerned with the way animals function. In order to find answers they have been forced to rely on the sister sciences of physics and chemistry, for it has become increasingly obvious that in the last analysis these sciences are most likely to give us the solution to our most profound problems.

Using these four men, Aristotle, Galen, Vesalius, and Harvey, as examples spaced over nearly 2,000 years, it is possible to see how the science of zoology took root and grew to what it is today. Men could have been selected from other sciences to demonstrate the same evolution in a way of thinking. In any case, it is obvious that science was slow in developing during its first 2,000 years. It has grown tremendously since then, however, particularly during the past 200 years, and in this century almost explosively. There seems to be no indication of any abatement in its growth at the present time, and if properly guided science will certainly help to make this world of ours an almost miraculously beautiful one in which to live.

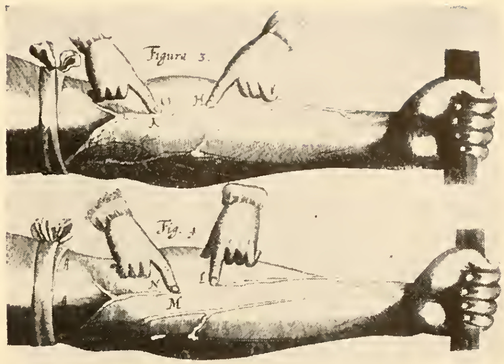


Fig. 1-5. These are two of the original sketches made by Harvey in his little book describing the circulation of the blood. The figures demonstrate the valves in the veins that permit the blood to flow only toward the heart.

WHAT SCIENCE HAS DONE AND CAN DO

Before we discuss the methods used by the scientist, let us consider for a moment what science has done for people of the world, what it is doing today, and what it could or might do in the future. We can use one example, world population in human beings. Approximately 250 years ago there was a world population of some 600 millions; that number has increased fourfold up to the present time and is now increasing at an unprecedented figure. This means that within the relatively short period of 250 years there has been a tremendous increase in population compared to the preceding period of approximately 500,000 years which produced the number of people alive in 1700. What has been responsible for this sudden burst of reproductive powers in man? Certainly there has been no physical evolution in man himself in so short a time. It is generally agreed that food is the limiting factor in the growth of any population, be it fish or man. Populations always encroach upon the food supply, just as closely as they can without widespread starvation. This increase in population, then, is due to increased food production; increased food production has come about through the application of the scientific method to food production problems. This might be all changed again by a single important discovery, for example, an economical method of producing food from inorganic sources, such as sugar from carbon dioxide and water. A discovery such as this would change the entire food problem of the world overnight. Feeding the half-starved world of today is within the realm of possibility now; it is not being done for reasons that are beyond the realm of science, at least for the present.

In colonial days the average life span was under 40 years for a man; today it is well over 60. It is not that men are any better physically today than they were then. It is due almost entirely to the progress made by science in understanding the cause and prevention of infectious diseases. All of the advancements that have been made in medicine have been accomplished through the agency of science. Before the scientific method was inculcated into medicine it was largely superstition and mysticism. Since the discovery of the Germ Theory of Disease, aseptic surgery, and anesthesia, many of man's ills have been partially or wholly conquered. There is no doubt that many of the infectious as well as organic diseases that plague man today will eventually be eliminated from civilized societies. If man would follow the scientific approach to the solution of his peacetime problems as avidly as he employs them in the preparation of war machinery, this world would soon be a near-perfect place to live. Unfortunately, the hope that he will do this seems rather remote at the present time.

It seems clear that the application of the scientific method to the solution of man's physical betterment has been good and bad. It has lifted many burdens from his shoulders by simplifying the work essential for his physical needs; it has extended his average life span also, but, at the same time, has provided him with deadly weapons, such as the atomic and hydrogen bombs. He has for the first time an instrument within his grasp that can annihilate the whole of the civilized world as we know it. Such a situation in an uneasy world certainly is not good when considered from the point of view of survival of a race. Perhaps the application of the scientific method to man's social ills might have some of the success it has had in the alleviation of his physical ills.

With all of the wonders that science has produced, it cannot answer all of our problems. We have found no way to measure love, beauty, or the faith people have in God. By common agreement the scientist deals only with the things he can measure, either with his senses directly, or with instruments that magnify their sensitivity, such as the telescope and microscope. The ultimate purposes and goals of life itself are not within the scope of science, and must be left to religion and philosophy.

HOW THE SCIENTIST WORKS

Having considered some of the accomplishments of science, we should now find out just how the scientific method operates. It follows a series of rather definite stages in the solution of a problem.

1. ***Statement of the problem.*** In so far as it is possible, the problem should be clearly stated, that is, the investigator should have

a rather clear-cut idea of his objective. Usually, this is relatively easy, although the final answer as a result of the application of the scientific method may not be as clear as the initial problem indicated. For example, the problem might be: what causes cancer? After many years of work by thousands of scientists, there is as yet no clear-cut answer. An apparently simple problem may become very complex once it is pursued for a time. In fact, this is the usual experience of most scientists in the search for the solutions to problems.

2. ***Hypothesis.*** Once the problem is stated, some kind of supposition or guess as to the answer should be formulated. This is the hypothesis or guessed theory. For example, thousands of various chemicals are frequently tested with respect to their ability to destroy bacteria in the bodies of animals. Continued testing is based on the theory that since some chemicals have been effective for the purpose of bacterial destruction, others may also be effective. This is rather remote evidence, for various chemicals are likely to react differently. However, there is always the chance that a new chemical may react in some new way or may even supersede the reaction of some known chemical in eventual effectiveness.

3. ***Gathering facts from observations or experimentation.*** Facts must be accumulated, based on observations with the senses or extension of the senses made possible by the use of instruments such as the microscope to increase the ability to see small things and the telescope to observe distant bodies. These facts must be gathered painstakingly and sometimes over long periods of time. The impressions received through one sense should be checked against those received through other senses, in short, all possible information must be gathered from all sources. In collecting these facts the scientist must not be influenced in the slightest by his own opinions. Facts must be collected without bias, and records must be accurately kept.

Some problems require observation alone, as, for example, the measuring of the orbit of the moon. It would be impossible to do other than to collect data on the activities of the moon over a long period of time. Other problems lend themselves to experimentation, that is, through alteration of the natural course of events it is possible to make observations over a short period of time, under controlled conditions. Whenever experimentation is possible, results are obtained much more rapidly than in those fields where observations must be taken on naturally occurring events. For example, the way in which color blindness is inherited in man can be detected by studying several generations of families over a period of 50 or 100 years, whereas the underlying mechanism can be demonstrated in a month or two by studying fruit flies bred in the laboratory.

4. ***Compiling and interpreting the data.*** Once the observations and experiments have been completed, the data must be arranged and coördinated. Frequently, it is impossible to note trends or to determine any noticeable effects while the observations are being made; it is only after arrangement and coördination into units that the real results can be detected. This systematization involves the construction of tables, charts, and graphs. Often mathematics will be required before true relationships can be stated.

5. ***Conclusion.*** The conclusion is probably the most important part of the scientific method, and it is the part where great caution must be exercised. Facts are the only basis for interpretation. Conclusions must be drawn logically and should be as nearly absolute as possible. These are most reliable when based on mathematics. Caution must also be used in drawing conclusions with absolute certainty, since nothing is absolutely final to the scientist. Science is relative and subject to change as more knowledge is attained. As new facts are discovered in the chemical and physi-

cal worlds, biology is subjected to change. This uncertainty that runs through all scientific thinking is often very annoying to people employed in pursuits which to them possess more certainty.

In order to illustrate the scientific method in operation, an example is included here:

1. *Statement of the problem.* Is vitamin B_1 necessary in the nutrition of a rat?

2. *Hypothesis.* Since vitamin B_1 is essential in the nutrition of other mammals, it is also essential in the nutrition of the rat.

In order to solve this problem, it will be necessary to obtain several rats, preferably litter mates from a pure-bred stock, since uniformity among the experimental animals is most important. Litter mates are brothers and sisters, therefore more alike than unrelated rats, and should give the same or nearly the same response to treatment. It is highly desirable that only one factor vary, and that one should be the factor under observation. From past experience it has been found that young rats are more responsive to dietary differences than older ones, and for that reason half-grown rats should be used. The increase in growth, absence of growth, or decrease in growth are used to measure effect.

The rats are separated into two groups of equal number, say five in each group. If the sexes are evenly divided, the males and females should be distributed evenly between the two groups. While it is unlikely that sex differences affect the nutrition of young rats, it is well to control all possible factors. To the one group, known as the *experimental group,* should be fed a carefully prepared diet that includes all food essential to the growth of a rat, with the exception of vitamin B_1. To the other group, the *control group,* should be fed the same diet in equal proportions, but with vitamin B_1 added.

3. *Gathering facts from observations and experimentation.* The rats in both groups must be weighed carefully at the beginning of the experiment. Normal growth charts for rats should be consulted in order that growth in the control group can be determined as normal. Each rat must be weighed every day and accurate records kept until the end of the experiment. Food and water must be abundant at

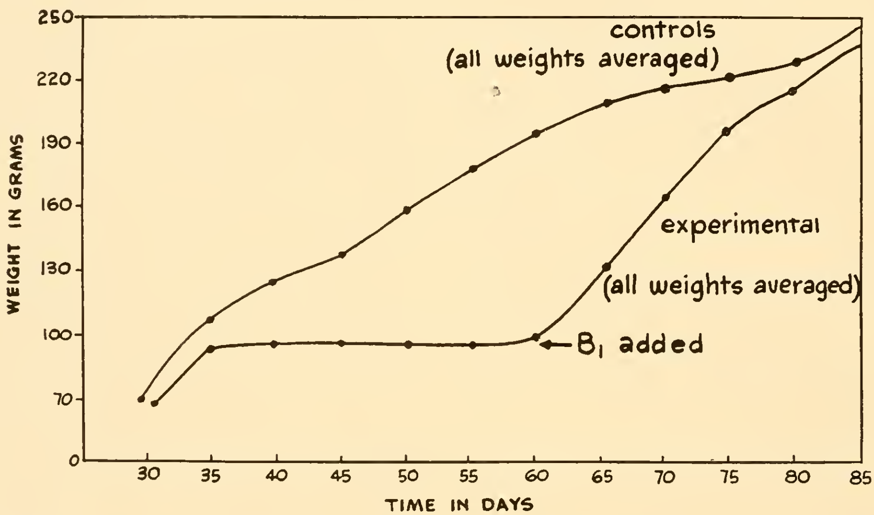


Fig. 1-6. A graph showing the effect of the lack of vitamin B_1 on the normal growth of rats. The average weight of the control rats increased throughout the growth period, while the rats on the experimental diet (lacking B_1) failed to grow after 5 days. When the vitamin was restored to the diet they grew normally.

all times. Temperature, humidity, air currents, and all other environmental factors must be controlled in the room where the rats are kept. Observations of any abnormalities among the rats must be recorded. These abnormalities would include infection or any other factor that might influence the results.

4. *Compiling and interpreting the data.* The data must then be assembled in the form of charts, tables, and graphs (Fig. 1-6). The rats which received no vitamin B_1 failed to grow normally, whereas those rate of growth within each group; also, the poorest control rat was only slightly better than the best of the experimental group. However, when averaged out and plotted as in Fig. 1-7, the results are clear-cut. If one studied only two rats and by chance got rats No. 5 (control) and No. 2 (experimental), the results might be inconclusive; hence the need for an adequate number of animals. This variation among animals can be measured mathematically and the significance of the variation computed very accurately. This is the field of *biometry* (ap-

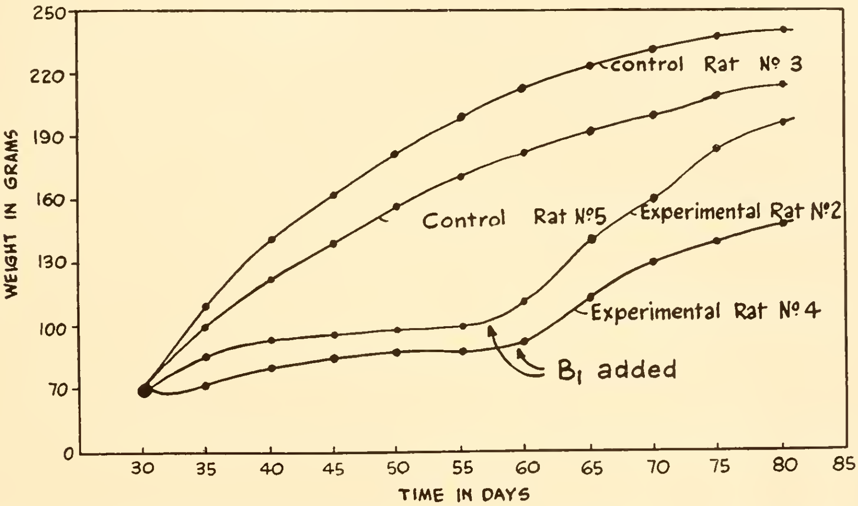


Fig. 1-7. Similar to Fig. 1-6 except the growth is recorded for specific control (#3 and #5) and experimental (#2 and #4) rats only.

receiving this substance were healthy normal rats. When the vitamin was added to the diet of the experimental animals, an almost immediate positive response was noted in their growth. It may be concluded, therefore, that vitamin B_1 was necessary for the normal growth of the experimental animals.

More can be learned about this experiment if more data are studied. For example, how much variation was there in the growth rate of the rats? The two extremes in both the control and the experimental animals are plotted in Fig. 1-7. It is obvious that there is considerable variation in the plication of statistics to biological problems) and is very important in determining the answers to many experimental problems.

5. *Conclusions.* It can be concluded that, within the limits of this experiment, vitamin B_1 is necessary for normal growth in rats. Such a statement leaves room for further research which might prove that some substance other than vitamin B_1 is the controlling factor. For example, one species of bacteria, growing in the intestine of the rat, might inhibit the use of vitamin B_1, whereas another species might actually produce the vitamin. Such a thing is possible, but until it is proved by further ex-

perimentation, the conclusions drawn from this experiment hold.

From these data a generalization can be made concerning the use of Vitamin B_1 by the rat. If, for example, all mammals, indeed all animals, required Vitamin B_1, it would then be possible to formulate a **theory** concerning this substance and nutrition in animals. Usually theories are applied to broad concepts such as the existence of atoms, molecules, gravity, and evolution. A theory is a tentative or probable explanation of a problem; once a theory is formulated, it must be tested in all possible ways, for if it fails to explain all of the subsequent findings, it must be discarded or altered. Many theories set forth by scientists have later found their way to the waste basket. If a theory continues to explain the facts after rigorous testing, it becomes a **law.** In zoology, "life from life" is a law.

A scientist either has acquired or innately possesses the spirit of inquiry; without this trait he would never be fired by the unknown and would, therefore, never be inclined to investigate that which was not already well understood. All first-rate scientists are endowed with this trait to a marked degree. A good example of a man who was imbued with the spirit of inquiry throughout his life was Pasteur, who could never allow a problem to rest until he had attained an acceptable answer to it. As a result he probably revealed more important information about disease and the cure for human suffering than any other man. The scientist must constantly have an open mind but he must also have a very critical mind. Not only must he criticize the work of others, but what is far more difficult, he must measure his own work by the same yardstick. It is only through checking and rechecking one another's work that scientists have been able to arrive at present-day knowledge. Scientists are their own severest critics and so they should be. Conclusions must be carefully drawn and must always allow for future discoveries which may alter the apparent facts today. The sole interest of the scientist lies in an explanation of the physical world about him and the life on it. To the pursuit of this task he is dedicated with unswerving devotion.

FIELDS OF THE BIOLOGICAL SCIENCES

There are many facets to the field of biology, each of which has become very specialized today. The oldest field is concerned with the structure and form of animals, and is termed **morphology.** It has several subdivisions. **Anatomy** has to do with gross anatomical structures that can be studied with the naked eye. **Histology** is the study of the microscopic architecture of organs, and **cytology** is the study of cell structure; both involve the use of the microscope. Another branch of morphology is **embryology,** the study of the development of an animal.

The study of animals in respect to their proper classification is known as **taxonomy.** The field which concentrates on the distribution of animals geographically is **zoogeography,** and the study of fossil remains is **paleontology.**

Physiology is the study of the manner in which animals function; this phase of biology is more recent and occupies the attention of a great many people in all branches of biology today including agriculture and medicine. It is probably the most fruitful of all in regard to the improvement of our physical shortcomings. **Genetics** is the study of the mechanics of inheritance.

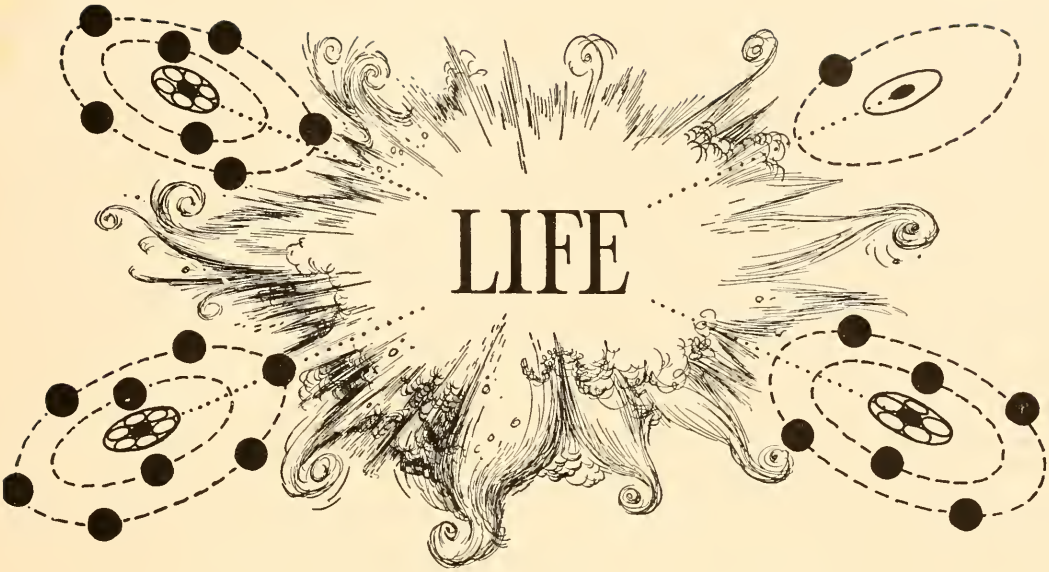
A study of the relation of animals to their environment is known as **ecology.** This is an important phase of biology because it provides the knowledge for the rehabilitation of stocks of wildlife. Naturally it involves plants as well as animals. The science of the mind alone resolves itself in the field of **psychology** and when the study includes the entire animal and its interrelationships, the field is known as **sociology.**

The science of zoology is so vast and so specialized that a zoologist may spend his entire life effort on one small phase of the subject. For example, the *entomologist* concentrates on insects and may be fairly familiar with a large number of them, but a *dipterologist* is an expert on flies, one order of insects. Likewise, a *parasitologist* may have a nodding acquaintance with many animal parasites, but a *helminthologist* is a specialist on worms, and a *malariologist* confines his work to causative organisms of malaria, which are protozoan parasites. The *ornithologist* studies birds and their habits, whereas the *mammalogist* concentrates on mammals. It is obvious that there are many small segments of the science of zoology that occupy the attention of zoologists today, and it is from this concerted effort that our knowledge is going forward at a tremendous rate. The possibility for future benefits to mankind are almost limitless, providing man has sufficient intelligence to utilize this knowledge for the advancement of the human race rather than for its destruction.

PART II

Life: Its Beginnings and Nature

CHAPTER 2



EARLY HISTORY OF LIFE

If we are to understand living things on the earth today, even in the most rudimentary way, we must have some understanding of the physical world in which they came into being. It must be remembered that the physical world was here first, and that all living things have sprung from it, using the materials and forces that are present in it. There can be no life without a surrounding world, an environment in which it resides. In a sense they must always be considered together, for the environment can exist without the living organism, but the reverse is not true. Since the environment was here first, it is well to consider some of the fundamental characteristics of this environment, so that when we study life later it will have more meaning.

THE SETTING—THE PHYSICAL WORLD

The earth was born two or three billion years ago. Along with the other planets of our solar system, it was probably formed out of a very large, flattened, and highly rarefied mass of gas and dust that surrounded the sun and rotated about it. As the rotation proceeded, with the regions near the sun moving faster than the outer regions, whirling eddies must have formed in different parts of this tenuous nebula. Although most of the gas and dust probably escaped the solar system, the larger and denser of these whirlpools were able to coalesce by the forces of gravitation and to attract additional matter into them. After some millions of years, these planetary nuclei had grown slowly and steadily by accretion into the solid planets we know today.

We are concerned with the conditions of the earth in this early period that led to the formation of the first living things. What were the physical factors that produced a setting in which such a delicately adjusted thing as life could have established itself?

At first a thin crust formed over the bottomless sea of molten rock; because of the tremendous heat, water could not exist at the surface, so a thick gaseous layer of superheated steam covered the entire earth. As the steam pushed upwards into the cooler regions, condensation occurred, causing dense fog and torrential rains. Eventually, after still further cooling, the rain drops penetrated the heat and reached the hot rocks below, only to evaporate as steam once more. Finally, however, with further cooling, water stayed in the depressions of the earth's extremely wrinkled surface, forming the infant oceans of the world. Hot rivers formed, of course, which were forever rushing to fill the oceans, carrying with them any minerals of the substratum that would dissolve. These substances were deposited in the young oceans, resulting in a constant increase in the chemical composition there. Water evaporated from their great surfaces, just as it does today, leaving the heavier salt particles behind and thus continually raising their total salt content. That is why the ocean water of today is salty. The importance of these great bodies of water lies in the fact that undoubtedly life originated in them, sometime during this early stage.

Here, then, we see a spinning new world, sufficiently far from the sun to be moderately warm in most of its parts and fixed in a never fluctuating orbit, which insures evenly spaced seasons. The surface is covered with rocks, gravel, sand, great water masses, turbulent streams of cool to warm waters, but no soil. A thick homogeneous gas, rich in nitrogen and oxygen, envelops its surface, with clouds of water vapor lazily floating with the moving air currents. This is the setting in which life started; this is the world that gave birth to that dynamic something which, once initiated, extended into every part of that world. As it extended it became more and more diversified. Finally it gave rise to human beings who can sit here now and consider how it all came about, a wonderful series of events, and certainly fascinating enough to stimulate the curiosity within us.

THE NATURE OF THE PHYSICAL WORLD

There are certain physical laws that influence all things, animate as well as inanimate, in the universe; therefore, it is well that we learn something about them, before we attempt to study life itself.

All things in the universe are composed of **matter**, and, since living things are derived from material in the world, they are also composed of matter and therefore behave as matter does. One of the characteristics of matter is that it occupies space and has mass. Mass may be defined as the amount of matter in a body which can be measured in terms of resistance to change of motion. This is more meaningful when it is considered in the light of attraction between bodies. Bodies attract one another according to their respective masses. For example, the earth has a greater attraction (gravity) for a man than does the moon because the earth has greater mass. We have a convenient method of measuring this attractive force between bodies; we call it **weight**. Weight, of course, changes, depending on where it is taken. A person weighing 180 pounds on the earth would weigh 30 pounds on the moon, although his mass would be the same. Weight simply measures the pull of **gravity**.

Animal bodies are constructed to compensate for the pull of gravity. For example, small animals, such as mice, have relatively light skeletons in comparison to their weights, whereas larger animals, such as the elephant, have much heavier skeletons with respect to weight. This fact limits the size of animals, for should they go on increasing in bulk, they would reach a point where the skeleton alone could not bear its own weight. If life, as we know it, occurs on other planets, it too would show relation to weight. Animals on Jupiter, for example, would have to be constructed on an entirely different plan from those on the earth, because the pull of gravity is so much greater. They would probably be heavily boned animals and greatly flattened.

One cannot mention the motion of matter without referring to another force that operates on bodies, namely, **inertia**. When a swift elevator starts up, one is conscious of a sudden increase in weight; likewise, when it comes to rest, one seems suddenly and momentarily lighter than usual. There may be a simultaneous peculiar feeling in the mid-section as the internal organs respond to the effects of inertia. This force is the resistance of a body to change in its rate of motion. If standing still, it resists movement; if moving at a certain rate of speed it resists any change in this rate. That is why we need low gear and good brakes on our cars—it requires more power to get started or to stop than to keep rolling.

Most animals are little affected by inertia except when suddenly stopped, such as a bird flying into the side of a building. The sudden cessation of forward motion can be fatal to bird or man, as attested by car accidents. Another modern machine that brings the effects of inertia into prominence is the airplane. Pilots often "black out" because their forward motion is suddenly changed, as in coming out of a power dive. The blood, being fluid, tends to follow the forward motion it has attained and is thus pulled away from the head, causing the "black out" or faint. The normal movements of animals are little affected by inertia, and the problem arises in man only when he steps into one of his mechanical contrivances which carry his body faster than it was made to go.

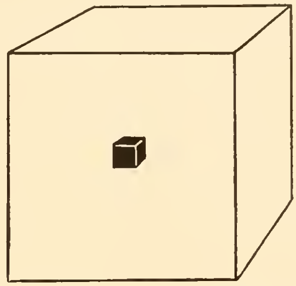


Fig. 2-1. Two cubes, one with dimensions 1/10th of the other. In respect to volume, the smaller has 10 times the surface area of the larger.

Surface phenomena

The behavior of matter depends to a large extent on its surface area. Large bodies have smaller surface areas in respect to volume than do small bodies. A mouse has more surface area in respect to its volume than does an elephant. This can easily be computed by simply measuring the surface area of a cube, say 10 inches on a side or 600 square inches, and then its volume, which is 1,000 cubic inches (Fig. 2-1). This is a ratio of 0.6 square inch of surface to every cubic inch of volume. If a cube one inch on a side is cut out of the larger cube, and the surface computed in respect to the volume, it will be found that each inch cube will have 6 square inches of surface, a tenfold increase. Since chemical reactions take place at surfaces, it is obvious that the activity will be much greater as matter is divided into smaller and smaller particles. This is a very important physical property, as we shall see when we discuss enzyme action and many other activities that go on within the animal body.

Particles of matter, especially small particles where the effect is more apparent, attract one another of the same kind and also have an attraction for other particles of a different sort. The first is given the name **cohesion**, and the latter **adhesion.** Particles of matter such as water tend to cling together to the extent that they actually form a film at their surfaces. This gives the effect of a stretched membrane and is spoken of as **surface tension.** Water has a rather high surface tension, but mercury surpasses it by a considerable margin. Anyone knows that when mercury is dropped it breaks up into hundreds of small perfect spheres. Water gives a similar but lesser response when dropped on a dry, dusty surface. Rain drops are usually near-spheres. Liquids, when free of external forces, will assume the shape of a sphere because the cohesive forces of the particles of which it is made form a surface membrane. This fact makes it possible for certain species of insects to walk on the water (Fig. 2-2). Their bodies are light and the weight is distributed over a large area, so that the cohesive force of the water is sufficiently strong to keep the membrane intact.

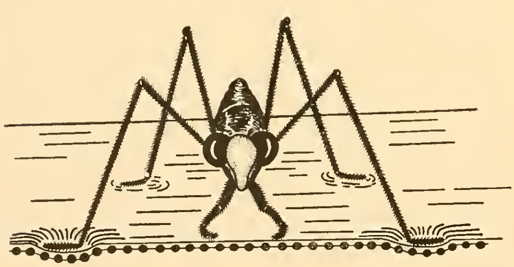


Fig. 2-2. Some insects, like the water strider, can walk on water because their evenly spread weight is not sufficiently great to break the surface tension.

Adhesive forces are simultaneously at work with cohesive forces. These have no significant influence on large bodies, but on small particles they become very important, just as important as gravity is to the larger bodies. Certain gaseous molecules, for example, will adhere to carbon particles so tenaciously that it requires high temperatures to remove them; this is the principle of the gas mask and certain purification processes. It is important in biological systems where enzymes, for example, adhere or **adsorb** (the process is called adsorption) to food particles, thus enhancing digestion. This physical property of matter manifests itself in many ways in the bodies of animals.

Composition of matter

Almost every school child knows that matter is made up of **molecules**, and some know that the molecules are composed of **atoms.** Any college student could hardly have missed newspaper discussions of the nature of atoms, how they are being investigated, and particularly what effect this knowledge is having on our lives today. There is a great deal of excellent experimental proof for the existence of these small particles, some of which we should consider briefly.

Matter exists in space in one of the three forms: **solids, liquids,** or **gases.** Water is a convenient example of matter. Below freezing it exists as ice, a solid; between freezing and boiling, it exists as water, a liquid; above boiling, it exists as a vapor or steam, a gas. In all of these states the substance is still water, its chemical composition unchanged. Whether it is in one state or another depends on the interrelationship of the molecules in space. In the solid they are close together and rather static in their position, although free to vibrate; in the liquid they are still close together, but not so close as in the solid and they are free to move within the liquid itself; in the gaseous state they are far apart and free to move. The particular state in which matter exists depends on the speed of movement of the individual molecules. In the solid state they vibrate, but stay in fixed positions within the solid; in the liquid they move faster and are free to move about within the liquid, whereas in the gaseous state they attain high speeds, so high that they exceed the intermolecular attractions and separate from one another to become independent free-floating bodies. In the gaseous state they demonstrate their smallness because they then are invisible. The rate of molecular movement is reflected in the phenomena of **heat** and **cold**. Molecules move faster in hot bodies than in cold ones. When there is no movement, the body is as cold as it is possible to get, a condition called **absolute zero.**

All specific chemical substances exhibit the same changes in state that water does, although they are not always so easy to observe. There are thousands of different kinds of matter, each composed of a specific kind of molecule, such as oxygen, hydrogen, or water. Since life is composed of matter, it must then also be composed of different kinds of molecules, and the properties of these molecules must be reflected in the properties of living things.

Molecules may be still further divided into atoms, which were until recently thought to be the ultimate irreducible particles of matter. With the advent of "atom smashing," a new interpretation has been placed on the atom and its place in the universe. Ignoring this recent information for the moment, chemists tell us that there are 98 different kinds of atoms, called elements, each with definite distinguishing characteristics. At least five more have been predicted although at present they are unknown. It is the various combinations of elements that make up all the thousands of chemical substances existing naturally or that can be produced in the laboratory. Water, for example, is made up of H_2O, two atoms of hydrogen (H) and one of oxygen (O). A more complex molecule is blood sugar, glucose $C_6H_{12}O_6$, composed of six atoms of carbon, twelve of hydrogen, and six of oxygen. It is obvious that with 98 building units millions of combinations of atoms are conceivable. Many of these molecules appear in living things and it is necessary to know something about their individual behavior in order to have some understanding about their combined effect as it occurs in a cell, for example. Chemists have been studying these for a long time, and their knowledge is so significant to the study of animals that today zoologists are dependent to a large extent on this information to aid them in solving some of their complex problems.

The arrangement of atoms in a molecule gives to that molecule its properties. Sugar is sugar because of the arrangement of the atoms in its molecule. If any of the atoms are removed or even changed in their respective positions within the molecule, the substance is no longer the same; the properties are different. For example, if the hydrogen and oxygen in the water molecule are separated, we no longer have water but two gases, neither of which acts like water in any way. When the molecules are all alike, we speak of the aggregate as a **substance;** if, however, there are several different kinds of molecules or substances present, we refer to the combined material as a **mixture.** A lump of sugar is a substance; when it is placed in a cup of coffee, the result is a mixture. The sugar exhibits specific properties which are always the same, whereas a mixture displays variable properties. Living things are composed of mixtures and therefore respond as mixtures. Mixtures are much more difficult to understand than substances, and because life exists in a mixture, a very complex mixture, it likewise is difficult to understand.

The nature of atoms

In attempting to understand the material in which life resides, we are compelled to study the nature of the atom itself. In a study of this particle we must rely on the physicist, who has revealed a great deal of information in recent years concerning the constitution and behavior of the atom. The atom is composed of still smaller particles, units which have been weighed, counted, checked for speed, and measured for their electrical nature. The significance of atomic structure came to the attention of everyone when physicists were able to manipulate atoms in such a manner as to have them release tremendous amounts of energy in the form of atomic explosions.

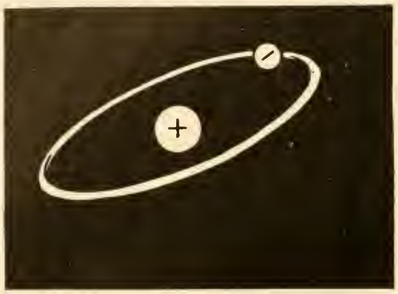


Fig. 2-3. The possible structure of the hydrogen atom. The proton with its positive charge lies at the center and the negatively charged electron revolves about it.

One might think of the atom as a miniature solar system with its relatively large, heavy **nucleus**, the "sun," and its revolving **electrons**, the "planets" (Fig. 2-3). Reminiscent of the universe, the most striking characteristic of an atom is the vast amount of space between the various particles of which it is composed. If we imagine the atom to be the size of a balloon 100 feet in diameter, it would appear as a hazy, transparent sphere. At the center would appear a nucleus, the only clearly visible part, about the size of a small marble. The electrons would be invisible, but because of their terrific speed they would appear as a dim blur, giving a vague limit to the entire structure. In some atoms there would be other concentric rings within the outer shell and these would appear as hazy as the outer shell; they might be intertwined with one another. Only the speed of the electrons would make these limits apparent, because the electrons themselves seem to have very little, if any, mass. They are "intangible units of energy," whirling at unimaginable speeds, yet maintaining remarkable stability. Atoms can be "smashed," as we all know, if unbelievable amounts of energy are directed at them. As a result of "smashing," the nature of the atom itself changes.

The nucleus of the atom consists of a dense cluster of positively charged particles, **protons**, and uncharged particles, **neutrons** (Fig. 2-4). These are held together by some unexplained intra-nuclear force. The protons and neutrons make up almost all of the mass of the atom. For every positively charged particle (proton) in the nucleus there is an **electron**, which carries a negative charge, in one of the orbits. Thus the total atom is neutral, that is, it carries no apparent charge. It is interesting to note that all of the 98 elements are made up of these units, differing one from another only because of the relative number and arrangements of protons, neutrons, and electrons.

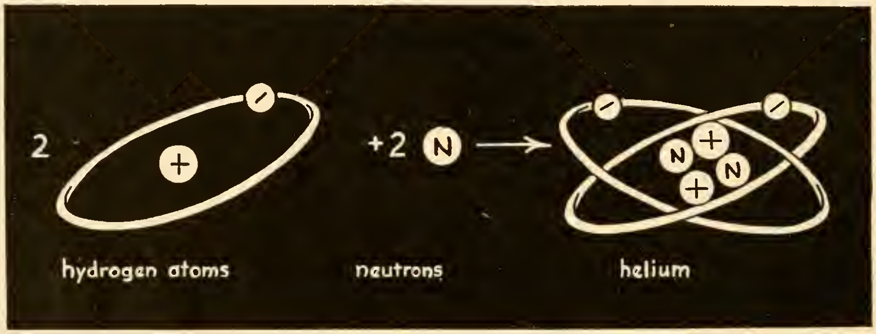


Fig. 2-4. A hypothetical explanation of how helium is formed by the combination of two neutrons with two hydrogen atoms.

A specific atom behaves the way it does because of the number of protons and neutrons in its nucleus and the number of electrons in its orbits. While there is always the same number of protons in the nucleus as there are electrons in the orbits, there may be a varying number of neutrons present in any specific atom. Since the chemical characteristics of the atom are controlled by the electrons in the outer shell or orbit, and since the number of electrons is controlled by the number of protons at the center, any additional neutrons will be without effect on the chemical properties of the atom. The only difference will be in its weight. Physicists have found that they can add or knock out neutrons as well as electrons, and thus change the physical properties of the atom itself. When only the number of neutrons is changed the resulting atom is called an **isotope**; isotopes have the same **chemical properties** as the naturally occurring atom but they have different weights, and therefore can be identified or "tagged." Tagging atoms has made it possible to trace various chemicals through the animal body. This has been very helpful in determining what happens to certain substances in normal life processes. If the isotope happens to be radioactive, that is, if it happens to give off radiations that can be detected with a sensitive instrument (Geiger counter) or by some other means, then the problem of tracing the chemical becomes less difficult. We are gaining a great deal of knowledge today from this type of so-called "tracer research," and the future holds out much promise in this field of investigation.

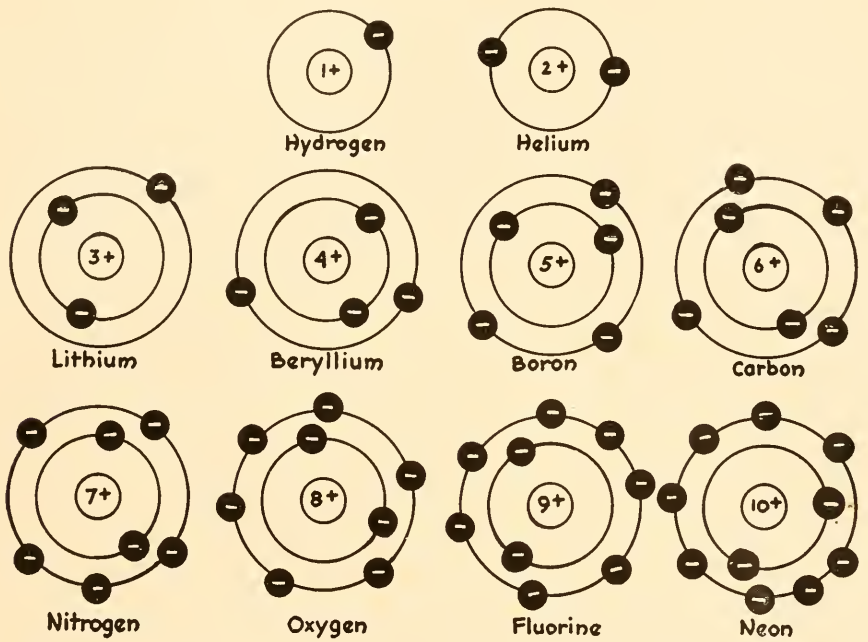


Fig. 2-5. A small portion of the Periodic Table. The number at the center (nucleus) indicates the atomic number. The electrons lie in the orbits, of which only two are shown here. The inner orbit requires only two electrons while the second needs eight, which is satisfied in neon. Of the ten elements indicated, hydrogen, carbon, nitrogen, and oxygen are important constituents of living material.

It would seem simple, then, to arrange all of the various elements in a series from 1 to 98, according to the number of electrons (or protons) in each individual atom. This has been done and we call such an arrangement the **periodic table.** It is possible to diagram this atomic sequence (Fig. 2-5). The **atomic number** corresponds to the number of electrons in the orbits, or the number of protons in the nucleus, limited in range, of course, from 1 to 98. The **atomic weights** are arbitrary figures assigned to each atom, and they depend on the number of protons and neutrons in the nucleus. Oxygen has been assigned the figure 16 and others all vary in respect to it. Since a single atom cannot be weighed, these figures must be based on measurements that starts a new outer orbit containing one electron; thus, with its two inner electrons and the one in the outer orbit, it has three altogether, giving it the atomic number 3. Sodium (not shown in Fig. 2-5) is the first atom that has a third ring, with 11 electrons in all. Usually the inner ring must be completed before the next one is formed. Following this principle the numbers of protons, neutrons, and electrons of nearly all 98 elements have been determined.

When the number of electrons in the outer orbit is less than half the total num-

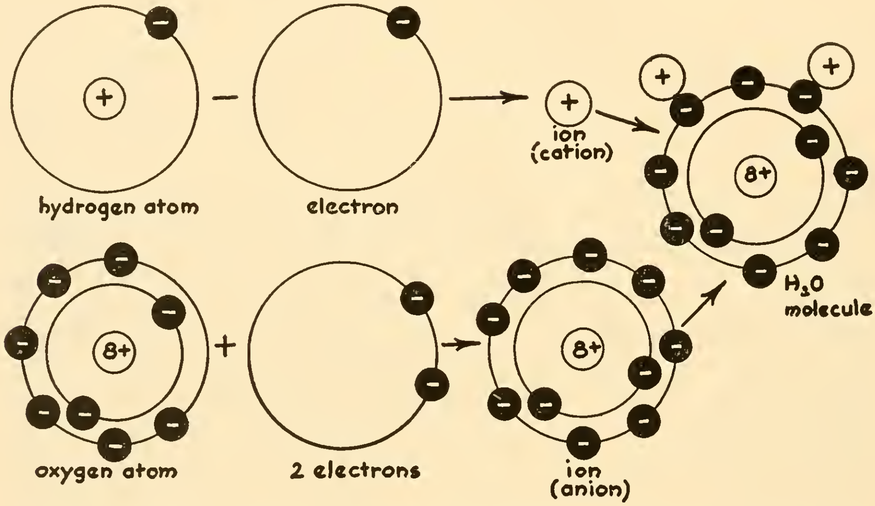


Fig. 2-6. A possible explanation for the formation of a molecule of water from two atoms of hydrogen and one of oxygen. Note that the hydrogen ion is a naked proton, and the oxygen ion is formed by the addition of two electrons. The union of the two kinds of ions produces the molecule of water.

include a great many individual atoms, hence are not absolute figures.

There are seven possible concentric rings of electrons among all of the atoms, the one closest to the nucleus containing two electrons, and each of those beyond having varying numbers. Hydrogen has one proton and one electron but contains no neutrons. It has the atomic number 1. Helium, the next in the series, has two electrons and, therefore, the atomic number is 2. However, it has an atomic weight of four, because it also has two neutrons in its nucleus along with the two protons. Lithium

ber it can hold, it may lose them, or if it has more than half, it may gain others to complete the ring. Any change in these numbers of electrons changes the electrical nature of the atom; if it gains electrons it becomes negative, and if it loses electrons it becomes positive. Whenever the atom is out of balance in respect to its electrons it is an **ion**; if it possesses an excess of electrons it is called an **anion** (because if placed in an electrical field it will move to the positive pole, the anode); if it has lost electrons it is known as a **cation** (because it moves to the negative pole, the cathode). A solution containing ions will conduct an electric current and is called an **electrolyte.** Atoms will unite to form molecules depending on the number of electrons they can deliver or consume in their ionic state. For example, the hydrogen atom has one electron; when it loses this it becomes a hydrogen ion, a naked proton. The oxygen atom lacks two electrons in its outer shell; when these are gained it becomes an oxygen ion, an anion (Fig. 2-6). When the hydrogen and oxygen ions are present in the same system, they are brought together because "unlike charges attract"; since oxygen requires two electrons to complete its outer ring, two hydrogen atoms are required to do the job. The result is a molecule of water, a stable **compound,** essential in all living things. Likewise, thousands of other molecules are formed from atoms, many of which play important rôles in biological systems.

Water forms only a very few hydrogen and hydroxyl ions (H^+ and OH^-), that is, only a very small proportion of the total number of molecules break up into these ions. Since water is the main constituent of living material it might be expected that any increase or decrease in these ions would be detrimental to life. When acids break up into ions, large numbers of hydrogen ions are produced. That is why they are called **acids.** Likewise, **bases** produce large numbers of hydroxyl ions. Because they do produce such large numbers of these ions, neither strong acids nor bases are tolerated by living things.

Of all the atoms in living things, carbon certainly is the most important. This may be due in part to its physical make-up. It possesses just one half the maximum number of electrons in its outer shell, which means that it does not lose or gain others. It unites with a large variety of other atoms by simply sharing its electrons. This arrangement permits combination with other carbon atoms to produce long chains or rings which may then join up with a large variety of other atoms to produce immense molecules. It was undoubtedly this nature of carbon that made it the central atom around which life was built. We find it permeating all biological systems and playing important rôles, not only in the construction of living materials, but also in storing and releasing energy which is essential in life processes.

From the foregoing account we see that life is a complex system of protons, neutrons, and electrons, combined into atoms and molecules, all committed by natural laws to follow specific patterns of behavior. Out of this have come all of the living things on the earth today, from amoeba to man. Our next step would logically be to find, if possible, when, where, and how the first living thing appeared on the earth.

THE FIRST LIVING THINGS

With the physical world settled down to a relative stable condition the stage was set for the beginning of this most remarkable drama, the inception and subsequent unfolding of life in all of its variety and complexity. The initial steps were almost imperceptible, extending over hundreds of millions of years, but once underway, life gathered momentum, spreading out in all directions over the extremely thin outer shell of the earth. This region, which extends only a few feet above and fewer feet below the crust itself, has become thoroughly inhabited except for small areas like the regions near the poles which possess such adverse conditions that life has never gained a foothold.

Some people have speculated that life might have come to earth from some other planet in the form of spores (capsules capable of withstanding unfavorable conditions) through interstellar space. This seems unlikely because of the intense heat it would have to endure en route. Bits of inorganic matter occasionally fall to earth in the form of meteorites; when they reach

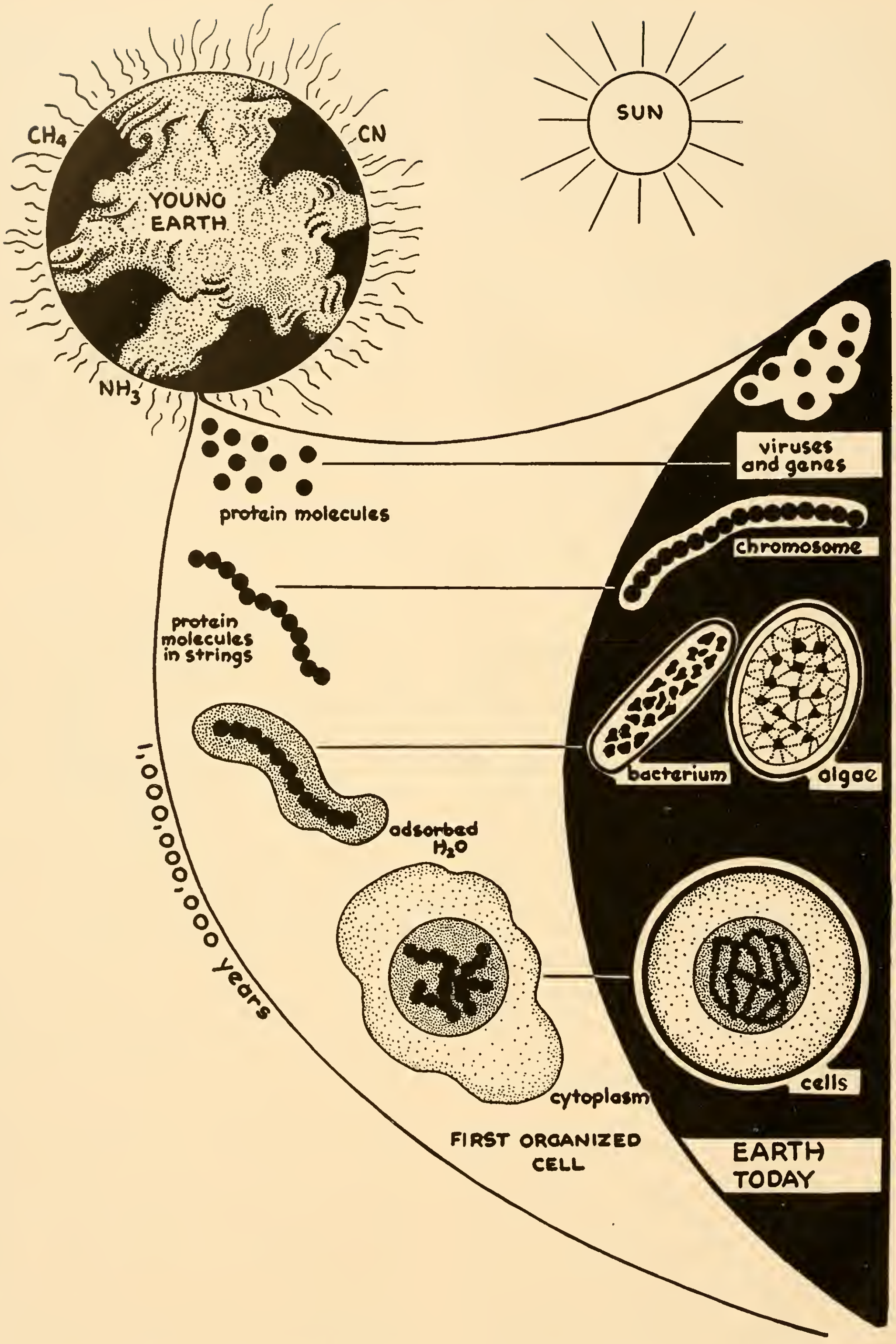
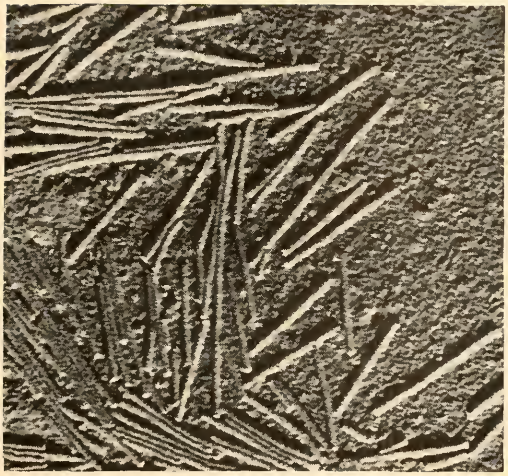
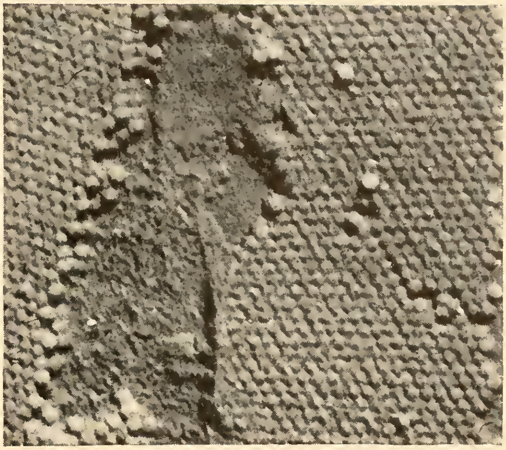


Fig. 2-7. A schematic representation of how life might have originated on the earth.



A



B

C

Fig. 2-8. Pictures of viruses taken through an electron microscope. *A.* Tobacco-mosaic virus (X60,000). *B.* Bushy stunt virus from tomato plants (X85,000). Note the regular arrangement of the particles. C. Virus that attacks bacteria (bacteriophage) are the tiny club-shaped particles. The large white spheres are used as a means of measuring the size of the virus particles.

our atmosphere they burn to incandescence. Life, as we know it, certainly could not withstand such high temperatures. It seems more within the realm of probability that life originated on this planet a long time ago. Geologists tell us that there was a time about 1 billion years ago when conditions were such that life could have started. Those conditions do not exist today, so it is unlikely that life is being generated now. Assuming this to be true, what are the most logical steps that could have taken place in its inception? From this point on, let us follow the speculations of Haldane (a British scientist) and Oparin (a Russian scientist), two men who have formulated a theory of the origin of life on earth. A sketch such as that shown in Fig. 2-7 might also be helpful. As plausible as this theory may seem, it is far from proven, and it is improbable that satisfactory proof will ever be forthcoming.

All living things are composed of complex substances called **organic** compounds. They contain carbon atoms as the central core around which hydrogen and oxygen have accumulated in a precise manner to form such substances as ethyl alcohol (C_2H_5OH), and glucose ($C_6H_{12}O_6$). Others have incorporated nitrogen into the molecule, in addition to carbon and oxygen, to form proteins, the complex compounds out of which living things are built. Therefore, conditions must have been right at this early period to bring about atomic combinations that produced these complex molecules, which later became the integral part of living material. There is reason to believe that this could have taken place because in the laboratory it has been possible, with the use of ultra-violet light, to bring about the conversion of simple substances such as methane (CH_4) and cyanogen (CN), containing carbon, nitrogen, and hydrogen, into complex organic compounds. If, during the days of the young earth, more ultraviolet light reached its surface than today, great oceans of these complex organic molecules, like great pools of organic "soup," could have formed.

These organic molecules could have formed aggregates that resembled proteins. These, once formed, must have found some way to organize themselves into reproducible entities. Such a condition is altogether possible and not pure speculation because we have reproducible protein particles with us today, namely, **viruses**, these invisible (under a light microscope) microbes so minute that they pass through the very small pores of a porcelain filter (Fig. 2-8). They cause many plant and animal diseases, including such dread human maladies as poliomyelitis, yellow fever, and many others. Viruses are composed of protein and very little else; furthermore, they reproduce themselves when placed in their normal environment, which is the internal parts of cells. They are able to organize the surrounding organic compounds into their own material and thus duplicate themselves.

Assuming that the original protein molecules were like the familiar present-day viruses, they would be forced to consume other molecules in order to reproduce themselves just as the viruses do within cells. There would come a time, however, when all of the organic molecules in these oceans of molecular "soup" would be used up. Some time before this suicidal state was reached these particles must have evolved a method of utilizing simpler and simpler substances to construct their own framework. These would be substances such as carbon dioxide and water that were present in great abundance. Once this was achieved, they could continue indefinitely without depending on a supply of complex compounds for their subsistence. This is the way plants manufacture their products today.

From non-living to living

If viruses are considered to be alive, the gap between the living and non-living has been spanned. Although, in general, viruses exhibit characteristics of living things, they do possess one property that is not usually associated with life. When properly treated, at least one virus, tobacco mosaic virus, will form crystals and remain in a state of absolute inactivity for an indefinite period of time. Living things may hibernate, form resting cysts, or otherwise remain relatively inactive for periods of time, but such vital processes as taking in of oxygen and giving off of carbon dioxide are still observable although in much reduced amounts. The crystalline virus does not demonstrate these properties. Indeed, for all purposes it seems to belong to the inanimate world. Chemists usually consider any substance that crystallizes to be a relatively pure compound; it would appear, then, that the virus is a near-pure protein, **nucleoprotein** to be exact.

When this apparently inanimate crystal is placed in the tobacco plant cell it bursts into activity, taking on all of the properties of living things. Is it possible that here is a form existing at the borderline between the living and non-living worlds? Perhaps so. At any rate, it gives us a possible clue as to how life originated.

Even with this start it is a long trek to an animal cell, to the simple single-celled animal living in stagnant water.

Genes and gene strings

All animals and plants are composed of **cells**, the details of which we shall go into later, but for the moment in order to continue our story of the origin of life, it is necessary to know something about certain vital parts of these cells. The cell is composed of a limiting **membrane**, **cytoplasm**, and a **nucleus** (see Fig. 3-1). Within the nucleus are dark-staining bodies called **chromosomes**, which are made up of **nucleoprotein** molecules or aggregates of such molecules called **genes** (Fig. 2-9). These are capable of reproducing themselves precisely, obtaining material from the surrounding cytoplasm for that purpose. In a sense, then, they resemble viruses, at least in being nucleoprotein in nature and being able to reproduce themselves. They also could be considered similar to the original protein molecules that formed in the early history of life. Here we see counterparts of these early substances in both the viruses that live at the expense of animal and plant cells and in the genes which are an integral part of all cells.

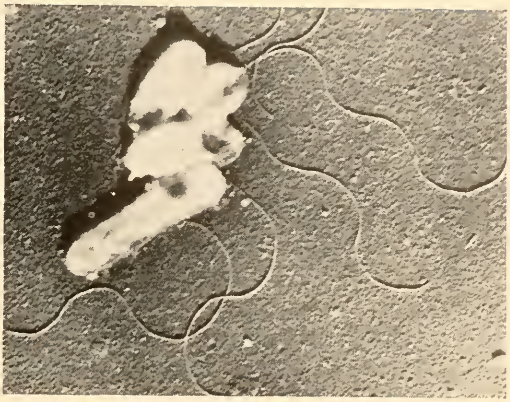


Fig. 2-10. A picture of a bacterium (*Pseudomonas flourescens*) taken with an electron microscope (X22,000). Note the long hair-like flagella that are used to propel the cell through the water.

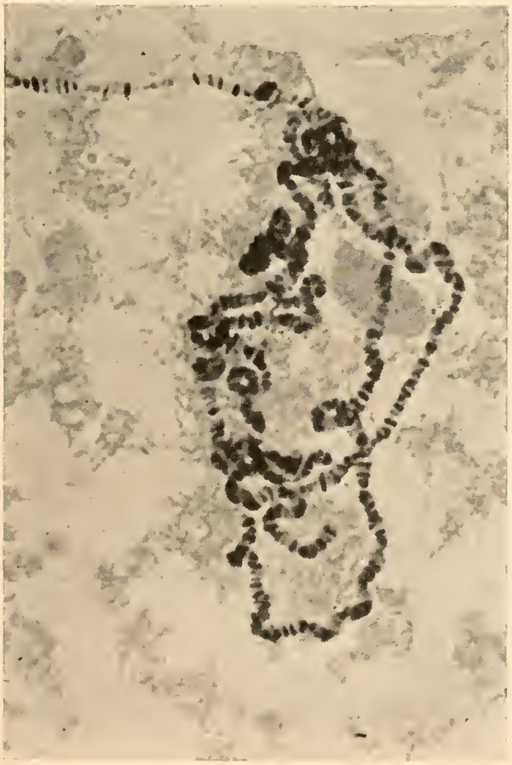


Fig. 2-9. Chromosomes are composed primarily of nucleoprotein molecules which show up in these stained fruit-fly salivary gland cells as dark bands or discs. These molecules or aggregates of these molecules probably constitute the genes.

Let us consider these independent, self-sustaining protein molecules as free-living genes. They could then aggregate into long strings resembling chromosomes, but of course they would be merely free-floating **gene strings** or **chromosomes**. Sometime later, because of their physical nature they could gather about themselves a semi-liquid, semi-solid mixture of substances which would set them apart from others in the same vicinity. Somehow a membrane could have formed, and a cell not unlike certain specialized cells alive today could have evolved. Some of the single-celled plants, such as the bacteria (Fig. 2-10) and certain blue-green algae, possess dispersed chromosomes without nuclear membranes. In fact, it is possible to select a whole series of algae which show succeeding stages from completely dispersed chromatin to those with the chromatin well centralized. The next step in this long competitive path would be the accumulation of more material about the free-living "nucleus" to make the **cytoplasm**, thereby forming the first cell as we know it today.

From this brief discussion it should be obvious that it is quite impossible to determine just what the first living thing was, and this is exactly what one might expect. By tracing living things backwards, the inevitable end would be the inorganic world; precisely when and where and how the point of departure was established is still a controversial question and will probably always be. Our biological studies have progressed far enough today to give us an inkling as to how it might have started, and with that we must go on to an examination of a few of the characteristics of living things that exist on the earth today.

THE NATURE OF LIFE

There are certain criteria which our study of living things has taught us to associate with them. No doubt exists as to whether or not a horse or rabbit is alive, but without some knowledge of a tree one might think that it is not alive, at least not in the sense the rabbit or horse is. Even the biologist becomes confused when he studies such things as viruses which fail to measure up in all respects to the living things he is accustomed to investigate. However, there are certain, rather well-defined, characteristics that pertain to living things alone, viruses excepted, which are not encountered in the inanimate world.

1. ***Movement.*** Life is endowed with the ability to move, and by that is meant **autonomous** movement, the energy for which comes from within (Fig. 2-11). To be sure, water moves in a river, a stone may roll down a hill, a car moves, but all of this movement is due to forces acting from the outside. The water in the river bed flows, the stone rolls down hill, both because of the pull of gravity; the car moves because a force from the engine is applied to the wheels, causing a forward movement of the vehicle. This type of movement is quite different from that seen in the rabbit scurrying through the thicket with the dog close at its heels. In this case, both are expending energy to move in whatever direction each desires. Life implies movement, life is dynamic. From the gross movement of the entire organism to the activity going on within each cell of the body there is always change, always movement. Such movements are linked with living things and are not duplicated anywhere in the inanimate world.

2. ***Irritability.*** All organisms exist in an external world which is spoken of as their **environment.** With this world they are all intimately associated, and it is impossible to think of the organism without its environment. If living things are to profit by this association, they must at all times be aware of the nature of their immediate external world. For this reason they are endowed with the ability to sense its characteristics and respond to them. The response may be favorable, in which case the organism stays in the environment. On the other hand, it may be unfavorable and as a result the organism moves out of the environment, sometimes very rapidly as when a pin makes contact with the skin of a small boy (Fig. 2-12). Such responses play a large part in the survival and ultimate success of a race.

An animal is equipped with an elaborate set of sense organs that keep it in constant contact with its external world; the functioning of these organs make the difference between life and death of the species. The eyes are sensitive to light, the ears to sounds, the nose to chemicals; all of these assist the animal to orient itself in its environment, and to respond in such a way as to permit its continuance as an individual and as a race.

3. ***Nutrition.*** In order that living things

Fig. 2-11. This type of movement is characteristic of living things.

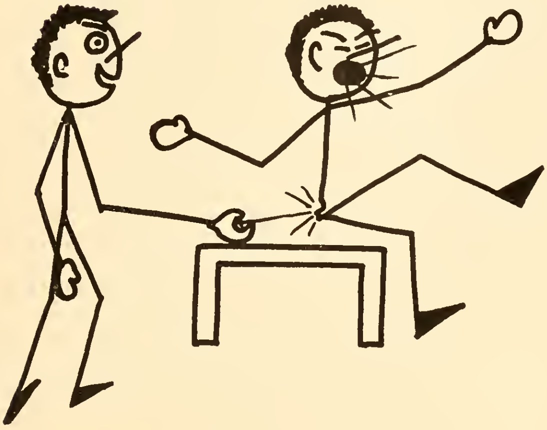


Fig. 2-12. Living things are irritable. They respond to their environment in very definite ways.

Fig. 2-13. Living things take in food from which they derive energy to carry on all their life processes.

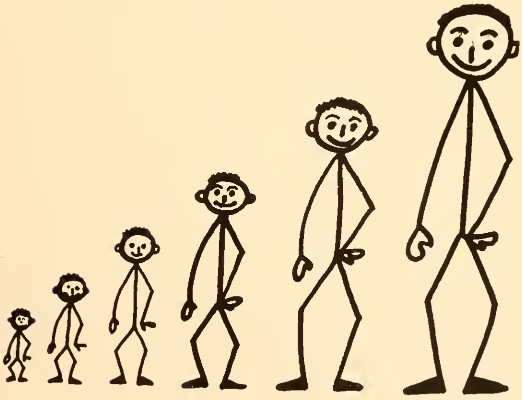


Fig. 2-14. Growth is a characteristic of all life.

Fig. 2-15. All living things reproduce and the offspring resemble the parents in most respects.

may carry on all of the processes that are essential for life they must have a constant source of energy (Fig. 2-13). They must also have building materials with which to construct more of their own substance if they are to grow or to replace parts that are worn out. The source of this energy and this building material in animals comes from the breaking down of large molecules into smaller ones and the delivery of these substances in utilizable form to all of the cells of the animal body. Animals must have food which usually exists as complex, insoluble molecules. These are broken down in the digestive tract and delivered to the cells where they can be used as needed. This is nutrition, which is confined to the animate world only; it is closely linked with metabolism.

4. ***Metabolism.*** Once the utilizable building materials and the energy-giving molecules are delivered to the cells, they undergo further changes depending on how they are used. If they are further degraded with large quantities of energy released, the process is referred to as **catabolism**, or **destructive metabolism**; if they are used in building new or repairing old parts, the process is called **anabolism**, or **constructive metabolism.** This constant building up and tearing down, storing and consuming, is referred to as **metabolism**, the crux of life itself.

During the dynamic process of metabolism oxygen is constantly utilized to release energy, with the resulting production of carbon dioxide; this is called **respiration.** The removal of the waste products of metabolism, such as carbon dioxide and nitrogenous wastes, is called **excretion.** These two processes are intimately linked with metabolism. All living things are characterized by metabolism, a process which is without duplication in the inanimate world.

5. ***Growth.*** When the constructive forces exceed the destructive forces in an organism, it increases in size, or, in other words, it grows (Fig. 2-14). This is typical of all organisms, particularly during their early life. However, a stage is reached where there is a balance between these two forces, and this is referred to as **maturity**; at the time of maturity the organism merely holds its own, becoming neither larger nor smaller. As life continues, the anabolic processes fail to keep pace with the catabolic processes, and the whole bulk of the organism loses ground and finally dies. This involves the processes of aging, the nature of which is understood only vaguely.

Growth of living things is quite different from that of inanimate bodies. A crystal may grow in size by the addition of other similar crystals to its own bulk, but the pattern and the method of executing it are quite unlike that of a living cell. The crystal merely adds other crystals to its own external mass (accretion), like a mason adds bricks to a wall, whereas the cell takes its building materials within, and there makes them an integral part of its own structure (intussusception).

6. ***Reproduction.*** As a result of growth and increase in size, the organism is able to duplicate itself (Fig. 2-15). It may do this by simple **fission**, that is, by dividing into two equal parts, or it may produce special reproductive cells, **eggs** and **sperms**, which subsequently unite to grow into a new organism similar in most respects to the parents. Duplication by the first process is called **asexual reproduction**, and by the latter, **sexual reproduction.** Reproduction by either of these methods is not shared by the inanimate world.

One of the remarkable things that stems from reproduction is the continuity of pattern from generation to generation. Offspring are endowed with structural and physiological characteristics that are exact duplicates of those found in the parents. The pup, colt, or child is expected to possess bodily form, and even personality traits, similar to those of its parents. This knowledge is so commonplace that it was taken for granted for centuries. The transmission of these characteristics from parents to offspring is known as **heredity**; just how this is done has stimulated biologists in recent years to search for the explanation at the level of molecules. The search has been fruitful, as we shall learn a little later.

PROTOPLASM AND LIFE

If the characteristics of living things are to be understood, it is necessary to study the physical material in which life resides. This material was observed by early biologists and was given the name **protoplasm** by Purkinje over 100 years ago. The word means the first form (*protos*—first, *plasma*—form). If tiny pieces of any plant or animal are examined with a microscope, they will be found to be composed of cells, each of which contains protoplasm. Therefore, a study of this material is essential if much useful information is to be had about *what life is* and *how it works.* We do not have the answer to the first of these questions at present, but some progress is being made on the second. If and when the answers do come, they will probably come from a study of protoplasm itself.

Recalling our earlier discussion of the origin of life, it must be concluded that protoplasm is very complex. It is so delicately adjusted physico-chemically that any attempt to find out how it behaves or of what it is made means immediate loss of the very thing sought for. It can be handled only with utmost care without killing it. A dead animal no longer possesses protoplasm, because by definition protoplasm encompasses that "something" called life. Biologists are not interested in "something," rather they are concerned with the underlying principles that explain life. What protoplasm is composed of, how these materials are organized in the cell and the body, and how they interact with one another to generate that which is referred to as life, are among the most fundamental questions which the biologist is seeking to answer. While the problem at the outset appears to be insurmountable by its very nature, some progress has been made by employing the methods of the chemist and physicist. Today a great deal is known about protoplasm, but there is much more to be learned before a complete understanding of life can be had.

HOW DOES PROTOPLASM LOOK?

The superficial examination of any living thing reveals a more or less homogeneous surface to the naked eye. If, however, small thin pieces are removed and placed under the microscope, an entirely different picture is seen. The over-all pattern of tiny repeated units, **cells**, is the most striking impression that one gets. Now, if one of these cells is observed with the highest power of the microscope, some of the visible features of protoplasm can be detected. It would not matter what cells we used for this study; they would all include protoplasm, which would appear remarkably alike in all of them. This fact was learned by the early biologists, which convinced them that protoplasm formed the "physical basis of life," a statement with which we fully agree today. One never finds life residing anywhere but in protoplasm, with the possible exception of the controversial viruses.

Since all cells are very similar in respect to their protoplasmic content, let us select a large animal cell for study. **Amoeba**, a single-celled animal, will do very well because it is huge as cells go and its parts can be seen very easily under an ordinary light microscope (Fig. 2-16). The general impression that one gets from observing this tiny animal is that its protoplasm is grayish in color and is usually moving about within the limits of the organism. The cell crawls about by sending out projections, called **pseudopods** (false feet). Such a pseudopod forms by forcing out a clear watery lobe which is immediately followed by granular

Fig. 2-16. A living amoeba, when viewed under the light microscope, gives us some clue as to the nature of protoplasm. Note the clear protoplasm that constitutes the pseudopods and the more or less opaque region that makes up the bulk of the cell. Tiny particulate matter floats about in the body of the cell, conveying to it a gray color.

material from within the cell. The most striking fact that one observes is that the entire mass of protoplasm is moving in what appears to be a more or less haphazard manner, even though the general flow is in the direction the organism is going. Another important observation is that there appears to be many different kinds of particles suspended in this semi-fluid, semisolid material. Some of the particles seem quite uniform in shape, whereas others are variable. Among them is the large flattened **nucleus**, several **food vacuoles**, and a clear **pulsating vacuole**, none of which will concern us now since they will be discussed later when we examine this little animal more thoroughly. Our concern now is with the material in which all of these are suspended, that is, the protoplasm.

Our observations so far tell us very little about the nature of protoplasm, but we can try a few experiments on it. For example, we can drop a little alcohol or mercuric chloride on it to see what happens. All activity suddenly stops, and the entire cell becomes rigid, much like the white of an egg when cooked. It coagulates and becomes slightly opaque. Nothing we can do will revive it, it has died, and in so far as we know now this is an irreversible reaction. It could then be given to the chemist who is able to give us a list of the elements and compounds of which it is composed. After this and many other experiments, we would still know very little about how the amoeba moved, how it reproduced, or how it carried on its metabolism. We need still more refined techniques if more is to be learned. Lacking these, we can only speculate from this point on, in order to obtain a little better picture of what happens in this beautifully complex protoplasm.

Let us suppose that we could magnify the protoplasm of an amoeba until we could observe its molecular structure. This is beyond the power of the electron microscope, which can magnify 100,000 times. The microscope we have in mind would also need to be designed to view living material, something the electron microscope cannot do. The most obvious characteristic, as we peer at this blob of protoplasm, would be the violent activity of molecules of all shapes and sizes. The most numerous would be the water molecules, which, because of their small size, would move faster than most molecules. Huge, slow moving molecules would be bound together, forming a continuous network of material that remained in one place most of the time, as an outer boundary of the cell marking it off from the outside world. This would be the plasma membrane, through which the water molecules pass freely in both directions. Many other molecules pass through also, but some are stopped because of their large size, whereas others are stopped because they possess electrical properties that prevent them from getting past the electrical barrier on the membrane. Oxygen molecules enter freely, uniting with larger molecules which suddenly break up into a great many smaller molecules, some of which immediately leave the scene through the plasma membrane. This is the union of oxygen and glucose, producing carbon dioxide and water. There would be many other kinds of molecules, small and large, apparently floating about but in reality performing very specific functions which we do not understand at the present time.

This mass of molecules in endless motion, constantly changing, adding new molecules, losing others, combining and separating, is protoplasm. This dynamic activity constitutes the thing we call life. The molecules are no different from those in the inanimate world; they react in the same way. It is only when they come together in the combination to form protoplasm that they exhibit the characteristics we associate with life.

Although much of the foregoing discussion is based on speculation, there is considerable evidence to demonstrate that perhaps the speculations are not too far from the truth. What can we learn about protoplasm with ordinary laboratory equipment? Let us go a little further into its chemical and physical nature.

CHEMICAL COMPOSITION OF PROTOPLASM

If a mouse, butterfly, elephant, or a plant were analyzed in the chemist's crucible and the elements named, they would be remarkably similar in all of these widely different forms of life. The four principal elements are carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). Carbon is the core element of the complex molecules found in protoplasm, probably because of its physical nature which was discussed earlier (p. 29). Additional elements regularly present in protoplasm are phosphorus (P), calcium (Ca), iron (Fe), potassium (K), sulfur (S), iodine (I), magnesium (Mg), sodium (Na), and chlorine (Cl). There are many others existing only as traces but nevertheless essential for the normal activities of protoplasm.

Elements in protoplasm usually are found combined in the form of **inorganic** and **organic compounds.** The former go to make up most of our world we live on, whereas the latter are always derived from living things. The **inorganic** compounds that are important in protoplasm are **water, inorganic salts,** and certain dissolved gases, such as oxygen, nitrogen, and carbon dioxide. Important **organic** compounds are **lipids** (fats and related substances), **carbohydrates,** and **proteins.** These we must consider in more detail.

Inorganic compounds in protoplasm

Water. Of all the inorganic compounds in protoplasm the most important is water, the substance in which all other materials are suspended and transported. Life without water would be impossible, because there would be no means of mixing and dispersing the energy-yielding and building materials of protoplasm. Water is important in protoplasm because of its many unique properties.

Water **dissolves** more substances than most any other liquid. This property of water makes possible the mixing of a large variety of substances that would not dissolve in any other liquid. Hence, the great complexity of protoplasm has come about because so many different substances could come together and mix freely in one common medium. Furthermore, interactions occur more readily between substances in a fluid condition where ample freedom of movement of the molecules is permitted. In a dry state, where substances are less free to mix with one another, chemical union would be greatly impeded.

Water has a high capacity for **holding heat.** It is reluctant to take on or lose heat, a physical property that is very important in living things. Anyone living near large bodies of water is aware of their tempering effect on the climate of the surrounding areas. The winters are not so cold and the summers not so warm as they are farther inland. The water warms up slowly and, likewise, cools slowly, conveying this difference to the adjoining land. Since our bodies are primarily water (approximately 65 per cent), we respond to heat much the same as water does. If this were not the case, it would be almost impossible for us to remain in the sun any length of time without becoming overheated; in fact, any place where the temperature differed greatly from that of our bodies could not be tolerated. The ability of the body to maintain an even temperature is a result of this property of water.

Water possesses some interesting **chemical properties** that make it an ideal medium in which life can be supported. Water has more ability than any other substance to dissociate molecules into their **ions** (see p. 28). Salts such as sodium chloride (NaCl) ionize readily in water; others such as sugars and starches do not ionize at all. Water itself ionizes slightly forming hydrogen (H^+) and hydroxyl (OH^-) ions. However, the number of water molecules that form these ions is so small (1:555,000,000) that water is a rather poor conductor of electricity. Both H and OH ions are extremely active and for this reason they seem to be tolerated only in very small numbers by protoplasm, that is, any increase of either over the other brings about prompt changes in the activity of protoplasm, and any marked increase or decrease terminates life. By employing delicate instruments capable of detecting the slightest increase or decrease of either one of these ions, it has been shown that protoplasm is approximately neutral all of the time, the numbers of each of these two ions being approximately the same.

Salts. Many inorganic salts of sodium, potassium, calcium, and magnesium exist in protoplasm. Inorganic acids are also found in small concentrations. The rôle played by these various compounds will come out as we progress with this study.

Gases. Because of their diffusing qualities, gases tend to enter protoplasm the same as they enter other material. Therefore, gases such as oxygen, nitrogen, and carbon dioxide found in the atmosphere are also present in protoplasm. Since the atmosphere contains over 20 per cent of oxygen, considerable quantities of this gas are found in protoplasm. **Oxygen,** of course, is very important in the release of energy. **Nitrogen,** on the other hand, is even more abundant, but because of its chemical inertness it takes part in no reactions that are important in metabolism. **Carbon dioxide** exists in small amounts both in the atmosphere and in protoplasm. It tends to accumulate in protoplasm because it is one of the end products of the oxidation of foods, but it is a waste product and is soon removed from the cell body.

Organic constituents of protoplasm

By definition organic compounds contain carbon. We have already spoken of the physical properties of carbon that make it an ideal element around which so many compounds can be built. The most significant organic compounds in protoplasm are *carbohydrates, lipids,* and *proteins.*

Carbohydrates. Carbohydrates, such as sugars and starches, are commonly defined as compounds composed of carbon, hydrogen, and oxygen in which the atoms are arranged in the ratio of 1C:2H:1O. Not all carbohydrates fit this description exactly, but most of them do. Two examples of common carbohydrates will illustrate the way the molecules are constructed. **Glucose,** the sugar in blood, has the formula $C_6H_{12}O_6$, and **sucrose,** common table sugar, has the formula $C_{12}H_{22}O_{11}$. Note that both contain carbon, hydrogen, and oxygen, and that the C atoms number six or a multiple thereof, while the ratio of H to O is 2 to 1, just as it is in water. Also note that sucrose is simply two molecules of glucose, less one molecule of H_2O. This is explained below.

In the leaf of the plant, CO_2 and H_2O unite under the influence of the sun's rays and in the presence of a green plant pigment called chlorophyll, to form glucose in this manner:

$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$$

This chemical reaction is known as **photosynthesis.** It is the starting point in the formation of all food substances. Glucose is known as a **monosaccharide.** By the simple subtraction of water (dehydration) from two glucose molecules a **disaccharide,** *sucrose,* is formed, thusly:

$$\underset{\text{glucose}}{2\ (C_6H_{12}O_6)} - H_2O \rightarrow \underset{\text{sucrose (cane sugar)}}{C_{12}H_{22}O_{11}}$$

If this is continued, large molecules can be built up. Such compounds are called **polysaccharides,** and are illustrated by **starch** in plants and **glycogen** in animals. Starch and glycogen do not dissolve readily in water and consequently are ideal storage materials.

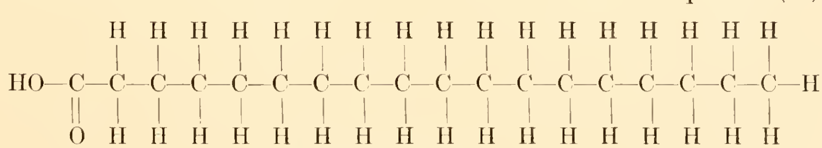
The reverse process is simple also, for by merely adding H_2O (hydrolysis), the large molecule falls apart into many molecules of glucose, the number depending on the original carbohydrate molecule. This is what happens during digestion in the animal body, a process we are to discuss in some detail later.

Glucose is the most important carbohydrate in protoplasm because it is the substance that unites with oxygen to release energy that is essential in the business of living. We think of carbohydrates as energy foods.

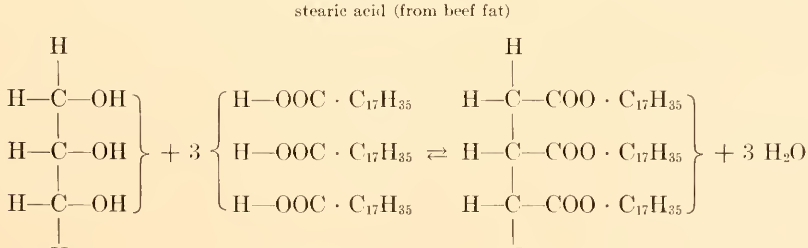
Lipids. These include all of the fats, oils, and fat-like substances identified by a greasy texture. They are relatively insoluble in water, but soluble in hot alcohol, ether, and chloroform. With a few exceptions they all contain C, H, and O like carbohydrates, the chief difference being their low oxygen content. This is easily illustrated by examining the formula of a common fat taken from beef tallow, $C_{57}H_{110}O_6$. Note that there are only 6 oxygen atoms as compared to 57 carbon and 110 hydrogen atoms. This means that when fats burn, they require more oxygen than does glucose. It also means that the molecule can release more energy per gram when burned. Their insolubility makes fats desirable material for the storing of energy.

Like the starch molecule, a fat molecule is composed of simpler components that can be separated by hydrolysis. These are **glycerol** ($C_3H_8O_3$) and fatty acids. A common fatty acid is **stearic acid** with the formula ($CH_3(CH_2)_{16} \cdot COOH$). This is called an acid because the carboxyl group (COOH) can liberate one hydrogen ion when dissolved in water. It can be written as in Equation (A) below.

Going back to the plant leaf again, fatty acids are joined with glycerol to form fats of different kinds. This is done by the loss of water, as shown in Equation (B) below.

(A) 

stearic acid (from beef fat)

(B) 

1 molecule glycerol | 3 molecules stearic acid | 1 molecule fat | 3 molecules water

As in the case of starch, the reverse action, hydrolysis, takes place during digestion when water is added, splitting the fat into fatty acids and glycerol.

There are other lipids called **phospholipids** and **steroids**, which have elements such as phosphorus in combination with one of the fatty acids. They resemble fats in many ways, but have other characteristics that tend to set them off in a group by themselves. Some of them play their rôle in the plasma membrane where they are responsible for the selective action of this delicate structure. They are also important in some of the intricate chemistry of the animal body which we shall touch on later.

Proteins. In addition to C, H, and O, proteins contain the elements nitrogen (N) and sulfur (S); usually phosphorus (P) is also included. These are all combined into huge molecules, some composed of thousands of atoms. Like starch and fats, protein molecules can be hydrolized to simpler components, called, in this case, **amino acids.** There may be hundreds of amino acid molecules in a single protein molecule but, when broken down, it yields only a few different kinds of amino acids. There are about 25 amino acids known, all of which are not usually found in any one kind of protein. The proportion of the different amino acids will depend on the nature of the original protein molecules.

The atoms of the amino acids are arranged in a definite manner so as to produce two distinctly specific groups by which they can always be identified. They have the general formula

$$\begin{array}{c} R \\ | \\ H\text{—}C\text{—}NH_2 \\ | \\ COOH \end{array}$$

where R represents the main portion of the molecule. The remainder is found in virtually all amino acids. It will be noted that there is one group containing NH_2, which is spoken of as the **amino group;** the other contains COOH, the **carboxyl group,** with which we are already familiar (p. 41). These two groups are responsible for the behavior of amino acids. It is obvious that the presence of the carboxyl group gives the molecule acidic properties, just as is true of any organic acid. Strangely enough, an amino acid can also act like a base due to the presence of the NH_2 group. It responds like a base by removing hydrogen ions, not by delivering hydroxyl ions. This is demonstrated by the following equation:

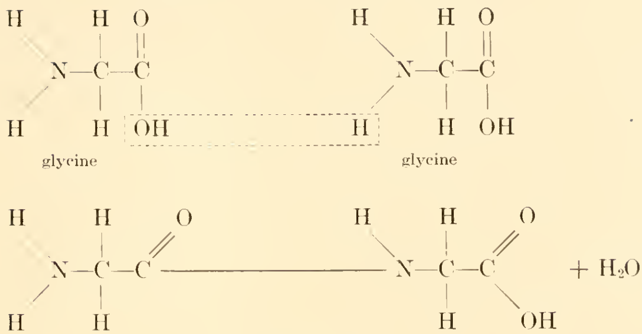
$$R \cdot NH_2 + H^+ + Cl^- \rightarrow R \cdot NH_3 + Cl^-$$

In the presence of an acid, then, an amino acid acts like a base by absorbing or removing the hydrogen ions. On the other hand, in the presence of a base it acts like an acid by delivering hydrogen ions from its carboxyl groups, thus:

$$R \cdot COO^- + H^+ + Na^+ + OH^- \\ \rightarrow R \cdot COO^- + Na^+ + H_2O$$

A substance that responds in this fashion is said to possess **amphoteric** properties. It therefore always has a tendency to bring a solution to neutrality, that is, to balance the number of hydrogen and hydroxyl ions. For this reason, amino acids tend to prevent too much fluctuation in the number of hydrogen and hydroxyl ions in a solution. Such a substance is spoken of as a **buffer;** amino acids are good buffers.

Amino acids unite to form proteins in the plant leaf by the same process that starch and fats were produced, namely, by the loss of water. Likewise, in every cell of the animal body proteins must be assembled from the amino acids that come to it through the blood stream. Just how this is done has puzzled chemists for a long time, but it is thought to occur through the so-called **peptide linkage.** The following equation will illustrate how this occurs:



glycyl-glycine

In this manner the various amino acids are tied together to form molecules that range in size from several hundred to several thousand atoms. Their size can be estimated by the relative molecular weights. For example, glycine has a molecular weight of 75, whereas that of the oxygen-carrying protein of the crayfish's blood (hemocyanin) is over 5 million. Obviously, by combining the 25 amino acids in various ways, limitless numbers of different proteins can be formed. That is why the proteins of every animal or plant differ from those of every other animal or plant. It is a well-known fact that proteins of one species of animal cannot be exchanged with those of another. For example, it is impossible to transplant skin, let us say, from the back of a dog to the face of a man because the proteins that go to make up the skin are different in both man and dog. Think what startling surgery could be performed if this were possible!

Proteins are the most characteristic and most abundant material (exclusive of water) in protoplasm. Besides forming the actual supporting structure of protoplasm, proteins afford excellent material in which the large variety of chemical reactions essential for life take place.

Enzymes. Enzymes have been mentioned from time to time in the foregoing pages without an explanation of what they are; that must be clarified now. Enzymes are frequently spoken of as **organic catalysts,** which may be defined as substances that hasten a chemical reaction but are not themselves consumed by the reaction. The numerous enzymes present in all protoplasm are responsible for the complex reactions that go on so smoothly within every cell. Without enzymes protoplasm loses its ability to start and maintain the multitude of activities that go on within it. They are absolutely essential in the business of living but the details of their operation are only now beginning to be understood.

A simple experiment will demonstrate how an enzyme works. A watery starch solution is placed in two test tubes, to one of which is added saliva, to the other, nothing. Any attack on the starch can be detected by using an appropriate test for **maltose,** one of the products of polysaccharide breakdown. Within a few minutes this sugar can be demonstrated in the tube containing saliva, whereas in the tube without it there will be no maltose for many hours. The enzyme **ptyalin** brings about this reaction without fuss or furor. The same breakdown can be accomplished without the enzyme, but it requires drastic treatment with strong acids at high temperatures, conditions that could not be tolerated by protoplasm. It is obvious, then, that enzymes can bring about a difficult chemical change at body temperatures and in a very short period of time. All of this is essential if the many reactions that go on in protoplasm are to occur as quickly and smoothly as they do.

In order that some appreciation may be

had of the number and variety of enzymes present in protoplasm, consider for a moment the burning of glucose to CO_2 and H_2O. This can be done in a test tube, providing external heat is applied, much more than could be tolerated in an animal body. However, this reaction proceeds speedily and without any marked temperature elevation in protoplasm. The impressive thing about this apparently simple process is that there are at least 25 steps involved in this oxidation, and probably a different enzyme is participating in each step. The glucose is broken down step by step, each enzyme contributing its part in the proper order. Furthermore, each enzyme involved in every step is specific for that step. It does that one job alone, and no other. Their specific action reminds one of union workers, each doing his own job and no other. Think of the myriad enzymes that must be present in protoplasm to make life possible.

The analysis of over 30 enzymes up to the present indicates they are protein in nature. The first one, **urease**, was crystallized in 1926; many others have been produced in pure form since. In general, an enzyme can accelerate a reaction in either direction, that is, its action is reversible. Experimentally, however, it is much easier to demonstrate the activity of enzymes that bring about exothermic reactions which liberate energy, than endothermic reactions which store energy. Theoretically, enzymes that break down a glucose molecule should be able to reconstruct the molecule, providing energy is supplied from the outside. This may be true, but it is difficult to prove because an exothermic reaction is required to supply the energy needed for the reconstruction at the same time as the endothermic reaction is going on. It is impossible to observe them simultaneously. These **coupled reactions** must always proceed synchronously and since they are locked up within the cell, they are extremely difficult to observe.

The activity of enzymes is controlled by the movement of molecules just as all chemical reactions are. As the temperature rises from 0 to 40 degrees Centigrade, enzyme action increases; with each 10 degree rise in temperature the action doubles, up to a critical temperature of about 40 degrees where all activity ceases. It is interesting to observe that cold-blooded animals (called **poikilothermal**, that is, those that cannot maintain a constant body temperature, such as insects, frogs, and lizards) are forced into hibernation because at reduced body temperatures enzymatic activity is slowed to a point where normal response is impossible. Warm-blooded animals (called **monothermal**, that is, birds and mammals) are not bothered in this respect because their bodies maintain a constant temperature. It is not sheer coincidence that the body temperature of these animals happens to be the point of optimal activity of the body enzymes.

Enzymes are particularly sensitive to hydrogen and hydroxyl ions, as well as certain other specific ions such as calcium. Digestive enzymes do their best work in solutions with the proper number of hydrogen and hydroxyl ions. **Ptyalin** in the mouth acts best at or near neutrality, whereas **pepsin** in the stomach requires a strong acid solution for optimal activity. **Trypsin** in the small intestine needs a slightly alkaline medium to do its best work.

Enzyme chemistry is an active field of research today and it is hoped that much more will be learned in the next few years about *how* enzymes work.

Coenzymes. Intimately linked with intracellular enzymes are certain simpler organic compounds which are essential in certain vital metabolic processes in protoplasm. These non-protein molecules are called **coenzymes.** They are so associated with certain enzymes that neither is effective without the other. Vitamin B_1 is a coenzyme which is essential for the operation of several oxidizing enzymes in both plants and animals. Strangely enough, animals are unable to synthesize many of these coenzymes so they must receive them through their food supply. The ultimate source of all of them apparently is plants.

PHYSICAL NATURE OF PROTOPLASM

We have examined the chemical composition of protoplasm and have found it composed of particulate matter in a vast array of sizes. These particles obey the same physical laws whether in or out of protoplasm. They behave in particular ways when isolated from others of the same kind, or when in close association with those of similar structure. If each particle follows specific laws of behavior when among its own species it will behave differently when mixed with others of a different sort. Since protoplasm is made up of many kinds of molecules, it follows that the operating forces become extremely complex. In spite of this almost hopeless confusion each particle seems to take its part in a definite pattern so that an orderly procession of reactions occurs. Let us examine some of these physical properties of protoplasm.

Size of protoplasmic particles

It was implied in an earlier chapter that the size of particles had a profound effect on their behavior. We should, therefore, have some appreciation of the relative magnitude of the innumerable particles of matter existing in protoplasm.

In order to speak with any degree of accuracy about the size of these tiny particles it is necessary to apply some unit of measurement to them. Scientists throughout the world employ the **metric** system of measurement almost exclusively. Fractions of the meter, **microns**,* are used by the microscopist because these units are convenient for measuring objects that fall within the range of the microscope. For example, red blood cells in man are about

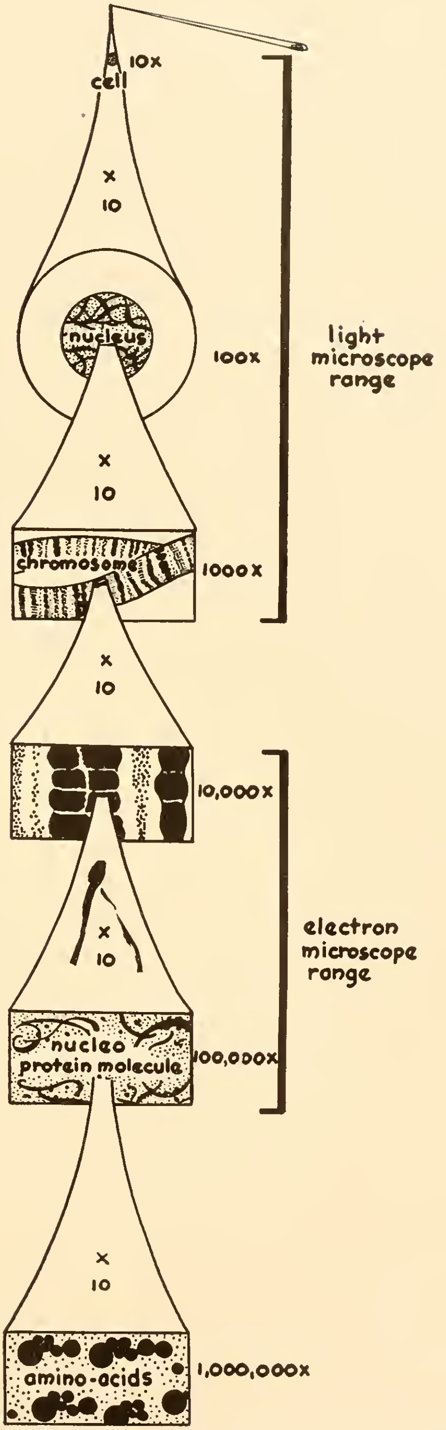


Fig. 2-17. Relative sizes of things that are of interest to the biologist. Magnifications greater than 100,000 are useful to the physicist and chemist.

* 1 meter = 1000 millimeters; 1 millimeter = 1000 microns; 1 micron = 1000 millimicrons.

7 microns in diameter. Smaller objects, such as the particulate matter in protoplasm, are measured in **millimicrons**. It is possible to measure particulate matter with the same degree of accuracy that can be attained in the macroscopic world.

To demonstrate the relative sizes of objects we may use a cell as the starting point. A large cell of your body, a cell lining your mouth, for example, would occupy a space about the size of a needle point (Fig. 2-17). If this were magnified ten times, you would see it quite easily with the naked eye but the parts would not be very well defined. Magnifying it another ten times (100X) brings the nucleus and cytoplasm into full view; even the nuclear structure can be made out. Another tenfold increase (1000X) shows the chromosomes in outline, but not in detail. A magnification of 100 to 3000 is the range in which the microscopist works with a light microscope. Any further increase in size must be viewed through the electron microscope, which operates much the same as the light microscope except electrons are used instead of light waves for a source of illumination. Of course, these cannot be seen directly with the eye because our eyes are sensitive only to light rays and not to electrons, but such objects can be photographed (Fig. 2-9). Furthermore, the treatment of the material is so drastic that living things cannot be studied under an electron microscope. In order to study any material it must be sliced into extremely thin sections (less than 1 micron). With this instrument, magnifications can go up to 100,000 diameters, which will reveal viruses and the larger molecules such as nucleoprotein molecules.

The electron microscope allows us to see things in the molecular state. Beyond this, we must rely on methods familiar to the physicist to demonstrate the size and shape of particulate matter, methods that are beyond the scope of this book. Physicists are able to measure the size, shape, and behavior of molecules and atoms, and are now working on the nature of the components of the atoms themselves. For the present discussion it is only necessary for us to think in terms of the size of particles at the molecular level, because protoplasm is molecular.

Colloids and crystalloids

If a solid is ground to particles the size of dust, and these placed in water, they will form a murky fluid and after a time will settle to the bottom of the container. If the particles are ground still finer they will reach a size when they remain in suspension and do not settle out even after a long time. These particles are then in the **colloidal** state. Therefore, whether or not a substance exists as a colloid is merely a matter of size. Physicists have set an arbitrary figure for colloids; they state that particles ranging in size from 0.1 to 0.001 micron are in the colloidal state. A **colloidal system** can often be observed with the naked eye. For example, if egg albumin, which is composed of large protein molecules, is placed in water the solution has an opalescent appearance. Light rays will strike the suspended particles and be scattered, rather than pass directly through as would be the case if the particles were smaller. We do not see the individual particles, only the effect produced by scattered light. However, if the particles are larger than 0.1 micron in diameter, the light will be blocked altogether and the system will appear opaque, as it does in milk, for example. The larger particulate matter in milk will, of course, separate out (cream on the surface) and is therefore not colloidal.

The large size of colloidal particles also prevents them from passing through an animal membrane. If egg albumin is placed in a loop of frog skin and submerged in water, very little, if any, of the albumin will be found in the water even after hours have elapsed. Furthermore, colloidal particles move slowly when compared to smaller particles such as atoms or ions. This might be expected from our knowledge of the movement of objects that come within our experience. Physicists tell us that the movement of particles is dependent on the absorption of **heat**; the higher the temperature, the faster the movement and the lower the temperature, the slower the movement. Movement is governed by the size of the particle; when the diameter of the particles is halved, the rate of movement is doubled. Therefore, the huge lumbering molecules in a colloidal system move slowly compared to the tiny molecules of a salt solution.

Particles that are smaller than 0.001 micron in diameter are called **crystalloids**; sugar or table salt dissolved in water forms a crystalloid solution. Such systems appear clear and transparent to the naked eye because light passes directly through without being changed in any way by the tiny molecules of salt and sugar. Furthermore, crystalloids pass readily through some membranes such as frog skin, and their individual particles move much faster than those in the colloidal state.

Protoplasm contains numerous crystalloidal and colloidal particles in the form of atoms, molecules, and molecular aggregates. The particles remain evenly dispersed and do not respond to the pull of gravity because of their continuous movement. Each particle is being bombarded by others of its own kind as well as by those of a different sort. This can be verified by observing even larger particles, such as certain pollen grains, under the highest powers of a light microscope. They will be seen to jostle about in a random manner, seeming to get nowhere. The apparent aimless motion has been given the name **Brownian Movement.** In an aqueous solution much of the activity is due to the bombardment of water molecules which, of course, are much smaller. It requires millions of hits of water molecules to move the huge visible particles and these must be concentrated more on one side than the other if movement is to occur in any one direction. It is the change in concentration of bombardment that causes the particle to move in the random fashion that is observed. This type of activity is essential in keeping the particulate matter dispersed.

Other factors complicate the behavior of particles in solution. We learned earlier that atoms and molecules may become ionized, that is, they may carry an **electrical charge, positive** when electrons are short, and **negative** when electrons are in excess. We also know that particles of the same charge repel one another while those of unlike charges attract. This fact has a profound effect on the behavior of particles in solution.

In a solution the dispersion medium is called the **solvent,** whereas the dispersed particles are the **solute.** Because of the electrical charges on the various particles of the solute, some are attracted to one another, while others are kept apart. Furthermore, some of the molecules of the solvent are attracted to those of the solute, thus increasing their bulk. The strange thing about the charge on a particle is that it may be stronger at one side or end than at the other; in other words, it can exhibit **electrical polarity** just as a magnet does. Because such substances as water, salts, and proteins exhibit polarity they are called **polar** compounds. Fats and starches do not possess these properties, so are called **non-polar** compounds. This property of particles has considerable bearing on their behavior in protoplasm.

When the dispersed particles are molecular aggregates of solid material they are spoken of as **suspensions**; if the aggregates are fluid they are referred to as **emulsions.** There may be a wide range in size of these particles from those that are so small as to constitute a colloidal solution to those that are visible under the light microscope. A familiar emulsion is milk, in which droplets of fat are dispersed in a watery fluid of sugar, salts, and a soluble protein.

It is essential to distinguish between the

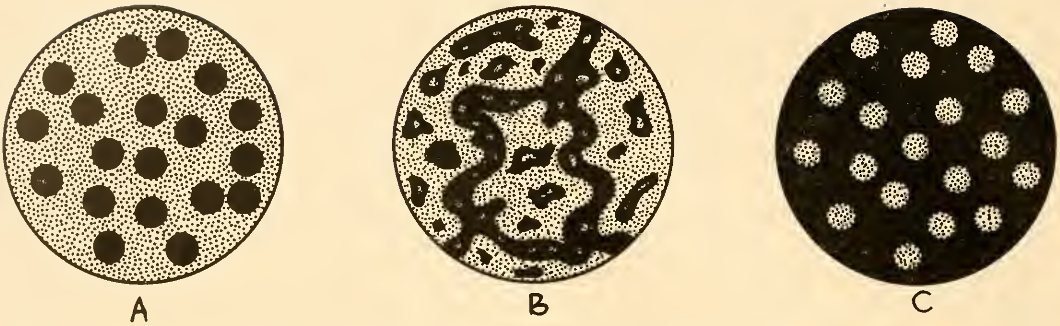


Fig. 2-18. Stable and unstable emulsions of water and oil (with a red dye) as seen under the microscope. *A* is the oil-in-water, *C* the water-in-oil, and *B* the unstable emulsion.

two phases of suspensions and emulsions, that is, to differentiate between the dispersed particles and the dispersing medium. The **continuous phase** refers to the latter, whereas the **discontinuous phase** identifies the former. Using milk again as an illustration, the fat globules constitute the discontinuous phase while the fluid portion identifies the continuous phase.

The nature of an emulsion can best be understood from a very simple experiment. If olive oil, a non-polar compound, is shaken up with water, a polar compound, an emulsion forms in which the tiny oil droplets are dispersed throughout the water. If, however, the emulsion is allowed to stand a few minutes, the oil will collect on the top of the water and there will no longer be two intermingling phases, merely two homogeneous fluids completely separated from one another. Such an emulsion is said to be **unstable.** Now, if a small amount of soap or soluble protein is added to the two and shaken vigorously an emulsion will form, but this time it will remain for an indefinite time; this is a **stable** emulsion. The soap or protein is known as a **stabilizer.** The reason why the stabilizer produces a stable emulsion is that it is both a polar and a non-polar compound, and therefore tends to accumulate at the surfaces between the oil and water, that is, it tries to find a place where the non-polar end of the molecules can rest in the oil (which is also non-polar), while the polar end can lie in the water (which is also polar). The stabilizer, when so arranged, forms a thin protective film at the surfaces between the oil and water, preventing the oil droplets from coalescing. Thus they remain permanently separated.

Phase reversal

Watching an amoeba crawl leads one to believe that its protoplasm does not always have the same viscosity or fluidity, and careful experiments with a micro-dissection apparatus (an instrument that makes cellular surgery possible) verifies this fact. The nature of the emulsion has some bearing on these constantly changing conditions within the protoplasm.

Returning again to the oil-in-water emulsion experiment, we find that when soap is added the typical **oil-in-water** emulsion appears (Fig. 2-18A). If, however, a few drops of a calcium salt are added and the container shaken vigorously, an emulsion will again be established, but this time tiny water droplets will be surrounded by oil (Fig. 2-18C). In other words, water becomes the discontinuous or dispersed phase and oil the continuous phase. This makes a beautiful experiment, particularly if a fat-soluble red dye is added to the mixture. In the first case, red spheres appear in a clear background of water; in the second, clear watery spheres shine out in a brilliant red background. Just what has gone on to bring about these striking changes?

Obviously, the stabilizer is responsible

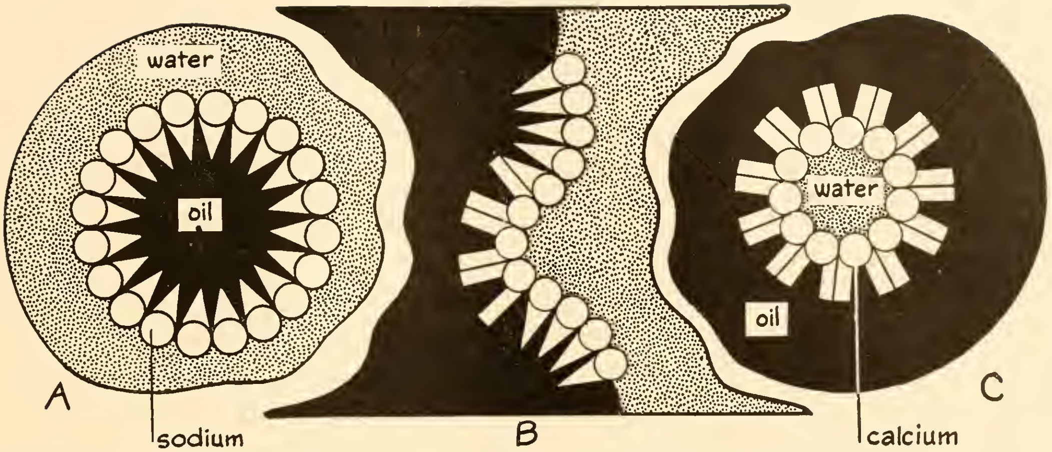
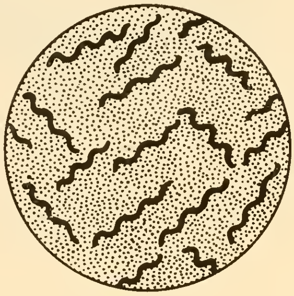


Fig. 2-19. Stable and unstable emulsions. *A* is a stable emulsion of oil-in-water where the polar and non-polar ends of the stabilizer (sodium soap) are "satisfied"; C, likewise is a stable emulsion of water-in-oil where both the polar and non-polar ends of the stabilizer (calcium soap) are "satisfied." *B* is an unstable emulsion where the stabilizer (a mixture of calcium and sodium soaps) forms a film separating the water from oil.

for the change. In the oil-in-water emulsion the stabilizer was soap, which is produced by the action of a sodium or potassium salt on a fatty acid. The resulting soap molecule is polar at the end bearing the sodium or potassium atom, the bulkier end, and non-polar at the end which is composed of the long chain of carbon and hydrogen atoms (Fig. 2-19A). Such a molecule may be considered to be conical in shape; therefore, when lying side by side their combined effect would form a film that would curve away from the thickened ends. In a water-in-oil emulsion, the heavy polar ends of the molecules would reside in the water while the lighter non-polar ends would lie in the oil. In this condition the soap molecules have satisfied both their polar or non-polar ends, thus producing oil droplets in water. Once these are formed they tend to stay that way; hence an emulsion remains stable indefinitely.

Now what took place when the calcium solution was added? It so happens that the calcium ion requires two chains of fatty acids in order to satisfy its electrical needs; therefore, the resulting calcium soap has two wings to it, shaped something like a V, both attached to the calcium ion (Fig. 2-19C). Again the long CH chains are non-polar and the calcium end is polar. When these molecules lie side by side they form a sheet or film that is curved in the direction opposite to the one formed by the sodium soap molecules. This time when in water and oil, the flared ends are emersed in oil and the calcium end is in water, thus capturing small droplets of water in oil. The phases have been completely reversed, and the response of such an emulsion is different from the former case. Such reversals happen continuously in protoplasm and account for some of the activities displayed by this material.

One might wonder what would happen if there was neither a preponderance of sodium nor calcium soap molecules, but an equal number. Under ideal conditions a completely flat film should form, separating oil from water, as if the soap were not present. This can happen, but the molecules may also form layers that curve various ways, producing a continuous wavy film separating water from oil (Fig. 2-19B). In this condition the emulsion does not behave as the oil-in-water or the water-in-oil emulsions. In both of these last two cases the colloidal particles move rather freely among one another and so the entire emulsion has a more or less fluid consistency (Fig. 2-20). In the half-way or critical condition the soap molecules act like those in a solid state, so that any change in shape of the emulsion must involve the rending and tearing of the soap film. In other words, the entire mass holds its shape; fragile though it is, it acts like a jelly. In protoplasm a similar situation exists; here, the large elongate protein and polysaccharide molecules tend to interlock, forming a cotton-like meshwork in which the water and crystalloidal components are trapped. This is called **gelation,** and the resulting emulsion is a **gel.** The emulsion can quickly change from the gel to the **fluid** or sol condition under the varying factors of the protoplasm itself. For example, such factors as hydrogen ion concentration or temperature directly determine the condition of the protoplasmic emulsion, and metabolic products constantly change, the condition of the emulsion changing with them.



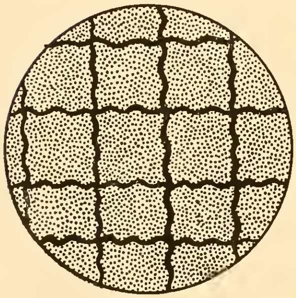


Fig. 2-20. A schematic explanation of how sols and gels form. In a sol the elongated molecules flow smoothly past one another in a more or less fluid state. In a gel a latticework effect is produced by the gelation of the emulsion. Such a physical arrangement of the particles produces a semi-solid material.

Myosin, the protein of muscle tissue, behaves like a gel, which is probably responsible for its ability to contract. In such a gel the large interlinked molecules can bring about contraction by folding upon themselves or upon other particles. The chemical and physical changes that go on in this process have been learned only recently, and they mark a milestone in the study of cellular physiology.

The protruding pseudopod of the amoeba is a result of a phase reversal from gel to sol; the clotting of blood is the opposite reaction, from sol to gel. Such changes are going on continually in protoplasm; it is hoped that the above discussion may give a little better understanding of how it occurs.

Limiting membranes

Protoplasm is confined within containers which are composed of molecules similar to those found in the rest of the emulsion, although they have different properties. They have the composition of a gel, that is, they are semi-rigid in order to contain the more fluid material within. Furthermore, they allow certain substances to pass through them in both directions in order that material essential for life can enter and leave. These membranes are thus **selectively permeable.** Let us see, at least in part, how this selective permeability is accomplished.

The large protein and lipid molecules float freely unless they are forced to gel by the relative proportions of calcium and potassium ions present within the protoplasm and the outside fluid world. The proportions of these ions are just right in the normal environment of a cell because they bring about the formation of the gelatinous membrane. Any change in the concentrations of these ions, either within or without, drastically affects the membrane. For exam-

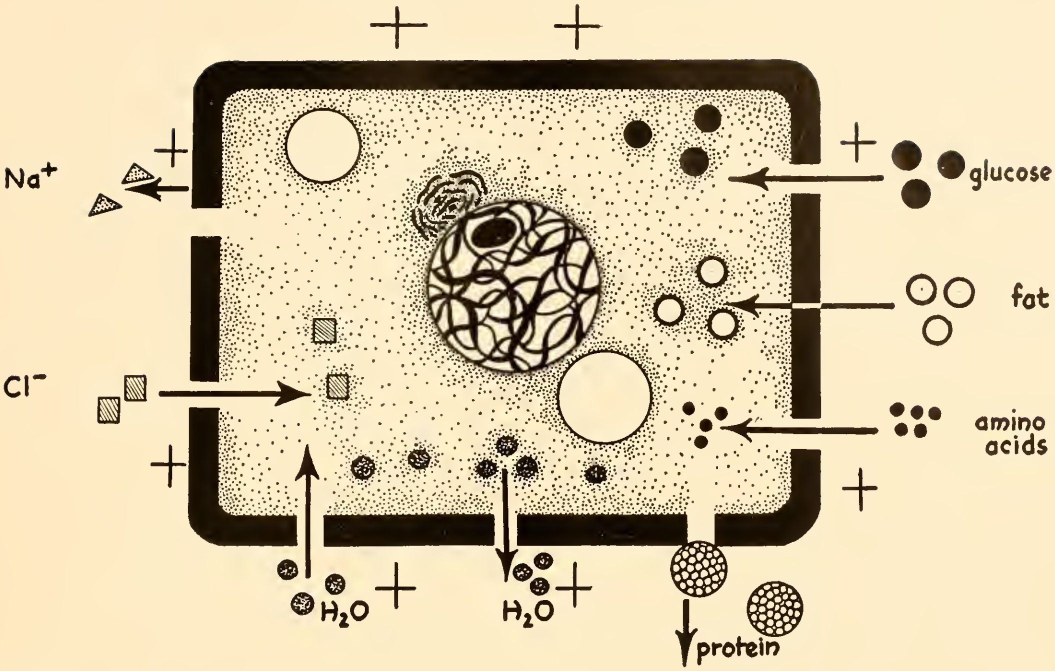


Fig. 2-21. A diagrammatic view of a cell showing how particles may enter and leave through the semi-permeable membrane. Glucose, amino acids, water, and some ions pass readily through the membrane due to its apparent porosity; fats enter by dissolving in the membrane itself. Ions with charges opposite to that of the membrane cannot pass through. Large protein molecules are denied entrance because of their large size.

ple, if an amoeba is placed in a solution high in potassium and low in calcium, a new membrane will fail to form if a rent is made in it, whereas in a solution with the proper proportions of these ions a new membrane forms at once. If the concentration is high in calcium and low in potassium, the entire organism gels, in other words, it loses all of its fluidity and becomes a congealed corpse. Therefore, a careful balance must be maintained between these two ions if a normal membrane is to form around the protoplasmic mass.

Such a sheet of protein and fat molecules must possess some unique properties if it is to perform the necessary functions of keeping the protoplasm from disintegrating. This is accomplished by the **physical nature** of the membrane itself. The lipid and protein molecules cling together but between them are small openings where they do not fit quite snugly, and through these water and other small molecules may pass freely from one side to the other. Fat-like particles can dissolve in the lipid molecules forming the membrane, pass inside, then slowly move out of the other side to the interior of the cell. Larger protein molecules cannot penetrate the membrane because the openings are too small to admit them (Fig. 2-21). Glucose and amino acid molecules pass through the openings readily but some of the ions, even though much smaller, are unable to get through because of the electrical charge which they bear. The membrane is charged either positively or negatively depending on the surrounding conditions of the environment. If it is negative, such ions as chlorine and carbonate are repelled and cannot get by this electrical barrier. On the other hand, sodium and potassium ions are attracted to the membrane and pass through readily. A constant flow of these ions both ways satisfies the needs of the internal pro-

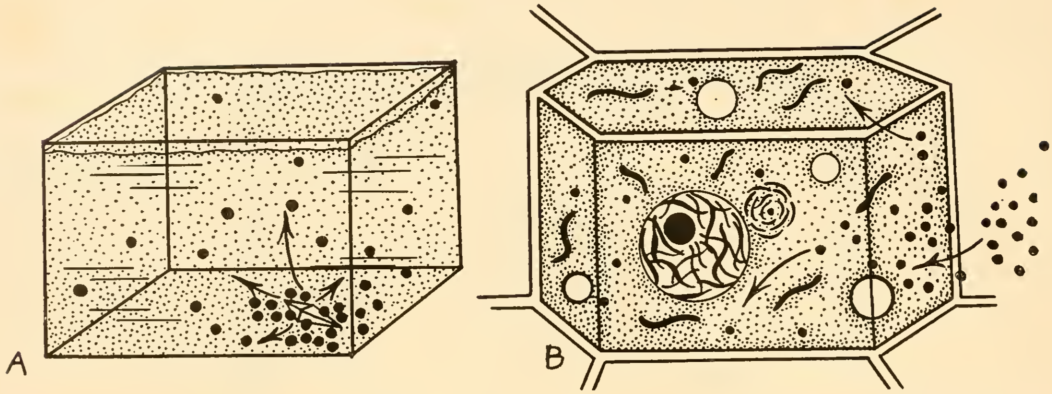


Fig. 2-22. Diffusion. *A.* Particles such as colored ions from a salt diffusing in water. *B.* Diffusion of particles through the cell membrane and within the cell itself.

toplasm. Any excess flow one way or the other can be fatal.

Diffusion and osmosis

The constant striving of particles of all dimensions to reach an equilibrium or even distribution in a mixture of two or more different kinds is known as **diffusion**, a process that is constantly at work in protoplasm. Once the ions and other particles pass through the membrane of a cell, they diffuse throughout the protoplasmic mass until they have become evenly distributed (Fig. 2-22). However, when some of the particles surrounding a cell cannot penetrate the membrane, a different situation exists. Let us suppose the membrane is permeable to water, as most membranes are, but impermeable to sucrose molecules. The sucrose molecules will constantly strive to intermingle with the water molecules on both sides of the membrane, but since they cannot pass through there will be an uneven distribution of the water molecules on the two sides. The water and sucrose molecules will bombard the membrane with about equal hits on one side; corresponding hits will be made by the water molecules on the other side, but since there are only water molecules present one will pass through for every molecule of sucrose on the other side which cannot get through. The water molecules will be passing toward the sugar side more rapidly than they pass in the other direction, thus building up a hydrostatic pressure on the sugar side (Fig. 2-23). This unequal

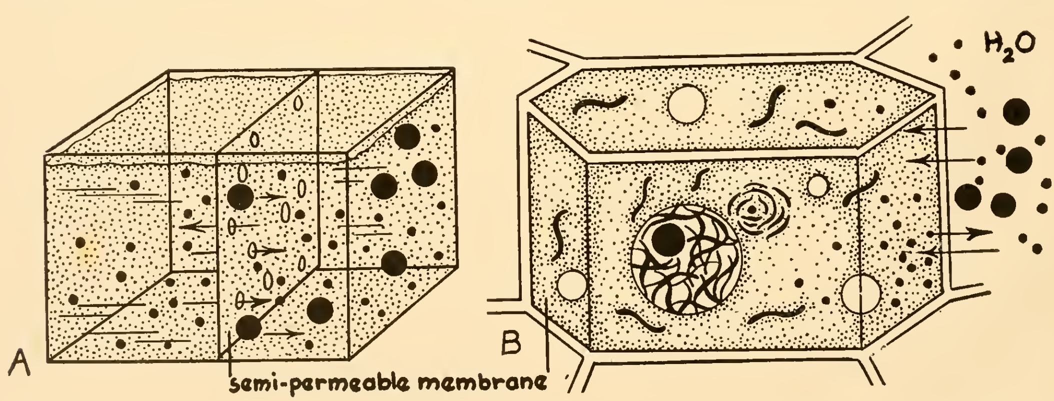


Fig. 2-23. Osmosis. *A.* Movement of water molecules through an artificial semi-permeable membrane. The larger molecules cannot pass through. *B.* A similar situation in which the plasma membrane of the cell is the semi-permeable membrane.

movement of water molecules through a semi-permeable membrane is called osmosis.

Osmosis can be easily demonstrated by placing a strong sugar solution in a bag of thin skin, such as frog skin, and tying it to a small-bore tube (Fig. 2-24). The water will pass into the bag, or toward the sugar, thus building up a pressure within the bag which will be registered by the rise of fluid in the small tube. If properly constructed, such an apparatus will demonstate a rise of the fluid column to many feet, the height being determined primarily by the effective semi-permeability of the bag. Usually such a preparation is not absolutely semi-permeable; some sugar goes the other way, that is, after a time some sugar molecules will have wedged their way through the membrane to mingle with the uniform water molecules outside.

Both diffusion and osmosis are important physical processes in the movement of particles, not only through the membranes but within the cells themselves. The practical significance of osmosis can be demonstrated with red blood cells. These tiny disks have a limiting semi-permeable membrane which encompasses a large variety of particles that constitute the internal protoplasm of the cell. Normally when these corpuscles float in the fluid of the blood, water passes in and out of the cell with equal speed, so the membrane is uninfluenced by the movement. Other particles pass in and out, but in so doing there is always an even distribution on both sides of the membrane, that is, for every particle going inside another comes out, so that the numbers, not necessarily the kinds, are approximately the same all of the time. Such a surrounding fluid is said to be **isotonic** to the corpuscles (Fig. 2-25). If the corpuscles are now separated from the fluid portion of the blood and placed in distilled water, a very rapid and sudden change occurs. The water moves into the cell because the dispersed particles are greater (less water molecules) inside than out (where there are more water molecules), so the water flows in, causing the

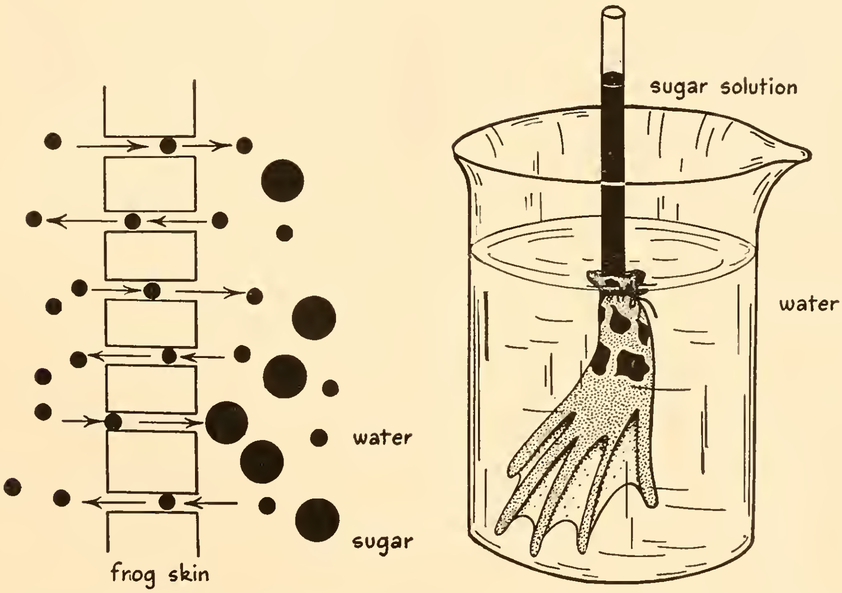


Fig. 2-24. An osmometer is made from the skin of a frog's foot into which a strong sugar solution is poured and a small-bore tube attached. A diagrammatic view of why the membrane is permeable to water and not sugar is shown on the left.

membrane to swell and eventually burst (Fig. 2-25). The water in which the cells were placed is said to be **hypotonic** to the blood cells. Hypotonic solutions should not be injected into the blood stream of an animal because the destruction of red cells, as well as others, could prove fatal.

Again, if the cells were placed in a salt solution in which the numbers of dispersed particles were much greater than on the inside of the cell, the direction of flow would be in the opposite direction, namely, out of the cell, causing it to shrink to only a fraction of its normal size (Fig. 2-25). The reason here is the same as in the previous case. Such shrunken cells are called **crenated** cells, and such a concentrated salt solution is said to be **hypertonic** to the blood cells. If such a hypertonic solution were injected into the blood stream, it might also prove fatal because of the wanton destruction of blood cells. It is important, then, that whenever cells are placed in any kind of solution, that the medium have the same number of particles, or, in other words, it must have the same osmotic pressure as the cells themselves, if severe trouble is to be averted.

Another illustration of the effect of osmotic pressure might be cited because of its practical application. Perhaps you have wondered why a person, floating upon vast quantities of water, must die at sea if he has no fresh water to drink. Sea water is heavily laden with salts and its osmotic pressure is considerably above that of the blood and tissues of man and all other land animals. If, then, he should take sea water into his stomach it would extract from his stomach the precious water that is already short, eventually filling his stomach so that he would be forced to throw it up. This would leave his body with less water than it had before he swallowed the sea water. That is why drinking sea water can be fatal.

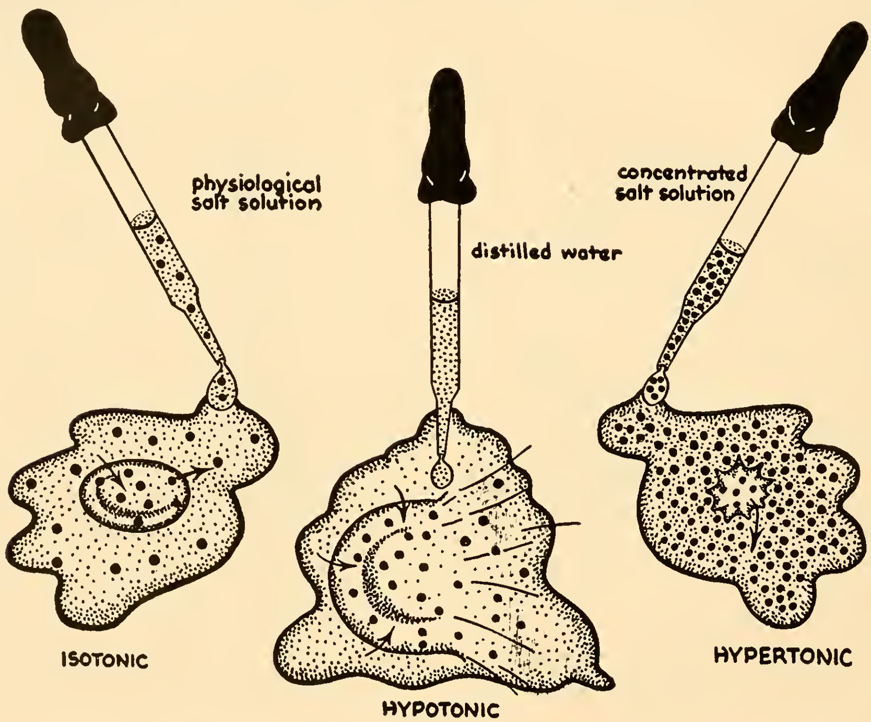


Fig. 2-25. The effect of salt solutions of various concentrations on the red blood cell.

IN REVIEW

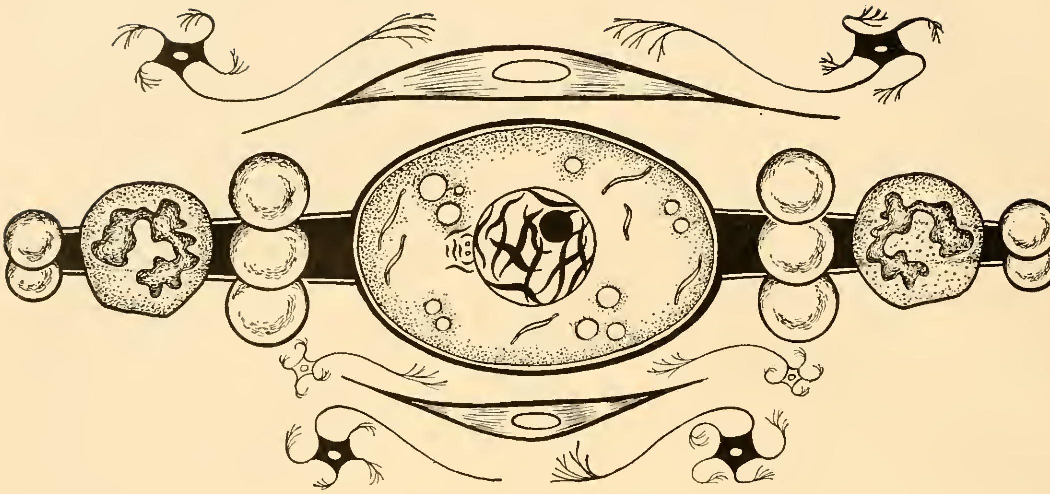
This discussion of the physical and chemical properties of protoplasm may seem unduly long and to belong more properly in a book of chemistry or physics. It is none the less basic to an understanding of life. Let us summarize briefly to emphasize this once more.

We have seen that protoplasm consists of molecules, atoms, ions, and colloids no different in constitution from similar entities existing in the inanimate world. However, their intricate and complex association in protoplasm bestows upon them the properties that we assign to living things. Although some of the properties of these particles have been described, certainly not all of them have been, nor could they be, because they are not known.

Many people have attributed to protoplasm a vague sort of "something" called life, that suddenly leaves a living thing when it dies. However, attractive though this may be, it is no explanation, at least in the scientific sense. The reason why we have difficulty in explaining life is because we do not know enough about the intricate workings of molecules, atoms, ions, and other particles that go to make up protoplasm. If we had sufficient knowledge about their behavior perhaps we could explain how protoplasm is put together and exactly how it works; indeed, we could explain life itself. That is a far distant goal, but one worthy of the most intensive research.

Can we define life? Perhaps we are somewhat closer to a definition of life than we were at the beginning of this discussion some pages ago. We can make a few statements but they need to be shrouded in vague terms which we still do not quite understand. Certainly life involves motion and interaction of particulate matter at size levels from atoms to huge colloids. It includes ceaseless chemical change, with its concomitant consumption or release of energy. Life means chemical and physical organization of pattern and design with a never ending trend toward greater complexity.

CHAPTER 3



UNITS OF LIFE—CELLS

Going back to the story of the origin of life, it will be remembered that protoplasm came into being very slowly and its organization into cells must likewise have required a very long time. All cells, from the free-living one-celled Protozoa to the many-celled animals, are extremely complex, and certainly the result of hundreds of millions of years of evolution. All cells perform essentially the same functions whether they are deep in the muscles of an elephant or exist as independent individual units like the amoeba. Before we examine the general cell structure more carefully, a little of the **historical background** of cell studies may help us in our perspective of modern science.

Long ago, about 1665, an English biologist by the name of Robert **Hooke** cut thin slices of cork and placed them under his newly fashioned microscope. He noted that this material was composed of numerous tiny compartments to which he assigned the name "cells," a name that has come down to the present time. He gave them this appellation because they reminded him of the cubicles in monasteries in which monks of his time lived. Today any beginning biology student can repeat Hooke's experiment and be rewarded with a much better visual image of cells, although he would probably lack some of the enthusiasm that compelled this inquiring man of the seventeenth century to make the discovery.

Everyone who was sufficiently curious to follow the exciting hobby of looking through the newly invented microscope of this early period saw that all parts taken from living things were composed of these tiny "bladders," as Grew called them. Their first and only interest seemed to lie in the fact that animals and plants were made up

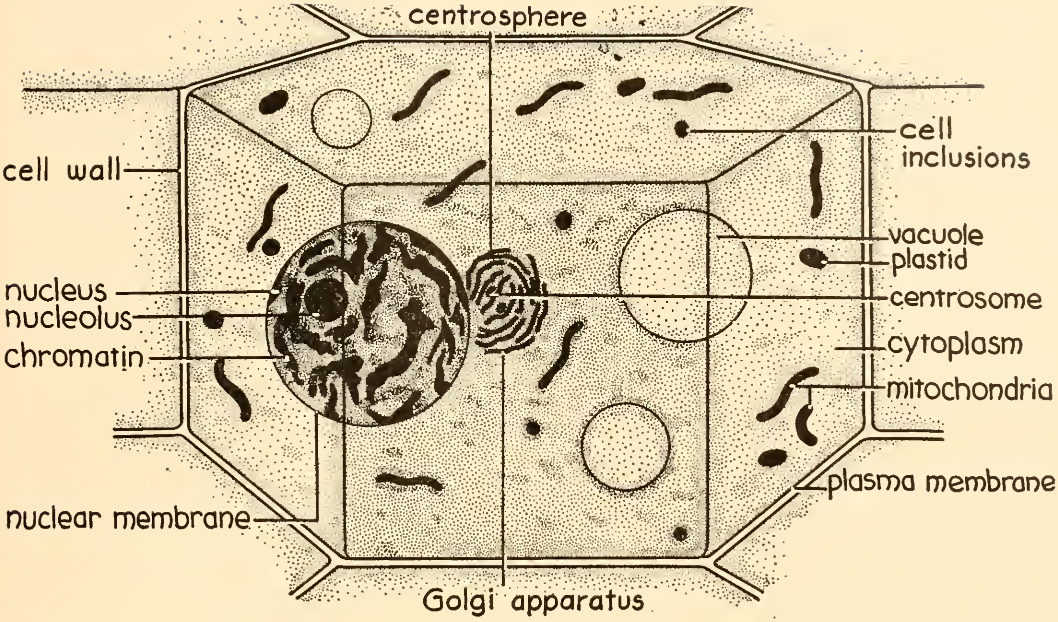


Fig. 3-1. A generalized cell.

of these tiny units, and they paid little or no attention to the internal parts of the cells for over one hundred years. By 1824, **Dutrochet** in France had noted that plants grew by an increase in number and size of the cells of which they were composed. By 1831, **Brown** had seen and described the centrally located body within the cell which he called the **nucleus.** This, together with the increased use of the microscope, centered the attention of investigators on the internal parts of the cell. **Purkinje** saw the universal occurrence of **protoplasm** within cells and gave it the name which it bears today. About this time (1839), two Germans, **Schleiden** (a botanist) and **Schwann** (a zoologist) advanced the **Cell Theory,** which was merely a concise statement of what had been learned by a great many men up to this point, namely, that all living things were composed of cells.

The Cell Theory gave biologists for the first time a tangible theory upon which to base further studies. It meant to them what the molecular theory did to the chemist and physicist, and as a result, biology became more and more a study of cells rather than a study of the organism as a whole. Because cells occupy the central core of studies in embryology, reproduction, growth, heredity, and behavior, they have been given steadily increasing attention through the years by investigators of fundamental biology. Today there is more activity in this field than ever before. Once a thorough understanding of the cell is acquired many of our most perplexing problems in biology will be closer to solution.

THE STRUCTURE OF CELLS

While all plant and animal cells possess specific morphological features that identify them as particular kinds of cells, they are all fundamentally alike in certain respects (Fig. 3-1). All are composed of protoplasm bounded by a semi-permeable plasma membrane, and somewhere within the protoplasm lies a **nucleus,** which is likewise bounded by a **nuclear membrane.** The protoplasm in which the nucleus floats is the **cytoplasm.** In addition to the plasma membrane, plant cells are enclosed by a **cell wall**, composed of a non-living carbohydrate called **cellulose** which lends to the cell a definite, rigid shape. This cell wall is porous enough to allow the passage of soluble substances through it. In animal cells the cell wall is usually absent, the boundary therefore being the plasma membrane.

Several characteristic structures are present in the cytoplasm of most but not all cells. Most animal cells possess a region near the nucleus known as the **centrosphere**, inside of which two small bodies, the **centrosomes** (*centrioles*) are sometimes found. Both of these structures are absent in higher plant cells, although they are found among the lower plants, such as some of the algae. There is some doubt as to their function in the life of the cell. Small bodies called **plastids** are frequently present in the cytoplasm in both animal and plant cells. In the former they are usually colorless, whereas in the latter they may contain **chlorophyll**, the green pigment essential in photosynthesis. Fiber-like bodies floating in the cytoplasm are the **mitochondria**, which have recently been identified as bundles of enzymes important in the metabolism of the cell. The irregularly shaped **Golgi apparatus** is scattered through the cell or collected near the nucleus, very often in the region of the centrosphere. The function of this structure is unknown, although it is thought to be associated with secretion in some cells. **Vacuoles** are spaces in the cytoplasm that usually contain gases, solids, or liquids. In addition to these more or less regularly occurring parts of the cell, there may be present also certain lifeless bodies floating haphazardly in the cytoplasm. They are referred to as **cell inclusions**. They may be stored starch or fat, or undigested bits of organisms which have been taken in as food.

The nucleus is the vital part of the cell because it contains the **genes**, carriers of heredity factors. Genes are localized in the **chromatin granules** that are visible under a light microscope. The chromatin is confined to discrete bodies called **chromosomes**, about which we shall learn a great deal more in a later chapter. The undifferentiated protoplasm of the nucleus is named **nucleoplasm** or **nuclear sap.**

Although these are the essentials of most cells, some possess additional structures which are particularly designed to do specific jobs. Furthermore, cells vary tremendously in shape, size, and special functions.

Size. There is as much difference in the size of cells as there is between different animals, an elephant and a mouse, for example. It has been thought that certain species of spherical bacteria, which have a diameter of 1 micron or less, are the smallest cells. Cells must not be confused with viruses which are not organized into cells and which, in fact, normally live at the expense of cells. Bacteria can be seen only with the best high magnification microscopes. Recently they have been photographed through the electron microscope which has made possible more detailed studies of their internal anatomy (Fig. 2-10). Most cells that compose the bodies of animals are considerably larger than the largest bacteria; on the average they are about 7 microns in diameter. The nerve cells are very long and thin, particularly those reaching from the tip of the toe to the spinal cord in the back. In an elephant or giraffe these cells are 6 or 7 feet long. The largest animal cells are found among bird's eggs, in which what is popularly called the "yolk" is a single cell. The largest cell known is the yolk of the ostrich egg which reaches a diameter of 2 or more inches. The large quantity of stored food (yolk) in eggs is responsible for their great mass.

Shape. The shape of cells depends a great deal on their function (Fig. 3-2). If they perform a tensile function, such as the cells found in tendons, they are long and thin because of the constant stretching action placed upon them. If they are conductive, as in the case of nerve cells, they must also be long and thin. On the other hand, red corpuscles are tiny discs, fitted by shape to float in the blood stream. Smooth muscle cells are spindle-shaped, which is the ideal shape for a cell that must shorten or contract. Cells that line the respiratory tract in our bodies are small cylinders with minute, vibratile, hair-like structures (**cilia**) on one end, which function in carrying the mucus along the tract by their whip-like action. Other cells, such as the amorphous white blood cells, resemble tiny bits of jelly that move by rolling along, taking in and destroying bacteria and other foreign particles in the blood and tissues.

Number. A glance through a microscope at a thin slice of tissue taken from any animal will demonstrate the fact that there are a great many cells in even a small animal like the mouse or spider. The larger the animal, the more the cells, although swift-moving and very active animals such as insects and birds usually have smaller cells per unit volume than do sluggish, slow-moving creatures such as the salamander. There is no correlation between the size of the animal and the size of its cells. The larger animals simply have more cells. Every cubic millimeter of human blood contains about 5 million red blood cells, and the total number in the entire blood stream approximates 30 quadrillions. The human brain alone has billions of cells; the number in the whole body thus takes on astronomical figures.

THE PHYSIOLOGY OF CELLS

As previously noted, cells function much alike, irrespective of their situation. All have certain needs which are satisfied in much the same way. To be sure, certain complications arise when they are grouped together in great masses but that problem will be the subject of a later discussion. Let us now examine the processes common to all cells whether they be independent organisms or members of large complexes.

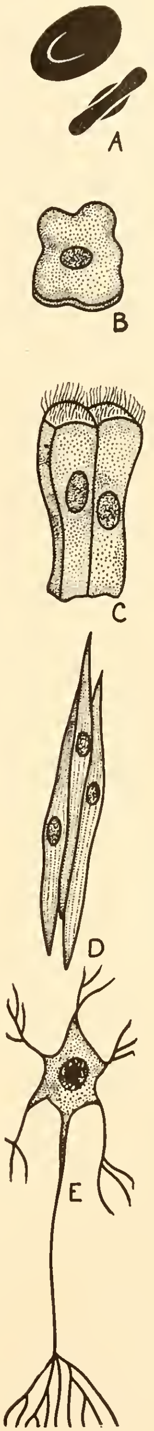


Fig. 3-2. Various kinds of cells. *A.* Red corpuscles. *B.* Flat (squamous) epithelial cell. *C.* Columnar ciliated epithelial cells. *D.* Smooth muscle cells. *E.* Nerve cell (neuron).

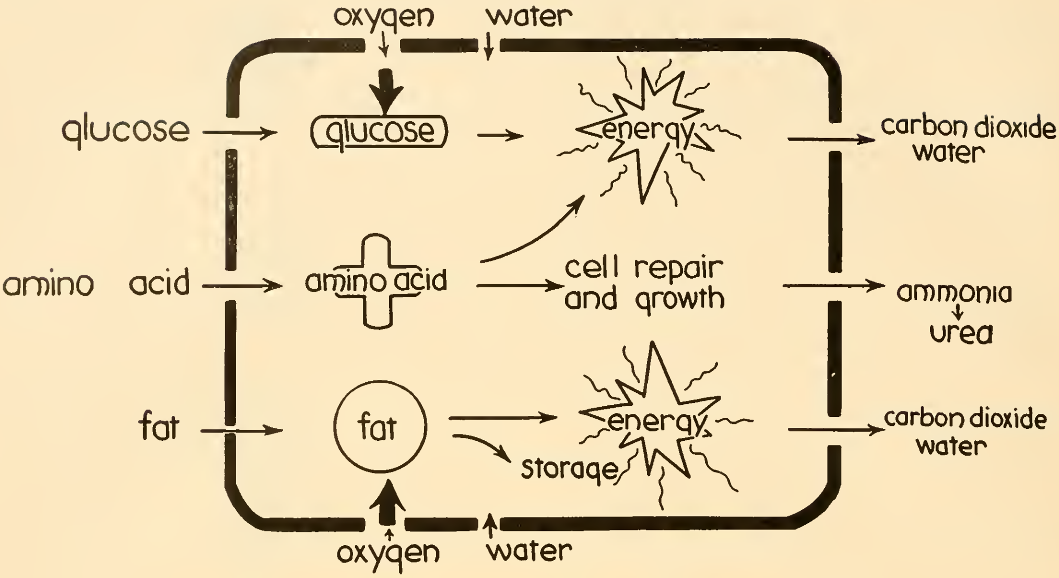


Fig. 3-3. Schematic drawing showing how food is metabolized in a cell.

Nutrition. In the broad sense, nutrition includes all activities that have to do with securing, consuming, and ultimately metabolizing food (Fig. 3-3). This is essential for cells because it is the only way they can obtain the energy with which to carry on their life processes (such as reproduction, motion, and generating heat). Plant cells require only simple inorganic material, whereas animal cells demand complex organic compounds in addition to certain inorganic substances, such as sodium and iron. As was pointed out earlier, animals depend on the plants for much of their food directly and all of it ultimately. This difference in food requirements between plants and animals has profoundly influenced the course each has pursued in evolution. The plant can remain serenely rooted in one spot throughout its lifetime, and under ordinary circumstances all of its needs in the way of food are in its immediate surroundings. The essential inorganic salts and water are in the soil at its "feet," and the carbon dioxide and sunshine are in the air overhead. It is not so with the animals. They must pursue and apprehend complex organic diets, necessitating a much more highly specialized organism, endowed with sense organs, coördinating systems, and machinery for rapid movement such as skeletons and muscles. The food they secure is not in a state for immediate utilization, but requires an elaborate digestive system to break the large insoluble molecules into smaller utilizable ones. This is the price animals have had to pay for being unable to satisfy their needs from simple inorganic food sources. Perhaps there are other compensations for being an animal. For man, there is the joy of a rare steak smothered with mushrooms, for example.

First of all, individual animal cells must receive their foods from the outside world, whether the cell is within the body of a complex animal or a single isolated cell. In the latter case, entire microörganisms are engulfed (Fig. 7-5), digestion proceeds within the cell body, and the products of digestion are absorbed into the surrounding protoplasm, ultimately to be utilized as a source of energy or for growth and repair. In the multicellular animal the individual cells receive their food in utilizable form so all they need to do is to use it. Each cell is bathed in a fluid (lymph in man) which contains all of the food requirements of the cell. Hence, the molecules need only traverse the membrane to gain entrance into the cell. Within the cell they are transported throughout the protoplasm by diffusion. Having reached this destination, the food is available for metabolism by the cell.

Metabolism of food is the most important part of nutrition because it is the process by which energy is released from the energy-rich compounds and building materials are incorporated into the structure of the cell. The business of providing the cells with food and removing the waste products is merely accessory to the real job of extracting energy from the food and building it into new protoplasm. During **constructive metabolism (anabolism)** the absorbed amino acids are built into the protein framework of the cell's protoplasm. Those not needed for this purpose are deaminized (amino groups removed) and converted to glucose. Fats are stored and some of the glucose is converted to glycogen and stored. In the **destructive metabolic (catabolic)** phase, the glucose is burned to carbon dioxide and water through a long series of steps producing many intermediary products. Fats are also oxidized and release large amounts of energy, leaving end products of carbon dioxide and water. Such energy is used to produce heat and movement, and to bring about the anabolic conversions just mentioned, for they are all endothermic reactions requiring energy before they can take place.

In order that oxidation can occur in the cell, oxygen must be supplied to it. This is abundantly furnished in the waters surrounding the single cells and it must likewise be supplied in the fluids such as lymph surrounding the metazoan cell. Oxygen must be available at all times if the process of metabolism is to go forward normally. This gas, like food products, passes readily through the membrane of the cell by diffusion and mingles with the molecules in the protoplasm, ready to combine with glucose or with fats in order to release energy.

As a result of these metabolic activities within the cell, certain **waste products** are formed which must be removed before they accumulate to toxic proportions. These wastes consist of **carbon dioxide** and **water** which result from the burning of glucose and fats, and nitrogen wastes including **urea** which results from the breakdown of nitrogen-containing compounds, principally amino acids. Some inorganic salts, such as phosphates and sulfates, accumulate as a result of the decomposition of phospholipids and certain sulfur-containing amino acids, and they too must be eliminated or excreted. Wastes leave the cell through the membrane by the same process that the food entered, and are deposited into the surrounding fluid in the case of metazoan cells (many-celled animals) or the enveloping water in the case of single cells. Anything that interferes with the elimination of these products affects the metabolism of the cell itself; in fact, the cell can survive only a short time if the waste products are forced to accumulate in any quantity.

Reproduction. Another fundamental problem that the cell must solve is reproduction. All isolated cells must duplicate themselves periodically if they are to increase their numbers. The ability to do this often determines whether or not a species will succeed as a race. The individual cells of a multicellular animal multiply rapidly during embryonic life and some do throughout life. Others are produced once and are never duplicated again. Just how this is accomplished at both the cellular and multicellular level will be discussed in subsequent chapters.

We have seen then that cells, while highly variable in size and morphology, all have the same fundamental needs which must be cared for whether they are a part of a many-celled animal or live as isolated individuals. Let us now consider how these needs are satisfied when cells began to live in groups, that is, in a metazoan.

PART III

The Organized Animal

CHAPTER 4

FROM SINGLE CELLS TO MANY CELLS

Once the fully organized cell had evolved on earth, it undoubtedly explored thousands of possibilities in structural patterns as well as environments in which to live. Some found niches in which they were "satisfied," where they have remained through the succeeding millions of years. We find them still occupying these same, or very similar, places today. They found no need for change, no need to search elsewhere for more favorable features in their environment. Others, however, were forced into situations where they were subjected to a variety of environments which compelled them to change or perish. It was from this group that we might expect to find not only new varieties of single cells but also some that banded themselves together in small groups for the sake of "better living," whatever that entails.

The colonial idea proved advantageous for survival, and more and more cells were added until the mass became so great that changes became necessary to permit the continuing of the vital life functions. Systems for surmounting these encroaching impairments of function were introduced in a diversity of form and structure; some proved efficient and allowed the animal to become still more complex, others must have been so poor that the organism changed no more or died out. From this long, tortuous path has come to us today the complex many-celled animal with all of its intricate machinery to do the jobs that were done so simply by the one-celled animals. The price has been a long and bitter struggle; whether or not it is worth while only man has sufficient intelligence to say.

Assuming that during the millennia required for the unfolding of animal life, some found satisfactory niches all along the way and remained essentially unchanged up to the present, it should be possible to find such representatives and to arrange them in order of their complexity, forming a continuous series from single cells to the most complex animals alive today. To be sure, we would expect to find gaps between groups and we would also expect that the animals we do find would not be exact duplicates of the originals. They too would undoubtedly have undergone some minor changes during this long period of time, even though they remained in a relatively unchanging environment. By erecting such a series the story of evolving animal life might become a little more clear.

Most biologists agree that the Metazoa took their origin from some single-celled form. Surveying the thousands of species of single-celled animals (Protozoa), it seems likely that the starting point could have been among those that bear **flagella** (Fig. 4-1), some of which also contain the plant pigment **chlorophyll** and are, therefore, closely related to the plant world. Among this large and varied assemblage of Protozoa are some that resemble one another very closely, except that they exist in groups of individuals which vary in number from one to several thousand. Starting with the single-celled *Chlamydomonas,* one can arrange a graded series where individuals differ only in the number of cells that cling together. *Pandorina* is composed of eight cells embedded in a spherical matrix of jelly-like material. Each of the cells is not greatly different from *Chlamydomonas.* The combined beating of their flagella causes the entire colony to roll along in a graceful manner. There is another form, *Pleodorina,* which is composed of many more cells, clustered in the shape of a hollow sphere; aside from the increased number of cells there is little difference between this one and *Pandorina.* We do note one rather interesting dissimilarity that will be discussed later but should be mentioned briefly now. Not all of the cells are the same size; some are smaller than others, and during reproduction the smaller ones are unable to produce new colonies, in other words, they are **sterile.** Therefore, in this form there seems to be two kinds of cells, **reproductive cells** and sterile or soma **cells.**

A much larger aggregate is illustrated by *Volvox,* a beautiful hollow spherical colony consisting of several thousand cells. Again these cells resemble *Chlamydomonas* in most respects, although there are tiny bridges between individuals which tend to lock them together more securely than the loose jelly of other forms. Most all of the cells are alike although there are some here and there that are larger and have a different appearance. These are the reproductive cells; all others are soma cells. A more careful observation will reveal that the reproductive cells are of several kinds. Some are bundles of tiny bodies, the **sperm** or male cells, while others are large ovoid **egg** cells. These special **sex cells** reproduce the colony by a **sexual process,** that is, the sperms are released into the water where they swim to and unite with the egg. This subsequently becomes a **zygote,** which overwinters in a heavy-walled case (Fig. 4-1). Other reproductive cells merely divide and move into the hollow of the sphere where they become small colonies, known as **daughter colonies.** These eventually burst out, destroying the mother and becoming adult colonies themselves.

Two striking events occurred in this gradual association of cells. First, similar cells aggregated into a mass which apparently succeeded better, that is, there was

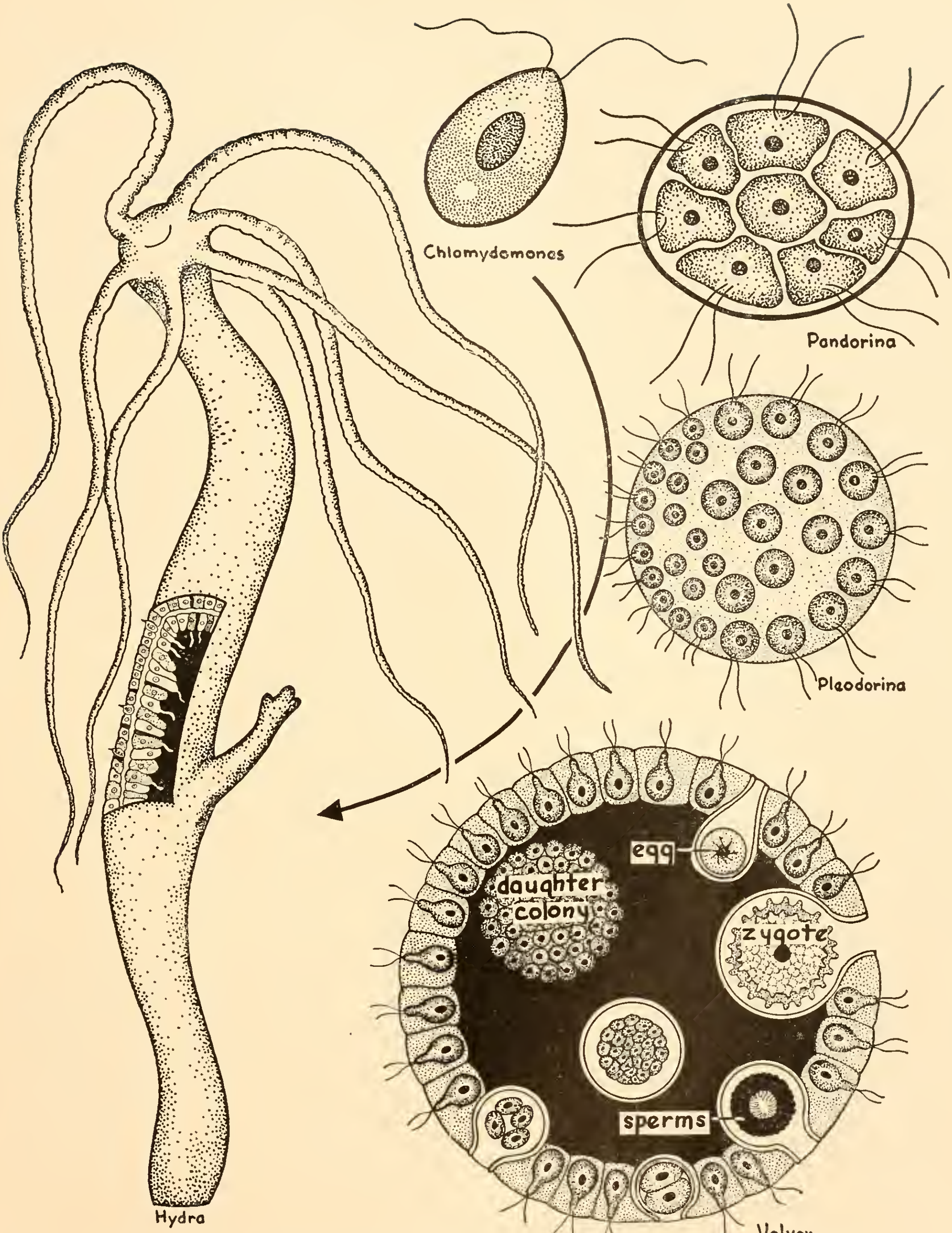


Fig. 4-1. A series of forms that illustrate the colonial theory of the origin of the Metazoa.

strength in union. Secondly, **division of labor** was initiated among the cells, some becoming sterile and functioning only in locomotion and food-getting, whereas others retained the primitive condition of colony-reproducing. Some of the reproductive cells became highly modified into eggs and sperms while others merely retained their primitive characteristics of reproducing by simple fission. In other words, a differentiation of function took place among the cells of the aggregate, definitely marking it off from the isolated single cells and at the same time creating the first step in the organization of a complex animal through the loss of the power of reproduction by some of the cells. Once this step was taken, differentiation of the soma cells continued in various directions toward greater and greater complexity, and thus up the long trail to such highly intricate forms as man.

This gradual advance in complexity might be compared to the evolution of our own society. The Protozoa may be compared to primitive man who lived alone and was compelled to obtain all of his own food, make his own clothing, and provide his own shelter. Existence by this crude means made chances for survival poor, and mortality high. Later, man associated himself with others in the common interest of survival and of making the drudgery of life less grueling. The first groups were made up of the immediate family; they lived together, hunted together, and made shelters together. In other words, they performed all the duties acting as a group rather than singly as heretofore. Food was easier to secure because they could surround and kill larger animals, their shelters could be more elaborate, and the burdens which fell upon each individual were not as great as when each lived alone. Such aggregation was continued to include larger groups until small villages were formed; with the increasing numbers of individuals participating in mass efforts, less responsibility fell to each one, and what was more important, each shared in the results of the mass efforts. They all lived better and longer. This has continued and finally developed into our modern civilization. There are places on the earth today where primitive peoples live just as they did many thousands of years ago. These people are unsuccessful, biologically speaking, because they have been unable to spread their kind over the world. Such is the criterion of biological success. Following this analogy, we can think of primitive society as resembling the single-celled animal and modern society as the complex metazoan, such as the mammal. As the cells began to aggregate into groups, individual cells specialized in particular jobs, and the group as a whole became more complex. There are animals all along the evolutionary scale which represent steps in increasing complexity.

The next step toward a more complex animal is a simple metazoan with further differentiation among its soma cells. The body is now a simple sac composed of two layers of cells. *Hydra* is an excellent example, and while more will be learned about it in a later chapter, we may briefly examine its anatomy at this point in order to carry further the idea of increasing complexity.

Hydra is made up of many cells, mostly soma cells, which are arranged in two layers (Fig. 4-1). Some of the cells in the outside layer (**ectoderm**) have differentiated into "nettle cells" for stinging purposes in defense or offense. Others are able to lengthen and shorten during locomotion and to convey impulses (**neuromuscular cells**). Still others have the ability to give rise to sperms and eggs, and to new individuals by bud formation. Here, then, we see that the soma cells have differentiated into several kinds, while the sex cells remain much like they were in *Volvox*. Division of labor has started among the soma cells which is the next step in the development of more complex animals.

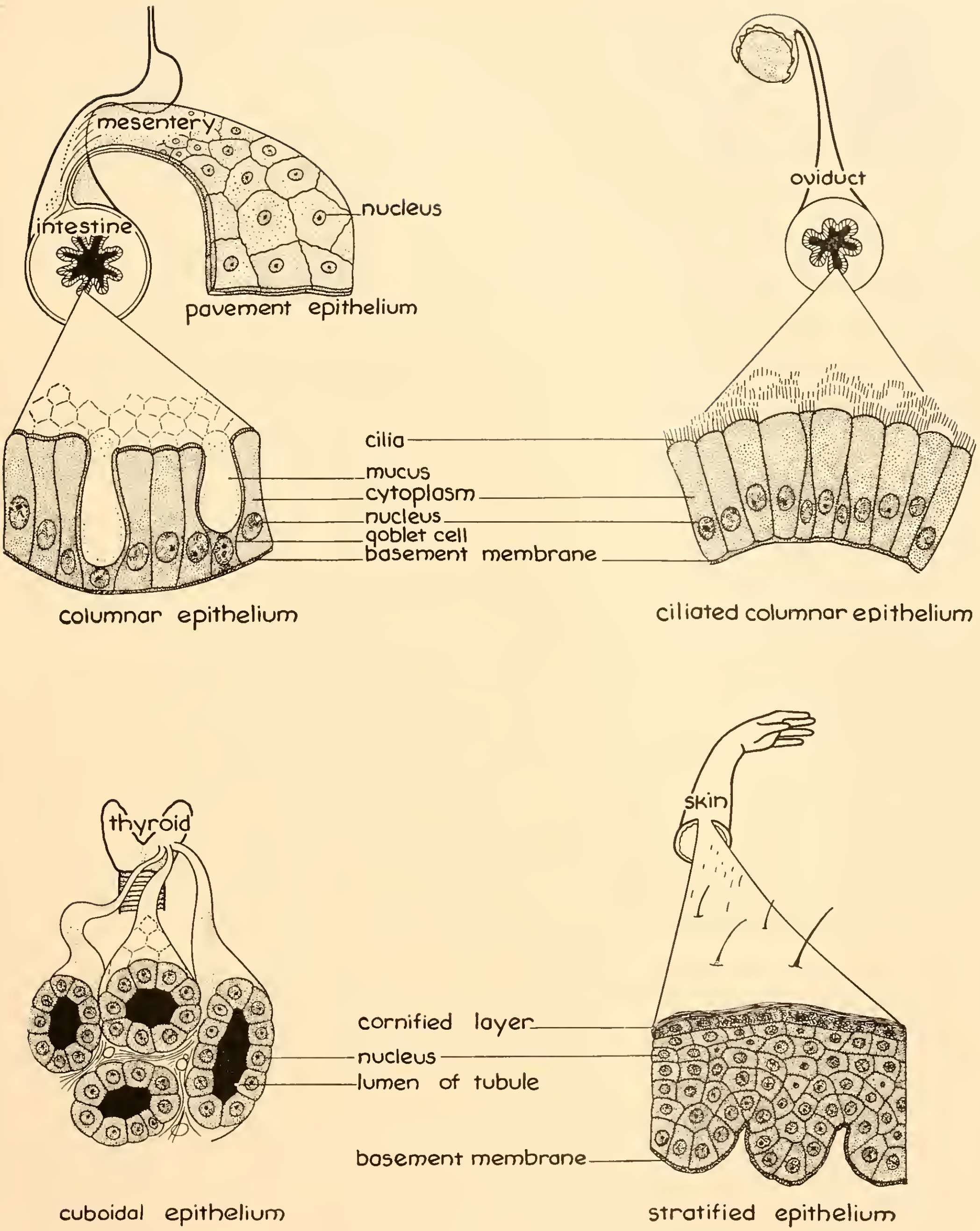


Fig. 4-2. Epithelial tissue.

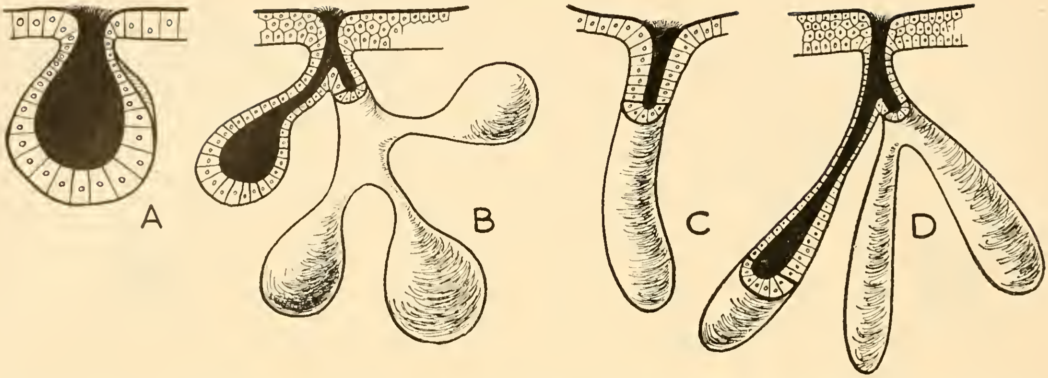


Fig. 4-3. Various kinds of glands that arise from epithelial tissue. *A.* A simple flask-shaped gland (alveolar) such as that found in the skin of the frog used to secrete mucus. *B.* A compound alveolar gland such as that found in the salivary glands. C. A simple tubular gland such as that in the lining of the intestine. *D.* A compound tubular gland such as that found in the stomach lining.

Once cells have established themselves in such intricate relationship as in *Hydra,* further differentiation is possible. That possibility becomes a reality as we go higher in the animal series. The result is a number of different kinds of cells, each carrying on its own metabolism, but specialized for some particular function. The major types of such specialization are not great in number but each type has many varieties. Let us examine these major forms of specialization.

ORGANIZATION OF CELLS INTO TISSUES

Division of labor among the soma cells spread throughout the Metazoa until a wide variety of cells was produced, each doing a specific job. Cells of the same kind grouped together in a continuous mass form a **tissue.** A particular kind of tissue is not necessarily limited to one region of an animal body, but usually is found in several different places, where it may or may not perform the same function. There are four major kinds of tissues, **epithelial, sustentative, nervous,** and **contractile.** Although tissues occur in all groups of animals, for simplicity let us consider only those found in a mammal such as man.

Epithelial tissues. These are the surface tissues which cover and line not only the outside of the body but the cavities within as well. They are composed of closely fitting cells forming continuous membranes and with very little intercellular material binding them together. Since the jobs performed by epithelial tissues vary greatly, these tissues exhibit a wide variety of form (Fig. 4-2). The tissue is usually named according to the shape of its constituent cells, for example, **squamous** (flat), **cuboidal** (cubes), and **columnar** (columns or pillars). They may also be described in terms of accessory structures such as **flagella, collars,** or **cilia.** Finally, the tissue may be referred to as **stratified** if the cells have different forms and lie several cells in thickness.

In addition to protection, epithelial cells that line cavities usually have the function of **secretion,** which is the production of special substances used by the organism in various ways. For example, the cells lining the digestive tract are mostly secretory in function. These cells form the secreting portion of glands whether the gland is single or many celled. In multicellular glands the secreting cells may lie beneath the surrounding surface forming simple tubes (**tubular glands**) or flask-shaped pockets (**alveolar glands**). Such tubes and pockets may be single structures (**simple glands**) or they may be grouped into aggregates (**compound glands**) (Fig. 4-3).

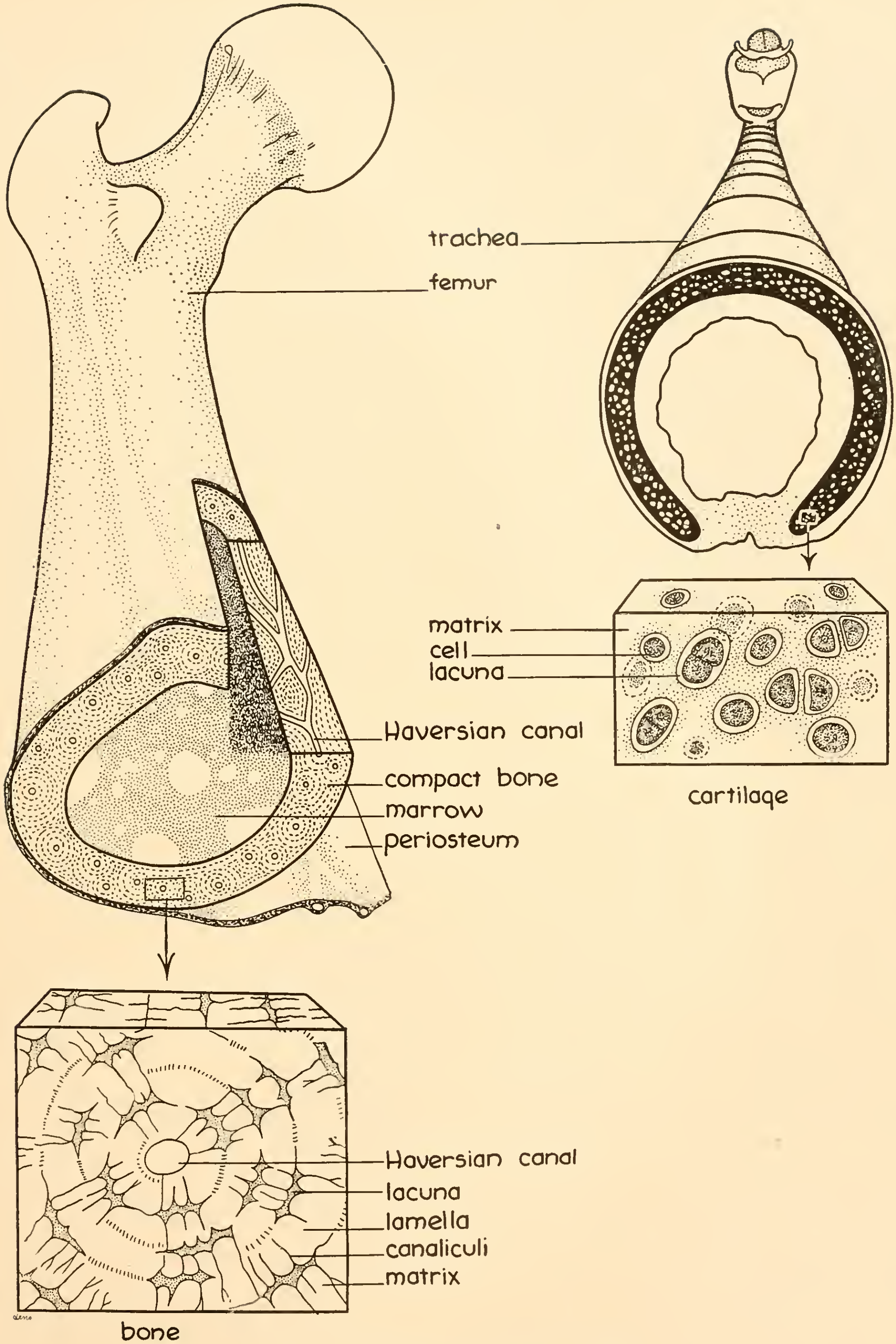


Fig. 4-4. Various kinds of sustentative tissue.

Sustentative tissues. These are the tissues that give the body form and support. They are composed of cells imbedded in a **matrix**, secreted by the cells and usually occupying more space than the cells themselves. The matrix may be composed of fluid, gelatinous material, long tough fibers, or hard mineralized material. There are several different kinds of sustentative tissue, all dependent on the type of matrix (Fig. 4-4).

The tough **ligaments** that fasten the bones together and the **tendons** that connect the muscles to the bones are composed mostly of tough fibers forming a matrix about the cells which produce them. Also, many of the internal organs of the body are laced together by sheets of similar tissue called **mesenteries.** In this type of tissue the fibers lie at random with no particular arrangement, which results in a thin layer of tissue that is soft and pliable, yet tough. A similar type makes up most of the deeper portions of the skin lying below the superficial epithelium. It is this sustentative tissue in its protective covering that gives the skin the qualities essential for an adequate body covering.

Animals, particularly land forms, require a very rigid skeleton to support their massive weights. This is provided by **bone** and **cartilage**, types of sustentative tissue that are composed of large quantities of matrix secreted by isolated cells. In the case of cartilage the matrix is a spongy semi-solid mass in which cells are embedded in tiny cavities (**lacunae**). The cells are usually single, although as they divide there may be as many as four in one cavity before they finally separate. Cartilage is excellent material to resist shock; therefore, it is found between bones such as the vertebrae. It also provides ideal support for the tip of the nose and the external ear where retention of shape and pliability are essential. Bone, on the other hand, consists of a mineralized matrix (calcium carbonate and phosphate) which is very rigid, imparting an element of solidarity to the entire structure. In this case also, the matrix is formed from cells embedded in tiny spaces (lacunae) within the matrix itself. These usually take on definite patterns around blood vessels and nerves, called **Haversian systems.** All of the cells have access to a food supply from the blood system by means of tiny canals (**canaliculi**), for these cells are alive and must be nourished like any other cells (Fig. 4-4).

Tissue in which fat is stored is often classified as sustentative tissue, primarily because there seems to be no other category for it. It performs no mechanical function other than to occupy space. The fat is stored within the cell itself and these cells are located under the skin and in the abdominal region as well as other well-known areas of the human body. During periods of starvation it is very scanty, but during good times it may be stored in quantities far beyond any usefulness to its owner, as attested by many overweight people.

Contractile tissue. This tissue, called muscle tissue, has the ability to shorten, that is, to pull its two ends closer together. This apparently very simple action is responsible for all of the movements of most organisms. Muscle tissue consists of elongated cells or fibers whose internal parts consist of **myofibrillae,** tiny contractile fibrils, lying in a fluid protoplasm called **sarcoplasm.** There are three well-defined kinds of muscle tissue, *visceral, skeletal,* and *cardiac,* each of which differs in its appearance under the microscope (Fig. 4-5).

Visceral muscle is found in the walls of the digestive tract, and other places in the body which are not under voluntary nervous control; this activity is primarily automatic, and is not under the influence of the will. The cells are spindle-shaped with centrally located flattened nuclei, and with myofibrillae running lengthwise in them. It is the shortening of the myofibrillae that pulls the two ends of the muscle cell closer together. Visceral muscle contracts and re-

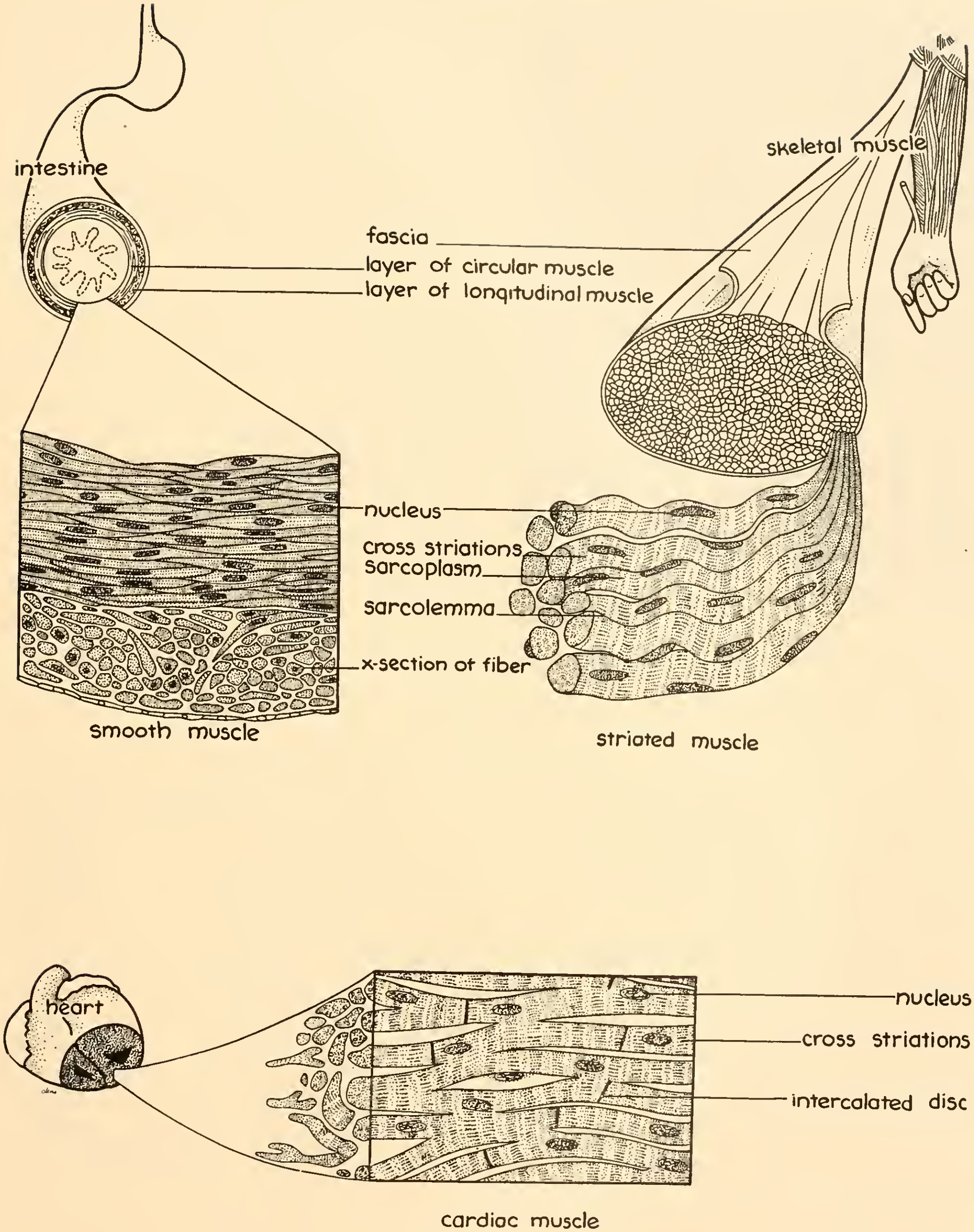


Fig. 4-5. Types of contractile tissue.

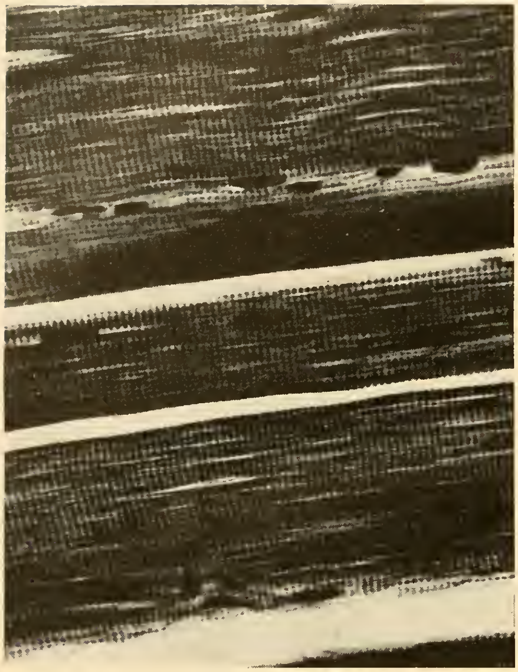


Fig. 4-6. Striated muscle is identified by the striking cross-striations that show under the microscope as seen in this photograph. The nuclei appear as black elongated elipses distributed along the edge of the fibers.

laxes slowly, a behavior which is quite satisfactory for the kind of job it has to do.

The **skeletal** muscles are usually attached to bones and they constitute the large muscles of the body. It is this muscle-bone combination that is responsible for the movement of the body as a whole. These muscle cells are peculiar in that they are not marked off by definite cell membranes, and a single skeletal muscle fiber is composed of many cells whose nuclei lie at regular intervals along the periphery of the fiber just under the surrounding membrane (**sarcolemma**). The fiber is called a **syncytium**, a name applied to any mass of protoplasm which contains many nuclei without discrete cell membranes. Another marked difference between this muscle and the preceding is that there are evenly spaced dark and light transverse bands extending throughout the fiber. These **striations** identify the tissue as striated muscle (Fig. 4-6). The skeletal fibers contract suddenly with considerable force, an essential feature in moving the body. They can contract rapidly again and again with only momentary rest periods.

Cardiac or **heart muscle** is characteristic of vertebrates and is not found in the heart of any of the lower forms. It differs from skeletal muscle in that all of the fibers

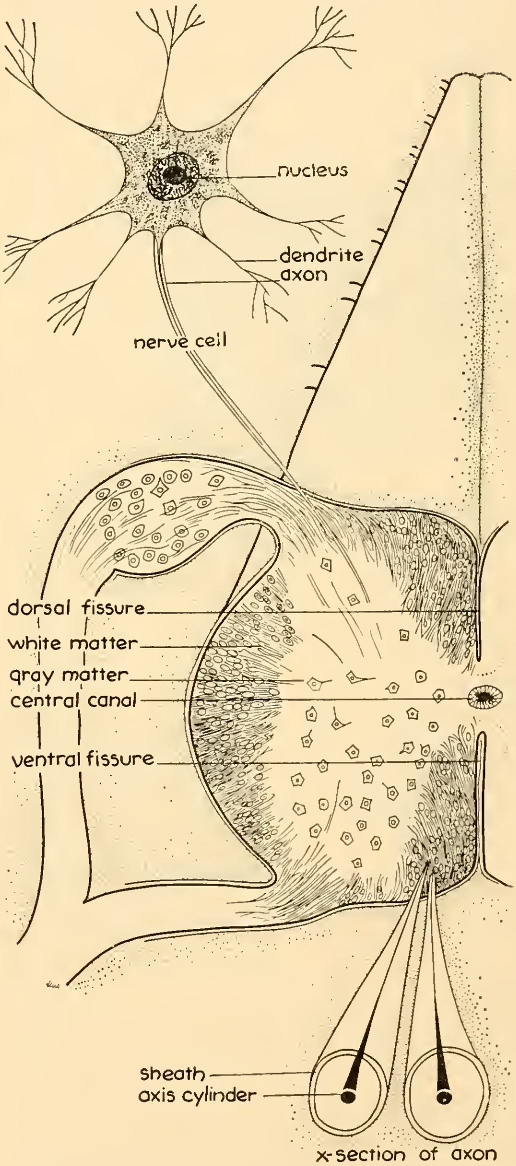


Fig. 4-7. Nerve tissue as found in the spinal cord and ganglia.

are connected with one another so that the entire organ functions as a unit, that is, as a **syncytium.** This is an apparent advantage because the nature of its job requires almost continuous operation. Striations are present, but the nuclei are located deep within the fibers rather than at the surface as in the skeletal muscle fibers. Cardiac muscle cells are so closely connected with one another that a single nerve impulse sets them all contracting at once, thus executing a single powerful contraction. This is obviously very desirable in a pump such as the heart.

Nerve tissue. This type of tissue is composed of **neurons,** special conducting cells that are found throughout the brains and nerve cords of all animals that possess a centralized nervous system (Fig. 4-7). The nerve cell is composed of a **cell body,** which contains the nucleus and surrounding cytoplasm. Extending out from the cell body are threadlike fibers, consisting of numerous **dendrites** which normally convey impulses to the cell body and a single **axon** which usually conducts impulses away from the cell body. The cell body maintains the nutrition of the entire neuron, and if it is destroyed the fibers die. However, nerve fibers severed from their cell body will usually be replaced by new fibers growing out from the cell body.

Cell bodies are concentrated into masses, the most conspicuous of which are in the **brain** and in the **spinal cord;** other masses called **ganglia** have special locations in the body. The nerves that we see on dissection are made up entirely of fibers, each of which is insulated by a fatty sheath, the **myelinated sheath.** These units go to make up the complex nervous system which we shall study in more detail in a later chapter.

ORGANIZATION OF TISSUES INTO ORGANS AND ORGAN SYSTEMS

In order to perform specific functions, tissues must be in someway incorporated into organs, because by definition any structure which performs a given function is an organ. Obviously, a single contractile cell could be an organ under this general definition. However, in the usual, restricted sense, an organ is a group of tissues assembled for the purpose of performing a specific function. The small intestine, for example, is an organ whose function is the digestion and absorption of food. It is composed of layers of different tissues—an outer layer of epithelial tissue covers the gut throughout its length; immediately inside this are two layers of muscle tissue, then a layer of connective tissue, and finally a thin layer, one cell thick, of lining epithelium. All of these tissues perform specific jobs in bringing about the greater function of digestion and absorption of food. Even so, the small intestine is not adequate to complete the job of ingestion, digestion, absorption, and egestion as a single organ. This greater function involves a series of organs, the mouth, teeth, esophagus, stomach, small intestine, liver, pancreas, colon, and anus. In other words, the entire job is done by a **system of organs.** Likewise, circulation, breathing, excretion, and indeed all bodily functions are performed by different organ systems. The combined activities of all of the organ systems constitute an **organism,** or an **individual.** This can be relegated to the cellular level, as in the case of an amoeba in which all of the activities take place within a single cell. On the multicellular level, tissues, organs, and organ systems have been assembled to make up an organism which functions as a unit, just as the single cell functions as a unit.

THE ORGANIZED ANIMAL

As cells became organized into groups they took on a definite relationship to one another, conveying to the resulting animal a particular shape that can be described in terms of **symmetry.** Symmetry refers to the arrangement of parts in relation to points.

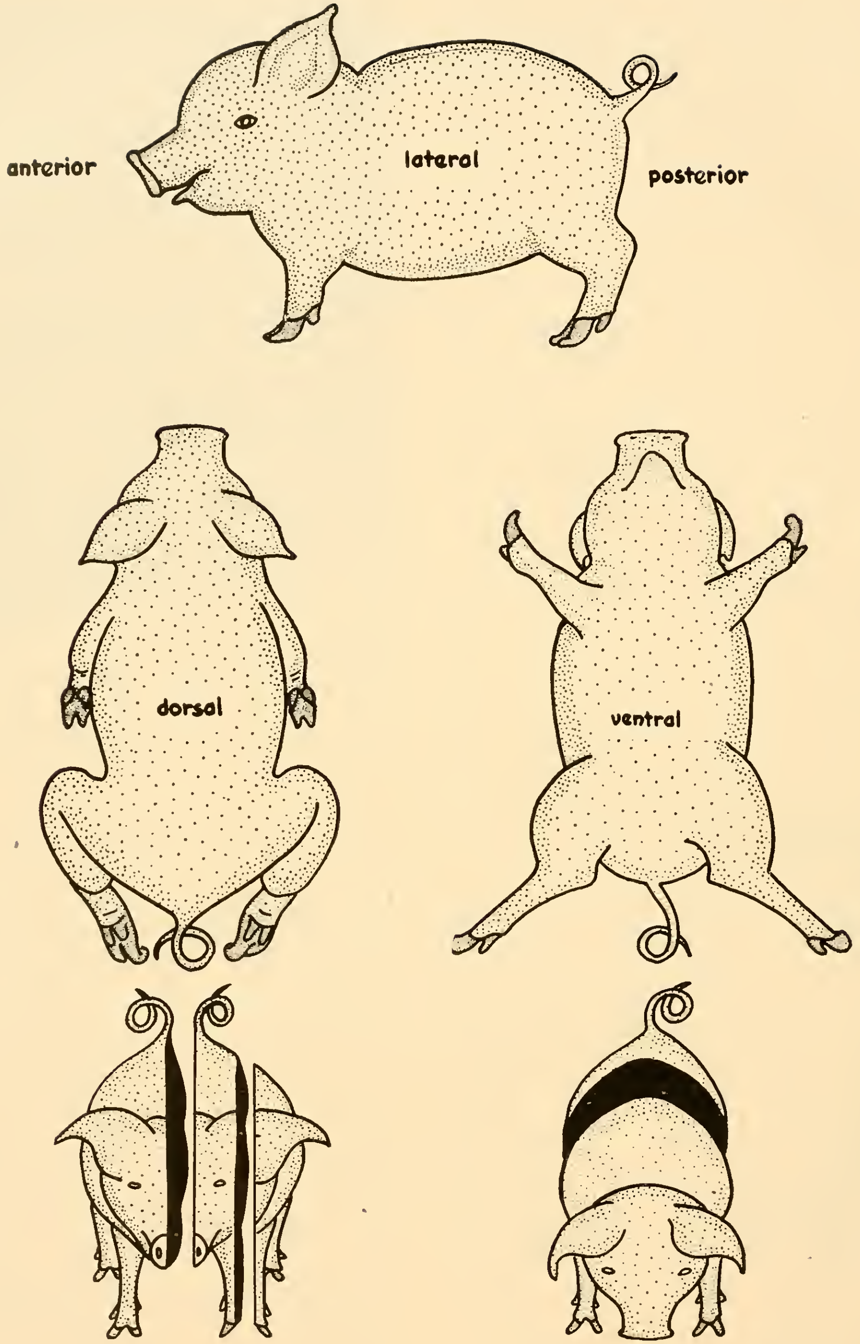


Fig. 4-8. Orientation of an animal possessing bilateral symmetry.

planes, and straight lines. In describing animals a reference to planes describes most of them. A plane has length and breadth, but no depth, that is, it is two-dimensional. Therefore, dividing an animal by a plane results in two halves, each of which is a mirror image of the other. Note that each half is not a duplicate of the other because all of the parts are reversed. When only one plane can be drawn, the animal is said to be **bilaterally** symmetrical. This is the case with most animals. A pig, for example, can be divided into two halves by a single cut extending from the tip of the nose to the tip of the tail, through the midline, and this cut becomes a plane of symmetry (Fig. 4-8). Such a bisected pig now consists of two mirror halves. A bilaterally symmetrical animal may also be cut transversely; such cuts are called *transverse sections*. Additional terms useful in orientation are the following: The back side is the **dorsal** side, while the opposite or belly side is the **ventral** side, the head is the **anterior** end, and the opposite end is the **posterior** end. The pig also has a **left** and **right** side. These terms

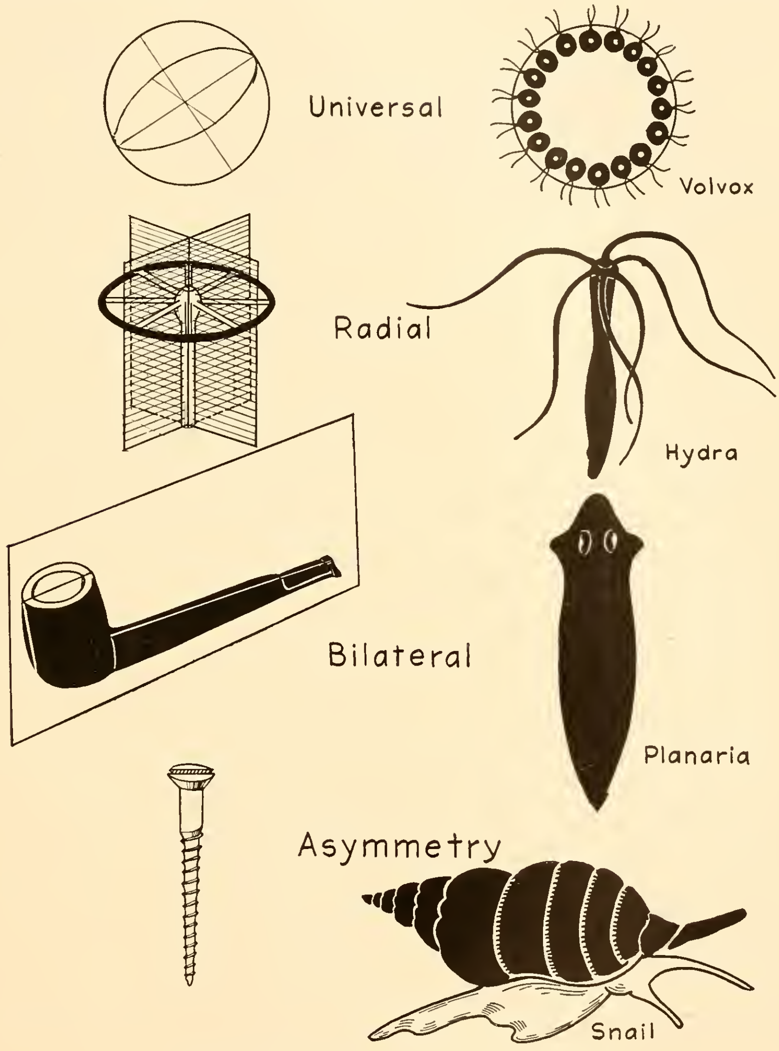


Fig. 4-9. Various kinds of symmetry in animals.

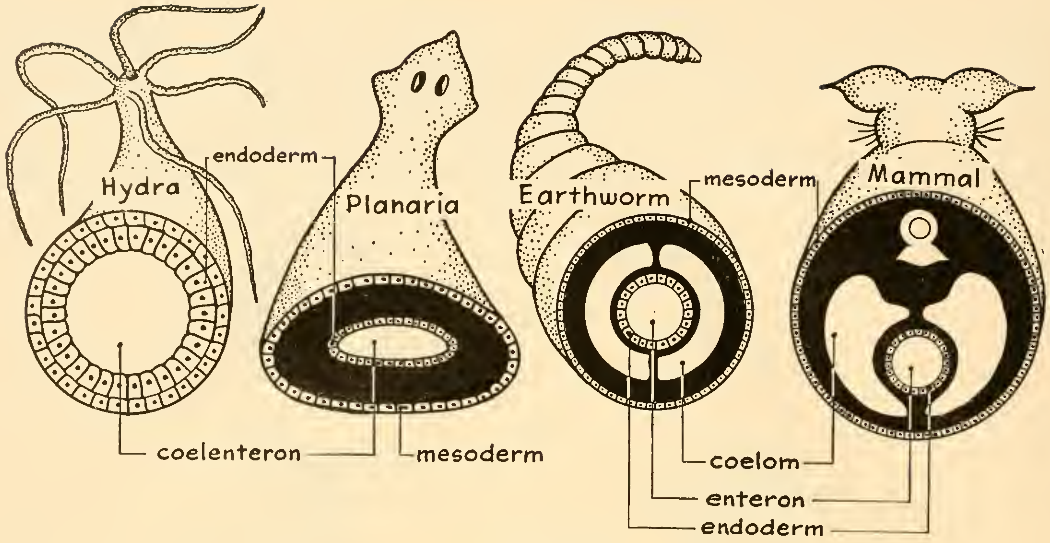


Fig. 4-10. Different types of cavities in various animals.

are important in describing the location of organs and other parts of the animal.

A small number of animals, some Protozoa and early embryos of higher forms, exhibit **universal symmetry.** In such animals it is possible to draw any number of planes passing through a central point which will divide the animal into equal halves. Obviously such forms are spheres, such as *Volvox* (Fig. 4-9).

In other animals it is possible to draw a number of planes through a central line or axis, dividing the animal body into equal halves. These animals are said to possess **radial symmetry.** *Hydra* has this type of symmetry. Radial symmetry is usually confined to lower animals, for such forms are more or less helpless in doing much about their surrounding world. These animals are usually sessile, though some move very feebly, and they must wait for their food to come within their grasp. In other words, unable to pursue and apprehend their food, they are passive animals that survive only because of the richness of their food laden environment. As animals have become more complex, this type of symmetry becomes unsatisfactory and gives way to bilateral symmetry which provides the animal with a body plan that is conducive to further development both in size and complexity.

Some animals, including many Protozoa, are without symmetry, that is, they are **asymmetrical**; there is no way of dividing them into halves by means of a plane. Animals may be symmetrical externally but asymmetrical in regard to their internal organs. Man is a good example of this. Externally he is symmetrical, but his liver, stomach, spleen, and heart are asymmetrically arranged. Some fish such as the flounder are asymmetrical as adults but symmetrical during their immature stages. A very young flounder looks just like any other young fish, but as it matures one eye migrates through the head so that both of them come to lie on one side and the fish lies flat on the bottom on one side. This is an apparent advantage in survival for this peculiar animal.

Body cavities. The formation of cavities is characteristic of the earliest metazoan forms. Such lowly forms as *Volvox* have a central cavity in which the young develop. Among the animals such as *Hydra* a more useful cavity has evolved, one which functions in the storing of food during digestion. Such a cavity is referred to as a **coelenteron**

(Fig. 4-10). It functions both as a digestive cavity and as a space where food can be circulated to the lining cells; therefore, it is referred to as a **gastrovascular cavity** as well. Such a cavity has but one opening through which food must pass upon entering and undigested food upon leaving the body. The flatworms also possess such a cavity.

As animals increase in complexity, the simple sac-like coelenteron of the lower forms is inadequate and becomes modified into an **enteron** with an additional opening, the **anus**, at the opposite end from the mouth. Thus food can follow a one-way path through the body, a more efficient arrangement, certainly, than the crude coelenteron of *Hydra.* In the earthworm and higher forms another cavity, the **coelom** or body cavity, appears, which lies between the digestive tract (enteron) and the body wall. It is a convenient space into which wastes, sex cells, and some foods can be dumped, later to be eliminated or utilized. It also provides space for the internal organs which become much more complicated as animals grow more complex. The entire body cavity is lined with a thin sheet of tissue called **peritoneum.** Once the coelom had arisen in those early invertebrates somewhat like the earthworms, it apparently proved highly satisfactory in furthering the development of animals, for it was retained through all higher groups of animals.

Segmentation. Another feature that was introduced early among animals and retained throughout subsequent groups was the clinging together of individuals, forming long chains which resulted in **segmented** or **metameric** animals. Certain low worms divide by transverse fission but fail to separate until a large number of fissions have taken place, thus producing a long contiguous series of worms clinging together head to tail (Fig. 4-11). It is thought that some of these failed to separate at all, thereby producing a long worm consisting

Fig. 4-11. A possible explanation of the origin of segmentation.

of many parts very much alike. Once this happened, an integrating system could be devised which would then result in a segmented animal such as an earthworm. This may be the way segmentation came about. In any case, segmentation is a persistent character of many higher animals, including man. Lower forms such as the earthworm show both internal and external segmentation, and most of its organs are duplicated in almost all of the segments. However, some organs, like the gonads, are confined to certain segments, and, in general, there is a concentration of nervous organs at the head end of the animal.

Segmentation is not very obvious in such higher animals as man because it is obscured by the specialization of individual segments. Nevertheless, a glance at the skeleton shows that the basic plan is segmental (Fig. 15-2). The vertebrae and the ribs, while varying slightly in different parts of the body, are serially repeated and resemble one another very closely. Segmentation is clearly indicated in the early embryos of vertebrates, and during the first few weeks of development the human embryo shows segmentation which in principle is like that of the earthworm. As it grows older the clear-cut segments are obliterated by fusion and reorganization.

With the gradual development of these various features, animals became organized into what they are today. Many new problems arose with the ever increasing complexity of the total organism, and the consequences of these we shall consider a little further.

THE CONSEQUENCES OF ORGANIZATION

As animals grew in bulk and complexity they were confronted more and more with the problems of transport and coördination. Such activities as respiration, nutrition, and excretion, which were simply performed when the cell was in constant contact with its fluid world, became difficult or impossible when it was separated from this environment by even a few covering layers of cells. Such inner cells would have to depend on diffusion to carry oxygen and food to them and to remove wastes from them. At best this is a slow process and certainly not rapid enough to allow an animal to grow very big or become very active. Therefore, specific organ systems had to be evolved if animals were to grow in bulk and activity.

In the following discussion we shall compare the activities of organisms at the cellular and multicellular levels, pointing out the problems involved in becoming complex and indicating how the metazoan animal has solved them. We can use amoeba for the single-cell level, hydra for a simple metazoan, and man for the multicellular level.

Respiration. Respiration is the taking in of oxygen and the eliminating of carbon dioxide. In the amoeba this is cared for very efficiently and simply by diffusion through the limiting membrane that envelops the cell (Fig. 4-12). Once in the cell, oxygen diffuses to where it is needed and the carbon dioxide which results from the combination of oxygen with food likewise makes its way to the cell or plasma membrane, passing out through it to the surrounding water. The only essential need is sufficient oxygen in the environment.

Respiration is essentially the same in a simple metazoan such as hydra where each cell is in contact with its external world. Diffusion is adequate to take care of the respiratory needs of this simple animal.

In a complex metazoan animal, respiration is, of course, the same, and oxygen and carbon dioxide exchange must take place in each cell. Since most of the cells lie deep within the organism there is no possible chance for gaseous exchange by diffusion with the external world, especially since the organism is covered with skin which is impervious to such gases. The metazoan

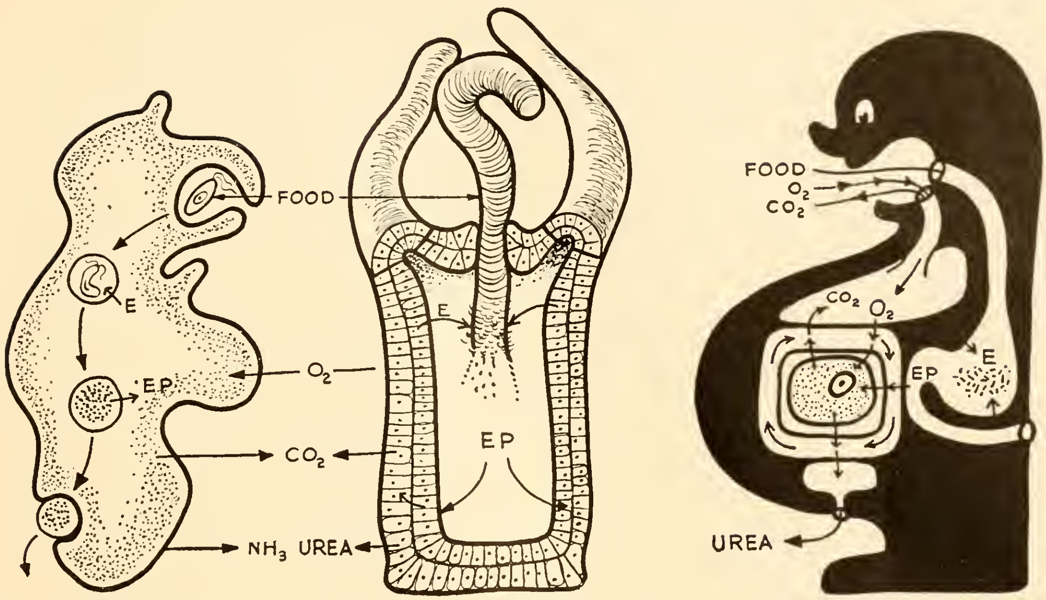


Fig. 4-12. The problem of consuming food, digesting it, burning it, and excreting the waste products is essentially the same at all levels of animal organization. Here it is compared in the single-celled animal, amoeba, the simple metazoan, hydra, and in a highly complex form such as man. The problem is always reduced to the level of the cell and must be solved at that level in all animals. The letters EP mean end products and E means enzymes.

then is forced to develop a **breathing system** in combination with a **transportation system,** which would make it possible for oxygen and carbon dioxide to get directly to and from each individual cell. In aquatic forms such as fish, the breathing organs are **gills;** in land forms such as man, they are **lungs.** Both must meet certain requirements if they are to function as breathing organs. They must be constructed so that oxygen in the surrounding medium (water or air) can pass readily into a transporting medium (blood) which will convey the gas to each cell in the body. This means that the blood must flow in thin-walled tubes (capillaries) very close to the external environment in order that the exchange can be readily accomplished. Microscopic examination of a gill filament or a lung sac will reveal that this situation is met beautifully. Blood flowing through thin-walled capillaries passes within two cells of the outside world (Fig. 18-19), which makes the gaseous exchange possible and simple.

The transporting system delivers the oxygen to the cells of the body and collects the carbon dioxide from them. Here again the circulating blood must come in close proximity to every single cell of the body in order that at no time will the cell be short of oxygen or have a surplus of carbon dioxide. When the blood reaches the cells it is no more than one cell away so that gaseous exchange can be accomplished quickly.

Nutrition. At the cellular level the business of securing food, digesting it, absorbing it, and ultimately metabolizing it is also a relatively simple procedure. The amoeba surrounds its food, thus forming food vacuoles which might be thought of as miniature intracellular "stomachs." Digestion is carried on in these tiny structures and the final end products (amino acids, glucose, fatty acids, and glycerol) are absorbed into the surrounding cytoplasm (Fig. 4-12). The food is burned and the locked up energy released to be utilized by the amoeba in the many ways that are essential for its life.

The simple metazoan obtains and digests

food by the coöperative effort of many cells. The food is captured by the tentacles and taken into the coelenteron where it can be retained until the lining cells secrete enzymes to digest it. The end products then can be absorbed directly.

The cells of the complex metazoan are confronted with the same difficulty in obtaining food as they were in receiving oxygen; therefore, something has to be done about providing space in the body where food can be satisfactorily digested and absorbed into a transporting medium that will deliver it to each cell of the body. The same transport system can be used that carries the gases in respiration. All that is needed is a place where food can be held sufficiently long so that digestive enzymes pouring into it will have time to break the complex insoluble molecules down into simpler soluble ones. Then proper facilities will be needed for absorption, that is, large surface areas, and so forth.

These conditions are met in the digestive tract of all higher animals very satisfactorily. They possess a portal of entry or mouth, which may or may not be armed with teeth for macerating food, and a long tube into which digestive glands empty their food-splitting enzymes. Undigested food leaves through the end of the tube, the anus. Once the food has reached the soluble stage it is absorbed into the blood and transported to each cell, which picks and chooses the particular energy-giving and constructive materials it needs to perform its own specific job in the organism as a whole.

Excretion. Closely linked with respiration and nutrition is the matter of getting rid of wastes, that is, *excretion.* In this discussion we shall consider only the nitrogenous wastes of metabolism as excretory products, although in the broad sense of the term *excretion* includes water and carbon dioxide. At the cellular level, nitrogenous wastes are also eliminated through the plasma membrane. At the multicellular level, excretory products, if not removed, accumulate very rapidly and soon reach a point where the cell cannot survive because such products in quantity are toxic. Hence, an effective excretory system is demanded in any animal where the cells are removed any distance from the surface.

Again the simple metazoan gets rid of its nitrogenous wastes just as amoeba does, by simple diffusion. Where there are but two layers of cells, each in contact with the external world, the problem of excretion is easily solved.

In the complex metazoan, nitrogenous wastes such as **urea** are removed by the **kidney,** an organ designed so that all of the transporting medium must pass through it at regular intervals. By a process involving filtration, selective reabsorption, and secretion (p. 524), wastes are removed from the blood and conveyed out of the body through a system of appropriate tubes. All metazoan animals above the simple two-layered animals possess such a system of excretory tubules. In the lower forms there are many units scattered among the cells so that fluid bathing these cells can find its way to one of these tubules and be relieved of its load of nitrogenous wastes. In higher forms the many excretory units become compactly arranged in a single organ, the kidney.

Reproduction. Amoeba reproduces itself by simply splitting into two offspring, the most primitive type (fission) of reproduction found in living things (Fig. 4-13). Whenever the amoeba reaches a certain size, it divides and continues growing. The rate at which it can increase its numbers when conditions are favorable appears to depend solely on the amount of food it can engulf and the rate at which it can build protoplasm. The daughter cells thus produced are all essentially alike and, barring accidental death, live forever.

Multicellular animals have nearly all given up simple fission as a means of increasing their numbers and have assigned

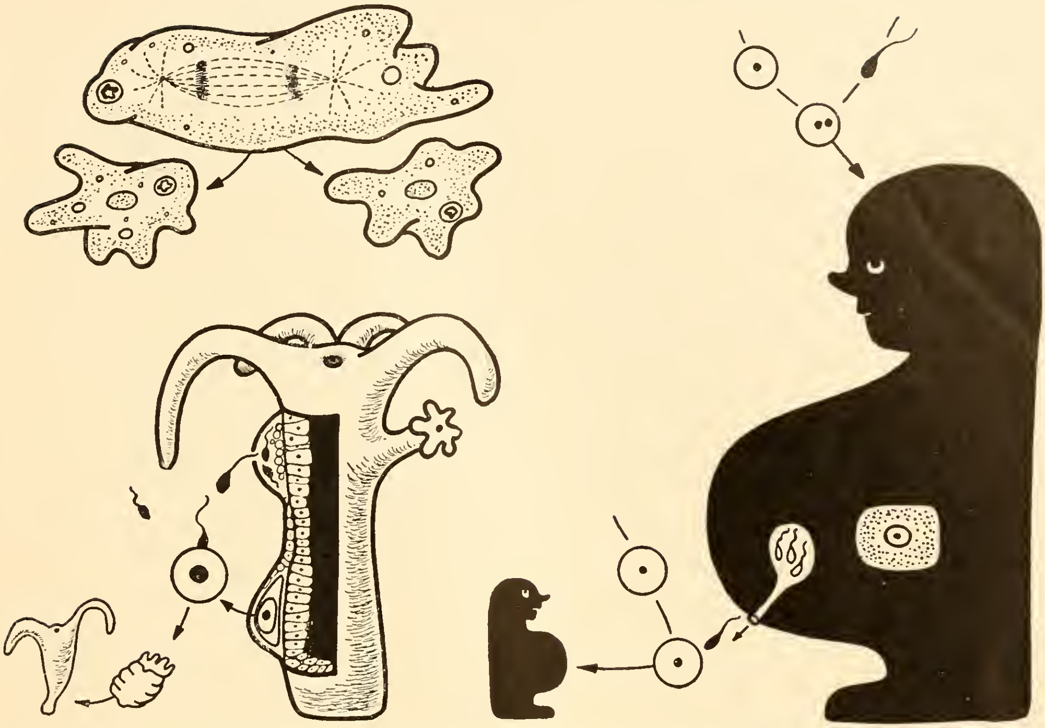


Fig. 4-13. A single-celled animal can reproduce by simply dividing into two individuals. Higher forms (some of the Protozoa likewise) provide special cells, eggs and sperms, which unite and give rise to a new individual.

the job of reproduction to special cells, eggs and sperms, which, with a few exceptions, must unite to form new individuals. This device has the advantage of bringing two lines of protoplasm together which results in variation in the offspring, for each offspring possesses a combination of the characteristics of its parents and is therefore different from either. Variation seems to have some advantage in survival of the species and probably has been important in the gradual evolution of complex forms.

Specialized reproductive cells are produced by special organs, the **gonads.** To insure the union of eggs and sperms special tubes are necessary to conduct these cells out of the body, and ultimate union is still more effectively assured in higher animals by the development of copulatory organs. To insure greater survival, the offspring of many of the higher animals are either retained within large egg shells or the body of the mother for various periods of their early development. All of this intricate machinery came into being because cells "insisted" on aggregating into large masses.

The penalty of organization. The organization of cells into masses and the subsequent specialization of different kinds have resulted in organisms that are able to penetrate a greater variety of environments because of their greater motility and intricately adjusted bodies. That means biological success. Along with all of the benefits derived from specialization, however, there has been at least one rather severe penalty, and that is **natural death.**

Recall that single cells reproducing by binary fission, barring accidental death, live on forever. The amoeba observed under your microscope has been alive since the dawn of life on the earth. Had death occurred along the road somewhere the one you see before you would not be there. Death put in its appearance when organization of cells occurred, that is, when some of the individual cells lost the power to reproduce, and hence were sacrificed in order that those that were able to reproduce could continue. This seems to have been the penalty for organization and specialization.

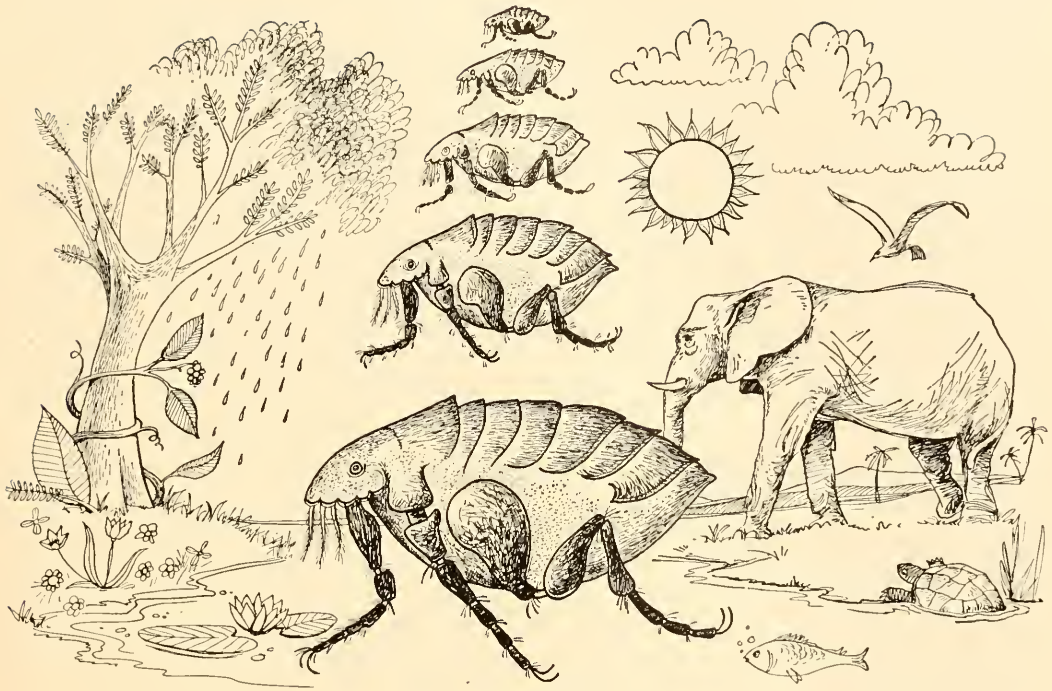
It is difficult to understand why cells that are separate, free from other cells, may continue living forever, whereas others that are bound together into a mass eventually die even though apparently all of their basic needs are satisfied. Perhaps during the process of evolution the organization was not quite perfect, that is, the individual cells were not completely cared for, or perhaps the whole organization slowed down after a certain period of time and could not keep pace with the demands of all the cells. This point has long intrigued biologists and has resulted in some very fruitful research.

If it were possible to grow tissues away from the animal of which they are a part, it would be possible to determine whether or not such cells once released from their intended environment could survive like single isolated cells. This was first done in 1907 by Ross G. Harrison, who grew embryonic tissues in flasks by feeding them special nutrients. Alexis Carrel, employing similar methods, kept embryonic chick heart tissues alive for over 30 years. At the end of this period of time, about three times the normal life span of a chicken heart that remained with its owner, the cells were active and appeared not to have changed at all. They apparently have the capacity to live forever, just as single-celled animals do. In other words, metazoan cells still retain their power of immortality. It is only when they become incorporated into a community of cells in the body that they undergo the changes which we associate with **senescence.** Something is not quite right in the animal body and causes a cell to fail. The delicate adjustment of youth and maturity is thrown out of tune so that eventually some cells do their job so poorly that the complete organism cannot maintain life. It is not at all impossible that some day the exact reason for this lack of adjustment will be discovered and metazoan cells will regain their immortality. Imagine the social upheaval such a discovery would cause!

PART IV

The Rise of Animal Life

CHAPTER 5



THE ANIMAL AND ITS ENVIRONMENT

So far we have considered the origin of animal life in a physical world, centering our attention on the animal itself rather than the environment in which it thrives. Since the animal is an integral part of its environment, it is necessary to devote some attention to this relationship, which is the study of **ecology**. Our particular emphasis will be on animal ecology, although no ecological study can entirely ignore the rôle played by the plants.

Great variations in the environments of the world are caused by such physical factors as light, temperature, and moisture, all of which have a profound effect upon the physical and physiological characteristics of animals. These physical factors not only determine the kinds of animals that are able to survive in certain regions but are also instrumental in building up associations between animals and plants. Thus the problem in ecology is twofold: first, to consider the individual animal in terms of certain physical factors in its environment; second, to study the relationship between animals living together.

PHYSICAL FACTORS IN THE ENVIRONMENT

Temperature

Everyone is fully aware of his own sensitivity to change in temperature. We usually want our houses at a relatively constant temperature of about 25° C. and experience discomfort if it deviates a few degrees one way or the other. Our internal environment is even more critical—there a rise of a few degrees indicates sickness of a serious sort. What is true of man in this respect is equally true of all animals. When we consider that the temperatures known to us range from 273° C. below zero to several thousand degrees above zero, it is rather remarkable that life exists in that extremely narrow range of a few degrees above freezing to about 45° C. Even within these narrow limits the physiological processes do their best work at an **optimal point** around the middle, on either side of which the rate of physiological reaction falls off. Animals tend to seek out a temperature that, at least most of the time, will permit their bodily activities to proceed at an optimal rate.

Since animals are found in all parts of the earth except the polar regions, they must find ways of surviving extremes of temperature with the least amount of discomfort to themselves. Those living in colder regions either have a constant body temperature (monothermal) or else have developed a hardiness to cold that permits them to survive. The internal environment of the warm-blooded animals—birds and mammals—is constant and always maintains the temperature at which physiological activities can proceed at an optimal rate. Cold-blooded animals (poikilothermal), on the other hand, vary their internal temperature and rate of reaction in accordance with the external environment. When the temperature drops, the animal becomes sluggish, even to the point of complete inactivity. Some can stand freezing for short periods of time. On a chilly morning in the fall of the year it is simple to capture a cold-blooded animal, from a common housefly to a rattlesnake, but the task becomes more difficult on a hot summer day when the temperature approaches 100° F. Only at the higher temperature are all activities at their maximum.

During cold seasons some mammals undergo a period of inactivity called **hibernation**, when their temperature drops and metabolic processes are reduced to a minimum. Hibernating rodents, such as the ground squirrel, pass into almost complete inactivity, their heart and breathing rates slowing down markedly. Indeed metabolism is just enough to keep the animal alive. The energy to maintain life is derived from stored fat, hence the fat bear in the fall and the lean bear in the spring of the year.

Other animals survive periods of intense heat by going into an inactive state called **aestivation.** This is strikingly demonstrated by the African lungfish which lives in regions that are apt to dry up during the summer months (Fig. 5-1). With the approach of hot weather and desiccation, the fish burrows in the mud and secretes a capsule in which it passes the warm dry months. When the temperature drops and moisture returns, it resumes its active life once more.

Some cold-blooded animals put forth communal effort to prevent too great a drop in temperature. Bees, for example, become very active on cold winter days, beating their wings almost continuously. This keeps the temperature in the hive above freezing even though the outside temperature may be several degrees below zero. Snakes frequently aggregate in dens in the fall of the year for the apparent purpose of keeping warm. Even though they are cold-blooded, their temperature stays slightly above that of the external environment. Coiling about one another in large masses, the whole group stays a little warmer because the individual heat loss is reduced.

Keeping in mind that all living things are

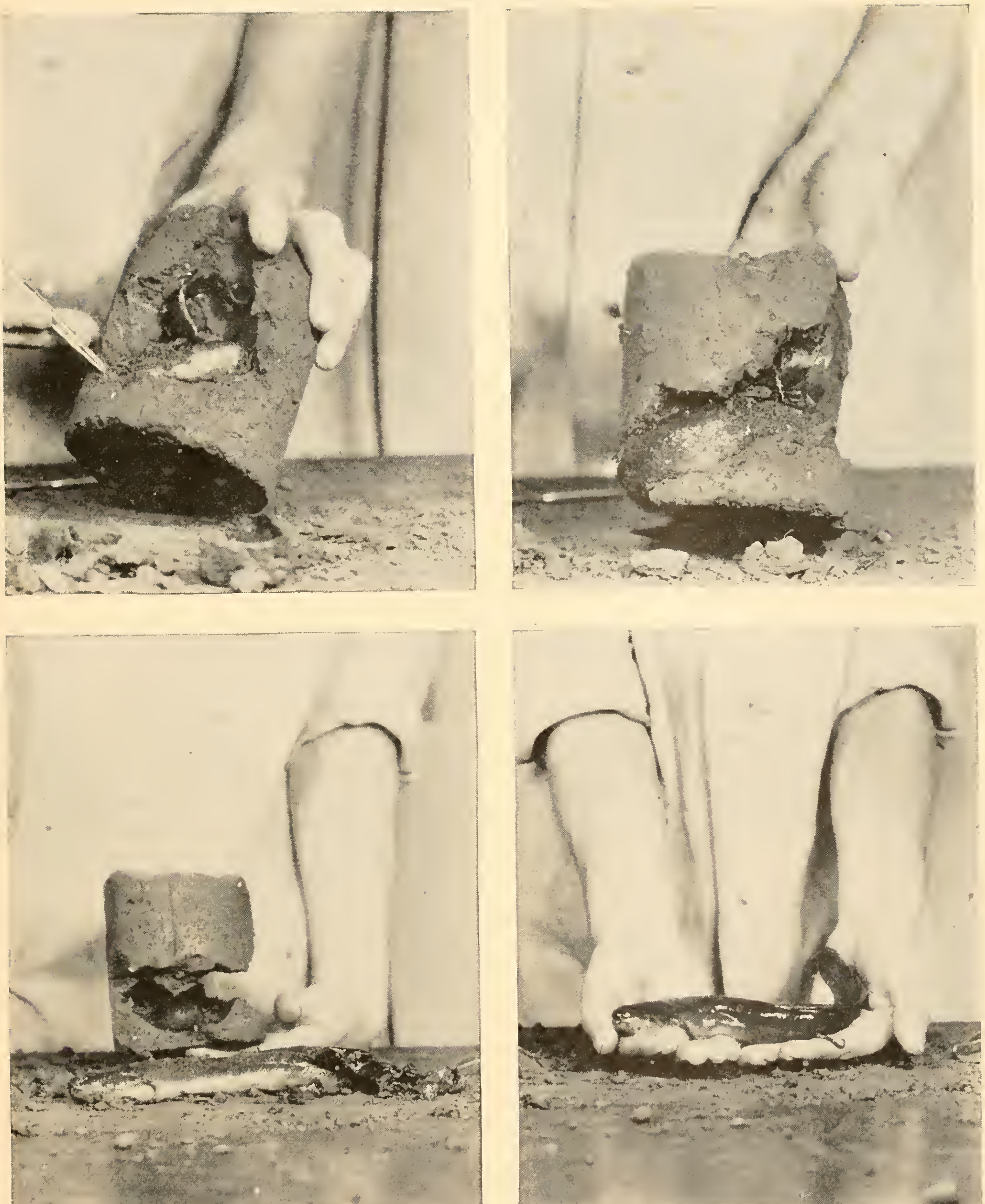


Fig. 5-1. The African lungfish (*Protopterus*) undergoes aestivation during periods of drought when the waters disappear from its normal habitat. If placed in a container filled with mud it will form its capsule and remain dormant for many months in this condition. Pictured here is such a fish being released from a can of mud. When placed in water the animal immediately breathes by means of its gills like any other fish.

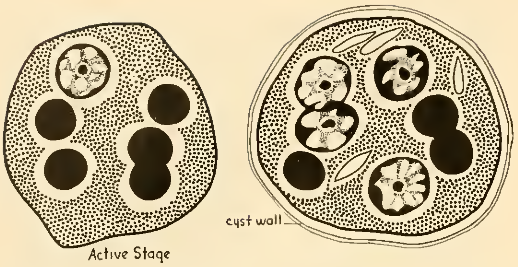


Fig. 5-2. Some Protozoa such as the human intestinal parasitic amoeba (*Endomoeba histolytica*) withstand periods outside the digestive tract where there is very little moisture. This it does by secreting a resistant cyst wall that prevents desiccation. It is in this stage that the parasite is transmitted from person to person.

tuned to such a narrow temperature band, try to imagine what would happen if the earth's orbit shifted ever so slightly, just enough to change the average mean temperature on the earth by a paltry 100° C. up or down. All life would stop abruptly; every living thing would congeal either from freezing or cooking. Think how precarious our existence is, reckoned in astronomical terms. A slight celestial slip would mean the end of life as we know it. Fortunately that slip has not occurred in the past one or two billion years, and probably will not for a few billion more.

Moisture

We are already familiar with the importance of water in relation to life processes (p. 40); here we need to consider it as an essential part of the environment. Getting the proper amount of water at the right time is one of the basic problems that confronts animals. This is sometimes very difficult and, as a result, animals have devised various means for maintaining their water supply at a constant level. Although too much water is as detrimental to some animals as too little is to others, probably the greatest problem for most animals is the conservation of water.

Even Protozoa have provided themselves with a method of withstanding desiccation. Amoeba, for example, forms a resistant cyst which is impervious to water loss (Fig. 5-2). While beautifully housed in this tiny container the amoeba can withstand long periods of drouth without ill effects. The eggs of many metazoan animals such as crustacea and rotifers are provided with a thick shell which resists drying. The eggs of many parasitic roundworms are likewise resistant to moisture loss. Some can be blown around in the dust for months and still become viable when picked up by the proper host. In fact, some even rely on this period of desiccation to disseminate the species.

Some larger animals, desert turtles and lizards for example, never require water in the liquid state; they manage very well on that which is taken in with their food. Camels are notorious for their ability to work long periods without water. They can exist a week or more on dry food and if green plants are available it is not uncommon for them to go without water for a month. Jack rabbits, mountain goats, jumping mice, and other mammals living in arid regions are very well fitted to conserve their water intake, which is usually only that provided in the food. Most mammals, however, require a great abundance of water, especially those that perspire, such as man and the horse.

Excessive moisture is fatal for some animals. The earthworm, for example, is driven from its burrows after heavy rains because it cannot get enough oxygen from the water. Even frogs may drown in spite of the fact that they are usually near water and require it in large quantities. High humidity often creates a favorable environment for certain types of parasites which under normal amounts of moisture could not gain a foothold.

Light

Wave lengths extend from a fraction of a submicron (cosmic rays) to more than a thousand meters (Hertzian or radio waves), yet most animals are sensitive to ethereal vibrations that range only from about 0.38 micron (violet light) to 0.76 micron (red). This extremely narrow range includes the so-called visible spectrum to which our eyes are sensitive. Most animals seem to be sensitive to it also, but some animals are known to respond to wave lengths to which we are insensitive. On the other hand, we respond to wave lengths that some animals are unaware of. Our receptors pick up only about 1/125 of the total range of ethreal vibrations which are constantly being showered on our bodies. Even though visible light is composed of such a small segment of this range, all animals are profoundly affected by it.

Light has a direct bearing on the orientation of some animals. Moths, for example, fly toward a light, whereas pillbugs avoid bright light. The advantage to the animal in the former case is questionable, but in the latter it has a distinct advantage because the pillbug breathes by means of gills and must seek out damp places. Dark places are more apt to be damp than brightly lighted areas.

The reproductive cycle of some animals, particularly birds, is definitely influenced by light. If daylight is supplemented by artificial illumination the reproductive organs are stimulated to work longer, hence more eggs and young. Farmers have taken advantage of this fact by installing in their chicken houses lights which burn long after the sun goes down. Linked with this is the stimulus that causes migration in at least some birds. Bees are known to determine direction by the angle of the sun (see p. 236).

Some of the lower vertebrates, particularly fish and amphibians, have the ability to change color. They usually attempt to match the background upon which they are resting, obtaining the obvious advantage of camouflage (Fig. 5-3). This is done by condensing or spreading out the pigments that are confined to special skin cells called *chromatophores.* Experimentation has shown that at least one mechanism involves the amount of light that enters the eyes of the animal. This is discussed more fully on p. 430.

Fig. 5-3. A case of concealment by acquiring the color and position of the surrounding environment. Note how the upper part of this swamp eel (*Fluta alba*) resembles the surrounding eelgrass.

Chemical cycles

The elements of which all organisms are composed come from the environment and return to the environment upon the death and subsequent decomposition of the organism. There is, then, a constant cycle of the elements. An atom of carbon residing in a protein molecule that goes to make up one of our muscle cells, let us say, may have been incorporated into any carbon-containing molecule of thousands of plants and animals before us, and will become a part of thousands of living things following us. It might be thought of as a kind of "reincarnation," so to speak, but not the variety that usually comes to mind when this word is mentioned. All elements found in protoplasm follow specific cycles, two of

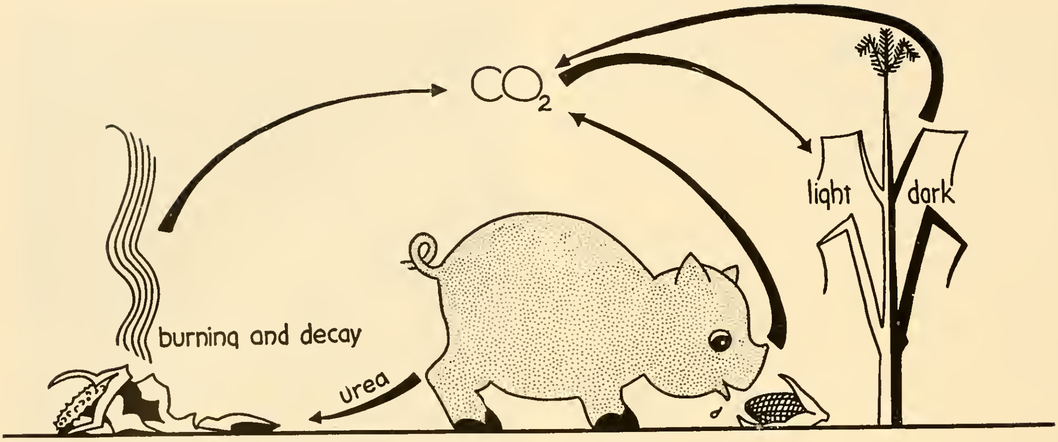


Fig. 5-4. The carbon cycle.

which—the **carbon** and **nitrogen cycles**—will be discussed briefly.

Carbon, being the core element of protoplasm, is conspicuously present in all living things and, like all elements, follows a cyclic pattern (Fig. 5-4). Plants utilize the carbon in carbon dioxide to manufacture fats, carbohydrates, and proteins, as well as many other essential food products. These foods are eaten, digested, and absorbed by animals, and the carbon becomes a part of the body of the animal. During destructive metabolism carbohydrates are burned, releasing carbon dioxide into the air again. Similarly, carbon dioxide is released at night by plants as they oxidize carbohy-

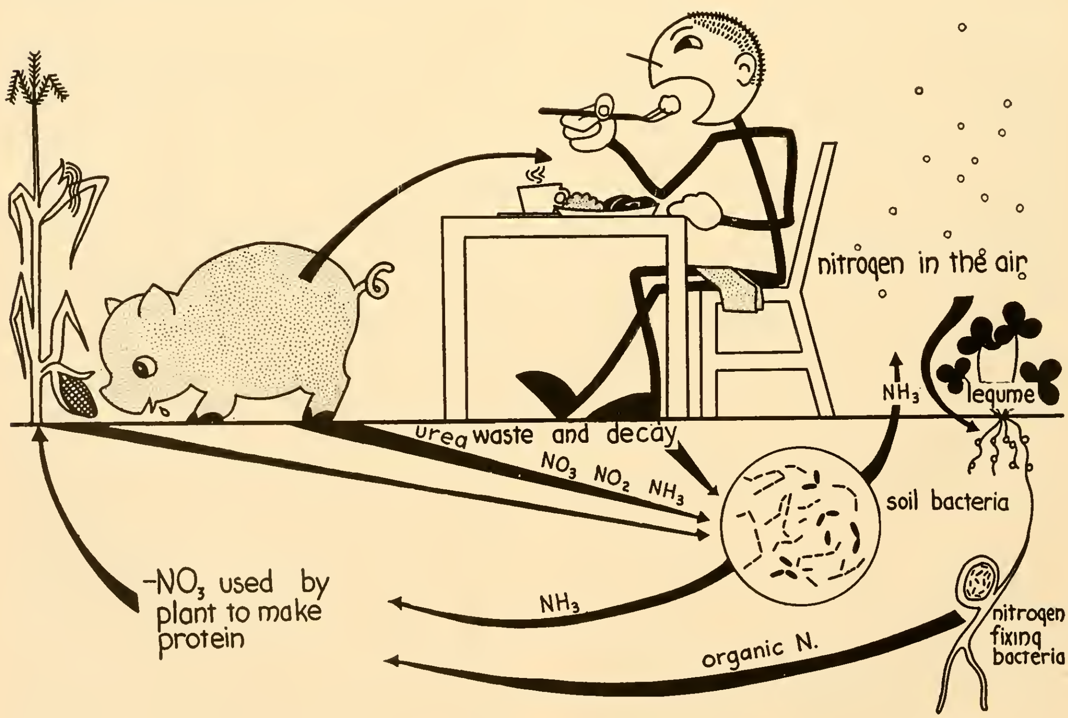


Fig. 5-5. The nitrogen cycle.

drates to obtain energy. It must be pointed out, however, that plants also produce carbon dioxide during the daytime, but because it is utilized immediately in the process of photosynthesis, its release is obscured. The burning of organic matter and decaying of dead plants and animals also release carbon dioxide into the air. Such is the extent of the carbon cycle.

The nitrogen cycle (Fig. 5-5) is somewhat more complicated than the carbon cycle, primarily because plants cannot utilize atmospheric nitrogen. Nitrogen in the air must be converted first to **nitrites** (NO_2) and then to **nitrates** (NO_3) before the plants can make use of it in producing proteins. This conversion is brought about by N-fixing bacteria in the nodules which

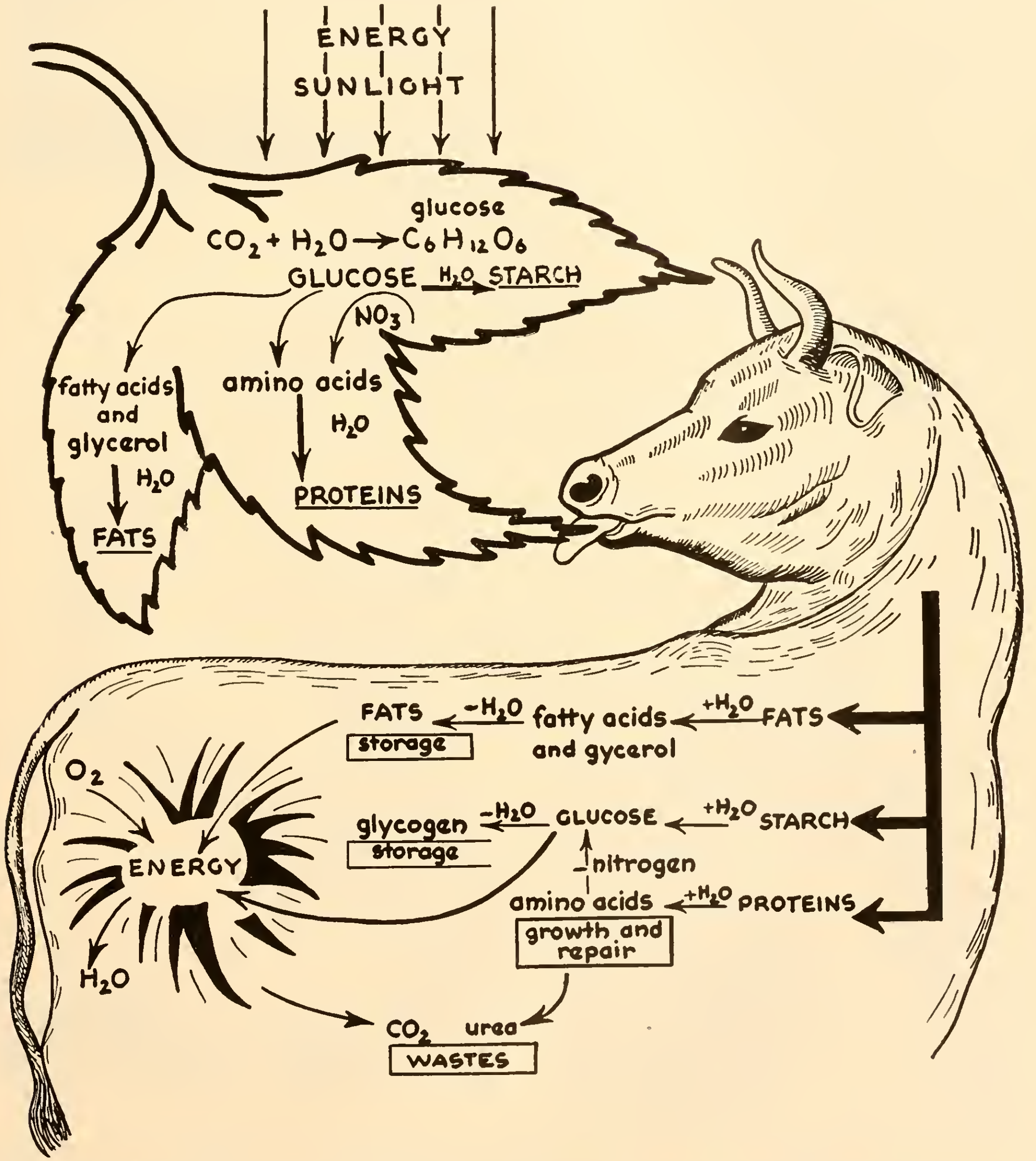


Fig. 5-6. Solar energy is incorporated into the foods manufactured by plants. This energy is released from the foods by animals for their own use.

protrude from the roots of certain leguminous plants, such as beans and clover. Again the plant proteins are consumed by the animals and converted into their own protein, or reduced to urea and lost from the body. Urea, as well as the dead body of an animal or plant, decomposes to form either atmospheric nitrogen or nitrates which are then used by the plants. Bacteria play an important part in the nitrogen cycle. If all bacteria suddenly disappeared from the earth, we would soon be short of nitrates and eventually of the basic materials that produce protoplasm.

Fig. 5-7. Food chains. In each case the chain starts with the plant where photosynthesis produces the first food; the plants are eaten by herbivores, which are in turn eaten by a series of carnivores, in one case ending with the large fish and the other with the leopard.

Nutrition: food chains

All animals with the exception of a few Protozoa depend ultimately on plants for their food. This is illustrated in Fig. 5-6, where we see that the plant manufactures fats, carbohydrates, and proteins, and the animal breaks these down for its own use. The plants, therefore, are continually building up the organic world while animals are constantly tearing it down. It is apparently a well-established relationship, and one that we hope will endure for a long time to come.

Energy passes from the plant where it has been stored from the sun to the animal that eats the plant. However, it does not always expend itself completely in a passage that involves only two organisms. Often there are many intermediates which transfer the energy through a **food chain,** in which one animal after another is eaten until the energy can be released only by the death of the last animal in the chain. All of the food chains in a given community constitute a **food cycle.** Let us consider several food chains.

In an abundantly populated fresh-water pond, plants and animals are constantly dying, falling to the bottom, and decomposing. This disintegrating organic material forms a source of energy for the growth of bacteria. In addition many algae, simple plants, grow by the utilization of simpler substances, just as all plants do. These two then, bacteria and unicellular plants, form the basis of food for tiny organisms such as Protozoa. Small Protozoa are eaten by larger ones, these in turn are eaten by rotifers, then crustacea, aquatic insects, and finally by fishes—first smaller fish, then larger ones. The latter either die or are eaten by fish-eating mammals such as mink, bear, or man. In the first case the chain ends with the death of the fish, in the second by the death of the mammal. A somewhat shorter pond cycle would be one starting with a snail eating a leafy plant, such as is depicted in Fig. 5-7. The snail is then eaten by a crustacean, the crustacean by a small fish, the small fish by a larger one. Here the food chain ends unless, as before, the fish is eaten by bird or mammal.

On land a food chain may follow a similar pattern (Fig. 5-7). In this case the zebra feeds on plants, and is then eaten by a leopard. This may end the chain, providing the leopard dies a natural death, which is highly unlikely. As it grows older and loses some of its faculties, sooner or later it falls prey to another carnivore. This transfer of energy may go on almost endlessly.

ANIMAL RELATIONSHIPS

Some very interesting interrelationships between animals have been established, primarily on the basis of obtaining food, although some seem to have other purposes. Collectively these relationships are spoken of as **symbiosis.** They range all the way from a loose, more or less haphazard, association to a closely knit relationship in which the two or more animals are forced to live together. These interrelationships have fascinated biologists and should also be of particular interest to beginning zoology students.

Between individual animals

Commensalism. This is a loose association of two animals in which one derives benefit from the combination while the other may or may not. There are many degrees of such associations. For example, a flatworm, *Bdellura,* can usually be found on the body of the king crab (Fig. 5-8). From this association the flatworm is able to pick up bits of food which are dispersed into the sea water as the crab tears up its prey. There seems to be no benefit to the crab from the association.

Another interesting association is that of certain jellyfishes (*Physalia,* Fig. 5-8) and several species of small fish. The fish live

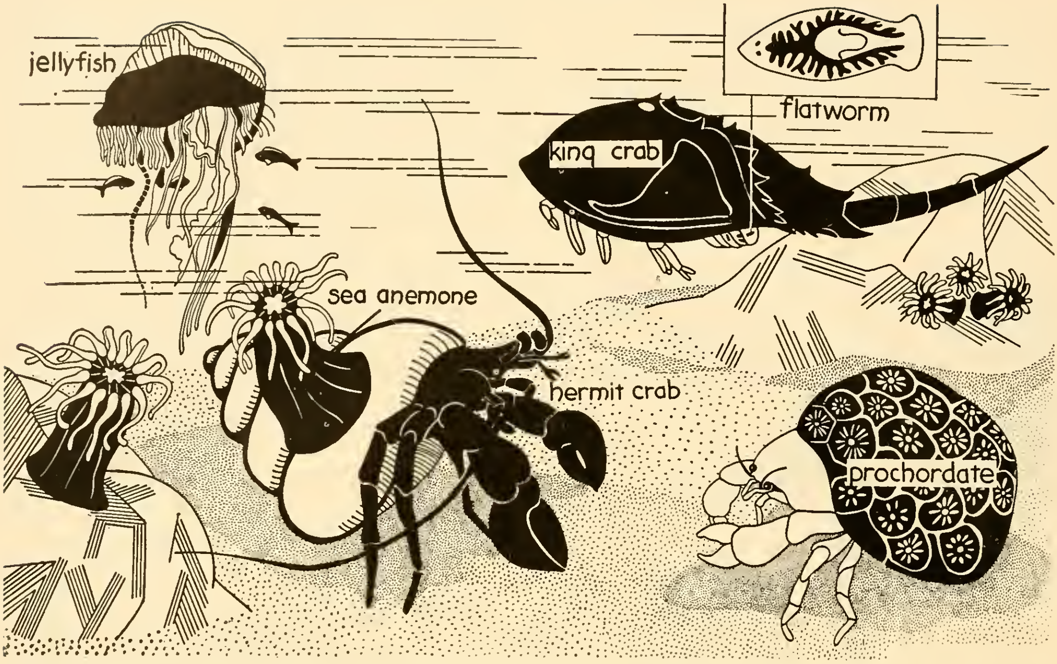


Fig. 5-8. Animals become associated rather intimately in many ways. Here are some illustrations of some of these associations.

among the tentacles of the jellyfish which offer protection by their stinging cells. The benefit to the jellyfish comes from food brought by the fish during its sojourns in the surrounding waters. In all cases of commensalism the relationship is a loose one, and neither party is forced to live in cooperation with the other.

Mutualism. A situation where animals live together with benefit to both is called **mutualism.** There are all gradations of this association, from those who only casually meet and become associated to those that are always found together and, indeed, cannot live apart. One illustration of the temporary associations is that of hermit crabs and sea anemones (Fig. 5-8). In this case the sea anemone, attaching itself to the shell occupied by the crab, gets free transportation to areas which the crab finds attractive because of an abundance of food. In return for the ride the sea anemone acts as a camouflage, making the shell resemble the rest of the ocean floor. In addition, because of its powerful battery of stinging cells, it functions as a line of defense against possible enemies of the crab. Some primitive chordates (prochordates) have adopted the same association with hermit crabs (Fig. 5-8).

Another interesting association, where the relationship is more or less compulsory, is the case of the metazoan, hydra, and a unicellular plant, alga (Fig. 5-9). The algae live in the hydra's inner layer of cells (endoderm) where they carry on photosynthesis, releasing oxygen which is utilized by the hydra. The hydra in turn releases carbon dioxide which is used by the algae. While in nature this situation usually exists, it has been possible to separate them in the laboratory and each can survive without the other.

In some cases of mutualism the association of two animals is so intimate that neither can live without the other. The best illustration of this is among the termites, or white ants (Fig. 5-9). This association came to the attention of biologists when it was discovered that termites could sur-

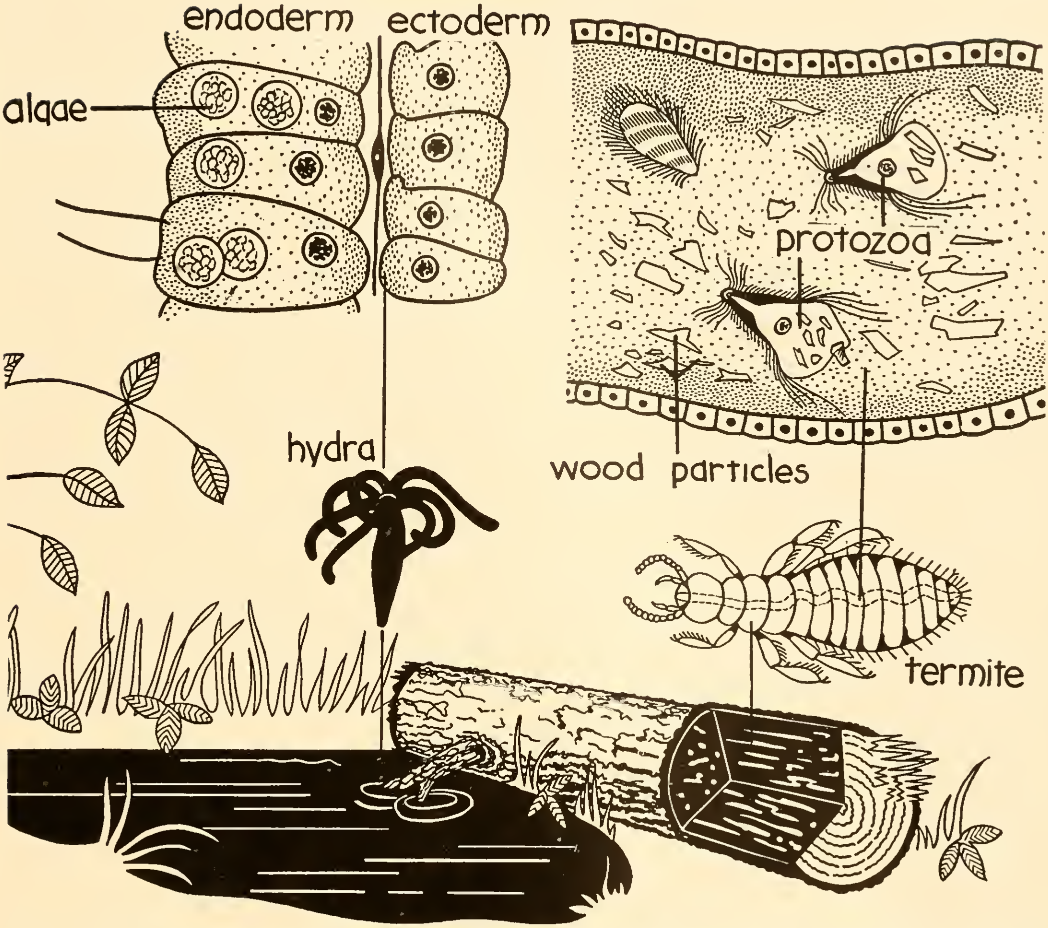


Fig. 5-9. Two examples of mutualism: the hydra with its algae, and the termite with its intestinal Protozoa. Note that the first instance is between a plant and an animal.

vive indefinitely on pure carbohydrate. They feed on wood alone, never receiving any observable nitrogen to build protoplasm. Upon investigation it was found that great hordes of complex Protozoa inhabit the termite's intestines. If the termite was warmed up a bit the Protozoa died and such defaunated termites lived only a short time. Likewise, the Protozoa could not survive outside the body of the termite. Apparently the Protozoa in some way provide the nitrogen essential for the termite. The termite, on the other hand, provides a good abundant home for the Protozoa.

Parasitism. This is also a forced relationship between two animals, but it is a one-way proposition. The **parasite** lives at the expense of the **host**, taking all and giving nothing in return, possibly even causing injury to the host. An ideal parasite withdraws just enough nourishment from its host to maintain itself in good health and in reasonable numbers. If the parasite removes too much from its host, so that the latter becomes sick and dies, then the parasite too is destroyed. Many parasites reach a satisfactory balance with their host in which the latter merely contributes a home for the parasite and is not apparently injured by it.

Parasitism should be distinguished from **predation,** in which one animal also lives at the expense of another. A predatory animal feeds upon another by eating its entire body, frequently at one sitting. A parasite might just as surely destroy the host, but it does so in an entirely different manner. A cat kills and eats a mouse; the cat is living at the expense of the mouse. The cat has a tapeworm inside its intestine; the tapeworm is living at the expense of the cat. The first case is predation, the second, parasitism. "The difference between a predator and a parasite is simply the difference between living upon capital and income, between the burglar and the black-mailer. The general results are the same although the methods employed are different." (Elton)

Parasitism probably arose shortly after life originated on the earth. Some animals soon found that they could live to advantage either in or on the body of another. Perhaps at first the relationship was a perfectly harmless one, something like commensalism, but as the association persisted the parasite became more and more dependent on the host for its existence. It modified its body both morphologically and physiologically in accordance with its parasitic habit. In earlier relationships the parasite probably clung to the outside of its host, later going into the shallow cavities such as the mouth and cloaca. Some, of course, were inadvertently swallowed with the food and these after a time became adapted to life in the gut where all of their food requirements were provided for. Others that learned to live in the bodies of insects such as mosquitoes, also learned to thrive in the blood of vertebrates because they were dumped into that environment every time the mosquito feasted on a blood meal.

Through similar food chains parasites must have learned to live first in one host, then in another, and sometimes in a third, all in sequence, in order to complete their life cycle. This arrangement had the advantage of spreading the species but it also had the serious disadvantage of depending not only on three hosts but also on the necessity that the hosts be sequentially arranged in time and space. Should any one of the hosts die out, the parasite would likewise be destroyed because it could not complete its cycle. In fact, this is a most effective way to control certain dangerous parasites. Killing mosquitoes in order to control malaria is a familiar example.

Parasites have been so intimately tied to their hosts for so many millions of years that ecologists today can often trace the history of certain species by comparing their parasites. In the subsequent chapters we shall study several different kinds of parasites as they occur in the various animal groups.

Between animals in communities

Up to this point in our discussion, relationships between individual animals have been considered. In addition to this special type of association, animals usually live in a much larger community in which a great many plants and animals are influenced by each other, in some instances more intimately than in others.

Some biologists consider an entire plant-and-animal community as a unit. Such a "superorganism," that is, an organism in which "the whole is greater than the sum of its parts," is referred to as a **biome.** Just how far one can draw a parallel between a community of organisms and an individual is a questionable. It begins to smack of anthropomorphism, which can be helpful in certain circumstances, ridiculous in others. Certainly it is well established that all life in a community is tightly woven together, like the fibers of a spider's web, so that no part can be disturbed without disrupting the pattern. However, to compare the community arrangement to the intricate interrelationship of parts of the human body, for example, is stretching the point beyond recognition.

Certain organisms live in specific habitats which are strangely similar no matter where they are found on the earth. Likewise, groups of animals that require the same set of conditions are usually aggregated in one locality. The types of animals present in neighboring habitats change only slightly due to minor variations in certain physical conditions. For example, the oxygen content of the water in one lake is slightly different from that of neighboring lakes. This tends to bring about the accumulation of animals that require just the amount of oxygen present in the lake, and those animals that require more or less are apt to seek water that satisfies their optimal needs.

Sometimes the introduction of a species changes the community of animals, such as the inadvertent planting of carp minnows in the northern lakes of the Midwest. Fishermen driving into the lake country frequently obtain their minnow bait at some southern point where carp minnows are abundant. After the fishing is over the remaining minnows are usually dumped into the lake where they propagate and flourish. Because of their feeding habits, fecundity, and general hardiness, they soon replace the more desirable game fish. Even under these conditions a balance will eventually be reëstablished and once it is the animal community remains much the same for a long period of time, although not indefinitely, for there are always gradual environmental changes that necessarily affect the life in it. Another similar illustration is the case of the introduction of the English sparrow into the United States.

In order to obtain some understanding of animal communities let us consider two diverse situations, one a fresh-water pond and the other a desert region. An examination of these two communities may provide some appreciation of the complexity of ecological studies.

A fresh-water pond. A pond is defined as a small body of fresh water, usually not more than two or three meters in depth, its temperature being approximately the same throughout (Fig. 5-10). Many animals and plants live in such a limited environment and even within its confines there are definite regions which support specific animals. The open water is largely devoid of both fish and plants, but the shores support a variety of animal and plant life, depending on the relative amounts of mud, sand, or rocks.

If the bottom is muddy, many plants, such as water lilies, grow in profusion. In protected places around the edge there may be several varieties of fish, principally bass and pickerel. Crayfish and small fish may be seen darting here and there in search of food. Tadpoles can be found near the bottom. The water teems with tiny crustacea and larvae of insects like midges (small gnat-like flies in the adult stage), which form the basic food for young fish. By scooping up some of the mud in a fine mesh net, many other animals can be noted, including snails of various sizes and shapes and perhaps a few leeches.

Many different kinds of flying insects make their home around the edge of the pond. The dragon fly (Fig. 11-31) and May fly nymphs can be found. An occasional diving beetle (Fig. 11-36) may be picked up. This is an interesting insect because it is so well adapted to aquatic life even though it must breathe air. It carries a film of air under its wings which acts as a reservoir for underwater maneuvering. The hind legs are large and beautifully designed for swimming under water.

The water boatman also carries a similar air film. Its long hind legs covered with hair, when in operation, remind one of a man rowing, and hence its name. Other insects such as the water strider (Fig. 2-2) and the whirligig beetle skim over the surface of the water, depressing but never breaking the surface film (see p. 24). Their food consists of air-borne insects that are blown out over the water and accidentally fall on the surface. The whirligig beetle

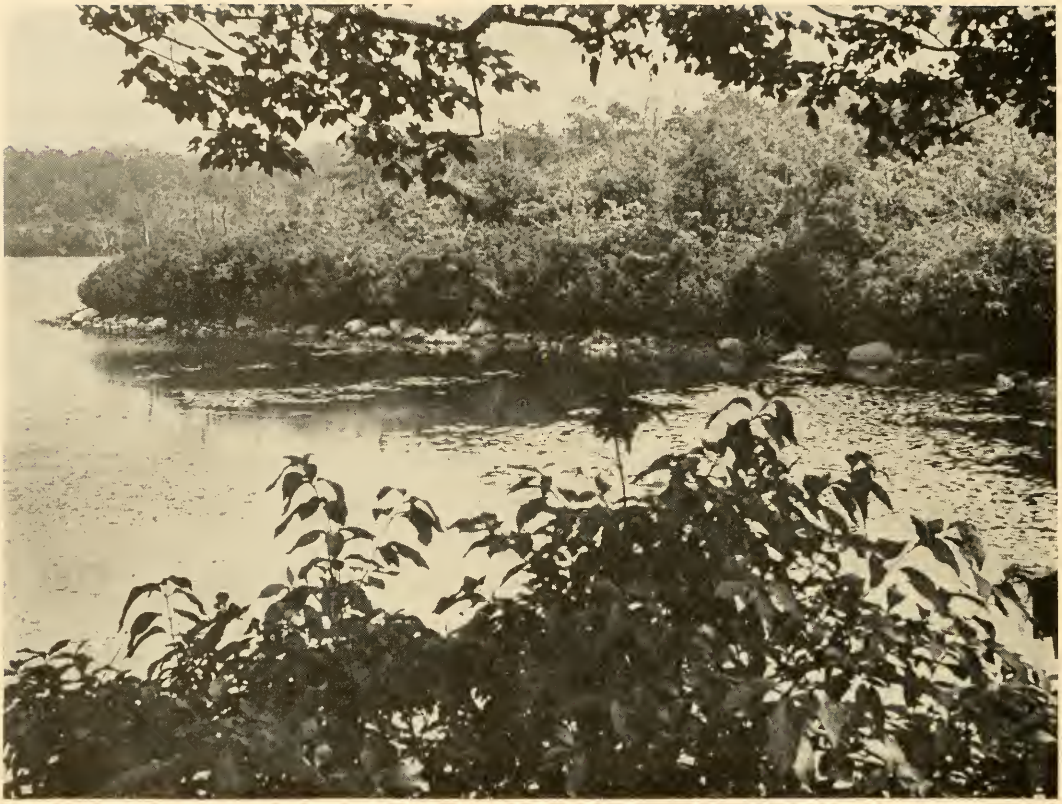


Fig. 5-10. A typical fresh-water pond. The association of plants and animals in such an environment is extremely complex.

possesses unique eyes which are divided into two parts; the lower part enables it to perceive objects in the water and the upper half gives it a clear view in the air.

The pond may include a sandy shore where animals of a different kind live. Snails, different from those found on the mud bottom, crawl over the sand from which they remove the unicellular plants growing there. Frogs, toads, and turtles may live around the edge of the pond, and birds such as the redwinged blackbird may inhabit the vegetation along the shore. Although these animals do not live in the water, they do contribute to the combined interrelationships of the community. They seek at least some of their food in the water and when they die their bodies may fall into the water where they are eaten by animals living there.

It is obvious that there must exist many complex food chains in such a well-defined community. The chief occupation of each living thing is to nourish itself, a need that results in a severe struggle for existence. Rarely does an animal die a natural death, for the moment it wavers it is pounced upon and destroyed by another, thus becoming a part of a long or short food chain. There is, however, a complete food cycle for the entire community which involves certain general groups of plants and animals. The green plants always provide the beginning of such a food chain. In the case of the pond, the water plants extract their simple needs from the water and manufacture food which is consumed by **plant feeders,** such as the tiny crustacea that feed on algae and the snails that eat larger plants. These animals are pursued and eaten by

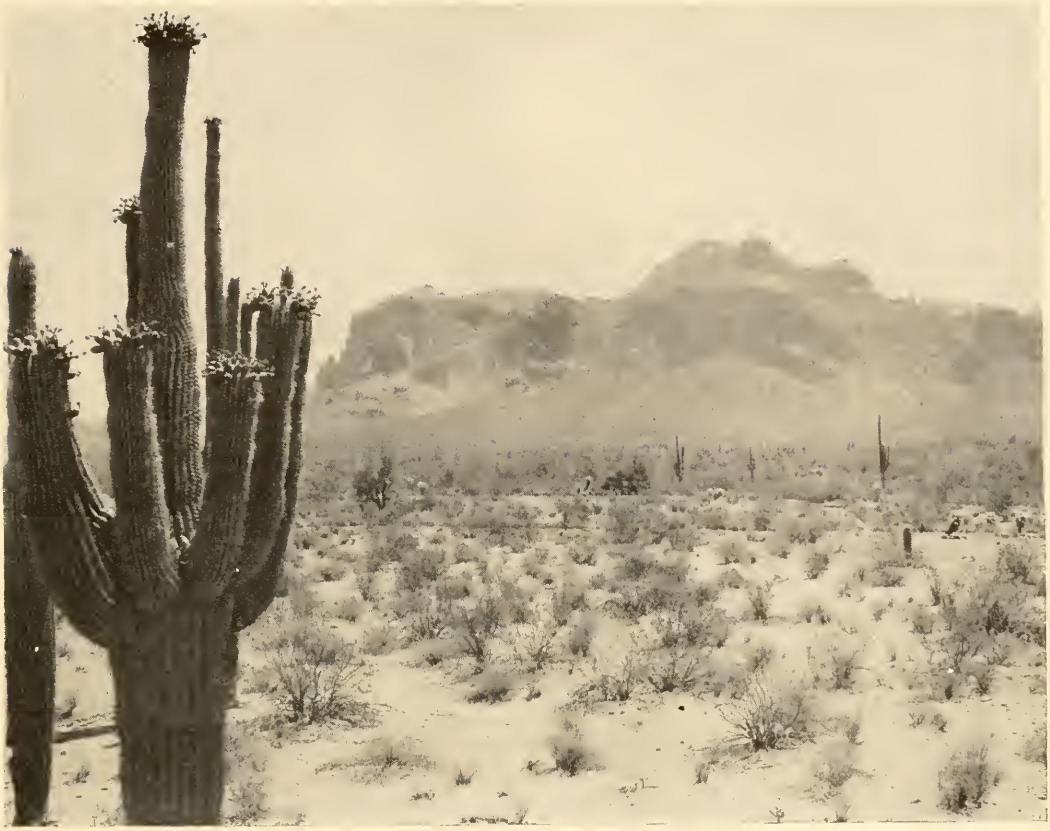


Fig. 5-11. Because of the exacting environmental conditions of a desert plain, there are few plants and animals. But even here there is an intricate relationship between them.

a large variety of predators such as the predaceous diving beetles. Others, like the midge larvae and May fly nymphs, are content with the dead bodies of plants and animals, and are known as **scavengers**. Finally, the organic matter that remains after all animals are through with it is decomposed by bacteria, known as **decomposers**, so that the inorganic compounds that are needed by the plants are restored to the water. Thus the cycle is completed.

Seasonal changes occur in the pond community and the animals living there must adjust to them. Usually there is an abundance of water in the pond during the spring of the year, but as fall approaches there may be very little water left. Consequently animals must migrate to other ponds or go into a resting stage until conditions improve. The sheet of ice which covers the pond during the winter excludes most of the light, which results in less photosynthesis, hence less oxygen. If animals are to survive the winter they must be able to get along on minimum quantities of oxygen as well as withstand low temperatures. Each animal living permanently in such a pond community is able to meet these situations and is found year after year in the same locality.

A desert plain. In contrast to the pond, the desert environment supports only those plants and animals that can survive on very little or no water, except that taken with the food. If we study the life existing on the plains of our own Southwest, we find a strange group of plants and animals, all of which are adapted in one way or another to life in a dry climate (Fig. 5-11). This region is not truly desert; it is about halfway between grassy plains and true desert. The vegetation is composed chiefly of cacti, yuccas, and other plants particularly well adapted to prevent loss of water through transpiration. They are protected from the marauding attacks of hungry and thirsty animals by their sharp stiff spines and tough outer coverings.

Several species of lizards and rattlesnakes are permanent residents of this region. One interesting bird, the so-called road runner or chaparral cock, is commonly seen racing down the road ahead of your car; it seems to prefer using its powerful legs when pursued rather than its wings. The most numerous mammals are the long-legged, long-eared, swift-running antelope jack rabbits, kangaroo rats, prairie dogs, and coyotes. The last-named feed on the others, all of which are vegetarians. Snakes and lizards, like the coyotes, are also carnivorous and feed on small mammals and some insects.

Compared to the pond situation, the desert food cycle is rather simple, as would be expected where there is so little life. Like the pond food cycle, the desert cycle begins with the plants. These are preyed upon by the various herbivorous animals, which in turn are eaten by the carnivores, which probably also eat one another. Eventually death overtakes them and the elements of which each is composed return to the soil to be used again by the plants.

There are many other communities of animals in a wide range of habitats. Some of these are the ocean, grassy plains, tundra, forest, and mountains. In all of these many niches have developed, inhabited by certain species of animals which are similar in respect to specific needs. Together they constitute the life of each community and the communities combined make up the complex life on the earth.

Population densities

Much can be gained from studying the interrelationship of life in a community. The study of populations alone has proved valuable not only in the control of insect pests and predators, in increased game and fish, and other redistributions of animal life, but it has also been very important in business and government, as for example in the formulation of insurance and retirement plans. During every census more and more information is gathered about people in order to learn what is happening to the status of our population. This makes it possible to predict future trends and also sheds some light on what might be done to influence the ultimate outcome. This is a hopeful field of investigation and shows promise of being of great value as time goes on.

Population, measured in terms of relative numbers and general distribution over the surface of the earth, indicates the biological success or failure of any species of animal. One of the important factors in achieving success is the rate of reproduction of a species. Here we find vast differences among animals, from those like the whale that produces one offspring every few years, to the tapeworm that can produce the incredible number of 100,000 per day. In general, the larger the animal the fewer the young, while the smaller the animal the greater the number of offspring. Even in this there are wide variations—rabbits, for example, can reproduce at such a rate as to overrun the entire earth in a matter of a few years. A single protozoan could fill all the oceans of the world in a few months if it were allowed to multiply at full speed and none of its offspring died. How successful these reproductive powers have been is indicated by a glance at some figures concerning numbers of animals. A quart of sea water may contain over 1,000,000 microörganisms; an acre of fertile soil, over 13,000,000 animals. Grasshopper eggs alone may exceed 200,000 per acre in heavy infestations.

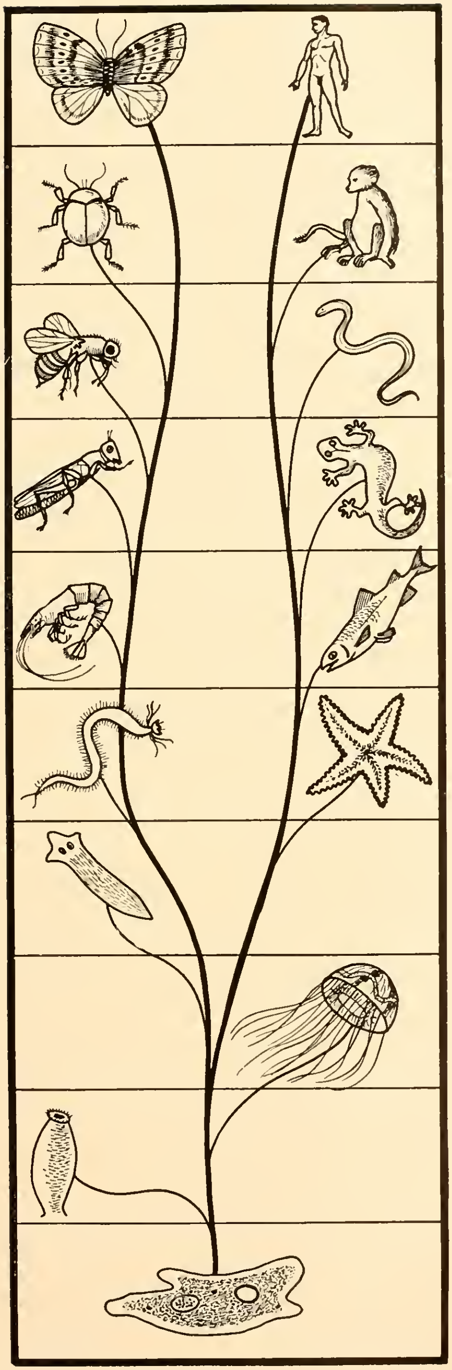
Although each species of animal has the potentiality for overrunning the earth, it never actually does. There are always controlling influences, such as competition for food, the ravages of the environment, infectious disease, and many others. Furthermore, a single species may fluctuate widely from season to season. Grasshoppers may be very numerous one year, devouring all vegetation over large areas, whereas the next year there may be very few. Barring man's intervention, this may be caused by unseasonal weather during the young stages when the organism is sensitive to adverse conditions. Ruffed grouse may increase steadily for several years until they reach great numbers, then suddenly decline, much to the disgust of the hunter. Indeed, this rise and fall in the population of certain species is called *rhythm,* and it is so constant that it can be predicted. Sometimes animals reach tremendous numbers, then go into a decline from which they never recover, and eventually become extinct. The passenger pigeon is a good example. In other cases, like the American bison and the whooping crane, an attempt is being made to save them from extinction by the animal who nearly caused it in the first place, namely, man.

We have seen that various controlling influences keep any one species of animal from realizing its potentiality for spreading its kind over the earth. However, if the so-called **reproductive pressure** is allowed to exert itself ever so little, the results are often unfortunate. One example will suffice. The English sparrow was first introduced in Brooklyn, New York, in 1850 and 1852 for the purpose of controlling certain insect pests that were destroying the shade trees of the city. In England the bird was desirable and because of its natural enemies existed in modest numbers. In America, however, it was free from its predators and the full powers of its reproductive capabilities came into play. Within a few years it became a pest. Instead of eating the insect pests, it fed on garden produce and cereal grains, man's own food, and in addition destroyed other insect-eating birds. By 1886 it had spread to Salt Lake City and today its distribution is continent-wide. One interesting fact has been noted about the English sparrow: it no longer populates the streets of our cities as it did a generation or two ago when the horse and buggy was a common means of transportation. Grasshoppers and other insects clinging to the car radiator are a poor substitute for the horse droppings that dotted the streets some years past.

Such mistakes as the one just described have been made on numerous occasions by man. Sometimes injurious animals are imported into new regions because they have escaped border inspections and have subsequently become established, later to become serious pests. Great care is now taken to prevent this from happening. Many states have inspections on railroads and highways to keep any injurious pests out. Airplanes must be carefully inspected when they fly from one region to another, particularly when the two are great distances apart. The danger of introducing certain disease-carrying insects, such as mosquitoes, into a new environment is obvious.

Man has intentionally introduced some animals to prey upon others with excellent success. One good illustration is that of the ladybird beetle introduced from Australia a few years ago to destroy the cottony scale which was playing havoc with the citrus crops of California. This required the research efforts of an entomologist who studied the enemies of the cottony scale in its native Australia. The ladybird was finally decided upon and when brought to this country proved very successful in partially controlling the pest. It has not, as yet, become a pest itself.

Our economic zoologists are well aware of the great precaution that must be exercised in interrupting the delicate balance of life in any environment. For example, when the insecticide DDT was first available for public consumption, many enthusiastic laymen wanted it spread from airplanes over wide swamp areas in order to destroy mosquitoes as well as other insects that have mostly a nuisance value. If our practical zoologists had not prevented that procedure, the damage might have been so tremendous that it would have taken several generations and perhaps many millions of dollars to repair. Think of the destruction to honeybees as one example. Besides destroying them as a source of honey, there would be untold damage to orchards due to unpollenated flowers. Birds, amphibians, and reptiles feed largely on insects, to say nothing of the aquatic life that subsists on these very numerous little animals. We can tamper with the environment only in small areas for specific purposes; any large-scale operation must be carried out with utmost caution so that the balanced plan of the community of animals is not disturbed.



CHAPTER 6

ORDERLINESS AMONG ANIMALS

Nearly all of the earth's thin crust is teeming with plant and animal life, each fitted by form and habit to its particular niche. Yet within this wide variety there exists a uniformity of structure and behavior that is recognized by anyone who has taken the time to make even casual observations. Such facts as the shape of fast-swimming animals, the warm blood and fur of mammals, the feathers of birds, all point to a uniformity of design which indicates basic kinships that were early recognized by men interested in natural history. Following man's innate tendency to catalog everything about him when it exists in sufficient numbers, animals were grouped according to similarities in structure, habit, and environment.

The first schemes for classifying animals were based on convenience alone. Animals were simply put into groups in order to prevent confusion, the method of cataloging resembling the design of present-day telephone directories. This system served the single purpose of arranging animals so that one might conveniently find the name of any one of them. Animals were classified according to their environments: those living in water, in the earth, in the trees, or on the surface of the ground. For example, whales were at first classified as fish because they lived in water and had a body plan resembling fish, in spite of the fact that

Fig. 6-1. Carolus Linnaeus (1707-1778) is considered the father of taxonomy because he initiated a system of classifying plants and animals that is still in use today.

they possessed hair and warm blood. The system served a useful purpose as long as the number of animals was not great, but with increasing knowledge it became cumbersome and almost useless. Over a million animals are known today and to classify them in such a way would be a formidable and fruitless task. It became obvious that other factors must be selected as a foundation upon which a satisfactory system of classification could be built. Let us consider briefly the man who was responsible for our present system.

Although John Ray (1627-1705), the English naturalist, has been considered the first true systematist, Carolus **Linnaeus** (1707-1778) is generally recognized as the father of **taxonomy** because he gave us the system of classification that is in current use today (Fig. 6-1). He was a Swedish physician who developed an interest in natural history that continued from childhood throughout his lifetime. In his early youth he recognized the need for a better system of classification and soon set down the basic principles on which he later built a satisfactory method of cataloging plants and animals. Linnaeus had the insight to select important fundamental characters as bases for his classification. This was a fortunate thought because not only did it give us a system which was workable and sound for an infinite number of additions, but it was also compatible with the doctrine of evolution, a theory Linnaeus himself did not subscribe to. He developed a branching type of system, just as evolution is, so the two go hand in hand, not because of the foresight of the author but by sheer coincidence.

Linnaeus used such fundamental structures as the skeleton, scales, hair, feathers, and so forth, in classifying the larger animals; for the soft-bodied invertebrate types he used characters like the foot of the mollusk, the body segments and exoskeleton of the arthropods. All animals and plants in this system of classification were given two names, a **generic** (a noun) and a **specific** (an adjective) name. This is now known as the **binomial system of nomenclature.** The generic name is comparable to our own family name, whereas the specific name is like our given name. Linnaeus decided that these names should be written in a language that would cause the least amount of international jealousy and therefore selected Latin. Animals that are most alike were placed in one species, such as *sapiens,* the specific name for all men alive today—there have been other species of men but they are all extinct. Likewise, man also belongs to the genus *Homo;* there have been other Homos but they, too, have been extinct many thousands of years. Under the Linnaean classification, therefore, man is known as *Homo sapiens.*

Linnaeus grouped all the various **genera** (plural of genus) into larger groups which he called **orders**; while these animals resembled one another in certain respects, they differed much more than did the various species in the separate genera. He further grouped the orders into six **classes**, his largest category. Since his time, of course, a great many biologists have unearthed information about more and more animals so that it became necessary to enlarge his classification extensively. This was done by adding two more groups, namely, **families** (between genera and orders) and **phyla** (the largest group of all). Furthermore, each group has been subdivided again and again, so that we now have the following general categories: phylum, subphylum, class, subclass, order, suborder, family, subfamily, genus, subgenus, species, and subspecies. However, not all of these divisions are necessary in the classification of every animal.

The differences are less and less as the selection moves from the phylum to the species. For example, the differences between the horse and the earthworm are various and striking; each belongs to a separate phylum. The differences between the horse and the alligator, while many, are not nearly as numerous as those between the horse and the earthworm; they belong to the same phylum but not to the same class. They show more differences than are observed between the horse and the dog, both mammals, belonging to the same class. The differences between the dog and the horse are sufficient, however, to place them in different orders, families, genera, and species.

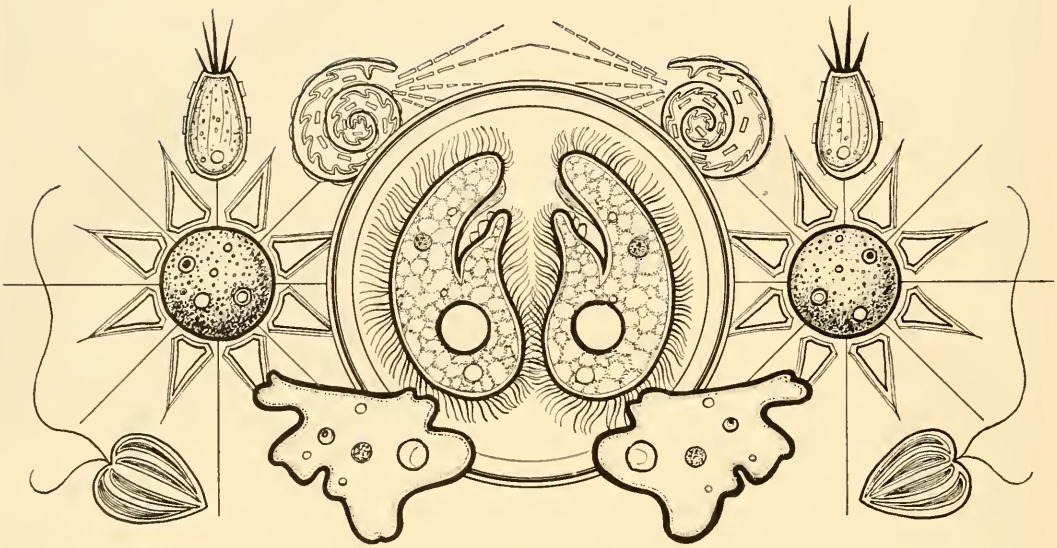
In many cases, however, the problem of separating species is much more difficult. In fact, a point is reached where biologists are frequently in doubt as to whether or not a given animal is actually a separate species at all. This is as one would expect if the theory of evolution holds, namely, that animals have originated and are indeed still originating from a common ancestral stock. Undoubtedly new species are forming at the present time and will continue to do so as long as there is life on earth. This problem occupied the attention of Charles Darwin, whose lifelong efforts culminated in his book, *The Origin of Species,* which conveys the answers to many questions concerning species differences.

The following table illustrates the use of the Linnaean system in classifying man according to his distinguishing characteristics and in outlining the basis of his relationship to other animals:

- Phylum Chordata—notochord, gill slits, nerve cord
  - Subphylum Vertebrata—backbone
    - Class Mammalia—mammary glands, hair
      - Subclass Eutheria—placenta
        - Order Primates—superior nervous system
          - Suborder Anthropoidea—flattened or cupped nails
            - Family Hominidae—no tail or cheek pouches
              - Genus Homo—manlike
                - Species sapiens—present-day man

Thus *Homo sapiens* includes all living men today. To distinguish between different colors and other characteristics of men, the subspecies is given. The scientific name then becomes trinomial, such as *Homo sapiens africanus,* which identifies a particular race of living men, the African Negro.

CHAPTER 7



MONOCELLULAR ANIMALS—THE PROTOZOA

THE RISE OF ANIMALS

So far we have considered the physical world, the first living things, the development of Metazoa, the problems associated with organization on the multicellular level, and finally the animal and its environment. We shall now discuss in some detail the various kinds of animals that have arisen through the millions of years since the inception of life on earth. It has been a long steady trek, with millions of species generating and few surviving. One should look with profound respect on any creature alive today because of the terrific struggle its ancestors must have gone through in order to provide a body organization able to cope with the environment through the millennia and come up still managing to fit into its particular niche. The nature of the struggle and the path over which each species has passed will probably never be known, but as one of these species we have come to appreciate something of the magnitude of the problem even though much of it is still beyond our comprehension.

We shall start with a discussion of the simplest animals, the Protozoa, then pass through the animal kingdom in the order in which we believe these animals appeared on the earth. You will note a gradual increase in complexity of structure and function from the Protozoa to mammals. Always try to keep in mind the story that is being told, rather than the details concerning the individual animals. Of course you must know certain specific points about representative animals, but the whole picture is more important than the isolated facts, no matter how fascinating they may be.

Fig. 7-2. This is a photograph (photomicrograph) of a living amoeba taken through the light microscope. Note the highly granular nature of the protoplasm in the main body of the cell and the clear regions where the pseudopods are forming.

PHYLUM PROTOZOA

The Protozoa display the full potentialities of protoplasm within the confines of a single cell. With a few exceptions, they are all unicellular, yet with so little they have done as much exploring with possible variations in pattern and function as have the multicellular animals. As a consequence, we see a vast array of sizes, shapes, and habitats among some 30,000 different species of these tiny animals. They range in size from 3 to 15,000 microns and live in almost any environment, from soils to the red blood cells of vertebrates.

Physiological and pharmacological research has and will continue to employ Protozoa for experimentation to find out about the effect of various substances, including poisons, on the animal cell. *Tetrahymena geleii* (Fig. 7-1) is a particularly valuable laboratory animal for many kinds of protozoan research. Before an understanding can be had of the more complex Metazoa it is essential that more knowledge be accumulated concerning the single-celled forms.

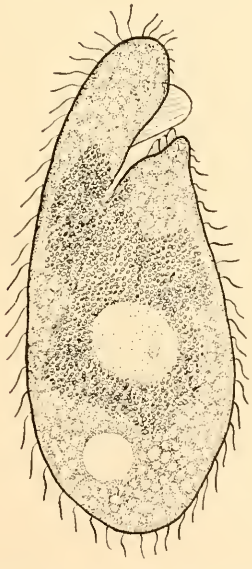


Fig. 7-1. This ciliated protozoan, *Tetrahymena geleii*, has many of the nutritional requirements of higher animals, including mammals, and for that reason has become valuable in research. The study of microorganisms has become an important field of research where the fundamental workings of protoplasm are under investigation.

In order to understand the Protozoa as a group let us first study two representatives in detail, and later in more cursory fashion a few additional forms to gain some notion of diversity. We have selected **amoeba** as a simple form and **paramecium** as one of the most complex protozoans. Both of these are ubiquitous in their distribution and because they are easily handled have been classic material for biology classes for many years.

Fig. 7-3. Amoeba with internal anatomy shown in detail.

AMOEBA

The common amoeba, *Amoeba proteus* (Fig. 7-2), spends its life today, just as it did many millions of years ago, in an aquatic environment from which it receives all of its nourishment and into which it deposits all of its wastes. A food-laden world lies within its ability to apprehend and devour. Its continual search for food keeps it on the move, crawling over vegetation on the bottom of ponds and streams. It resembles an amorphous blob of nearly transparent jelly and its only outward manifestation of animal affiliation is its movement, which consists of an interesting and bizarre method which seems to be confined almost exclusively to this tiny animal.

Locomotion

Amoeba moves about by means of minute projections of its protoplasm, called **pseudopods** (pseudopodia—false feet). They are formed by what at first seems to be a very simple process—the fluid protoplasm merely flows out into an apparently weakened region in the outside layer, called the **ectoplasm.** Further observations indicate that the process is not a simple one. For example, pseudopodial formations seem to be "intentional" because they develop only in order to approach food or to move away from danger. Evidently there is some type of coördinating mechanism located within the cell body which makes this possible.

The first indication of pseudopod formation is activity in the protoplasm at a particular point (Fig. 7-3). The ectoplasm then flows out into this region. Simultaneously, the temporary posterior end gives up its position, and that protoplasm moves forward, filling the region left by the protoplasm which is actively forming the new pseudopod. Pseudopods form vertically and anteriorly, that is, in the direction of the cell's general progress. The amoeba is able to "step over" particles which are not food and to engulf those which are a part of its diet.

The inner portion of the cytoplasm (known as **endoplasm**) consists of a very fluid inner region called the **plasmasol,** and a more viscous region just outside the fluid region, the **plasmagel.** These two may quickly change from one consistency to the other (phase reversal, p. 48) and that is what happens when the amoeba "walks." Precisely, the plasmasol flows in the direction in which the pseudopod is to form, and changes to plasmagel as it spreads out at the tip. The flow of plasmasol is continual as long as the cell moves in that particular direction. Most descriptions of this process point to the fact that the pseudopods form in several directions at one time. There follows an apparent "tug-of-war" until finally the pseudopods on one side or the other accumulate the bulk of the protoplasm, causing the others to retract and follow the cell body in a specific direction.

Ingestion of food

The activity of amoeba is about the same during locomotion and in food-getting, with one or two minor exceptions. When it approaches a motionless particle of food, such as an immotile alga, the pseudopods are spread around and over the plant cell in close proximity until they meet, forming a **food vacuole.** If the food is active, as in the case of a small protozoan, the amoeba spreads its pseudopods over a larger area in order to capture the organism first before closing in on it to form the vacuole (Fig. 7-5).

Once the food vacuole is within the cell body, digestion begins, much the same as it begins in man's stomach when a morsel of food is swallowed. The surrounding protoplasm secretes enzymes into the vacuole where they proceed to digest the captured food. This interesting process can be observed under the microscope. A captured protozoan, for example, slows down in its activity and finally ceases movement altogether. It then begins to disintegrate and after a time there is very little left of the original organism, except the undigested parts which, incidentally, are left behind as the amoeba moves on its way. The digested food passes into the protoplasm where it is metabolized. This is the source of energy which enables the amoeba to keep continuously on the move and which also provides the materials from which it is able to grow and reproduce.

Respiration and excretion

The exchange of oxygen and carbon dioxide is a simple business in amoeba. Oxygen moves into the protoplasm of the cell by diffusion whenever the concentration of the gas is greater outside than inside. Likewise carbon dioxide diffuses out of the cell into the surrounding water when it forms as a result of metabolism within the organism. Since this little creature demands an abundance of oxygen continuously, you would not expect to find it in stagnant water where there is little or no oxygen.

As a result of the metabolism of nitrogen containing compounds (amino acids), poisonous wastes tend to accumulate in the cell. These are removed by diffusion to the outside fluid world also. They are not allowed to accumulate because of their toxic effects.

There is a prominent organelle (little organ) located variously in the cytoplasm of the amoeba which requires some explanation. It is the **contractile vacuole.** As the amoeba is watched, a clear, spherical area forms, which, while small at first, soon grows to maximum size, then suddenly disappears. It forms and disappears at regular intervals. Those who have studied this carefully believe that the contractile vacuole probably functions only as a device for getting rid of excess water that accumulates inside the cell. In other words, it acts like a bailer who works to get rid of the water that is constantly flowing into a leaking boat. Because of the hypertonicity of the amoeba, water is constantly flowing into its protoplasm. If it were not removed the little animal would soon become waterlogged. Furthermore, if the concentration of dissolved substances in the surrounding water is increased (hypertonic), as it is in sea water or in a solution with high salt content, the contractile vacuole disappears. If the marine amoeba, which has no contractile vacuole, is placed in fresh water, vacuoles form very soon. All evidence points, therefore, to the fact that the contractile vacuole functions merely as a hydrostatic organelle, a mechanism that controls the flow of water out of the amoeba.

Reproduction

Amoeba, like all other living things, reproduces itself. It does this in the simplest way, namely, by dividing into two equal

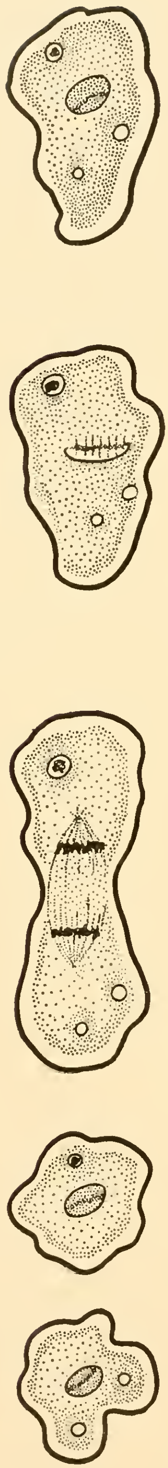


Fig. 7-4. Amoeba undergoing binary fission.

parts, a process known as **binary fission** (Fig. 7-4). After the cell has grown to a certain size, it rounds up into a ball. The nucleus divides first, then the entire cell cleaves into two parts which are usually spoken of as "daughter cells" (they are called daughter cells perhaps because they give rise to other cells; "son cells" would be unable to do this). The amoeba seems to have to reach a certain size before dividing; for if a small piece of cytoplasm is cut off periodically as the amoeba grows, never allowing the animal to reach the proper size, it will not divide.

Amoeba is "immortal," as was pointed out in an earlier section (p. 83). If death occurs, it comes only through accident. Occasionally its watery environment may dry up, leaving it to desiccate and die if no provisions were made for it to exist through periods of adverse conditions. When such a times comes, the amoeba (there seems to be some question about *A. proteus* forming a cyst although other amoebas do) secretes an impervious outer covering called a **cyst** (Fig. 5-2), which allows life to continue at a very low ebb until it is once more submerged in water. The cyst then splits open and the amoeba resumes its active life. This provision has made it possible for the animal to survive long periods of unfavorable conditions and has been an important factor in its survival.

Behavior

Another innate quality of amoeba which makes possible its survival is its responsiveness to changes in its external world. Its response is usually such as to protect itself from harm or to lead it to a rich food area. This is spoken of as its **behavior**. Although gradual changes in intensity of light elicit very little or no response, intense, sudden light causes it to send out pseudopods in such a way as to withdraw and move away from the light source (Fig. 7-5). Likewise, if a concentrated salt solution is placed near the amoeba, a definite response is noted.

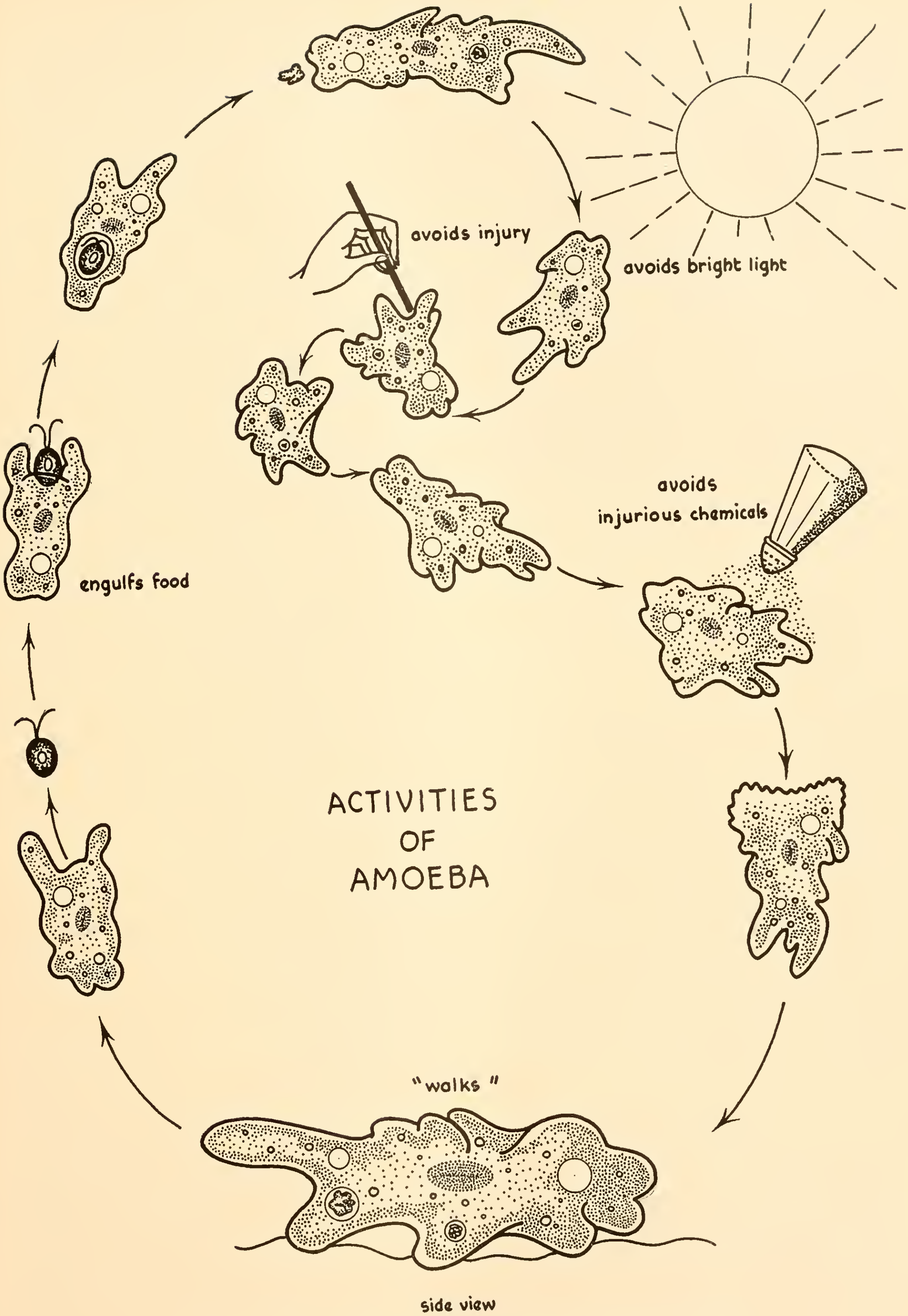


Fig. 7-5. Amoeba responding to various conditions in its environment.

Fig. 7-6. Paramecium has been studied perhaps more than any other protozoan. It is large (100-200 microns in length) and very easily cultured in the laboratory.

If it is floating free in the water and one of its pseudopods contacts a surface, it at once adheres to the substratum. However, if a sharp point is pressed into its protoplasm at the surface, an immediate avoiding reaction follows. Amoeba thrives best at room temperature. If it is subjected to lower temperatures, all of its activities slow down and cease altogether as the freezing point is reached. Activity also ceases if the temperature is raised to approximately 30° C.

In general, then, the behavior of amoeba is geared to its needs and is responsible for its survival. If more were known about the amoeba's response to its external world, problems which arise in the more specialized animals would be easier to solve.

PARAMECIUM

Not all Protozoa are as simple as amoeba. A study may now be made of a protozoan which is perhaps one of the most complicated of all single cells—paramecium, the "slipper animalcule" (Fig. 7-6). This form has been experimented upon and studied as much, if not more, than amoeba and a great deal of fundamental biological information has been derived from this source.

As one might guess, the animal is shaped like a slipper, pointed at the posterior end and blunt at the anterior end (Fig. 7-7). A groove extends throughout most of its length and the **mouth** or **cytostome** (cell mouth) is formed in the groove on the ventral side, about two-thirds back from the anterior end. Paramecium has an outer covering, the **pellicle**, which is sufficiently rigid to maintain a constant shape. Careful examination with excellent optical equipment shows that the covering is made of minute hexagonal plates, and that the middle of each plate is perforated by a central opening through which a tiny "hair-like" **cilium** (plural, *cilia*) passes. The animal moves by the combined rhythmic beating of these cilia. At the junction of the plates are other tiny holes through which threads are thrust when the animal is disturbed. The threads originate from small bodies lying just beneath the pellicle, called **trichocysts**. They are apparently used in defense and perhaps also in attaching the animal to detritus in the water. Adding a small amount of acetic acid to the water near the paramecium discharges them.

Locomotion

The power stroke of the cilia is diagonal, so that the animal turns on its long axis. Since the cilia in the oral groove are larger and beat with more vigor, the anterior end describes a circle and causes the animal to swim in a spiral manner (Fig. 7-8). When the posterior end is stationary, the long axis of the body describes a cone (Fig. 7-9). When the animal is confronted with an obstacle, the cilia reverse their effective beat so that the cell moves backward a short distance, turns slightly, then moves forward again. If it meets the obstacle again, the process is repeated until the animal passes around and goes on its way (Fig. 7-10). This is known as an **avoiding reaction.**

In order to discover how the cilia operate in such perfect coördination, biologists have made careful studies of the mechanism involved. It has been found that the cilia are attached to one another by tiny fibrils just beneath the pellicle. The fibrils concentrate at a focal point in the region of the gullet where the protoplasm must form the equivalent of a miniature "brain." If this is destroyed experimentally, the cilia fail to beat in a coördinated manner, and the animal loses all control of its movements. Clearly something similar to the nervous system in multicellular animals exists in paramecium, which makes it possible for this tiny cell to carry on in such a complicated manner.

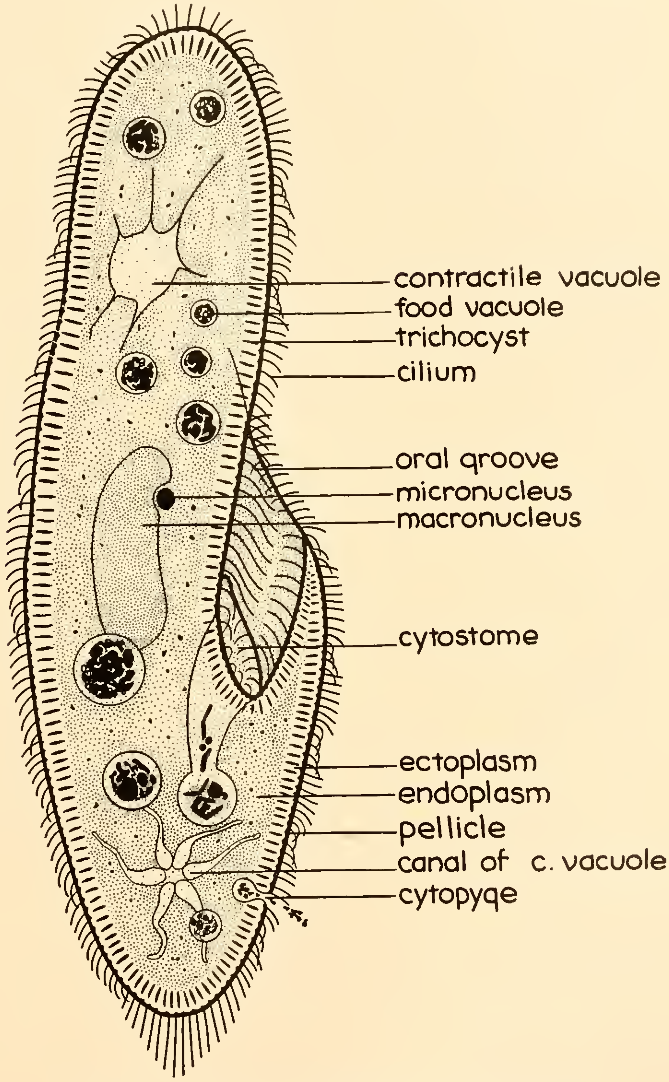


Fig. 7-7. Paramecium with internal parts shown in detail.

Ingesting of food

A simple experiment can be performed to demonstrate how paramecium feeds. Some yeast cells that have been heavily stained with Congo red (a dye) are placed on a glass slide containing a drop of paramecia. By studying the region of the gullet, one can see the cilia beat in such a way as to pass the yeast particles along its oral groove and down into the gullet. There they are rounded up into a mass which finally pinches off into the cytoplasm as a **food vacuole.** Once in the cytoplasm the yeast cells remain deep red for a time, but gradually begin to turn blue as they approach the anterior end. This means that the contents of the food vacuole are alkaline at first (Congo red is red in alkali, blue in acid), just as is the case in the mouth of man. As digestion proceeds, the vacuoles become acid as indicated by the blue color, reminiscent of the condition found in the human stomach. The digested material passes through the wall of the vacuole and out into the protoplasm where it is metabolized, the same process that was noted for amoeba. Finally the undigested portions left in the vacuole pass through a tiny opening to the outside, the **cytopyge,** which is equivalent to an anus in higher animals.

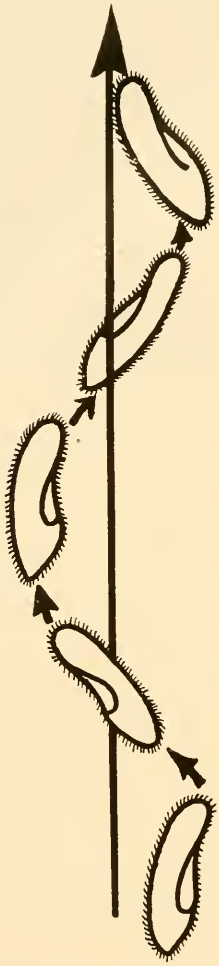


Fig. 7-8. Path taken by paramecium when moving freely through the water.

Fig. 7-9. Movement of paramecium when attached at posterior end.

Some species of ciliates are able to receive nourishment from dissolved organic matter in the medium. In fact, one species, *Tetrahymena geleii* (Fig. 7-1), a small paramecium-like ciliate, grows in a culture medium entirely free from bacteria or other microörganisms. This tiny animal has about the same food requirements as higher animals, including man himself. Recent experiments have shown that to grow it requires a diet containing amino acids, sugar, salts, and vitamins. This seems to indicate that even a single-celled animal maintains metabolic processes almost as intricate as man's.

Respiration and excretion

Respiration and the excretion of nitrogenous wastes take place in paramecium much the same as in amoeba. The **contractile** or **pulsating vacuoles** which lie at either end of the cell contract alternately at about 15-second intervals. Several **radiating canals** empty into each contractile vacuole, being most obvious when the vacuole is nearly empty. Each vacuole discharges its contents to the outside through a minute **pore** in the pellicle. The rate of contraction

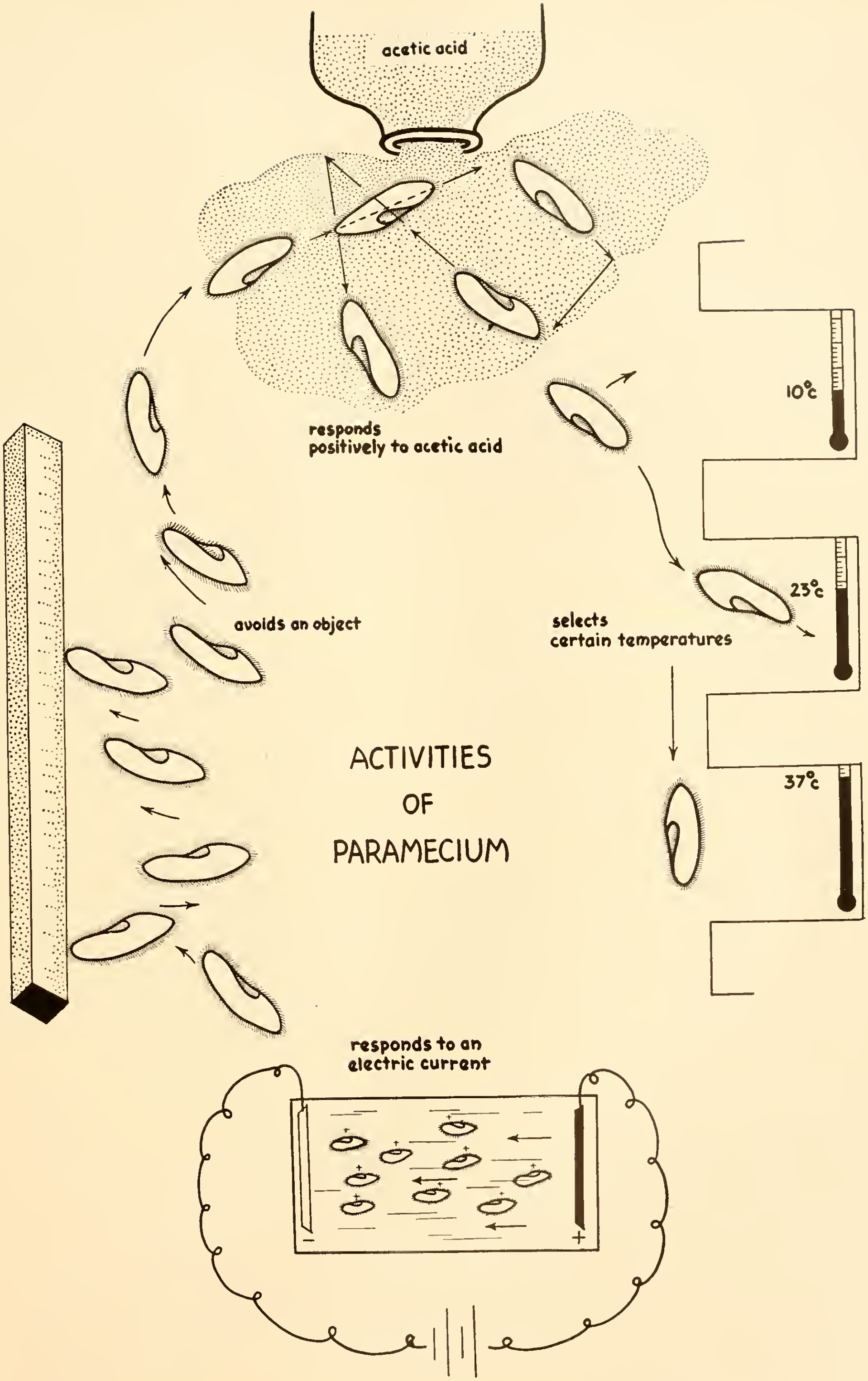


Fig. 7-10. Paramecium responding to various conditions in its environment.

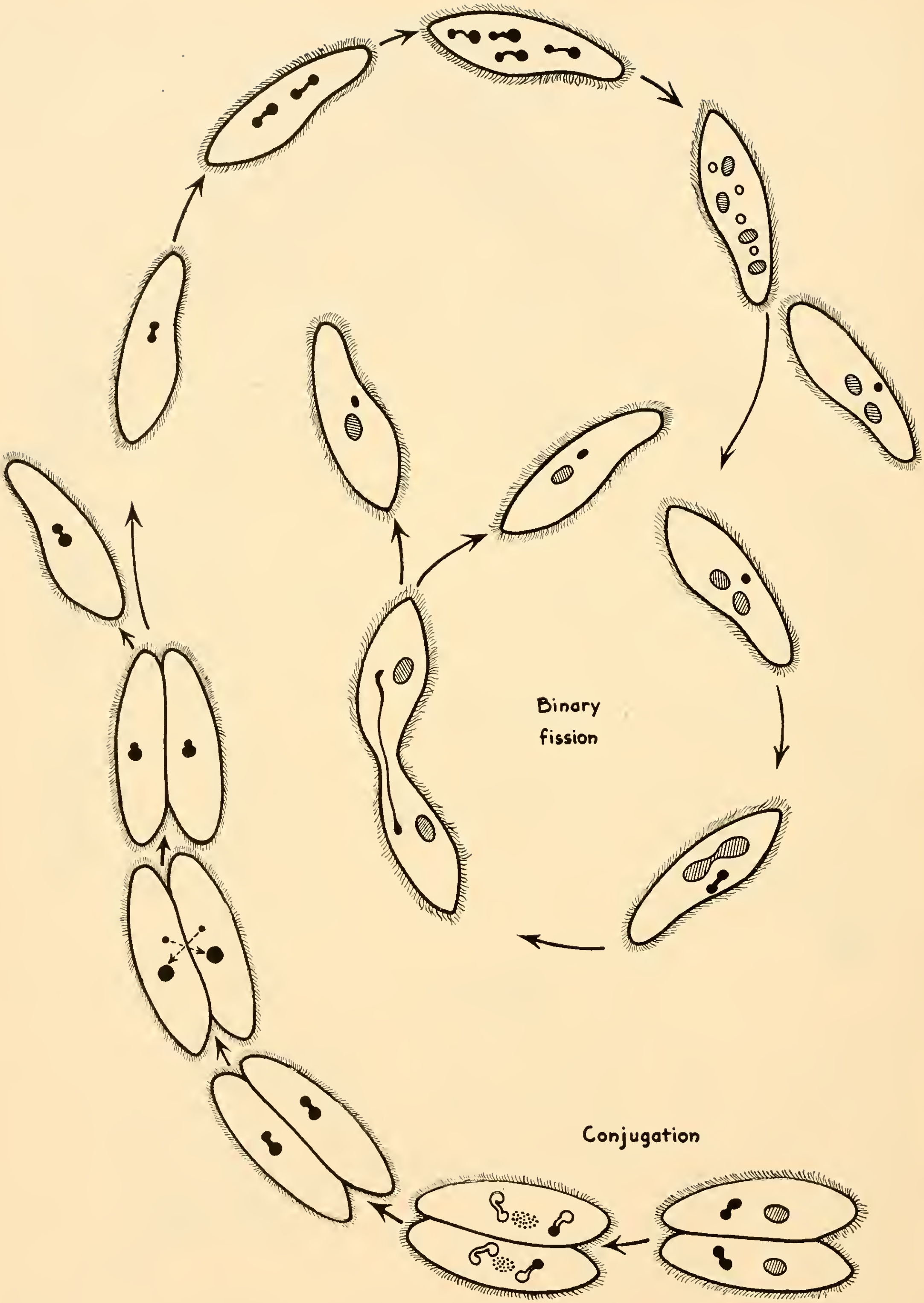


Fig. 7-11. Conjugation and asexual reproduction by binary fission in paramecium.

varies with temperature, activity of the animal, and the concentration of salts in the surrounding medium. As in the amoeba, the contractile vacuole functions normally as a bailer to rid the animal of excess water constantly entering the cell.

Behavior

Paramecium is very sensitive to the relative acidity and alkalinity of its environment (Fig. 7-10). It responds positively by going toward an acid environment, even though the acid may be of sufficient strength to destroy it. If a drop of weak acid, for example, acetic acid, is placed on a slide containing paramecia, they will move toward the acid region and remain there. If they get away from this region and approach a less acid surrounding, the paramecia give the avoiding reaction, and thus return to the more acid medium. This sensitivity is probably owing to the fact that, in large numbers, paramecia give off carbon dioxide in such quantity that the water in the immediate vicinity becomes weakly acid.

Paramecium selects a temperature optimal for its activities, usually around 25° C (Fig. 7-10). If given a choice, it seeks this temperature. If placed in an electrical field of direct current, it responds in a very definite manner, always orienting itself with respect to the flow of the current (Fig. 7-10). It moves toward the negative pole, indicating that externally it is positively charged.

Reproduction

Paramecium, as in the case of amoeba, maintains its numbers by dividing transversely across its long axis (Fig. 7-12). The first sign of division is a change in shape of the nuclei. Paramecium has two nuclei, a large **macronucleus** and a small **micronucleus**; it is not quite clear how these differ in regard to function. When the nuclei have divided, a second gullet and two more contractile vacuoles form. Other structures are

Fig. 7-12. Paramecium divides by binary fission as shown in this photograph of stained specimens.

also duplicated before the two daughter cells separate. After a growth period they are ready to divide again. Under optimum conditions division occurs about every six to twelve hours. If division occurred three times a day and all individuals survived, their bodies would fill all the oceans of the world within a month. Under natural conditions they very soon cease dividing, because of accumulation of waste products, lack of food, low temperatures, desiccation, or falling prey to other aquatic animals.

When placed in a suitable culture, paramecia periodically undergo a sexual process called **conjugation** (Figs. 7-11 and 7-13). Just why they do this is not clearly understood, but it can be induced by reducing the bacterial food supply. During the process two individuals interchange micronuclear material, which means that genetic factors are involved. This has the effect of sexual reproduction, although there is no increase in numbers, as the term *reproduction* would imply. Actually conjugation seems to be unnecessary for division. Professor L. L. Woodruff, some years ago, separated paramecia after each fission so that conjugation was impossible. He followed through 15,000 generations over a period of

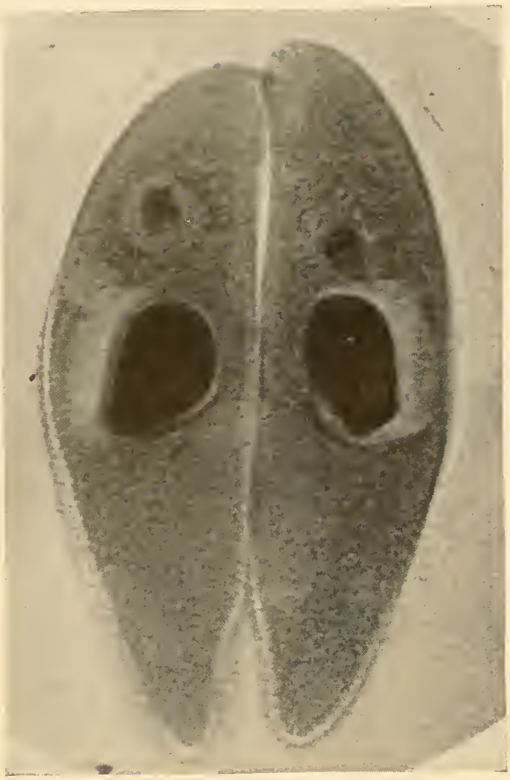


Fig. 7-13. Conjugating paramecia which have been killed and stained. Note the large macronuclei and the smaller micronuclei.

25 years without conjugation ever occurring. Just how important conjugation is to the success of the race can only be conjectured.

Research has recently shown that within a single species there are so-called "mating types," which are distinguished by their conjugation reactions. When known mating types are mixed in a culture, the animals form large clumps. They seem to become covered with a sticky substance which causes them to adhere to one another. After an hour or so they pair off, rather securely attached at their oral grooves (Fig. 7-11). Very shortly the micronuclei in both animals divide twice in rapid succession; at the same time the macronucleus starts to disintegrate and disappear. Three of the four nuclei in each cell degenerate, leaving a single one which immediately divides into a large immotile micronucleus and a small motile one. The latter then moves across a kind of protoplasmic bridge between the two animals and fuses with the immotile micronucleus of the opposite animal, a process resembling fertilization in higher forms. The animals then separate. Three successive divisions of the fused nucleus follow, producing eight nuclei, four of which grow into macronuclei, three degenerate, and one remains as the micronucleus. The paramecia and their micronuclei then divide twice, eventually producing four paramecia from each ex-conjugant. This is followed by ordinary fission (Fig. 7-11) until conjugation is once more induced.

Recently several different groups of "mating types" have been discovered by Jennings and his co-workers. Individuals from different groups do not conjugate, nor do individuals from the same type within the group. They mate only with other types of their same group. From these studies much is learned about the mechanics of inheritance, an important phase of genetics which will be discussed in the chapter on that subject.

OTHER PROTOZOA

This brief introduction to two different Protozoa gives us a basis for considering the importance of the group as a whole in respect to numbers, variety, and classification. Over 30,000 Protozoa have been described as distinct species, and in numbers of individuals they exceed all other animals. They live in water of all kinds, in soil and dust, in and on the bodies of plants and animals. Some of them cause the most destructive diseases known to man, malaria, for example. Most Protozoa are free-swimming, although some are sessile; most live singly, some form colonies. Many form a source of food for aquatic animals such as fish, but they are of little value to man, except a few which are useful in sewage treatment. They are such a large and varied group of animals that some biologists have considered placing them in a group larger than the phylum, that is, a subkingdom.

The Protozoa are divided into four classes, based on their means of locomotion. In the probable chronological order of their appearance in the evolution of life on earth, they are: class **Mastigophora**—those that move by means of **flagella**; class **Sarcodina** or **Rhizopoda**—those that employ **pseudopods**; class **Sporozoa**—those that have no clearly defined method of locomotion; finally, class **Ciliophora**—those that move by means of **cilia**. The student is already familiar with representatives of two of these classes, the Sarcodina (amoeba) and the Ciliophora (paramecium). Undoubtedly there was some overlapping, and there is no assurance as to which types actually preceded which others, except in a general way. For our purposes the order above will be followed, that is, we shall consider the Mastigophora as the most primitive and the Ciliophora as the most complex.

Class Mastigophora

This is a widely diverse group of Protozoa in which some members are colored and live independently like plants, whereas others are colorless and require food from the outside, such as parasites living in the intestinal tract of termites.

Colored flagellates. Although there are wide divergences in structure and habitat of flagellates, a brief description of *Euglena* (Fig. 7-14) will help in understanding the group as a whole.

Anatomically, euglena is quite different from amoeba. It has a rather definite general shape, which is something like a spindle, although it is sufficiently elastic to be able to undergo animal-like movements when confined to a small space (Fig. 7-14). It moves by means of a single, hair-like, vibratile **flagellum** (plural, *flagella*) which, when active, pulls the organism through the water in a spiral path. In its cytoplasm euglena bears bodies known as **chloroplasts**, which contain the green plant pigment, **chlorophyll.** Because it is able to live on the simple elements that plants utilize, and at the same time possesses certain animal characteristics of behavior, euglena is thought to be intermediate between the plant and the animal world, and is frequently referred to as a **plant-animal** type.

The anterior end of euglena is usually more blunt than the posterior end, in fact, the latter is pointed in some species. There is a **gullet** at the anterior end, the walls of which give rise to the flagellum, and lying near the gullet is the **contractile vacuole.** In the immediate region of the gullet is the *stigma* or eye-spot, a conspicuous red dot which apparently functions in aiding the cell to find the proper light intensity for photosynthesis. In order to manufacture its own food, euglena must receive the proper amount of light, hence the significance of the stigma. Euglena can, however, live in the dark providing nutrient materials are present in the surrounding medium, in which case it absorbs its food directly. Under favorable conditions euglenas are frequently found in such numbers as to produce a green scum at the surface of the water. As some species grow old they produce a red pigment called **haematochrome** in their cytoplasm. If this happens when they exist in great numbers, a visible red layer appears on the surface of the water. This has sometimes given rise to the name "bloody pools."

Euglena divides longitudinally, that is, in an anterio-posterior direction, splitting the cell into two equal parts (Fig. 7-14). In a rapidly growing culture, cells can be observed in all stages of division. Because this protozoan can be grown in sterile cultures, that is, free from all other microörganisms, it has been used in experimental work in an effort to determine its basic nutritional needs. It is an example of the increasing use of Protozoa as experimental animals in fundamental biological research.

Other colored flagellates. All kinds of fresh water as well as the oceans are teem-

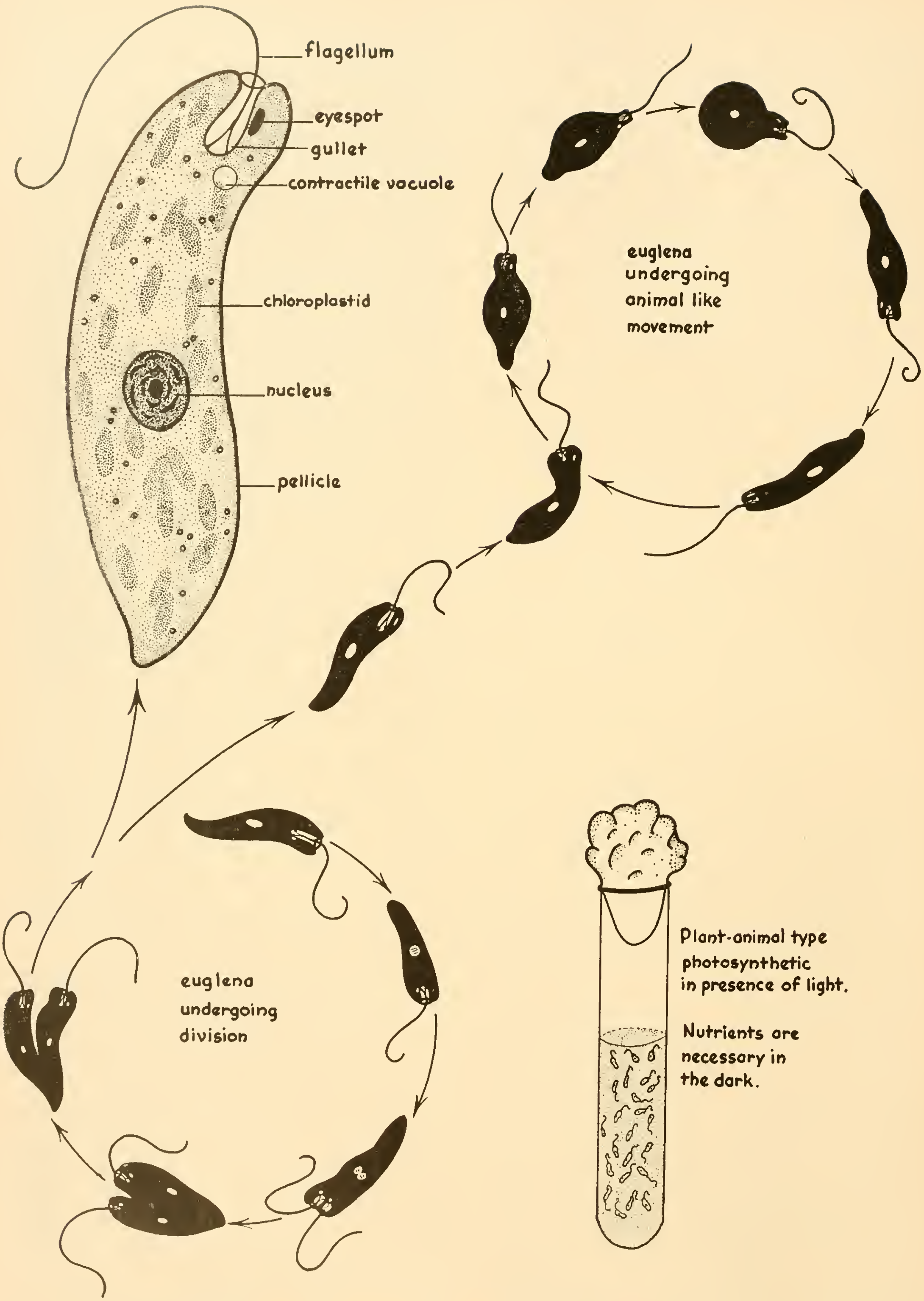


Fig. 7-14. Euglena in detail and undergoing some of its life processes.

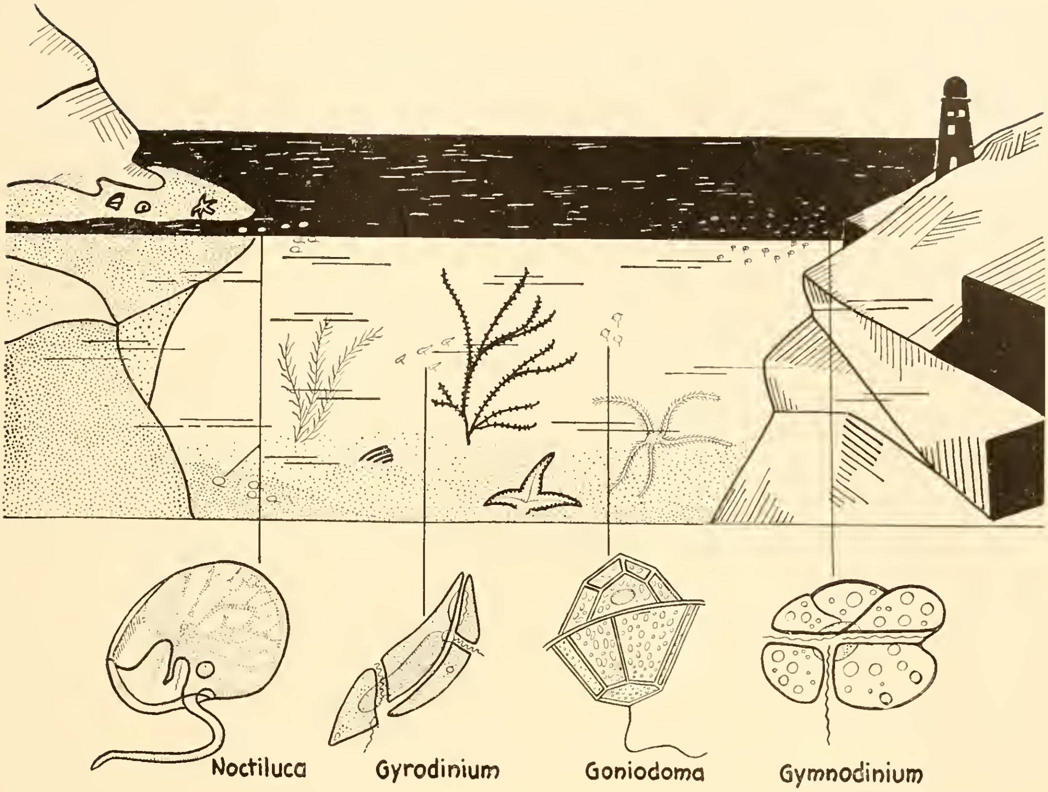


Fig. 7-15. Various types of marine flagellates.

ing with free-living flagellates. The **dinoflagellates,** for example, live in the ocean for the most part and constitute a large portion of the diet for small crustacea and other animals. Some members, such as *Noctiluca* (Fig. 7-15), possess luminescent properties which cause them to glisten in the dark when the surface of the water is disturbed. This is a particularly attractive sight in the wake of a boat. Another interesting dinoflagellate, *Gymnodinium brevis* (Fig. 7-15), has appeared several times during the past hundred years along the Florida coast in extremely large numbers (50,000,000 per liter—a normal count is about 100,000 for all kinds of protozoans). Furthermore, this protozoan apparently secretes a by-product which is lethal to all other kinds of animal life in the vicinity. In 1947 half a billion fish were destroyed along the Florida coast, presumably by this toxin.

Fresh water, particularly that containing a considerable amount of organic decomposition, supports a large variety of flagellates (Fig. 7-16). Many of them play a very important function in providing food for aquatic animals, especially during their early life when their mouths are so small that no other food but a protozoan could be ingested. Without these tiny animals there would be no fish in many of our lakes and streams. Some, like *Haematococcus pluvialis* (Fig. 7-16), are bright green in color and can reach unbelievable numbers in small pools. Like euglena, they produce haematochrome at certain times of the year, imparting a reddish color to the water. In some Alpine passes they have been responsible for the so-called "bloody snow," a familiar sight to mountain climbers.

Colorless flagellates. Some colorless forms, such as *Peranema* and *Chilomonas*

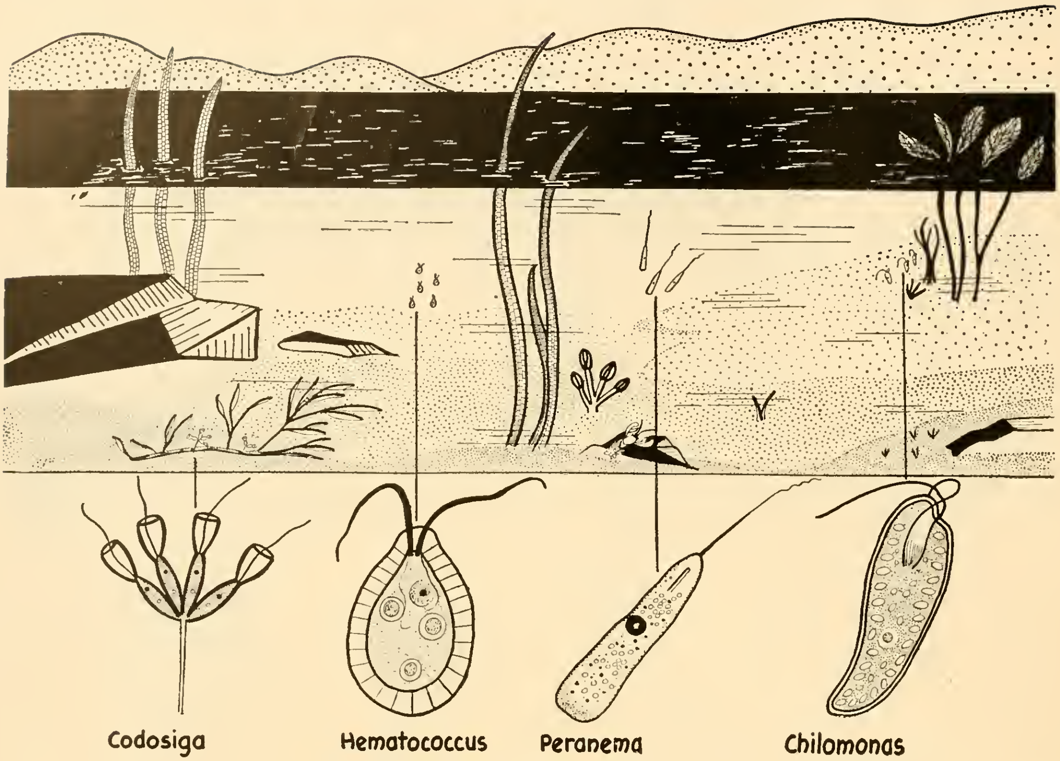


Fig. 7-16. Various types of fresh-water flagellates.

(Fig. 7-16), live in stagnant water where they feed upon bacteria or other smaller Protozoa. Although in its normal environment Chilomonas seems to live on a complex diet, it can be grown in a test tube on a diet consisting of ammonia, as a source of nitrogen, and carbon dioxide, as a carbon source. Here apparently is an organism that in nature lives much like an animal but in the laboratory can be forced to live like a plant, or even more simply, since it does not require nitrogen in the form of nitrates. This may mean that Chilomonas has a full set of enzymes to utilize very simple food sources for the construction of its protoplasm, but since it is not forced to use them normally, has taken up the animal type of nutrition. This would mean that this small organism had a very simple beginning and has not changed much through millions of years of evolution.

Most colorless flagellates live as single

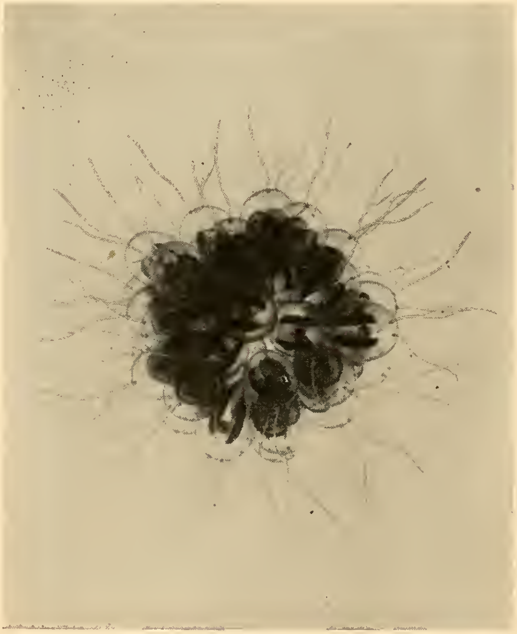


Fig. 7-17. This is a colonial colorless flagellate, *Synura uvella*, which conveys bad odors to water supplies by the release of aromatic oils when its body decomposes. This is a plastic model.

cells, although some live in colonies, such as *Synura* (Fig. 7-17) and *Codosiga* (Fig. 7-16). The latter form possesses a collar at the anterior end of each cell from which the flagellum emerges. With this single exception, collared cells such as these are found only among the sponges. Food is brought to the walls of the cell by the flagellum, then taken into the cell body to form a food vacuole.

Parasitic flagellates. There is a wide variety of flagellates that have made their way into the body cavities and the blood streams of almost every group of animals. They are particularly common in the blood of vertebrates, including man. The most common offenders in this respect are the trypanosomes (Fig. 7-18), tiny leaf-like, elongated cells. A single flagellum, which lies at the outer edge of the membrane, undulates as the organism is propelled through the body fluids of the host. Frequently the parasite is transmitted from one vertebrate to another by means of an intermediate host, either by a blood-sucking insect or some other arthropod. Some of the diseases caused by this group of parasites are African sleeping sickness and kala azar, an oriental disease caused by *Leishmania donovani.*

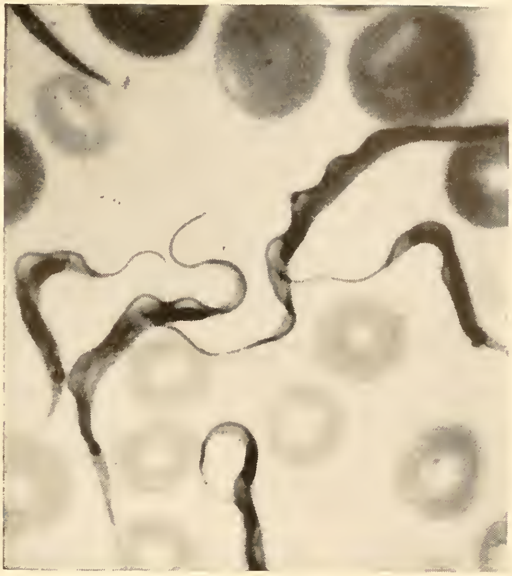


Fig. 7-18. These tiny leaf-like trypanosomes live in the blood of vertebrates and other animals. This is a blood smear showing the parasites among the red blood cells.

Kala azar has had devastating effects on the populations of North China, various parts of India, the Sudan, and South America. It has occurred primarily in the past, although even today it is rampant in many sections of the world. With the advent of knowledge concerning epidemiology, diagnosis, and treatment, many of the evil effects of this disease have been greatly lessened.

Leishmania is a tiny (2-4 microns) ovoid parasite which attacks the cells of almost all of the tissues of the body, particularly the large cells of the tissues lining the circulatory system, both blood and lymphatic. Upon entering the cells it multiplies (Fig. 7-19) until eventually the host cell bursts and the released parasites attack other cells. Some enter the blood stream where they are picked up by the intermediate host, the sand fly (*Phlebotomus*). In the gut of this insect they become flagellated and change considerably in shape. When the insect bites another person, some time after it has received the parasite, the flagellated forms are injected directly into the blood where they attack the lining cells of the blood vessels and the cycle is complete. Like most blood-sucking insects, the sand fly introduces a small amount of saliva, which has an anticoagulating effect on the blood. If this were not the case, a blood clot would shortly interrupt the anticipated meal. Therefore, the parasite is inadvertently introduced along with the saliva, through no "intent" on the part of the sand fly.

The disease runs its course in a matter of months or several years, frequently ending in death. It has been shown that the flies also bite dogs, which in turn act as reservoirs for the disease. So the problem of eradication consists not only of preventative measures and treatment of infected persons, but also control of the dog population of any affected community. The most

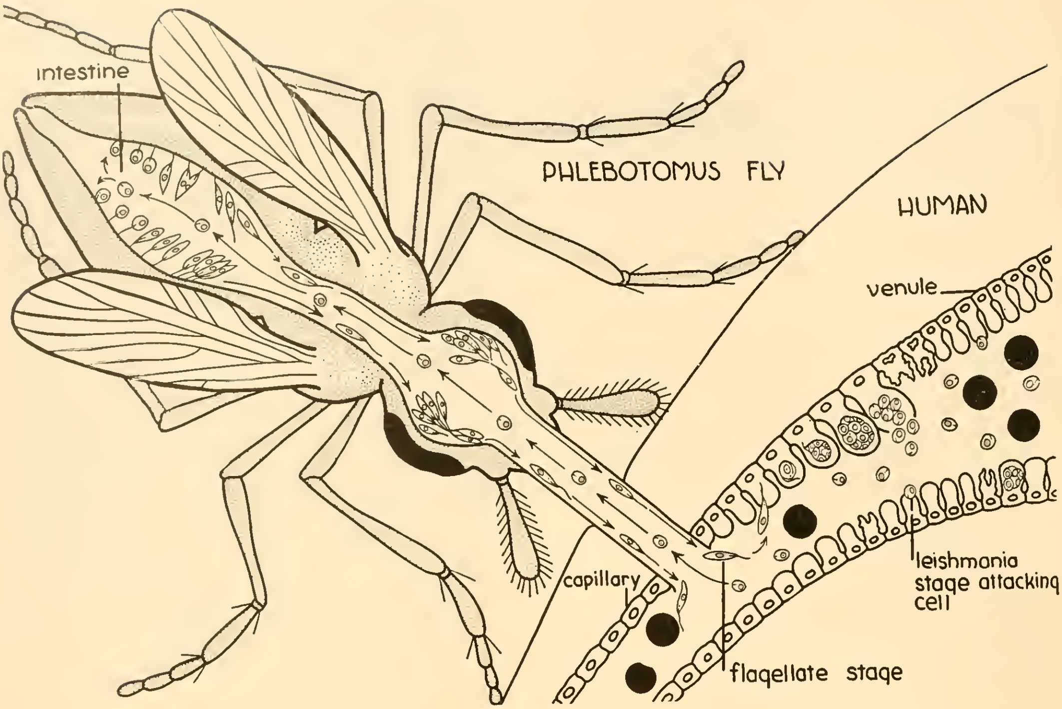


Fig. 7-19. Life cycle of a *Leishmania* causing kala azar.

common method of prevention is the destruction of the breeding places of the fly as well as the fly itself.

A trypanosome is the cause of nagana, a disease of domestic animals. It has been found that sleeping sickness, common among the populations of certain parts of equatorial Africa, was also caused by a trypanosome. The fact that the tsetse fly carried the infection was long known, even

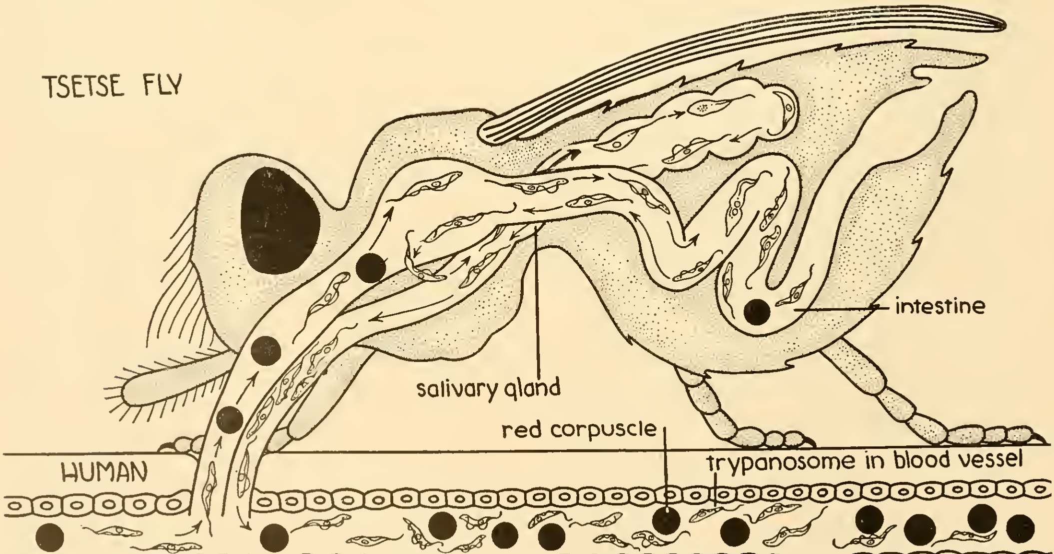


Fig. 7-20. Life cycle of a trypanosome causing African sleeping sickness.

before the cause was discovered. By 1909 it was established that the tsetse fly was not only a mechanical vector but an intermediate host in which the parasite went through a definite part of its life cycle.

The trypanosome is sucked up into the gut of the fly during its blood meal (Fig. 7-20). Here it undergoes some changes in morphology and eventually makes its way into the salivary glands, a common procedure among parasites of blood-sucking insects. Some time later, if the fly bites another person, the parasite is injected along with the saliva. It remains free in the blood for a time but finally makes its way into the fluid surrounding the brain and cord. In this stage the metabolic products of the parasite have a paralyzing effect on the person, eventually causing "sleep" from which he usually never awakens.

Vast regions of Africa are denied man because of the ravages of this disease. Like so many diseases, the parasite is ineffective against the local wild animals, which, however, act as reservoirs, always keeping the parasite circulating in goodly numbers. For this reason the wholesale destruction of the tsetse fly is the only satisfactory control measure; this is not at all impossible now with the recent discovery of such effective insecticides as DDT.

The future development of a large fertile area of Africa must await the control of this disease. This has become an urgent need in the face of an expanding world population. It was once thought that the white man could not thrive in the tropics, but data collected during the past war, when large numbers of white men lived in tropical countries for several years, have disproved this conjecture. There is no reason why he cannot be as successful in the tropics as elsewhere, once we gain control of the tropical diseases to which the white man is very receptive. Much of the backwardness of other races living in the tropics is due to the mur-

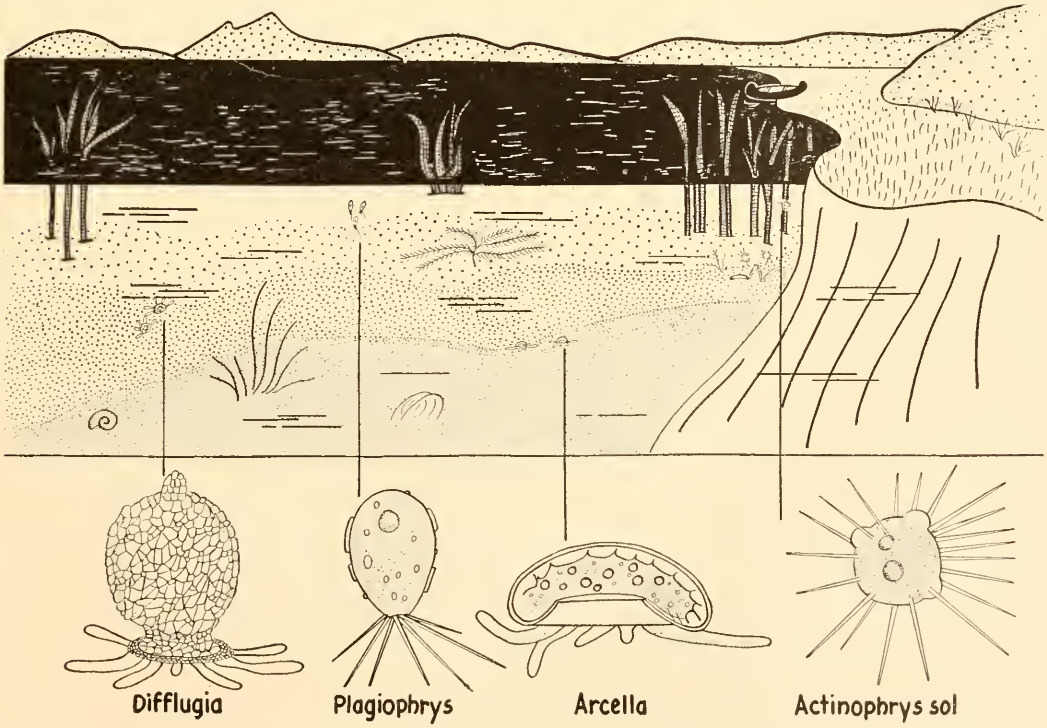


Fig. 7-21. Various types of fresh-water sarcodinids.

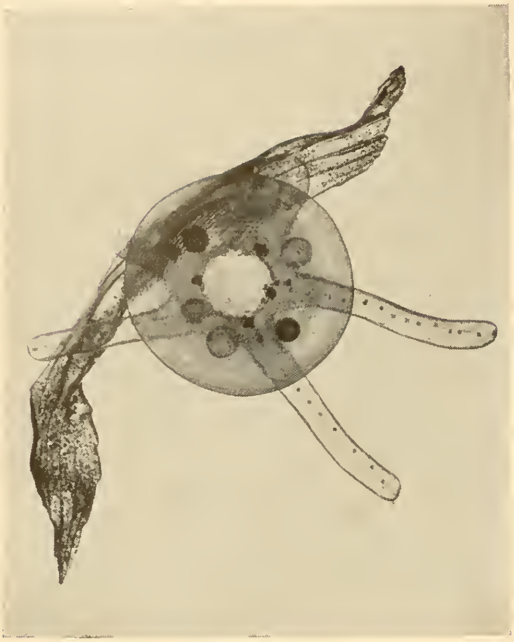


Fig. 7-22. This amoeba-like protozoan (*Arcella*) carries around a "house" into which it may retreat when its life is endangered. The shell is brown in color and, because the opening through which the animal passes lies in the center, it resembles a doughnut. Note the long pseudopods protruding out from the shell. This is a plastic model.

derous attack of parasites of all kinds, rather than any fundamental inability of the people themselves to thrive.

Class Sarcodina

Although members of this class resemble the amoeba to some extent, there is wide variation in form and structure in the group as a whole. Among the fresh-water forms there are those, such as *Difflugia* (Fig. 7-21), that build houses for themselves. This tiny animal gathers grains of sand and cements them together to form a pear-shaped outer covering into which it may retreat when in danger. *Plagiophrys* and *Arcella* (Figs. 7-21 and 7-22), likewise, build houses for themselves, but in this case they are secreted by the animals. When observed through the microscope, the shell of Arcella resembles a doughnut. Corresponding to the hole in the doughnut is the opening through which the amoeboid form passes as it retracts or extends itself from the shell.

Another fresh-water sarcodinid of interest is the "sun animalcule," *Actinophrys sol* (Fig. 7-21), which resembles a miniature sun when it is floating in the water. The radiating, ray-like pseudopods seem to have a paralyzing effect upon other Protozoa, such as euglena, which serve as a food source. There are many related species of this spectacular protozoan. Together they constitute the order *Heliozoa,* a group that is commonly found in the oceans of the world. One, *Oxnerella* (Fig. 7-23), is a particularly beautiful heliozoan.

A large group of forms closely resembling Heliozoa form the order *Radiolaria.* These are also distributed throughout the oceans of the world and float near the surface of the water. Most of them possess a siliceous skeleton which sinks to the ocean floor when the animal dies, forming a thick, mucky layer called "radiolarian ooze." This is particularly extensive in the Pacific and Indian Oceans. Skeletons of these animals are also found in rocks and have been used by geologists in learning about the history of the earth.

Marine sarcodinids that have even greater significance to the geologists are found in the order *Foraminifera,* which secrete shells of almost pure calcium carbonate. While some, such as *Boderia* (Fig 7-23), possess extremely thin, delicate outer coverings of this substance, most of them secrete a heavy shell, for example, *Discorbis* and *Peneroplis* (Fig. 7-23). These many-chambered, snail-like shells, are produced as the animals grow larger and are perforated with tiny holes through which the fine pseudopods project. When they die their skeletons, like those of the Radiolarians, form a "globigerina ooze" (named after the most dominant form, *Globigerina*). This eventually becomes chalk many hundreds of feet thick. The Cliffs of Dover are an outstanding example of this phenomenon. Wherever this chalk appears on land, one can be certain that it was once

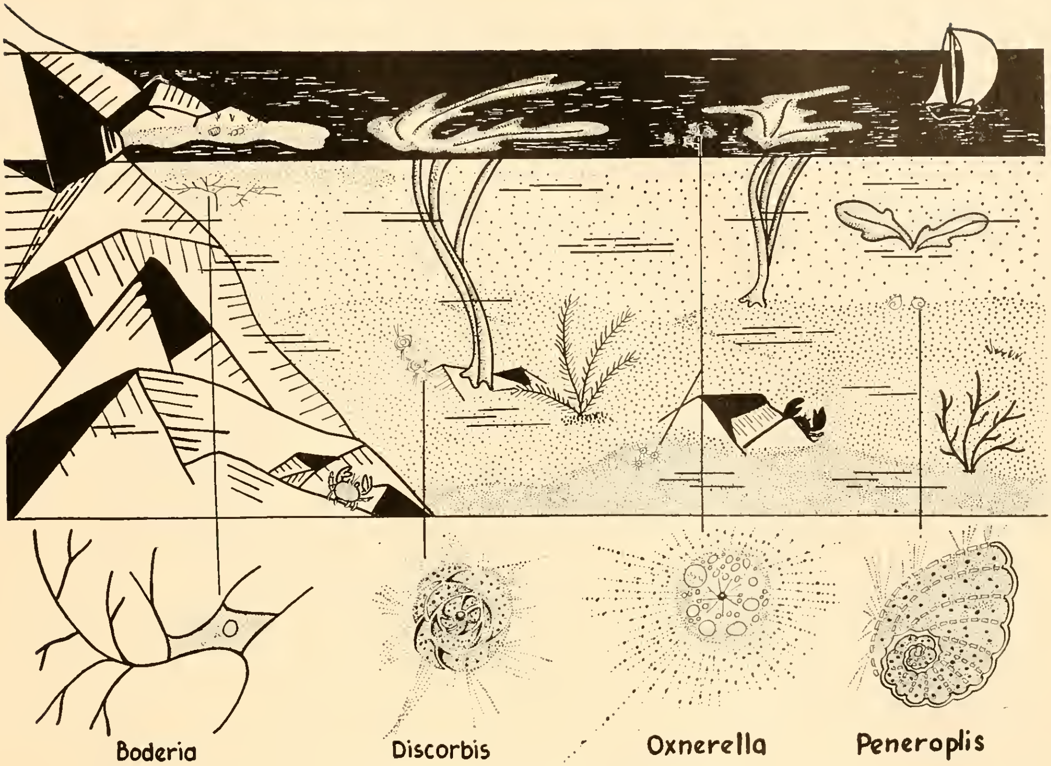


Fig. 7-23. Various types of marine sarcodinids.

at the bottom of the sea. While the globigerina ooze covers much of the ocean floor and chalk has formed in some places, particularly along the shorelines, there has usually been a mixture of other deposits. Globigerina deposits appear in certain strata of the earth's surface and have a definite relation to the formation of petroleum. Therefore, knowledge of foraminiferans has been useful to geologists in predicting the location of oil deposits.

Parasitic amoebae. Some amoebae, like some flagellates, have become adapted to life in the body cavities of many different animals, including man. Of the half dozen or so amoebae that inhabit the various cavities of man, only one, *Endameba histolytica,* causes any great harm. This amoeba is responsible for the well-known **amoebic dysentery.** Though not common in the population as a whole, it became an important disease among our armed forces fighting in the tropics in the past war. Native villages were often infected 100 per cent, providing a rich source of parasites for spreading the infection to newcomers.

The parasites are transmitted from person to person by contaminated food and water (Fig. 7-24). There may also be an indirect transfer by way of flies and other insects that pick up the infective stages on their feet and proboscis, carrying them directly to food and water. Hence, the obvious method of control is to instigate sanitation in respect to human excreta and to destroy the flies. Both of these measures can easily be accomplished in civilized communities, but not among primitive peoples where both the knowledge and the facilities are lacking.

Some notorious outbreaks of amoebic dysentery have occurred in the United States which have been traced directly to faulty plumbing. Studies among groups in re-

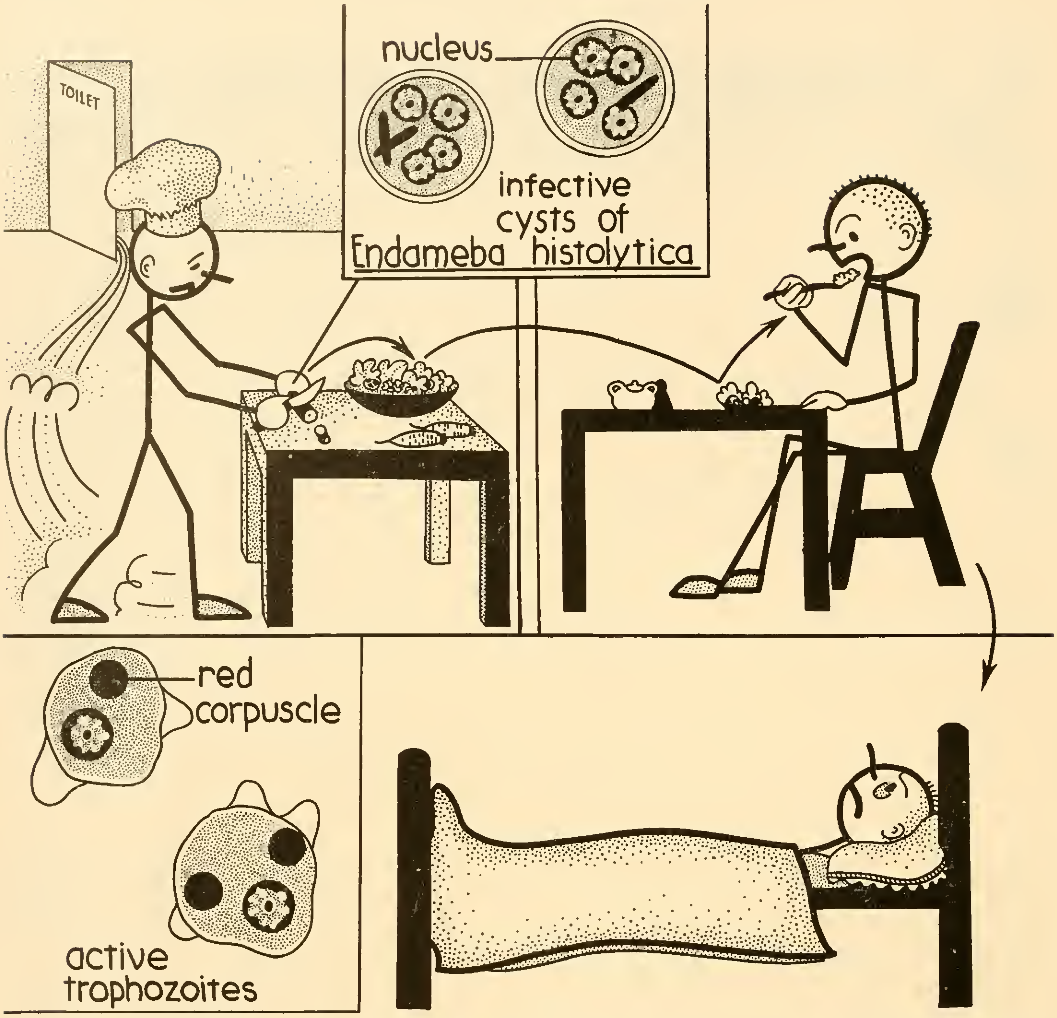


Fig. 7-24. Life cycle of the dysentery amoeba (*Endameba histolytica*). Infective cysts are carried on the hands of food handlers and thus transmitted directly to uninfected people on uncooked food. The trophozoites emerge from the cysts in the intestine where they multiply and feed on the tissues and blood of the host, thus producing serious illness.

tarded areas of this country show an infection rate as high as 23 per cent, although for the nation at large it is around 5-10 per cent. Varying degrees of success have been achieved with a great many substances in attempts to combat the disease. Of the antibiotics, **penicillin** and **chloromycetin** have recently proven the most effective in experimental animals.

Class Sporozoa

Members of this group possess no apparent means of locomotion and they lack contractile vacuoles. They reproduce asexually by multiple fission, and they are all parasites. At some stage in their complex life cycle they produce sex cells, **macro-** and **microgametes**, which fuse in the formation of **zygotes.** The asexual stage produces the sexual stage, which in turn gives rise to the asexual phase, thus completing the cycle. This alternation of sexual and asexual generations is spoken of as **metagenesis.** We will have occasion to study this biological phenomenon in metazoan animals a little later. One or both of the asexual and sexual phases are spent in the body of a plant or an animal, and through transfer from one to the other the cycle is kept going. Many diseases are caused by this group of Protozoa, the most significant of which is malaria.

The malarial parasites (*Plasmodium vivax* is the most common) infect large numbers of warm-blooded vertebrates besides man. In fact, the life cycle was worked out originally on birds by Ronald Ross in 1898. The widespread occurrence of the disease in human populations is indicated by the fact that over 300 million people are infected all the time. It has been estimated that 3 million die of malaria each year—over half of all the deaths in the world. This certainly places it in the number one position among deadly diseases. These figures come as a surprise to most Americans because we now have the disease under control, although a hundred years ago it was responsible for a great many deaths in the South. During World War II it once again became a very important health problem for men in the tropics, and the large number of men continuing to suffer from the disease attests to the fact that we were not altogether successful in our preventive program.

Two factors are necessary for the propagation of malaria, a large population of the appropriate species of Anopheles mosquito and infected humans (Fig. 7-25). Only female mosquitoes bite. In order to become infective the female anopheles must bite a person suffering from the disease and withdraw blood that contains the parasite in a particular stage called the **gametocyte.** There are two kinds of gametocytes, male and female, both of which must be taken into the stomach of the mosquito, where each type of cell undergoes certain modifications. One remains pretty much as it is, producing a single large **macrogamete,** whereas the other produces 6 or 8 smaller motile, threadlike cells or **microgametes.** The macro- and microgametes unite in pairs to form zygotes which are able to bore through the stomach wall under their own power. In the outer part of the stomach wall each zygote multiplies many times, producing a great many tiny infective **sporozoites.** These swollen zygotes protrude from the outside walls of the mosquito's gut like tiny beads. They puzzled Ross when he first saw them, and one can imagine his surprise when he squeezed them and saw thousands of spindle-shaped bodies emerge. Normally they burst into the blood which fills the space between the gut and the body wall, and via the blood the sporozoites make their way into the salivary glands. With each bite of the mosquito from this time on sporozoites are injected into the blood of the next host.

After entering man's blood stream the sporozoites seem to disappear for a few days. This fact has puzzled biologists for many years until the recent discovery that they undergo their early multiplication stages in various tissues of the body, notably certain cells of the liver. At any rate, within ten days some of the parasites are in the blood stream, each entering a red blood cell where it grows and multiplies asexually. After a remarkably regular period of time—namely, 48 hours in *P. vivax,* the most common form of malaria—the infected red cells burst, each releasing 10-20 tiny oval bodies called **merozoites.** These immediately enter other cells, and so the infection keeps increasing in intensity. When there is a sufficient number of infected cells, the person suffers alternate chills and fever with the bursting of the red cells at 48-hour intervals. The symptoms become more intense for the next two weeks when either the person is unable to combat the infection and dies, or he is able to and lives, although intermittent chills and fever continue for a long time, sometimes for several years. During this time some of the merozoites become modified into **gametocytes.** If some of these are taken up by the mosquito with its blood meal, they pass to the stomach and thus complete the cycle.

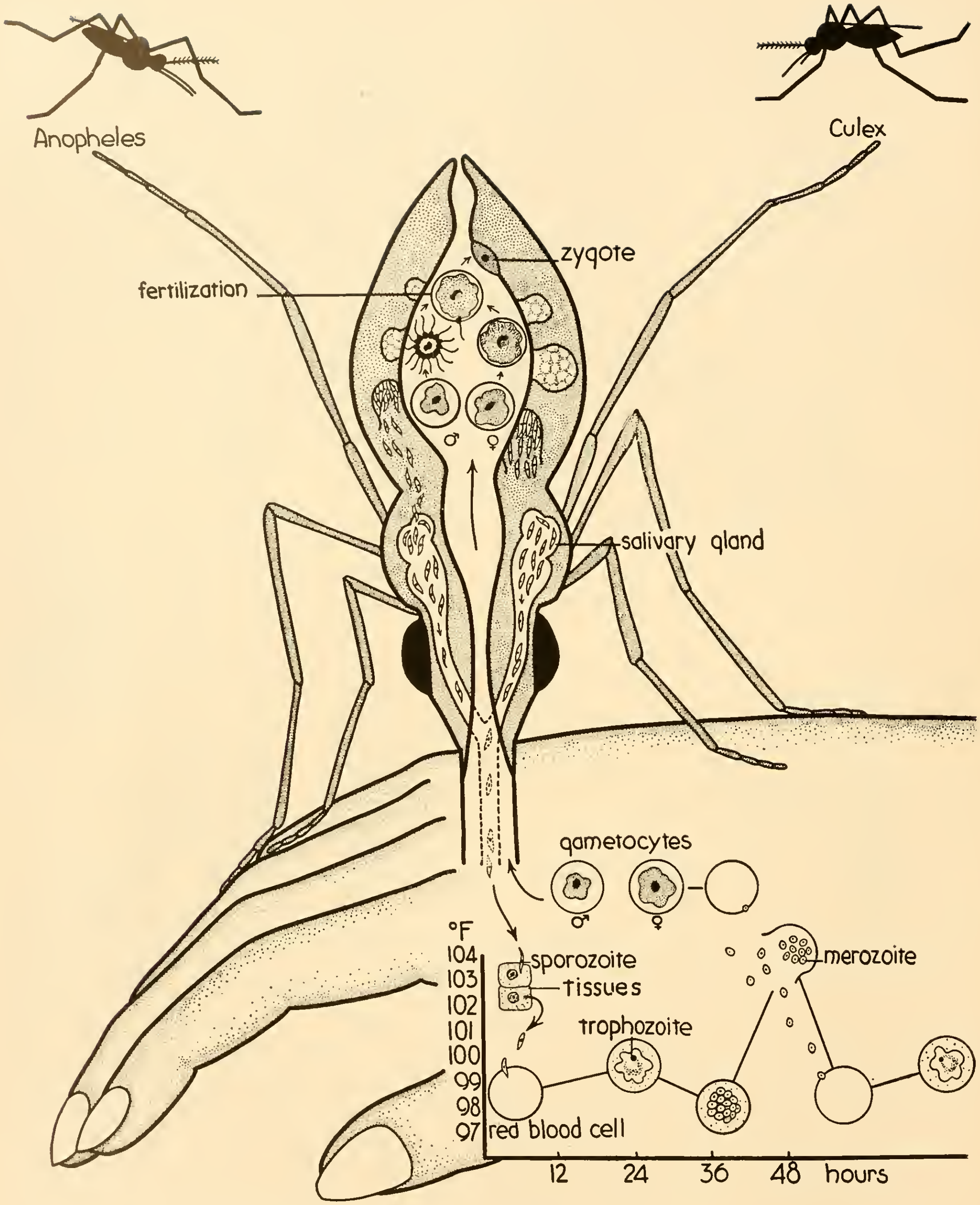


Fig. 7-25. Life cycle of the malarial organism, *Plasmodium vivax.*

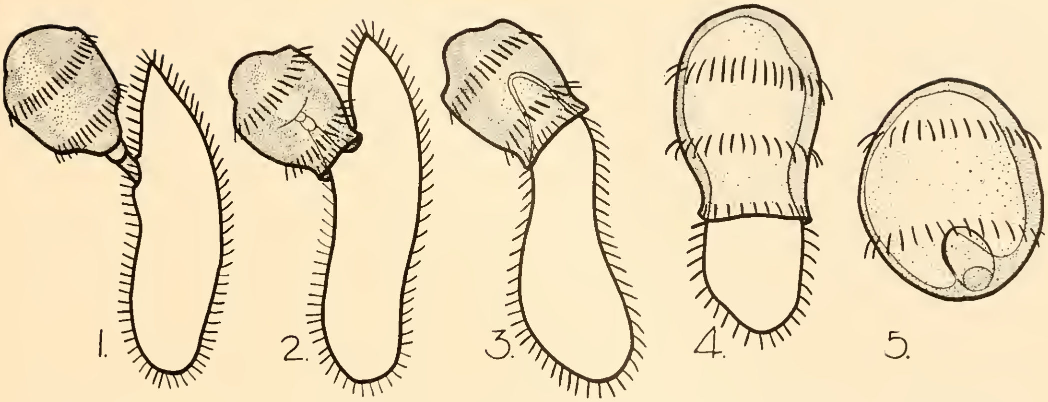


Fig. 7-26. Some ciliates are voracious carnivores. *Didinium*, for example, is able to engulf a paramecium much larger than itself.

The treatment for malaria has an interesting history. About 1640 a countess visiting in Peru became ill with malaria and when given extracts from the bark of a tree, since named cinchona in her honor, she recovered. She was so impressed with the drug that she brought some back to Europe where it was shown to be extremely effective in the treatment of malaria. From that time to the present quinine, the effective drug in cinchona bark, has been used as a specific treatment for malaria. It has probably saved more lives and relieved more suffering than any other drug ever discov-

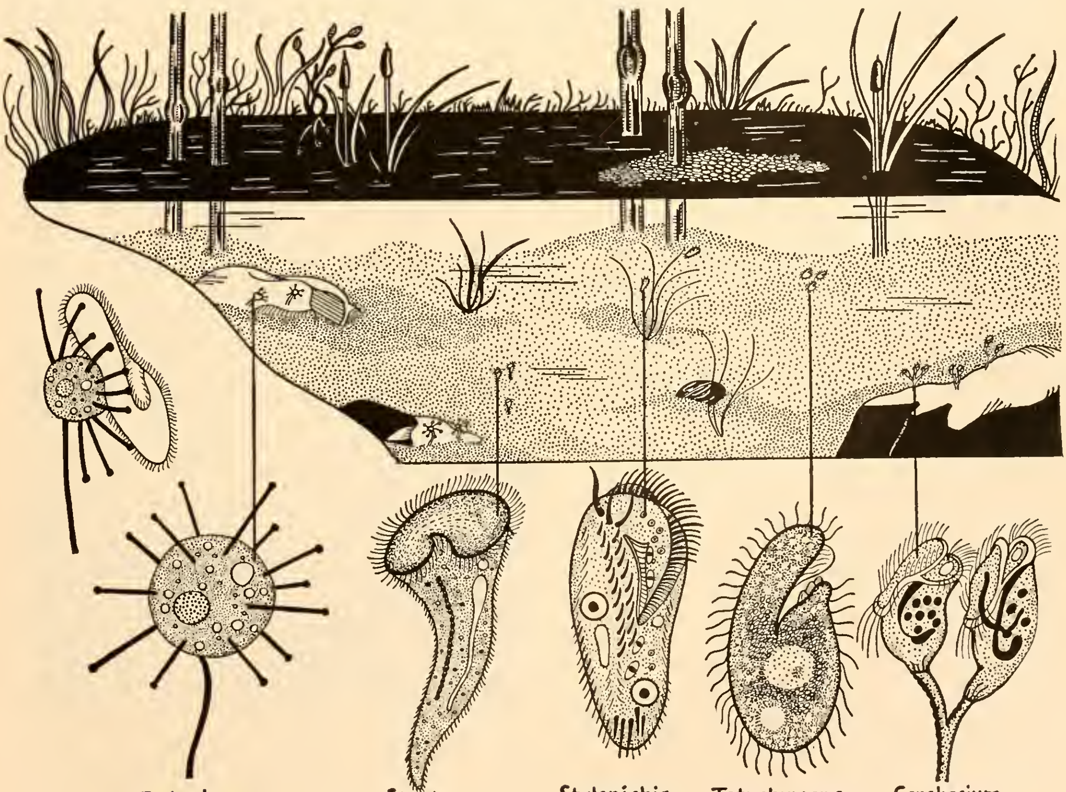


Fig. 7-27. Various types of fresh-water ciliates.

Fig. 7-28. A stalked-ciliate, *Vorticella*, in various stages of its life history. The two animals to the left are undergoing division while on the extreme right is the free-swimming stage which enables the species to spread to new environments. The fine contractile thread which can be seen in the stalk makes it possible for them to suddenly become coiled as some of the organisms here. This is a plastic model.

ered by man, the recent antibiotics and sulfas included. During the past war our supplies of quinine were cut off, so we had to rely on substitutes such as **atabrine** and **plasmochin**. The problem of synthesizing quinine went ahead during the war years with unrelenting vigor until finally it was successfully accomplished by the war's end. At present, however, natural sources are used since they are cheaper than the synthetic product. A constant search is made for a new specific for malaria and some success is reported from time to time. Perhaps the ideal one will be found in the future.

Class Ciliophora

The members of this class are distinguished by the possession of **cilia** and two or more nuclei. These characteristics were observed in paramecium, which is a representative of this group. The class has been subdivided according to the arrangement of the cilia into four orders, the more interesting members of three of these will be described briefly.

Those belonging to the order **Holotricha** possess evenly distributed cilia over most of their body. Paramecium is typical.

Didinium is an interesting member of this group because of its carnivorous habits. It is oval-shaped, with two bands of cilia encircling the anterior and posterior regions (Fig. 7-26). Protruding from the anterior end is a formidable-looking **proboscis** which is an effective organelle for impaling paramecia prior to engulfing them. The magnitude of this feat can be realized by imagining a man eating a full-grown horse at one sitting. This is only one illustration of the voraciousness of these carnivorous ciliates which abound in almost any stagnant water.

The order **Spirotricha** includes a large variety of diverse ciliates, one of which, *Spirostomum,* is a veritable giant among the Protozoa. This cell reaches a length of 3 millimeters and can easily be seen with

Fig. 7-29. Anton Leeuwenhoek (1632-1723) was the first man to see and describe many Protozoa as well as other microörganisms. He was not trained in science, but his devotion to the disciplines of the field places him among the foremost scientists of his day.

the naked eye. In fact, when first observed, it might be mistaken for a tiny worm because of its apparent crawling movements. Another large form, *Stentor* (Fig. 7-27), vase-shaped and colored a beautiful greenish blue, is a spectacular sight for the microscopist.

This order also includes several species in which the long cilia are fused into stiff bristle-like organelles called **cirri.** Cells of this type are flattened dorso-ventrally and seem to use their cirri in "walking" along the substratum. One of these is *Stylonichia* (Fig. 7-27), which is about the size of paramecium but whose actions are quite different. It moves along in a jerky fashion, darting forward and backward, and sometimes crawling along on the bottom. Professor C. V. Taylor, working with a closely related ciliate, *Euplotes,* some years ago, was interested in how this cell controlled the cirri in locomotion. With the use of a delicate dissecting instrument he was able to cut the tiny fibrils that connect each of the cirri with the others. Such an operated animal lost control of its cirri and was unable to coördinate its movements sufficiently to move in any one direction. Thus he discovered that even this tiny animal possesses some kind of coördinating system resembling the nervous system of higher forms.

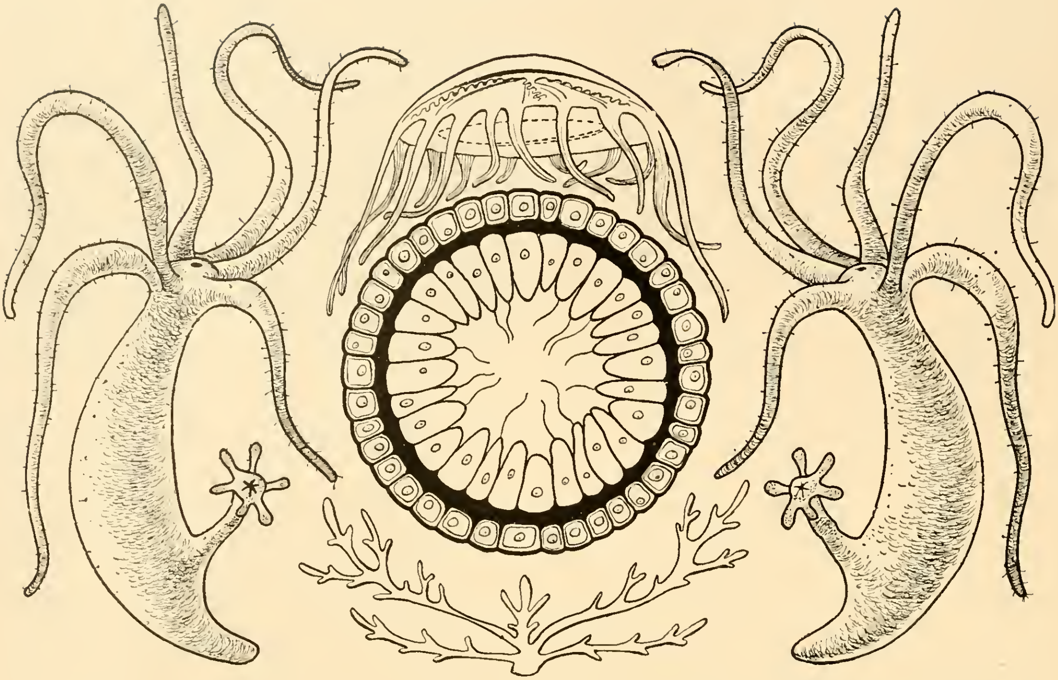
Ciliates belonging to the order **Peritricha** have their cilia conspicuously arranged in the anterior region. Most of these forms are vase-shaped and many are stalked. Common examples are *Carchesium* (Fig. 7-27) and *Vorticella* (Fig. 7-28). Of the two, the latter is more common and is familiar to anyone who has persisted in examining stagnant water under the microscope. It was seen and described for the first time by Anton Leeuwenhoek in Holland during the seventeenth century (Fig. 7-29). Vorticella is usually attached to the substratum by means of its contractile stalk. When disturbed or sometimes for no apparent reason, it suddenly contracts and at the same time the cilia around the funnel-shaped mouth disappear and the entire cell rounds up into a ball. Shortly, it emerges again and starts its oral (mouth) cilia beating so that food particles floating by are wafted into its mouth.

Fig. 7-30. Plastic model of a suctorian (*Ephelota coronata*).

A peculiar group of Protozoa, the *Suctoria* (Fig. 7-30), are usually considered as belonging to Ciliophora because they possess cilia during the young stages, although they are absent in the adults. In their place these animals possess long and numerous "tentacles" which are used in capturing food (other Protozoa). Like Vorticella, the suctorian has stalks and is sessile most of its life.

From this cursory survey of the Protozoa one is impressed with the tremendous diversity of form and habits of life that are available to a group of animals even though confined to one cell. Think of the much greater opportunity for diversity when cells are aggregated into masses. Our course now is to study representatives of succeeding phyla where each is more complex than the preceding, finally terminating with the most complex of all animals, man. This great and wondrous story should be followed with keen interest because it is the way life came to where it is today on this earth.

CHAPTER 8



THE SPONGES AND THE TWO-LAYERED ANIMALS

PHYLUM PORIFERA

The sponges constitute the phylum Porifera, which means "pore bearer," the presence of pores being one of the characteristics of the group. This rather unique group of very simple animals is not in the direct line of ascent to higher forms and is sometimes placed in a separate subkingdom, the Parazoa. Sponges possess flagellated collared cells which resemble some of the protozoan forms (Fig. 7-16), indicating that they may not be far removed from the one-celled group. Digestion is wholly intracellular and, except for simple epithelia, there is no arrangement of cells that can be considered tissue. For this reason sponges are usually considered to be of the **cellular grade of organization.**

Living sponges have a gelatinous texture, quite different from the familiar bath sponge sold on the market. Being sessile, they are easily mistaken for plants. Sponges assume many shapes, vary in height from 1 millimeter to more than a meter, and are usually drab in color. Some forms, however, take on shades of red, yellow, blue, black, or green, the last being caused by the green

Fig. 8-1. A common marine sponge (*Sycon*) which is about 1 inch long. The individuals grow in clusters and are very commonly found clinging to debris in the ocean.

A B

Fig. 8-2. Two deep-sea sponges. Their skeletons are composed of siliceous (glass) spicules. *A.* Venus' flower basket (*Euplectella*). *B.* The glass rope sponge (*Hyalonema*).

Fig. 8-3. A fresh-water sponge collected in a Michigan stream; it measures about 14 inches long and is a green-gray in color due to the presence of unicellular algae growing in the body cells.

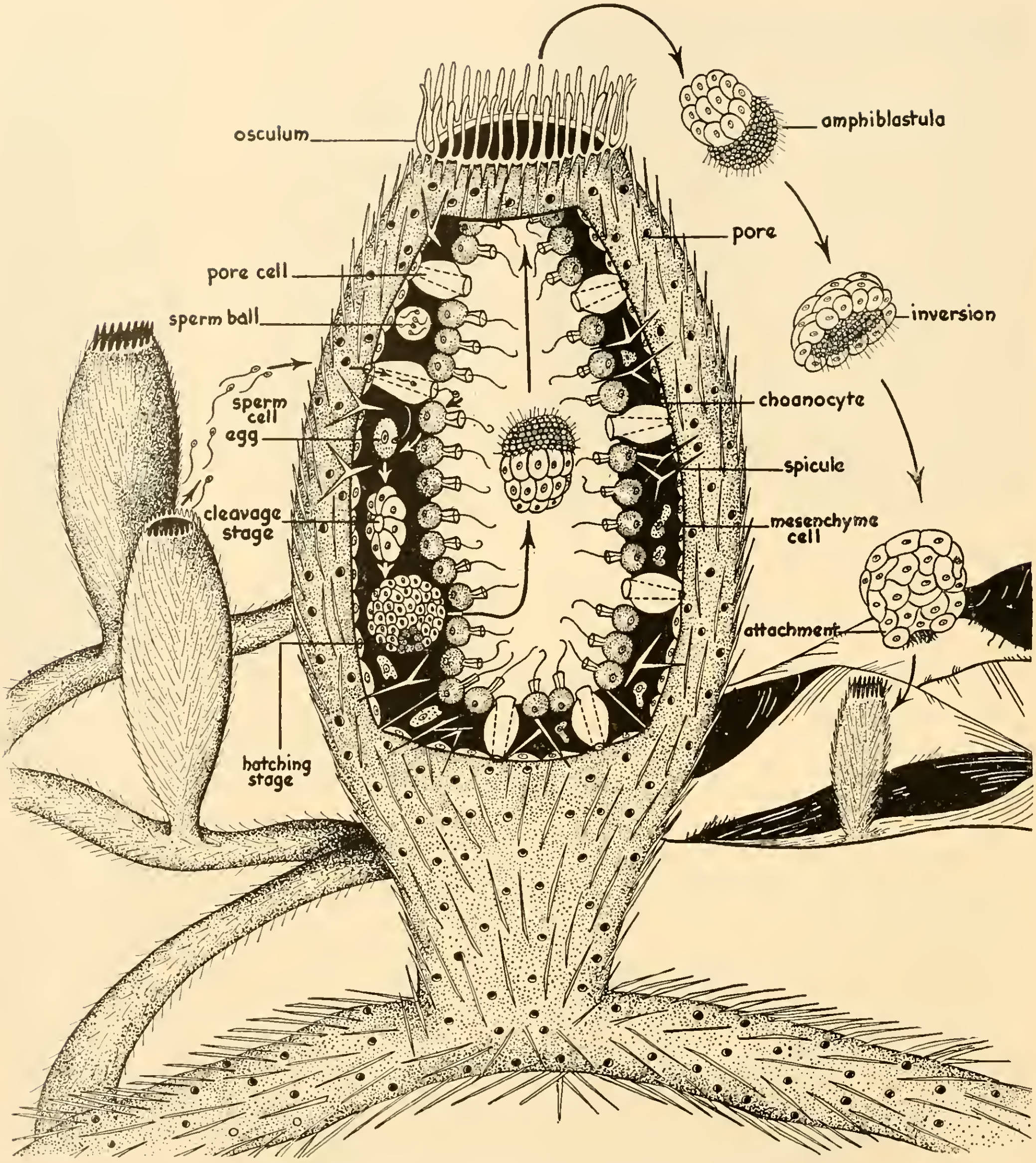


Fig. 8-4. Anatomy and life history of a simple sponge.

alga, *Chlorella,* living in the body cells. Their most common habitat is some feet below the tidal zone of the sea (upper and lower limits of the tide) (Fig. 8-1), although some, like the glass sponge (Fig. 8-2), live as much as three and a half miles below the surface of the ocean. Fresh-water forms are also known, some of these attaching themselves to twigs and rocks in the streams (Fig. 8-3).

Morphology of a simple sponge

In order to have some knowledge of the morphology of the sponge, it is best to discuss a simple sponge, *Leucosolenia,* as an example. It lives beneath the low tide level in the sea and consists of many slender upright tubes which are joined at their bases in a many-branched common tube (Fig. 8-4). The upright portions are thin-walled sacs perforated with hundreds of microscopic holes (**incurrent pores**) and one large opening, the **osculum** (**excurrent canal**) at the upper tip. The cavity of the sac is called the **spongocoel.** Its wall is made up of an outer **epidermis** or skin-like layer of flat cells, and an inner continuous layer of the flagellated collared cells (**choanocytes**). A third jelly-like layer, the **mesenchyme,** lies between these two, and in this layer several kinds of amoeba-like cells, called amoebocytes, are present. This layer also contains the skeleton formed by **spicules,** which resemble crystals. In the glass sponge the spicules consist of siliceous material and in horny sponges, of fibers and spongin. In most forms, however, they are composed of calcium carbonate. A combination of spicules and fibers also occurs.

Scattered among the ordinary epidermal cells are the tubular **pore cells,** each with a central canal or pore. A pore cell, together with "helpers" surrounding it, controls the flow of water into the sponge. The vigorous beating of flagella on the collared cells lining the spongocoel causes water to move in through the pores and out through the osculum. This movement causes a constant stream of water, heavily laden with microscopic organisms, to pass within reach of the choanocytes. The manner of beating of the flagella in the collared cells propels tiny food particles to the cell body which engulfs it, forming food vacuoles much like amoeba. Any food not needed by the choanocytes is passed to the amoebocytes for further distribution. Waste products are borne out through the osculum in this same current of water.

Sponges in general

Sponges reproduce asexually by means of **internal** and **external buds,** as well as sexually by means of eggs and sperms. Buds form on the outside of the sponge and sometimes move away, but as often remain a part of the parent sponge. During unfavorable conditions, as in drought or cold winters, sponges develop internal buds, called **gemmules,** which are merely masses of cells with a hard outer covering. They drop to the bottom of the stream or sea during these adverse conditions and grow into sponges the next season when circumstances are again favorable.

Some sponges are **monoecious** (of one household), that is, both sexes are present in one animal; others are **dioecious** (of two households), the sexes being found in separate animals. There are no special sex organs, and the sperms and eggs simply develop from certain of the amoebocytes in the middle layer or mesenchyme. Fertilization occurs *in situ* (in place) and is followed by rapid division until a **blastula** is formed with many flagellated cells (future choanocytes). The flagella are directed inward toward the central cavity, the **blastocoel.** A hole appears later and the embryo turns inside out, bringing the internal flagellated cells to the outer surface. In this stage, called the **amphiblastula,** it leaves the mother sponge through the osculum and swims around for a few days, finally settling and attaching itself to a rock or some other solid object where it grows into a sponge (Fig. 8-4). The larger cells of the larva overgrow the flagellated cells and completely surround them. The cell layers of the sponge seem to be the reverse of those found in higher forms and for that reason are not comparable to them.

Some very interesting cases of commensalism are found among the sponges. They occasionally strike up a friendly relationship with animals such as crustaceans, worms, and mollusks. Many animals make the channels of the sponges their home; even fish as long as 5 inches have been found swimming about inside of sponges. Certain species of crabs enlist the aid of the sponge in camouflage by placing small pieces of the sponge on their backs until they become attached. Thus the crab is amply hidden from its would-be food and

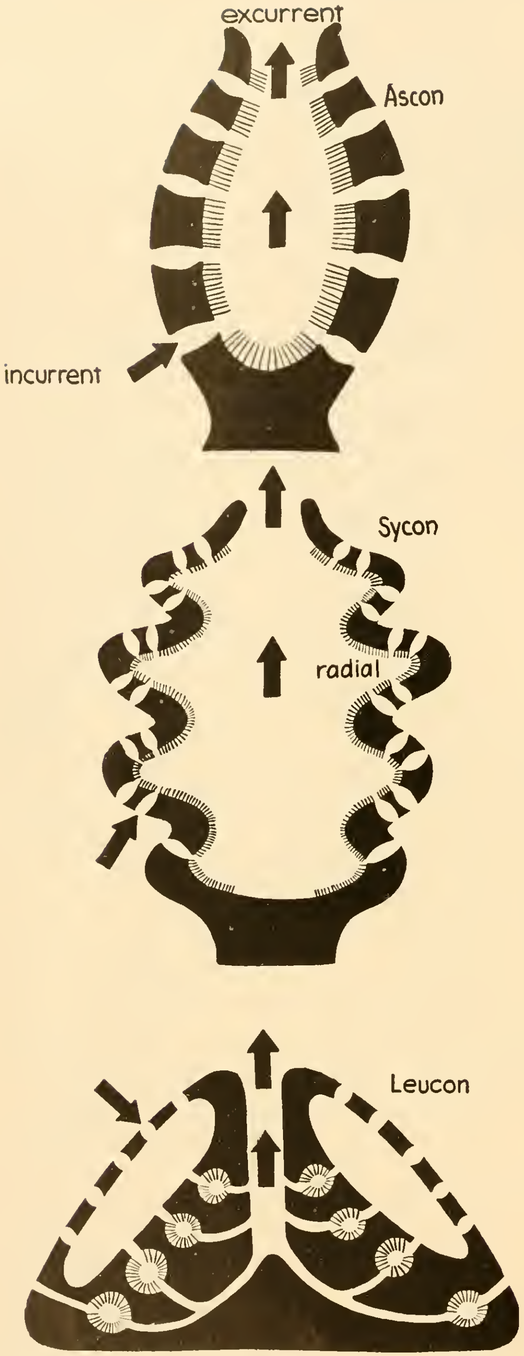


Fig. 8-5. Various types of canal systems among sponges.

from its enemies. Sponges can become a hindrance in oyster beds where they cover the oysters and compete for the food supply.

Sponges have canal systems which vary in complexity (Fig. 8-5). The simplest, the **Ascon** type found in *Leucosolenia,* is merely a thin-walled sac. The first step in increasing complexity occurs in the **Sycon** type, which has two kinds of canals, **incurrent** and **radial**, the latter being lined with choanocytes. The most complicated of all is the **Leucon** type, which possesses a vast array of multiple tubes and chambers, with choanocytes lining only certain restricted chambers. Leucon sponges may reach more than a meter in diameter.

Sponges have been used by man for cleaning purposes from earliest times. The part used in the bath sponge is the skeleton, composed largely of **spongin**, a protein. It has many fine fibers which, through capillarity, have remarkable water-holding properties. Sponges for commercial use are found most frequently in the warm seas such as the Mediterranean, the Gulf of Mexico, and the Gulf of Florida. In preparation for market, sponges are pried loose from rocks by divers or dredges, and the living portion is allowed to dry and decay. They are then beaten, washed, and finally bleached. Needless to say, the bath sponge has considerable commercial value. In recent years it has even become necessary to cultivate it in order to prevent it from becoming extinct as the result of the constant ravages of man. Two million pounds of sponges are taken annually, even though the sponge must compete with its rubber and plastic imitations.

In review, we may think of the sponges as "blind alley" animals that came to their present state millions of years ago and have "stood still," failing to evolve any higher on the animal scale. They are sufficiently well adapted to their environment to carry on in their primitive way and they probably will continue for millions of years to come. Since they are not on the direct line of ascent to higher forms, we must leave them in their isolated position without further reference to them and pass on to the next group which has much more significance in our story of the rise of animal life on earth.

PHYLUM COELENTERATA

The first true metazoan animals to have their somatic cells organized into definite tissues are the two-layered, sac-like coelenterates. Greater differentiation of somatic cells and well-established division of labor make this form considerably more complex than the sponges.

Coelenterates possess special epithelial cells, called **cnidoblasts,** which produce the **nematocysts** used for offense and defense. In many coelenterates there are two types of individuals, the **polyp,** representing the asexual phase of the life cycle, and the **medusa,** the sexual phase. In their life histories each generation successively gives rise to the alternate type, a phenomenon called **metagenesis.** The asexual polyp is tubular in shape, with a mouth at one end, surrounded by tentacles richly supplied with nematocysts. The other end of the tube is closed and forms an attachment organ, the foot. These animals are usually sessile or nearly so. The free-swimming sexual medusa is a delicate transparent animal, shaped like an umbrella. Around the periphery or edge of the umbrella are tentacles, which are also heavily fortified with nematocysts. Both the polyp and the medusa have primitive muscle fibers which make movement possible.

The coelenterates are water-inhabiting animals, most of them marine. One form, **hydra,** has invaded fresh water and is very successful, being found in nearly all the ponds and streams of the world. The large marine **jellyfishes** and the **sea anemones** are members of this group in which the asexual generation has been greatly reduced. In both the sea anemones and their close relatives, the corals, the asexual forms have been completely lost.

With the exception of some jellyfish, which may annoy bathers by the stings of their nematocysts, and the coral animals, which are used for jewelry, the group as a whole has little direct significance to man.

There are three classes of coelenterates (Hydrozoa, Scyphozoa, Anthozoa) whose characteristics can best be understood by studying two representatives, Hydra and Obelia, of the class Hydrozoa. Members of the other two classes are discussed briefly later in the chapter.

Hydra

This tiny animal may be found clinging to underwater vegetation in nearly any fresh-water pond, lake, or stream (Fig. 8-6). At some periods of the year they may be so numerous in swift-moving streams as to impart a gray color to the rocks to which they are attached. Hydra moves about very little, hence it must seek its food by means of its long tentacles. Though the column of the body may be less than half an inch in length, the tentacles in some species may reach 10 to 12 inches. The cylindrical body may extend so that it is many times longer than its diameter or it may contract into a pear-shaped, compact body with the tentacles resembling tiny stumps. The hollow tentacles surround a raised conical **hypostome,** in the center of which is the **mouth.** The mouth opens into the digestive cavity, the **coelenteron** or **gastrovascular cavity,** which continues into the tentacles (Fig. 8-7). At certain times of the year small swellings, the sex organs, appear on the external walls. At other times or, in some cases, at the same time, small buds form on the sides which grow into tiny hydras, and finally detach themselves to grow into adults. Ciliate Protozoa are found crawling over the surface of the body of most hydras. Just what their relationship is to the hydra is not known. Perhaps they play the same part for hydra that a flea does for a dog.

It might be expected that in the evolution of Metazoa the primitive body organization would be very much as it is in hydra. When cells group themselves to-

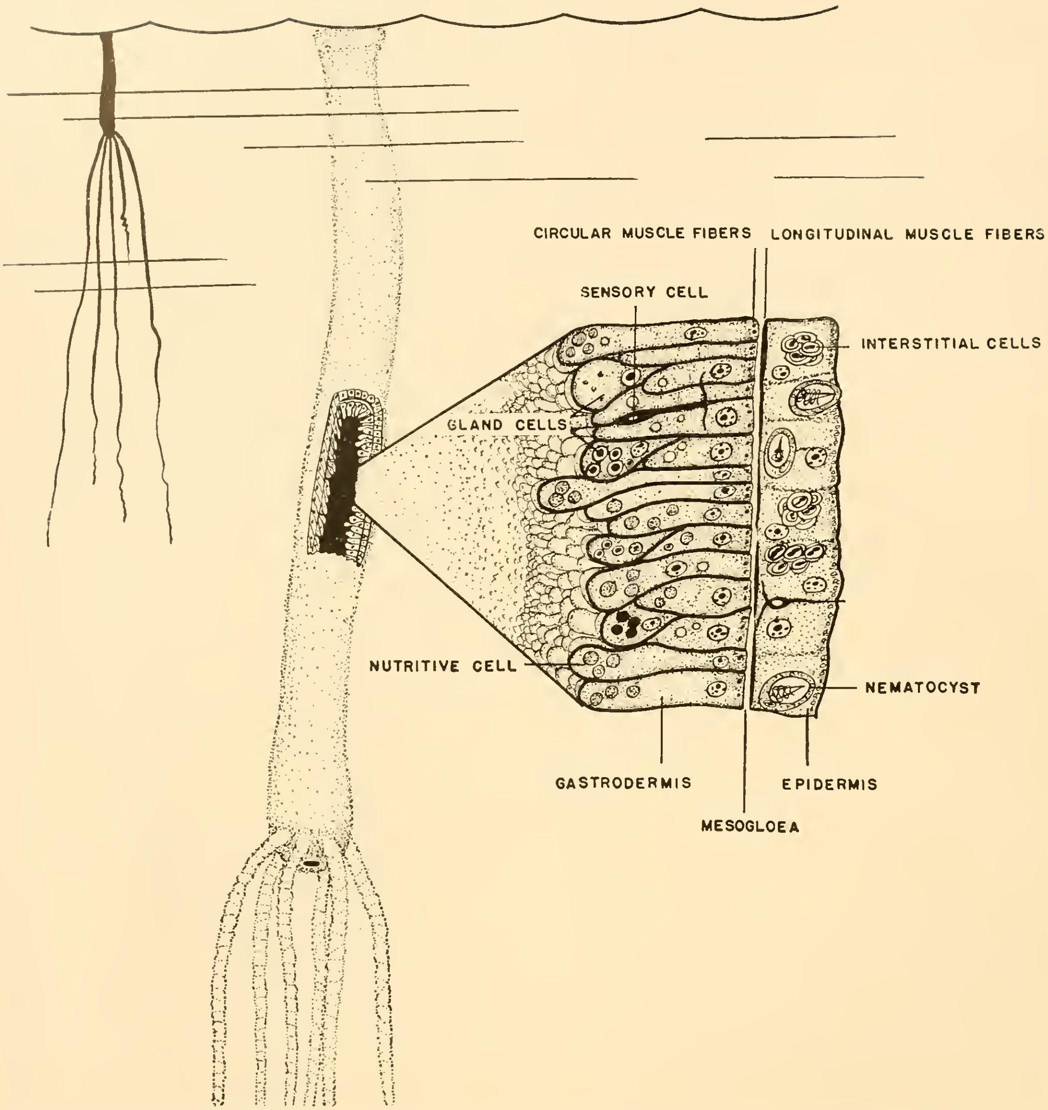


Fig. 8-6. Hydra often "hangs" from the water surface. A portion of the body wall is magnified here in order to distinguish its cellular structure. Note the variety of cells in both the epidermis and gastrodermis.

gether, there is a need for some cells to protect the entire group from the outside world, others to locate food, and still others to detect the possibility of danger. This is observed in hydra. The outer layer, the **ectoderm**, sometimes called the **epidermis**, is made up of cells which form a protective covering. Some of these cells have an inner contractile portion which enables them to serve as muscle cells. Finally, scattered among the cells of the epidermis are specialized sensory cells. The inner layer of cells, the **endoderm** or **gastrodermis**, provides all other cells with nourishment. These tall, glandular cells secrete the **enzymes** which digest food that is brought into the coelenteron (Fig. 8-6). These cells also possess muscle fibers at their bases which run at right angles to those in the epidermis. It is by the combined action of these muscle cells with those of the ectoderm that hydra is able to contract and extend itself. Lying

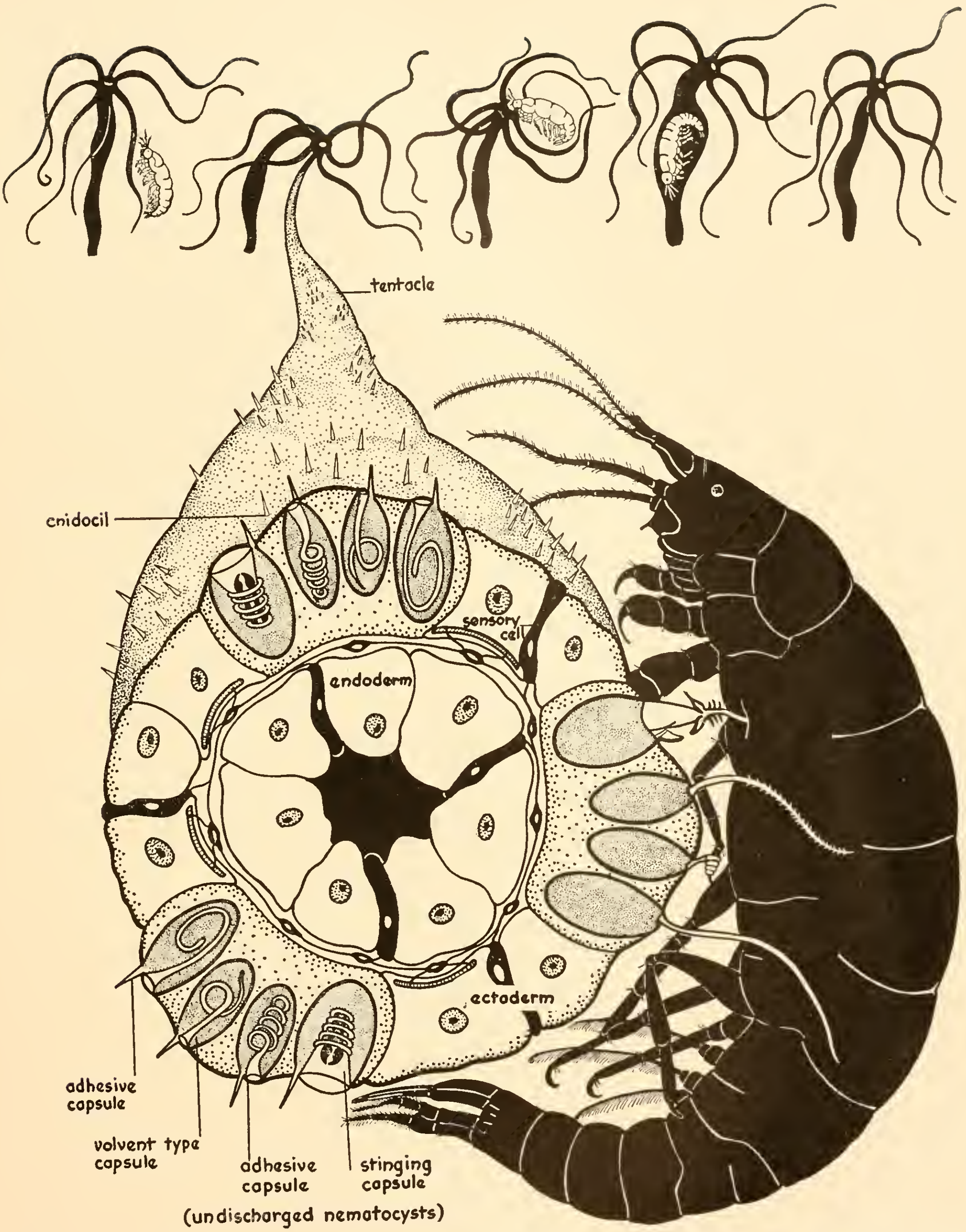


Fig. 8-7. Hydra feeding on a small crustacean. One tentacle is enlarged to show the undischarged and the discharged nematocysts in detail.

Fig. 8-8. Hydra somersaulting.

between these two layers, the ectoderm and the endoderm, is a thin, non-cellular layer, the **mesogloea**, which lends support and holds all the cells together. Lying embedded in both the ectoderm and endoderm are the nerve cells, which are connected by minute fibrils to the sensory and muscular cells. They function in coördinating the activity of all the cells. The nerve cells form a network, called the **nerve net**, which connects all parts of the animal, although there is no centrally located mass which could in any way be compared to the brain of higher forms. External **stimuli** initiate impulses in the **sensory cells** which are conveyed to the nerve net and through it to the **contractile fibrils**. This is the simplest form of a central nervous system, but it contains the fundamental elements of which all higher nervous systems are built.

An interesting and intricate part of hydra's response mechanism is the **cnidoblast**, with its contained **nematocyst**. Cnidoblasts are located in nests or "batteries" along the tentacles, for the most part, although they may occur over the entire body with the exception of the foot, or basal disc, on which the hydra "walks." Nematocysts are derived from the interstitial cells and are usually arranged with one large and several small ones in each battery. There are four different kinds of nematocysts, each having a different use. The largest and most conspicuous type is the penetrating or stinging **nematocyst**, which upon discharge pierces the body of small crustacean or other aquatic animals that happen to touch the tentacles (Fig. 8-7). This nematocyst contains a hollow, coiled thread which everts through the trigger-like action of the **cnidocil**, a slight projecting bristle, when it is touched or stimulated in some other way. It is ejected with such force that it penetrates the soft and even some hard parts of the prey, injecting a small amount of poison which has a paralyzing effect on the victim. Once paralysis sets in, the tentacles move in a manner that draws the prey into the mouth and thence into the coelenteron. Other types of nematocysts function in a mechanical rather than chemical manner. When discharged, some wrap their threads about a portion of the attacked animal and hold it securely. Others fasten themselves to a portion of the substratum and by contractions of the tentacles make possible a slow, somersaulting type of locomotion (Fig. 8-8).

A second method by which hydra moves from place to place in search of food is to "shuffle" along on its basal disc by means of special cells located in this region. Some species are able to secrete a bubble of air at the basal disc, which carries them to the surface where they float upside down. In this position it is not uncommon for the tentacles to stretch out into thin threads as much as 10 or 12 inches in length.

Most of the actions of hydra are related to food-getting. A hungry hydra responds readily when a small crustacean or worm comes within reach of its tentacles. If meat juices are placed in the surrounding water, it responds by increased extension and contraction of its entire body. On the other hand, a well-fed hydra responds very little, if at all, to the presence of food.

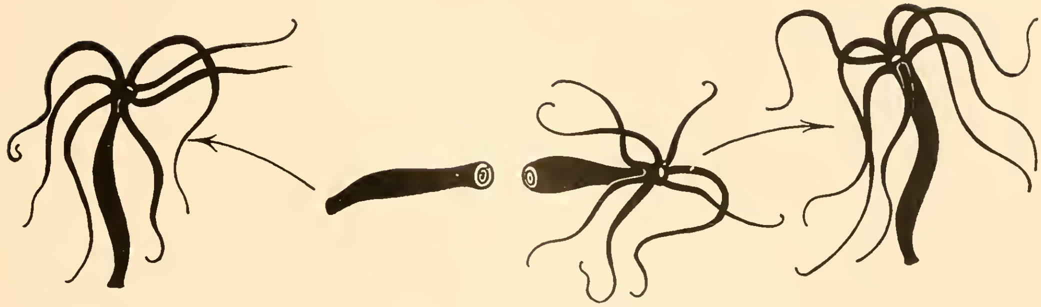


Fig. 8-9. Regeneration in hydra.

The presence of food in the coelenteron stimulates the gland cells to secrete digestive enzymes into the cavity where the soft parts of the ingested animal are partially digested (extracellular digestion). The hard outer coverings are indigestible and are eventually regurgitated through the mouth. Thus a single opening functions both as a mouth for the entrance of food and as an anus for the exit of undigested food. The breakdown of food molecules is probably not as thorough as in higher forms, for it has been observed that many of the endoderm cells take in particles of food by an amoeboid process. Food vacuoles are formed and intracellular digestion proceeds, the same as in the Protozoa. This might be expected, since this animal is not so far removed from its protozoan ancestors. The cells of the epidermis and other portions of the body receive their food supply from the endodermal cells.

Hydra is sensitive to light and seeks out a suitable illumination. The intensity sought is usually that in which food is most likely to be found. The colorless hydra seeks a lower intensity of light than its green relative (*Hydra viridis*). The latter has tiny green algae in its endodermal cells, which require more light for photosynthesis (Fig. 5-9). Hydra prefers cool, clear water and seeks it out. If exposed to various concentrations of injurious chemicals, it avoids each with regularity. If unfavorable conditions are forced upon it, such as desiccation, it undergoes a series of regressive changes called "depression." The tentacles and body begin to disintegrate and this continues until the animal is destroyed. Under favorable conditions, however, it may recover at almost any stage in its disintegration.

In a suitable environment, hydra reproduces asexually by forming one or more buds along the body wall where cells are congested with a surplus of stored food (Fig. 8-10). This is accomplished by a proliferation of the cells pushing a part of the body wall outward. Small blunt tentacles develop and a mouth breaks through. Food obtained by the parent hydra circulates into the coelenteron of the bud during its formation, thus providing means for rapid growth. Eventually the bud constricts at the point where it joins the parent and divorces itself from the latter to carry on its own existence. Sometimes several buds form simultaneously, indeed, buds may have buds upon themselves. This is very close to a colonial form, such as obelia, another hydrozoan, which will be considered a little later.

Since buds form so readily from almost any part of its body wall, it should follow that hydra could perhaps be made to reproduce itself experimentally by simply cutting off small pieces of the body. This idea apparently occurred to a Swiss naturalist, Abraham Trembley, around the middle of the eighteenth century (1744). He did just that and gave us our first experiments on **regeneration** in animals. Trembley was em-

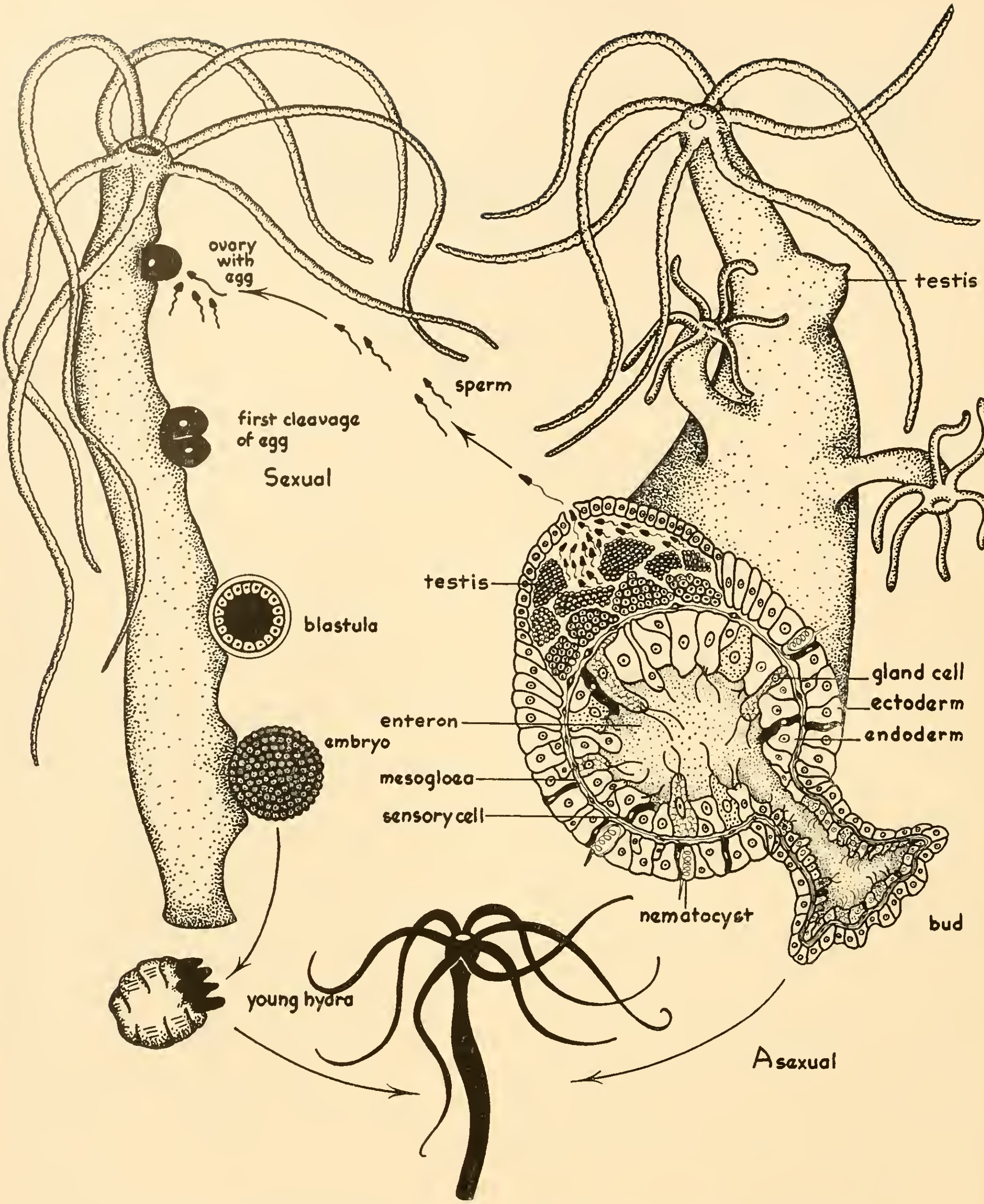


Fig. 8-10. Life cycle of hydra. One hydra is cut transversely through a bud and testis.

ployed as a tutor for a distinguished French family where one of his duties was to teach natural history to the young men of the family. He entertained these boys by cutting hydras, as well as other coelenterates, into small pieces and watching them regenerate into adult forms (Fig. 8-9).

By splitting the hypostome region Trembley was able to obtain a double-headed animal. He also found that by passing a needle with a knotted thread through the mouth and the basal disc, he could completely invert the two layers; in other words, he turned the hydra inside out. Then, instead of inverting back to its original condition, the animal simply moved its epidermal cells in between the endodermal cells so that both layers of cells found their original location. Since Trembley's time, a great deal of work has been done on regeneration, not only of hydra but also of many other animals. In general, if pieces of hydras are grafted together in various positions, the parts retain the characteristics which they originally possessed. It has been shown, for example, if the mouth region of one animal is grafted to the basal disc of another, the development of tentacles is induced. In other words, an anterior end develops so that the resulting animal has two "heads" and no "foot."

An understanding of regeneration among these simple Metazoa has considerable significance. Experiments demonstrate that, as the animal scale is ascended from simple to complex, this ability to replace lost parts or regenerate whole bodies is gradually lost. Hydra can replace its entire body from a fragment. In animals slightly more complex than hydra this ability is confined to the replacement of a part. Finally in animals as complex as man all power of regenerating parts has been lost, and the only remnant of this endowment left is the ability to heal or close over a wound. The significance of this comes closer when it is realized that this is the basis of all plastic surgery, which is playing a more and more significant rôle in the lives of people where exposure to serious injury is so common.

Fig. 8-11. A hydra with many testes. The fourth testis from the anterior end is nearly mature. Note the nipple-like tip from which the sperm will be discharged. This is a stained specimen.

Hydra also reproduces sexually by the production of eggs and sperms (Fig. 8-10). Usually both ovaries and testes are formed

Fig. 8-12. Only the posterior portion is shown of this hydra bearing several ovaries. Several eggs have already matured and have dropped off leaving only the "cups" where they were attached. A newly formed ovary, evident at the anterior end, is in the process of producing an egg. This is a stained specimen.

on the same animal, although as a rule not at the same time. In formation of the sperm, interstitial cells lying in the ectoderm undergo a series of divisions, forming a protuberance which gradually grows large as the sperms mature. A sexually mature hydra may have several "ripe" testes along its walls which resemble miniature mammary glands, "nipples" and all (Fig. 8-11). An opening appears in the "nipple" end of the gland and the mature sperm cells swim out into the surrounding water in search of a mature egg found on another individual. The sperms live and remain active for a day or two.

The eggs develop from interstitial cells also, the difference being that only one egg is formed in an ovary, whereas thousands of sperm cells are produced in a single testis. Several eggs usually form at the same time on one hydra, giving it an unusual appearance (Fig. 8-12). The eggs at first resemble large amoeboid bodies. As they mature they become spherical in shape, resting on the outer wall of the hydra attached to a cup-like depression in the epidermis.

After fertilization, cleavage is immediate and continues until a hollow **blastula** forms. An outer resistant shell then develops and simultaneously the cavity (**blastocoel**) is filled with cells from the lining. The young embryo then drops off and lies quietly until favorable conditions eventually arise, when it emerges as a very small hydra with blunt tentacles. Sexual reproduction usually occurs in the fall of the year and seems to be a safeguard for passing the winter months because the young embryo resides in a capsule which resists adverse temperatures. Temperature is apparently the controlling factor because sexual organs can be induced in hydra at any time by reducing the temperature.

Hydra possesses no medusa stage and hence does not exhibit metagenesis, which is common among most Hydrozoa. The next representative is a more typical example of this class and is discussed primarily for that reason.

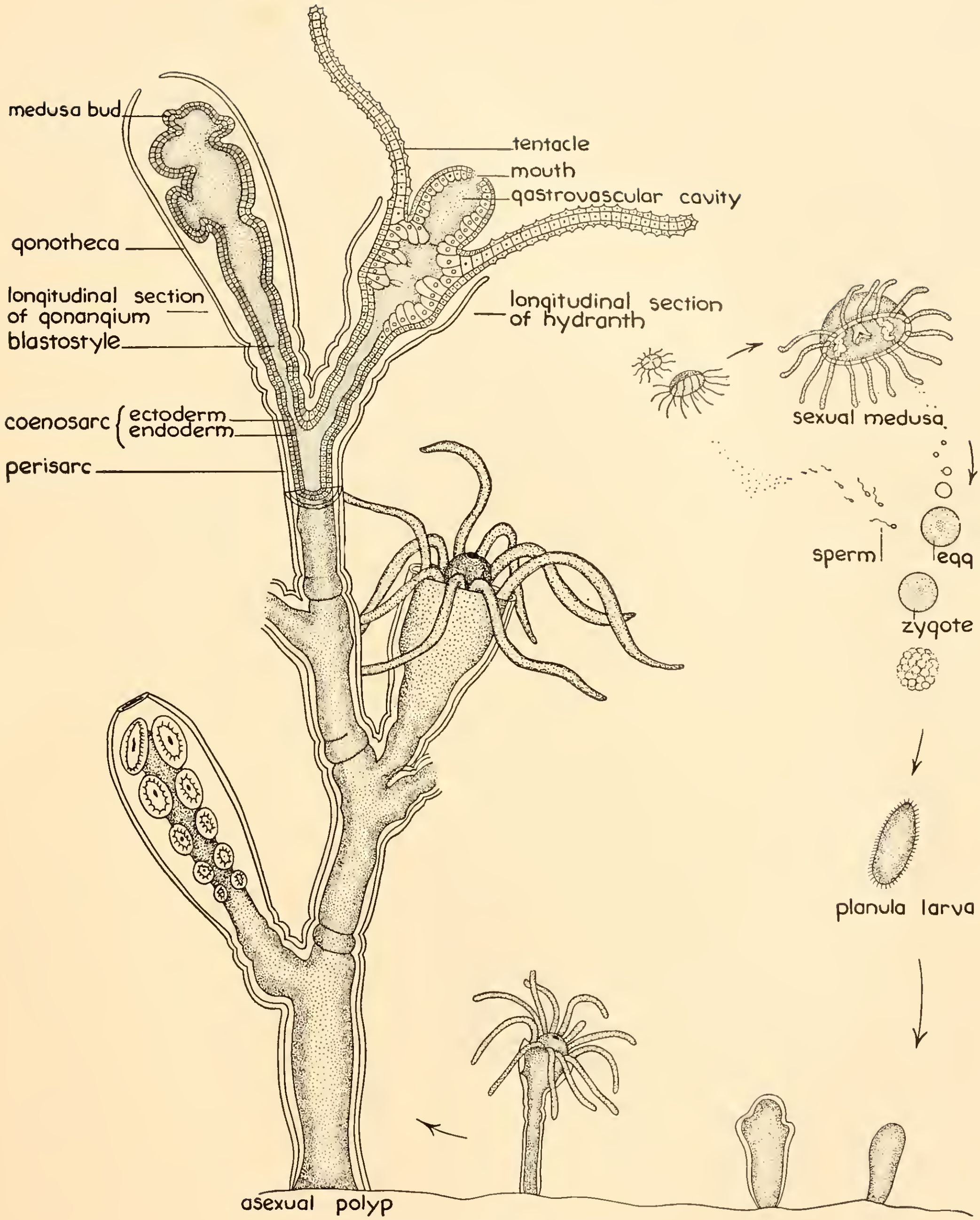


Fig. 8-13. Life cycle of *Obelia.*

Obelia

This tiny colonial coelenterate may be found attached to seaweed and other objects lying in the clear water of tide pools and below low tide level to a depth of several fathoms. It is attached to the substratum by means of a horizontal branching basal portion.

An obelia colony begins as a **single polyp** which by budding and the subsequent clinging together of the buds forms a colony (Fig. 8-13). The process is reminiscent of the bud-upon-a-bud condition observed in hydra. The tissues and gastrovascular cavity are thus continuous throughout the colony. There are two types of polyps in an obelia colony, the feeding polyp, or **hydranth**, and the less common reproductive polyp, or **gonangium.** The hydranth is not greatly different from hydra except that it possesses solid instead of hollow tentacles and it is surrounded by a tough, horny outer covering called the **perisarc,** which invests the entire colony. The transparent vase-like portion of the perisarc surrounding a hydranth is called the **hydrotheca.** The cellular portion just beneath the perisarc is known as the **coenosarc.** After food has been captured and partly digested by an individual hydranth, it is carried through the gastrovascular cavity by the beating flagella which line the cavity. Thus all polyps share in the good fortune of any one. Digestion is finally completed intracellularly in the lining cells.

Obelia reproduces asexually by forming buds either on the horizontal parent stalk or on the upright stalk. Sexual reproduction occurs in a second type of individual, the **gonangia** (singular, *gonangium*), which have no tentacles and no mouth. This cylindrical polyp is covered by the transparent **gonotheca,** a continuation of the perisarc. Each gonangium contains a central stalk, the **blastostyle,** upon which are borne small

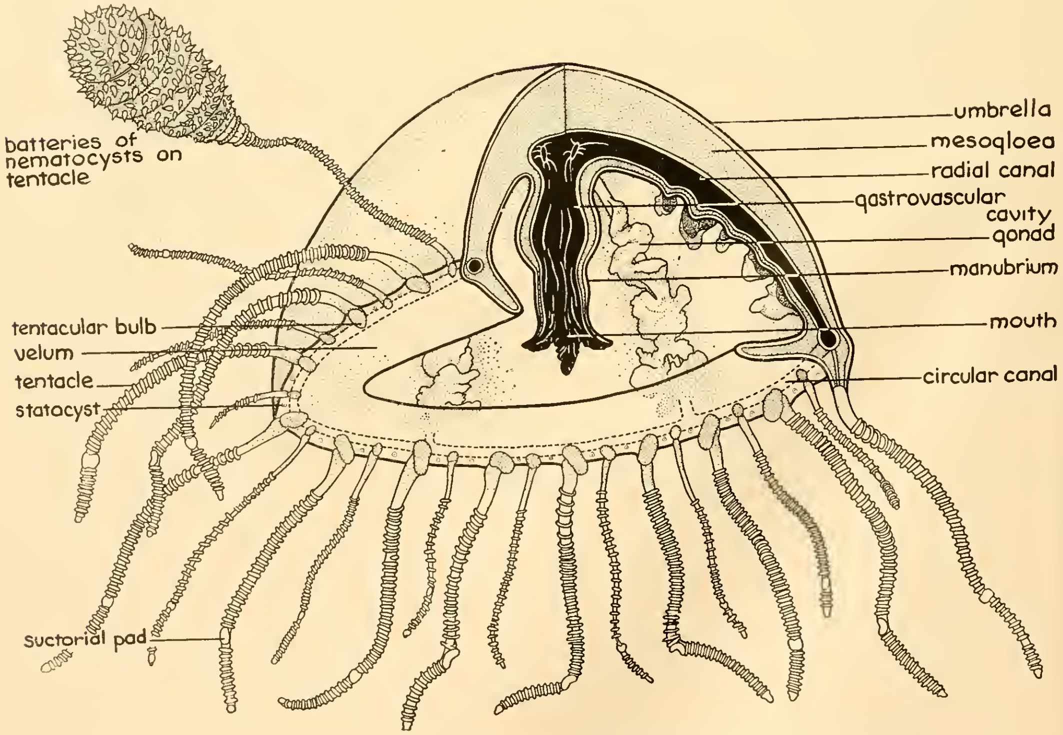


Fig. 8-14. Gonionemus sectioned to show internal structure. Also the tip of one tentacle is enlarged.

medusa buds. As the buds mature they approach the distal end of the blastostyle, finally leaving the gonotheca through a terminal opening and swimming away. These free-living medusae are the familiar jellyfish, which, since they are able to move about, spread the species to new areas.

Medusae develop gonads which produce eggs and sperms that unite in the sea water. The resulting embryo, the **planula**, swims about for a time but eventually settles to the bottom, becomes attached to the substratum, and grows into an asexual colony, the polyp thus completing the cycle. This species is an excellent illustration of **metagenesis.**

The medusa of obelia appears to be quite different from the polyp, but basically they resemble each other closely. The former has a central hanging **manubrium**, located on the concave side. At the center of the manubrium is the mouth, which opens into four **radial canals**, continuing into the circular **ring canal** in the margin of the bell. This constitutes the coelenteron and is equivalent to the same organ in hydra or the polyp of obelia. The space between the epidermis and the coelenteron is filled with the rather extensive gelatinous mesogloea. The medusa of obelia is microscopic and these structures can best be seen in larger jellyfish such as *Gonionemus*, which is commonly used for laboratory studies (Fig. 8-14).

Obelia illustrates the beginning of division of labor among the polyps, but this is carried to a greater degree of efficiency among some of the other Hydrozoa. For example, in *Hydractinia* (Fig. 8-22), a colonial form that is often found on the shells of hermit crabs, some of the polyps gather food, others reproduce the species, and still others protect the colony by use of large batteries of nematocysts. This is one step higher than obelia. **Polymorphism** (many shapes), the name applied to this type of division of labor, is carried even farther in *Physalia*, the **Portuguese man-of-war** (Fig. 8-15), which comprises at least four types of individuals. In addition to the various types of individuals found in the Hydractinia colony, Physalia also has a type that forms a gas-filled float which supports the colony on the surface of the sea as it is borne here and there by the wind and currents in a never-ending search for food. The tentacles bear unusually large nematocysts which are occasionally a menace to bathers if they happen to become entangled in them. This can easily happen in some species of Physalia, since the tentacles trail as much as 50 feet beneath and behind the float. Physalia has little difficulty in paralyzing a fish several inches in length and eventually consuming it. The many types of individuals in this colony illustrate polymorphism in its most advanced form among the coelenterates.

Other coelenterates

The second class of coelenterates, the **Scyphozoa**, includes most of the larger jellyfishes (Fig. 8-16) which either have a reduced polyp stage or lack it altogether. *Aurelia* (Fig. 8-22), one of the most common examples, is found in great numbers up and down the coasts of the United States. Its rather flattened umbrella is fringed with small tentacles that are interrupted at eight equally spaced spots where a **sense organ** is located. The rhythmic contractions of the circular muscle in the bell are responsible for the graceful movement of this beautiful creature. Four long **oral lobes**, which are located on the short manubrium, are heavily armed with nematocysts and function like tentacles in capturing food and directing it into the mouth. The coelenteron is divided into four large **gastric pouches** from which radiate smaller **canals** that connect with the **ring canal** at the periphery of the **bell.** The gonads, lying in the gastric pouches, form four horseshoe-shaped bodies when viewed from the aboral (opposite the mouth) side, and constitute a ready mark of identification.

The sense organs, consisting of **eye-spots**

Fig. 8-15. Portuguese man-of-war (*Physalia*) stinging a fish. Note the large gas bag which functions as a float and sail combined. The numerous tentacles perform all of the functions of the animal. Some are heavily armed with nematocysts which are effective weapons against other animals, as this photograph shows. Note dead fish.

Fig. 8-16. A giant jellyfish (*Cyanea capillata*) common on our eastern seaboard. The dome is flattened during relaxation; during its power stroke it becomes more oval in shape.

(sensitive to light) and **statocysts** (sensitive to gravity), are located at the edge of the bell where the nerve net is somewhat centralized. The statocysts are hollow spheres containing small calcareous granules which, as they tumble about in the cyst, stimulate nerve endings and indicate to the animal its relation to the rest of the world. In other words, it functions as an organ of equilibrium, much the same as the semicircular canals in our ears. This is the first appearance of such an organ in the animal kingdom.

Sometimes, following a strong in-shore breeze, thousands of large jellyfish are swept up on the beaches to perish. Although they are thought to be very jelly-like, they do maintain their shape out of water and seem almost semi-solid. They also retain some of their delicate beauty. When they are swimming in the open sea, they provide a sight that, once seen, is not easily forgotten.

Representatives of the next class, **Anthozoa,** are characterized by a heavy body, supported by numerous **septa,** transverse sheets of tough tissue. Members of this group possess no medusa stage, eggs and sperms being produced within the body and discharged into the surrounding sea. The most common representatives are the **sea anemones** and **corals;** others less common are the **horny, black,** and **soft corals,** the **sea pens,** and **sea pansies.** They compare favorably with the jellyfish in respect to beauty and numbers. Both the Atlantic

Fig. 8-17. A common Pacific Coast sea anemone (*Cribrina*). These feed on small fish which they capture with the aid of their powerful nematocysts.

Fig. 8-18. A common sea anemone (*Metridium*) with many tiny tentacles which it uses to catch minute organisms instead of large animals as is common for most sea anemones.

Fig. 8-19. A giant sea anemone (*Condylactis gigantea*) found near Bermuda. The tentacles are highly colored.

and Pacific Coasts, extending from Alaska and Maine to Southern California and Florida, abound with anthozoans (Figs. 8-17, 18, 19, 20). Some are found in the polar regions, some at great depths, but they are most numerous in shallow waters in the warmer seas.

The sea anemone usually remains in one place for a long period of time; some have been observed to live for years in a small depression in rock just below low tide level. It can move slowly on its pedal disc and some of the smaller ones are able to swim by beating their tentacles. It feeds on any unsuspecting crustacean, mollusk, or even fish that comes within reach of its tentacles. Once the prey is paralyzed by the nematocysts it is taken into the coelenteron, and digestion goes on much the same as in other coelenterates. The sea anemone, in spite of its tough outer covering, is preyed upon by a variety of animals such as fish, starfish, and crustacea. When in danger it can retract its tentacles, fold them inside the body, and contract its entire body until it is nearly flat against the substratum. In this condition it is very difficult to remove, in fact, the body is often torn apart before its grasp is released. Although it usually reproduces sexually, occasionally an anemone is found undergoing fission, either longitudinally or transversely.

Other interesting anthozoans, resembling the sea anemones in many respects, are the corals (Fig. 8-20). These are usually very small and live in stony cups, of specific design, made by the limy secretions from the base. The colonies lie in close proximity and after thousands of generations, produce the massive corals, bits of which are frequently seen reposing as mantelpiece ornaments in many homes. Corals live in warm waters for the most part, although there is one species, *Astrangia*, living as far north as Maine. They abound in many tropical seas of the world, particularly in the Coral

Fig. 8-20. A typical coral reef with the abounding life associated with it. The fish are strikingly colored to match the background of corals, sponges, and other marine life. The tentacles of a large sea anemone can be seen in the lower left. The corals are numerous and highly varied in size, shape, and color.

Sea. Our overseas forces in the past war became familiar with the corals around the Philippines and Australia.

Perhaps the most interesting thing about coral is its ability to form reefs, some of which reach many miles in length, like the Great Barrier Reef of Australia, for example, which extends over 1,100 miles in length. There are three kinds of coral reefs, depending on how they were formed (Fig. 8-21). The **fringing reef** lies along the shoreline of an island or mainland and usually extends up to a quarter of a mile out into the sea. Boats approaching such shores are in great danger, particularly in rough weather. Sometimes, as the result of a shifting shoreline, a lagoon appears between the main reef and the shore; this type is called a **barrier reef.** The **atoll** is perhaps the most unique of the three kinds of reefs. It is a rim of coral taking on varying shapes, usually a completely enclosed circle. These have always fascinated biologists. One of the greatest among them was Charles Darwin who gave an explanation of how they formed, a theory which is still considered

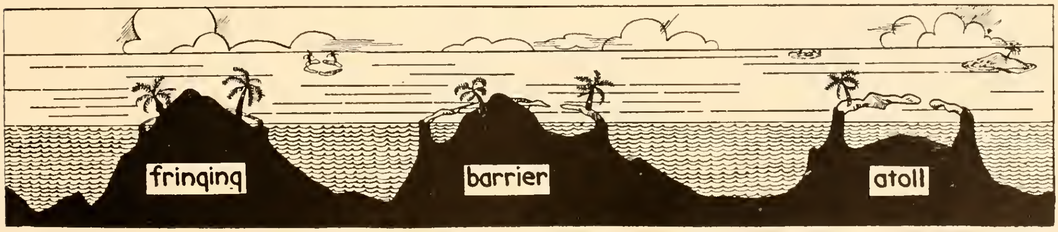


Fig. 8-21. Various types of coral reefs.

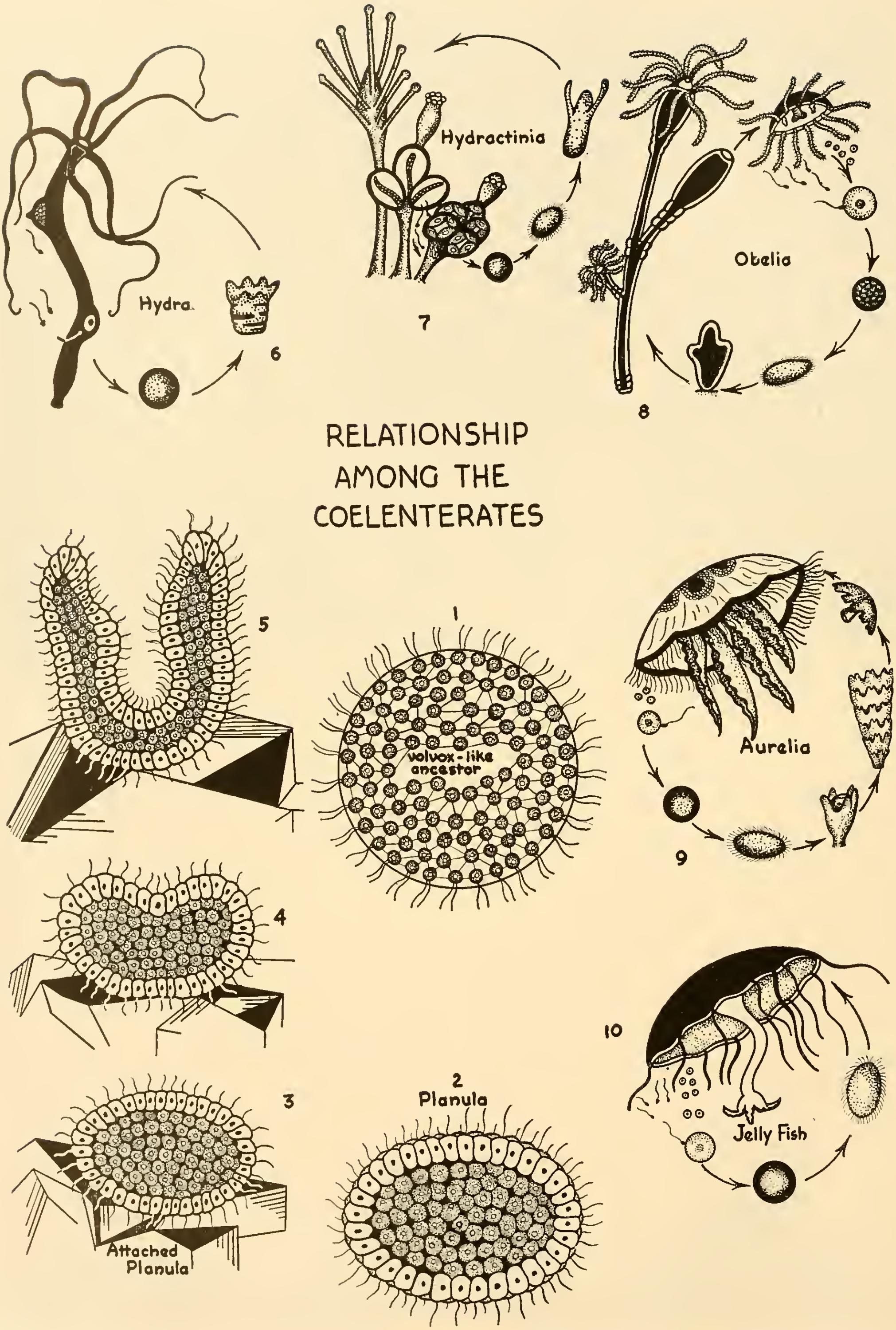


Fig. 8-22. A hypothetical representation of how the various relationships among the coelenterates might have come about.

fundamentally sound. He thought the peculiar formations started out as a fringing reef around an island, but due to shifts in the earth's surface the island gradually began to sink. The rate at which it submerged was about as fast as the corals were able to secrete lime and keep themselves in the tidal zone. By keeping pace with the sinking island, the corals built the fringing reefs sufficiently high to catch vegetation and support growth of plants while the central portion gradually became submerged below the water's surface. This then produced a rim of coral, inscribing the outline of the old island and producing the strangely-shaped atolls seen in tropical seas today.

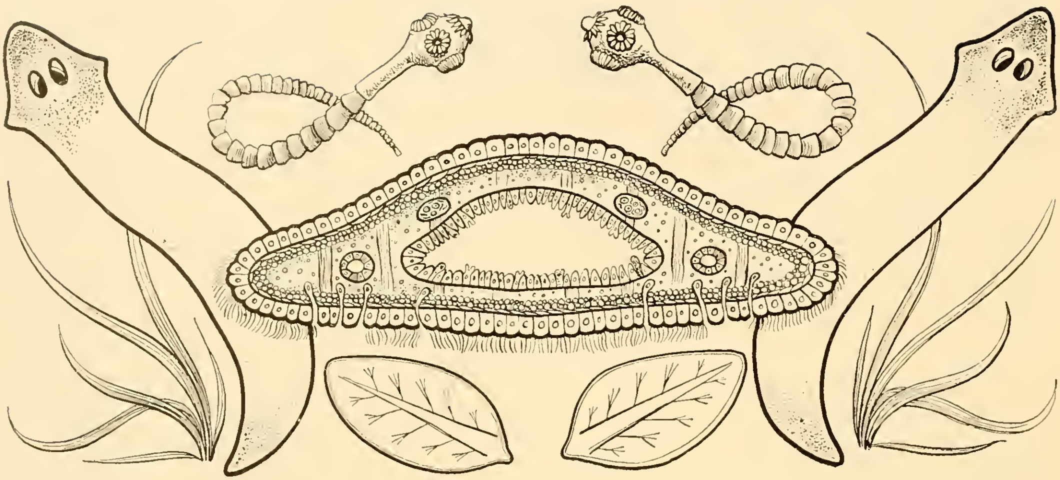
RELATIONSHIP AMONG COELENTERATES

A possible explanation for the many different life cycles among the coelenterates might be that the original primitive coelenterate was much like the **planula larva**, which is found rather consistently in all of the groups, with the notable exception of hydra. The planula is a ball of cells that might be compared to *Volvox* except that the former is solid and the latter is hollow. It would not be difficult to understand how the early planula-like coelenterate might become temporarily attached to the bottom of the ocean and invaginate, to form the hydra-like polyp (Fig. 8-22: 1 to 5). The formation of the sex organs would be similar to those found in hydra (Fig. 8-22: 6), and the life history would also be the same, except that the zygote would develop into a planula which would eventually settle down and grow into the polyp.

From the hydra-like type could be produced a form resembling *Hydractinia* (Fig. 8-22: 7), where the sex organs develop into separate bodies, although they are not detached from the polyp. The next logical step would be an obelia-like form in which the medusae detach themselves from the polyp and become the free-swimming sexual stage of the animal (Fig. 8-22: 8). This affords an opportunity for the species to spread both by means of the planula and the medusa stages. The next variation might be a continued emphasis of the medusa and a de-emphasis of the polyp stage, as is seen in *Aurelia* (Fig. 8-22: 9). This can be carried still further until the polyp stage disappears altogether, which is the case with many of the large jellyfish (Fig. 8-22: 10). This is merely a possible explanation for the great variety of forms found in this phylum of animals.

In review we have found the coelenterates a widely diverse group of animals that have explored many possibilities of form, structure, and habitat, remaining all the while within the limitations of two body layers, ectoderm and endoderm. Animals could have gone no further in complexity had they remained within the limitations imposed by these two body layers. The next group surmounted this difficulty by the introduction of a third body layer which resulted in a modification in the entire body plan of the group. Let us see how this was accomplished.

CHAPTER 9



THE THREE-LAYERED ANIMALS

Quite different from the symmetrical beauty of hydra, the jellyfishes, and the sea anemones, are the drab representatives of the next group of animals, the **flatworms.** Their flattened and elongated bodies account for the name of the phylum to which they belong, **Platyhelminthes** (from the Greek, *platy*—flat). Just as the two-layered animals showed distinct advantages over the unicellular animals, so the flatworms demonstrate a higher form of life than was observed among the coelenterates.

The most important single morphological structure acquired by this group is a third body layer, the **mesoderm.** It is only with the advent of this additional layer that animals were able to reach higher levels of complexity. Most of the intricate and massive structures of not only platyhelminthes but all higher animals have been derived from this layer. We see a forerunner of the mesoderm in the mesogloea found in the coelenterates, although in this group it never became a distinct layer. Once the mesoderm was established in the flatworms it was retained by all subsequent groups of animals.

As a result of the introduction of a third body layer other modifications were possible. One of the most obvious of these was a change from radial to bilateral symmetry. This meant the acquisition of head and tail ends, dorsal and ventral sides, and left and right sides. Localization of the sensory system in the head region was initiated in these forms, signifying a definite step toward centralization of the nervous system. Moreover, the animal now moved in one direction to seek food rather than acquiring its meal in a passive manner as was true of the coelenterates. All of these changes resulted in a much more complex animal, one that was well on its way toward higher forms.

Of the three classes of the phylum Platyhelminthes only the class **Turbellaria** includes free-living animals. Members of this group may be found among the rocks in cool streams or ponds, or upon the shady side of submerged plants. Turbellarians are carnivorous, feeding on small animals, either living or dead. There are also marine forms in this group which sometimes live in the intestines of sea urchins and other forms of ocean life.

The other two classes of the phylum are the **Trematoda,** or flukes, and the **Cestoidea,** or tapeworms. All members of these two classes are parasitic and will be described further in a later section, but first let us examine the free-living turbellarians.

PLANARIA

The study of **tripoblastic,** or three-layered, animals may well begin with planaria, a common inhabitant of North American streams. It seeks shelter in darkened, secluded spots and comes out at night to move around in the cool waters in search of food. Planaria is flattened dorsal-ventrally and is darkly pigmented. It is covered with **cilia,** which enable it to glide along the substratum over a mucous path (Fig. 9-1) secreted by glands on the ventral surface of the body. By use of a muscle layer developed in the **mesoderm,** planaria can crawl in true worm-like fashion. Certain muscle groups produce a twisting motion so that it sometimes appears to raise its head and look about. Although it may appear that planaria can see when this occurs, actually its two large **eye-spots** form no image and are only sensitive to varying intensities of light.

Unlike most heads, that of planaria has no mouth, for the mouth is located on the ventral side of the body near the middle. It opens into a muscular **pharynx,** which lies in a sheath extending anteriorly, and

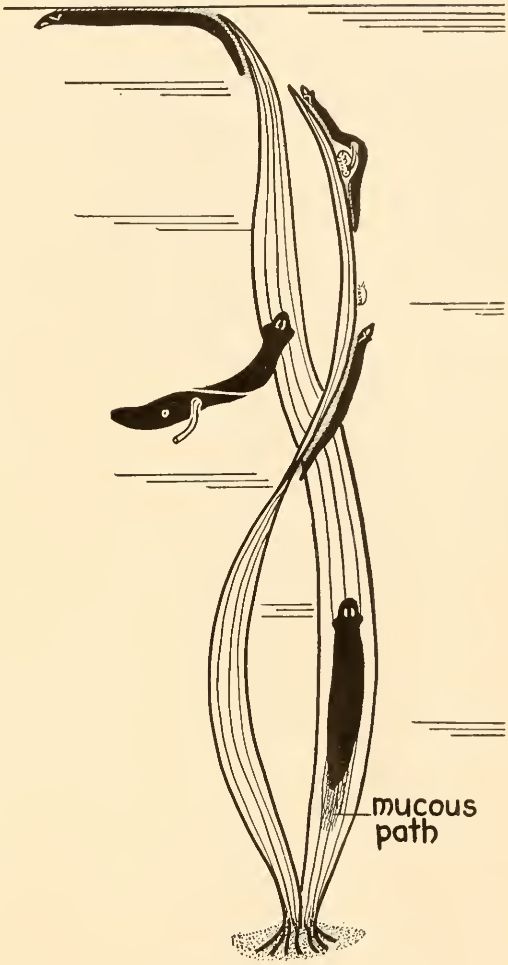


Fig. 9-1. Planaria crawling and feeding.

when planaria is hungry and in search of food, it often protrudes its pharynx and moves about with it thus extended. When a small piece of meat is tossed into the water, hungry planarians attach themselves to it. A digestive fluid pours out from the pharynx to aid in the disintegration of the meat. The partially digested food is then taken into the digestive tract where digestion is completed. Planaria's chief food consists of small crustacea. In this case the epidermal slime glands secrete a sticky substance which is sprayed over the victim, rendering it helpless. It is usual for planaria to grip its prey with the head region first and then attach its muscular pharynx to the food, bits

Fig. 9-2. Planaria stained so as to differentiate the digestive tract. Note its ramifications into every part of the animal. The protrusible pharynx is clearly shown in this photo.

of which are drawn into the mouth by a sucking action.

The digestive system of planaria is saclike, similar to hydra, with but a single opening for the entrance of food and the exit of waste materials (Fig. 9-2). In some of the platyhelminthes, particularly the parasitic members, the sac is merely a straight and unbranched tube, but in planaria it branches into three distinct parts to form a **tri-clad intestine.** Each part, in turn, ramifies into many smaller branches which supply food directly to the various regions of the body (Fig. 9-3). Large thin-walled, unciliated cells line the gut and secrete digestive juices which carry on extracellular digestion. In addition, the cells lining the intestine are able to ingest solid food by means of pseudopods and digest it intracellularly, as in the case of hydra.

Between the ectoderm and the endoderm is a mass of large star-shaped mesodermal cells, the **parenchyma.** It is possible for food substances to pass not only from the gut into the lining cells, but also from the parenchyma into the lining cells. Thus, when planaria cannot find food, it may consume certain organs in the parenchyma by passing them into the intestinal cells where they are digested. This enables planaria to go without food for quite a long time, through gradual reduction in size. In one species of planaria it was found that during starvation the absorption and digestion of its internal organs occurred in regular order. First the reproductive organs disappeared, leaving the animal reduced to sexual immaturity; next the parenchyma, the gut, and the muscles were consumed in that order. The nervous system remained essentially intact so that the animal appeared as a weird form with the bulk of its remaining body in the head region. On feeding these starved forms, all the lost parts regenerated to normal size.

Special excretory organs appear for the first time in a metazoan among the flatworms. In planaria this system consists of a pair of branching tubes running down each side of the body. The main tubes or canals divide into small branches, each of which finally ends blindly in a single **flame**

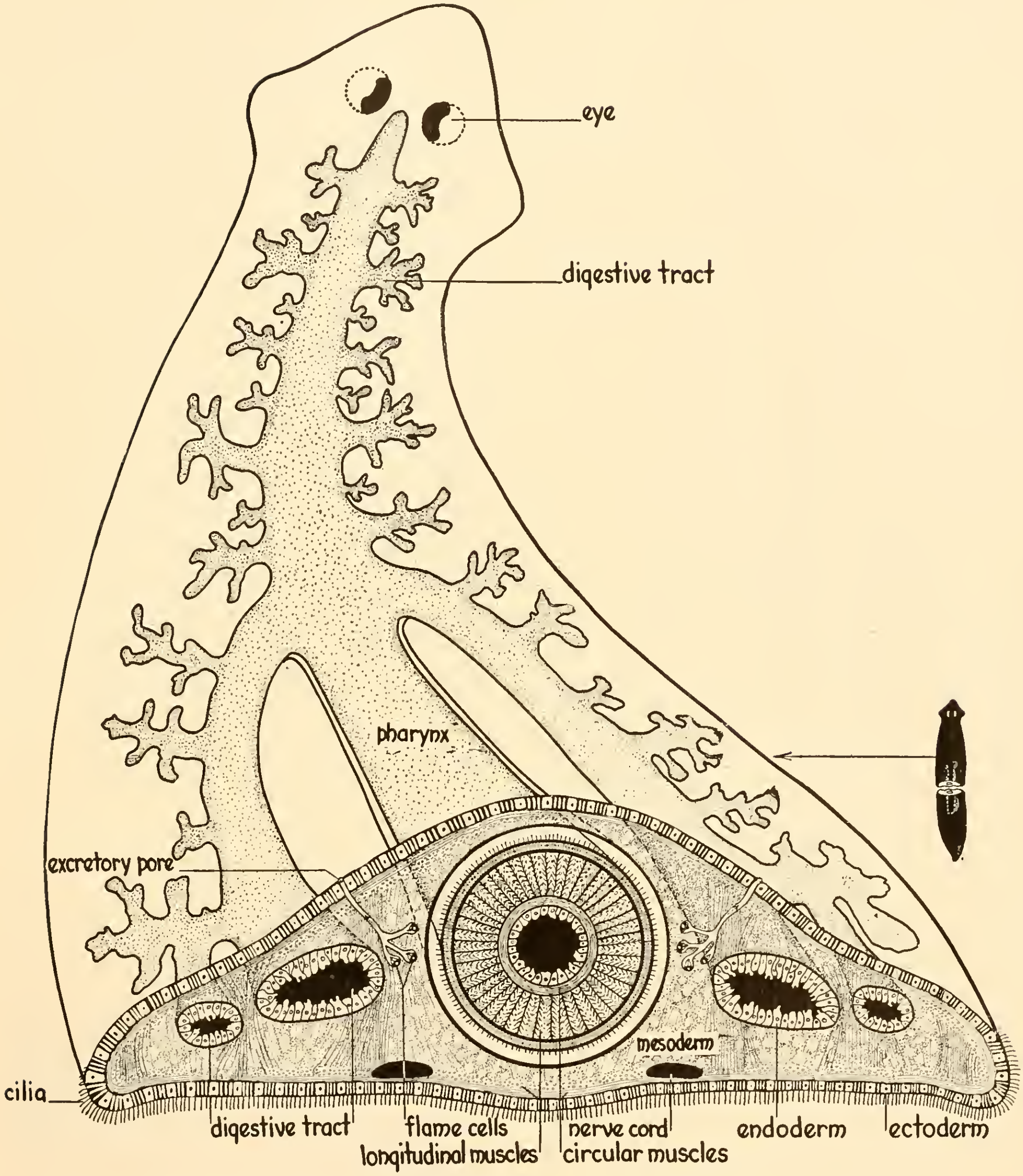


Fig. 9-3. A dorsal and sectioned view of planaria to demonstrate the systems, particularly the digestive.

cell (Fig. 9-4). These cells have long cilia which extend into the lumen of the canal and it is their flickering motion that suggests the name. The movement of the beating cilia carries nitrogenous wastes into the lumen of the tube and to the exterior through a number of **excretory pores.** Probably this system's chief function is in regulating the water balance, because most of the nitrogenous wastes are lost through the endodermal cells. Because the tubes of this system are a primitive type of **nephridium** (kidney), they are called **protonephridia.**

The **nervous system** of the planarian is simple (Fig. 9-4), yet it is strikingly more advanced than the primitive nerve net

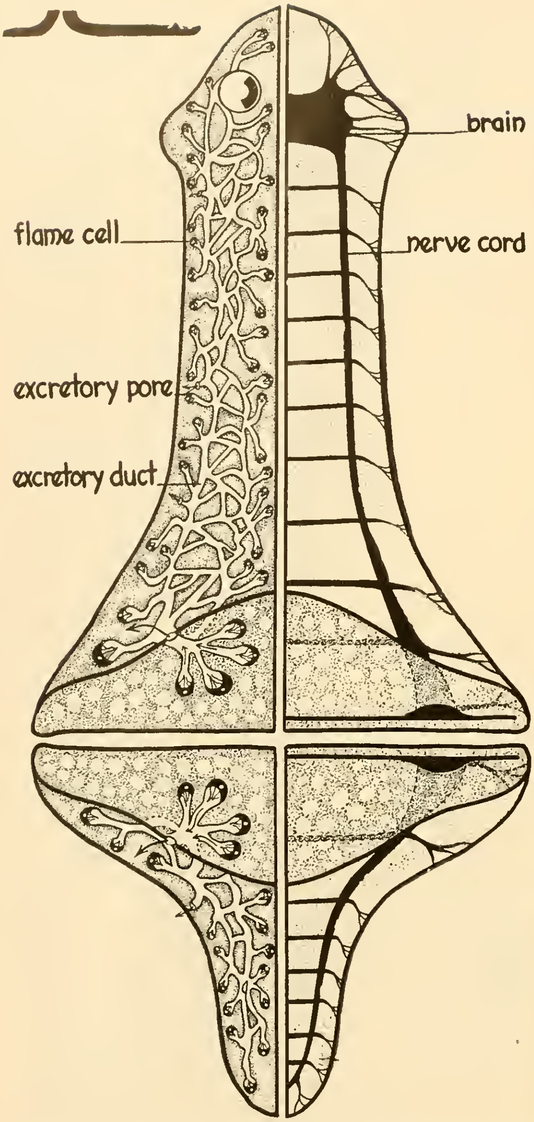


Fig. 9-4. Planaria in dorsal view and cross-section, showing the excretory system on the left and the nervous system on the right. Upper left indicates side view of how cut was made.

of the coelenterates. Perhaps most unique is the concentration of the nervous tissue in the head region below the eyes. The nerve cell bodies are contained in two masses of nervous tissue, the **cerebral ganglion**, commonly referred to as the **brain**. From this concentrated point two longitudinal **nerve cords** pass posteriorly and two short nerves extend anteriorly to connect with the eyes. Along the two longitudinal cords are many transverse nerves, which are distributed to the internal structures of the body.

The eyes of planaria are found on the dorsal surface where they appear as two dark spots (Fig. 9-5). There is no lens, as such, although the ectoderm over the eye is without pigment so that light can pass through to reach the **sensory** cells below, which connect with the brain. Without a lens no image is possible, but the eye is sensitive to varying intensities of light and the animal withdraws from bright light and seeks out moderate illumination. Other sensory cells protrude from the surface of the body and act as receptors for registering changes in the flow of the water or other variations in the surroundings.

Although it is evident that the nervous system of the Turbellaria is still very simple, the increase of special sensory cells, their grouping into such an organ as the simple eye-spot, and the aggregation of nerve cells into the cerebral ganglion, are the beginnings of a definite central nervous system.

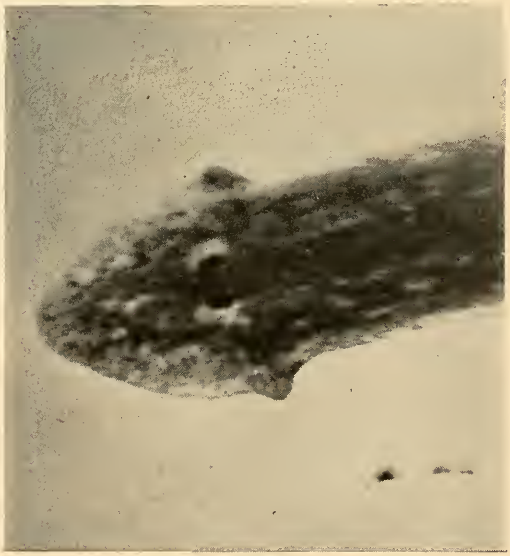


Fig. 9-5. Head of planaria (*Euplanaria* or *Dugesia*) highly magnified. Note the "crossed" eyes and the two ear-like extensions of the head region in which tactile sense organs are located.

Of the various systems, the planarian reproductive system shows the greatest advancement over that of the coelenterates (Fig. 9-6). In the sexually mature worm, male and female reproductive systems are present in each individual, a condition known as monoecious (hermaphroditic). Both **ovaries** and **testes** develop from the cells of the parenchyma. The numerous testes are rounded bodies which lie along both sides of the body. They give rise to the **spermatozoa**, or **sperm cells**, which are conveyed through small ducts, the **vasa efferentia**, to a larger tube, the **vas deferens**, or sperm duct, running the length of the body on each side. The two seminal vesicles terminate in a pear-shaped **copulatory organ** or **penis**. At rest the copulatory organ opens into the **genital atrium**, which leads into the **genital pore**, the external opening through which the penis is thrust during **copulation**.

The two **ovaries** of the female reproductive system are found near the anterior end of the body; these produce the **ova**. The **yolk glands**, which give rise to the yolk and shell of the egg, are found along the **oviducts**. The two oviducts lie parallel to the nerve cords and join before entering the atrium. The **seminal receptacle**, a sac for storing sperm, also opens into the atrium, very near the external opening. The genital atrium, therefore, receives the openings of both the female and the male organs.

At the start of copulation the ventral surfaces of the two animals come together, so that the openings of the genital atria are opposite one another. The penis of each is extended into the genital opening of the other and the sperm cells are exchanged. At the time of copulation the ova are also ripe. To prevent self-fertilization, the genital area has been elaborated. The penis, when extruded and dilated, completely fills the atrium and thus blocks the openings into the oviducts, so that neither can the ova escape nor sperm cells enter the oviduct, but sperm can be deposited into the

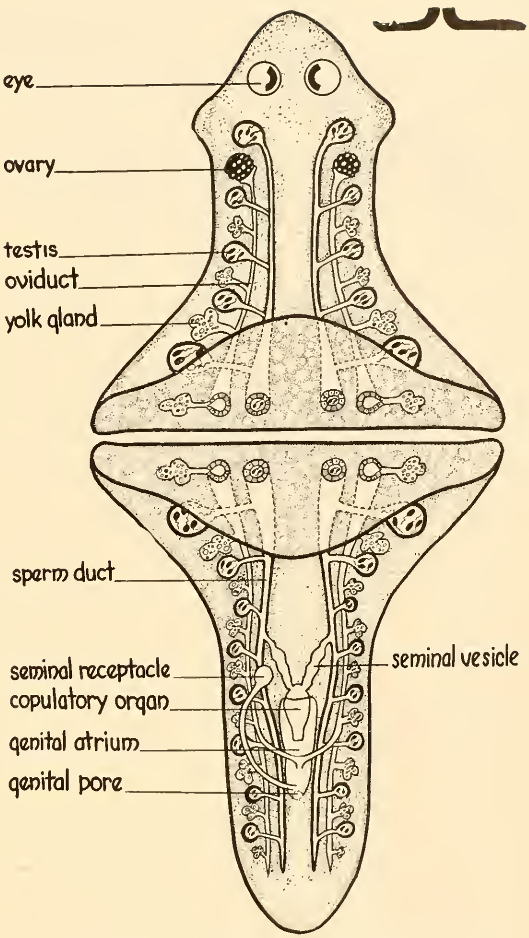


Fig. 9-6. Planaria in dorsal view and cross-section showing the reproductive system. Upper right indicates side view of how cut was made.

seminal receptacles. At the completion of copulation the penes are withdrawn and the sperm cells then are able to enter the oviduct. The ova are fertilized in the oviduct and, as they move down toward the atrium, the products of the yolk glands are discharged. The mature fertilized egg is released from the atrium through the genital pore, and the capsule-like shell becomes attached by a stalk to submerged objects. The egg cases may undergo a rest period before growing into young planaria.

Planaria also reproduces asexually by means of transverse fission. Indeed, this is much the more common method of repro-

Fig. 9-7. Regeneration in planaria.

duction. The worm constricts itself in two and the parts which are missing after the fission has taken place are then regenerated. Planaria is an excellent animal for regeneration experiments. For example, if the head of planaria is split and if the parts are kept separated for a short period of time, a double-headed monster is formed (Fig. 9-7). Should the animal be cut transversely into two separate pieces, two little planaria will result. An animal can be cut into as many as six pieces and each will give rise to a miniature worm one-sixth the size of the original. The significance of regeneration was pointed out in an earlier section.

OTHER TURBELLARIA

Although members of the class Turbellaria are, for the most part, free-living, some live on the exterior of other animals and others are true parasites living in the intestines of mollusks and various echinoderms, such as the sea cucumber. Economically, they are of little importance.

The small primitive marine forms of the order **Acoela**, have a mouth but no digestive system, the food being digested by the endodermal cells. *Convoluta*, an animal that lives on sandy ocean shores, is a good example of this order. As it matures, algae enter and inhabit its parenchymous tissue, giving it a green color. *Bdellura*, referred to earlier (p. 95), is also a member of this group.

Members of the order **Rhabdocoelida** are turbellarians with a straight tubular gut. In certain forms the gut has lateral pouches, but not as highly branched as that of planaria. These turbellarians are commonly found in fresh water, but because of their small size are not as easily studied as planaria. The largest of these forms is *Mesostoma*, which, like members of the order Tricladida, has its mouth on the ventral surface. The smaller rhabdocoeles have their mouths in the anterior region, ventral to the brain. Some of these animals have such remarkable powers of reproduction by fission that individuals form long chains which remain together for some time before separating. This was mentioned earlier as a possible explanation of the origin of segmentation.

Members of the order **Polycladida** are marine forms, usually small, although some attain a length of 6 inches. This order includes a few rare species found only in isolated places, such as the Gulf of Naples. The digestive system is well branched and the body is unusually flattened. In some of the simpler forms, the mouth is centrally located and the pharynx, which is funnel-like in structure, can be extended from the mouth to enclose food. One difference between this order and the others is that development is not direct, but must pass through a rounded, ciliated larval form which possesses projecting arms. As the animal grows, it loses the cilia and the arms, develops a crawling movement, and becomes considerably lengthened and flattened.

CLASS TREMATODA

The trematodes, commonly called **flukes**, are characteristically flat like all platyhelminthes, but their gut is reduced in complexity. Because of their parasitic life they

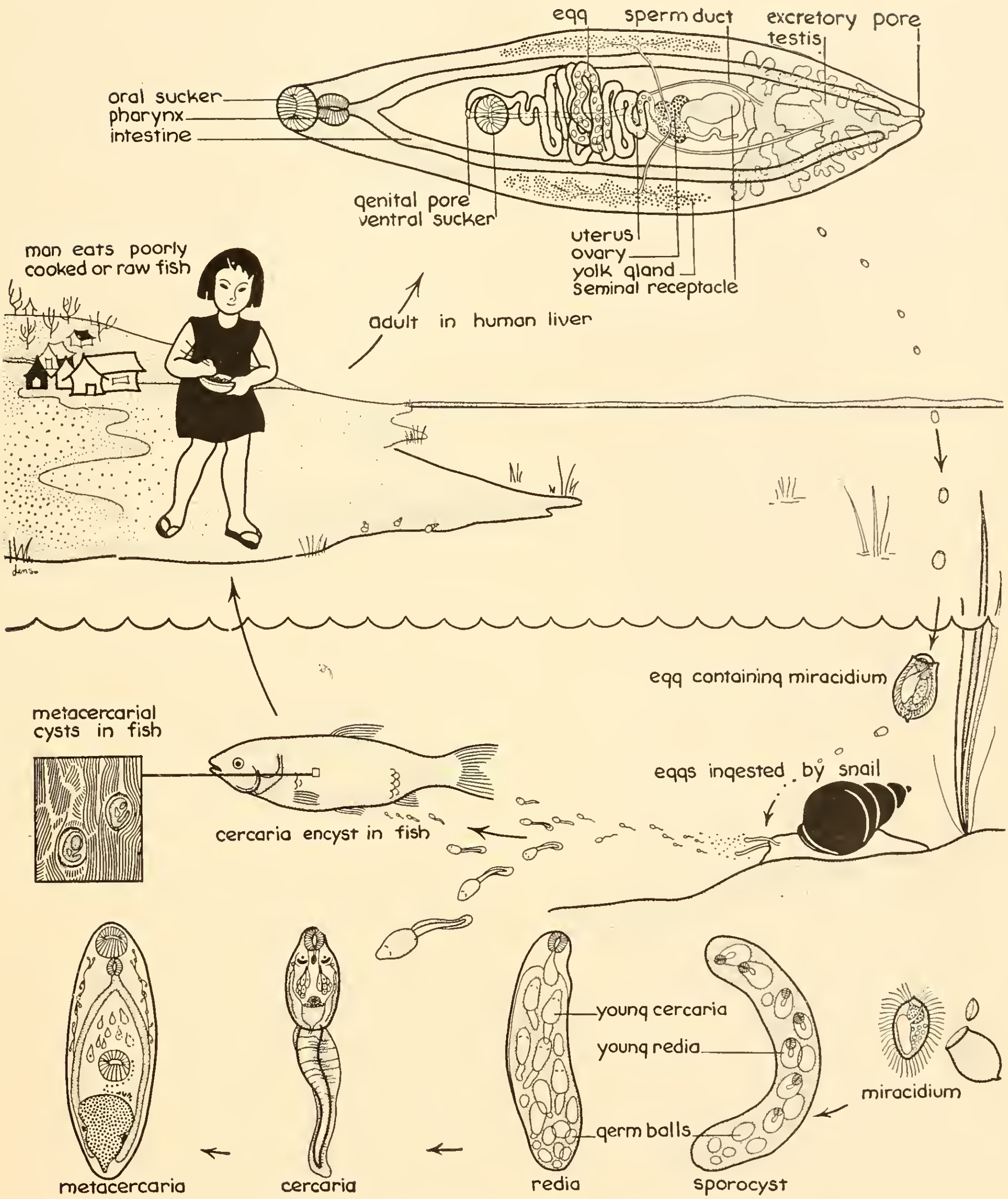


Fig. 9-8. Life cycle of *Opisthorchis sinensis*, the human liver fluke.

have lost their cilia and have developed hold-fast organs called **suckers.** They have no apparent sense organs, but the nervous and excretory systems are well developed. In general, the entire anatomy is adapted to a parasitic mode of life.

All grades of parasitism are found in this group, from those that live on the outside of their hosts to those that inhabit the internal cavities. The life history of parasites that cling to the outside of animals such as fast-moving fish is relatively simple, its main characteristic being the development of hold-fast organs or suckers. The case of the internal parasite is an entirely different one. There is no great problem of staying put,

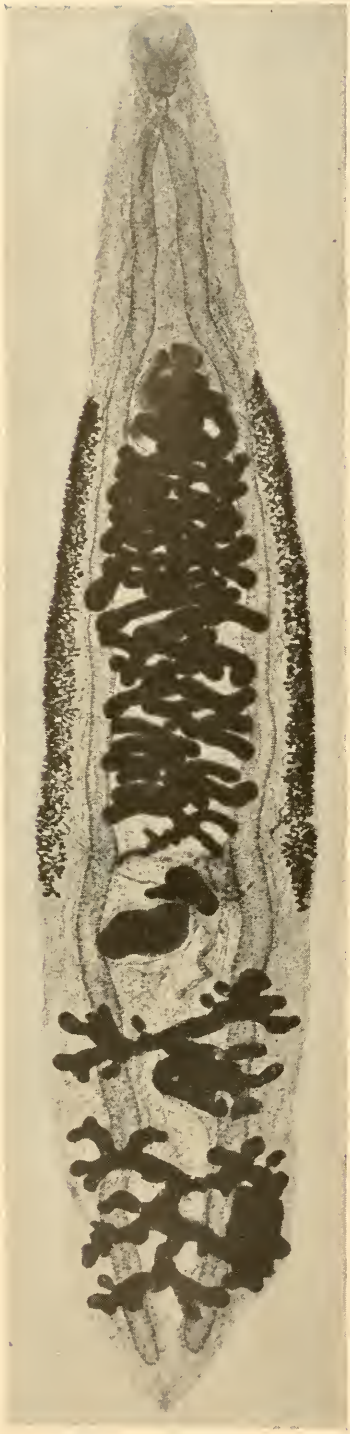


Fig. 9-9. A stained adult human liver fluke (*Opisthorchis sinensis*). Compare this photograph with the drawing in Fig. 9-8 in order to make out the parts.

hence the suckers are small, but in order to complete its life cycle an enormously prolific reproductive system has been developed. Not only is the production of large numbers of potential offspring necessary, but also various kinds of larval stages that are able to pass through several hosts, all of which are instrumental in spreading the parasite far and wide. Let us consider two examples of flukes that infect man, one that lives in the liver (*Opisthorchis sinensis*) and another that lives in the blood (*Schistosoma haematobium*).

The life cycle of the human liver fluke can serve as a typical example of most related flukes that are so prevalent in wild and domestic animals (Fig. 9-8). It involves two **intermediate hosts** which harbor the larval stages of the parasite, and, of course, one **final host** in which the adult lives. The human liver fluke infects 75-100 per cent of the people in certain parts of China, Japan, and Korea, constituting a real health problem in these regions. This situation should be alleviated with the advent of improved sanitation and a better educational program.

The adult fluke (Fig. 9-9) lives in the small bile ducts of the liver, where toxic products excreted by the flukes and the subsequent mechanical occlusions of the ducts may cause serious damage. For a heavily infested individual, this may eventually develop into cirrhosis, together with complicating infectious disease which usually terminates his life. The adult fluke is about three-fourths of an inch in length and has two suckers, one at the anterior end, another about one-third of the way from the posterior end. It feeds on blood which is drawn in through the anterior mouth.

Eggs laid by the adult pass through the bile duct into the gut and eventually pass out of the body in the feces. Because of the oriental habit of using human excrement (night soil) as fertilizer in the rice paddies, the eggs usually get into water. Unlike most

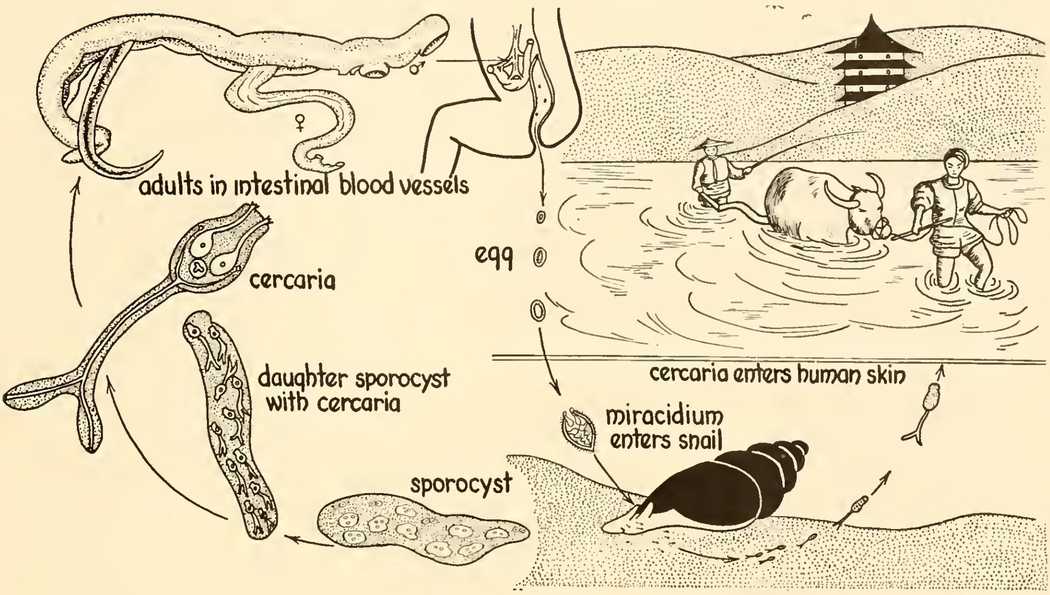


Fig. 9-10. Life history of a typical human blood fluke.

flukes, the egg does not hatch into the larval stage known as the **miracidium** until it is eaten by a certain species of snail of the genus *Bythinia.* Inside the snail the egg hatches, releasing the miracidium which makes its way into the tissues of the snail and develops into a **sporocyst.** The next stage, the **redia,** develops inside the sporocyst. Both the sporocyst and the redia stages make possible a tremendous increase in numbers by asexual reproduction. The redia finally develops **cercariae** within its walls, which make their way out of the snail into the surrounding water where they swim about by means of their large vibratile tails. The cercaria then becomes attached to the next host, one of several different fish and, after losing its tail, bores its way into the flesh of the fish. It rounds itself into a ball and produces a cyst wall; in response to the parasite, the fish secretes another wall around the invader. Here it lies until the raw fish is eaten by man in whose gut the cyst wall is digested away, releasing the young worm which makes its way up the bile duct and finally into the smaller tubes of the liver where it grows to maturity.

The control of the disease is obviously very simple, destroy the snails or cook the fish, either of which interrupts the cycle and kills the parasite.

Some of the most important flukes are the blood-inhabiting **schistosomes** such as *Schistosoma haematobium* (Fig. 9-10). Unlike *Opisthorchis,* these worms are **dioecious,** that is, there are two separate sexes. They are long slender worms, beautifully adapted for living in the small blood vessels. A strange relationship exists between the males and females; the male holds the extremely slender female in a groove on his ventral side, from which she ventures forth during the business of laying eggs. Her slender thread-like body is ideally adapted to fit in the tiny blood vessels of the intestinal wall or over the bladder where she lays her eggs. The eggs have a single sharp spine by which passively they work their way through the wall into the cavity of the intestine or bladder where they are voided with the urine or feces.

Again through the use of human excrement for fertilizer, the eggs usually find their way into water. They hatch into **mira-**

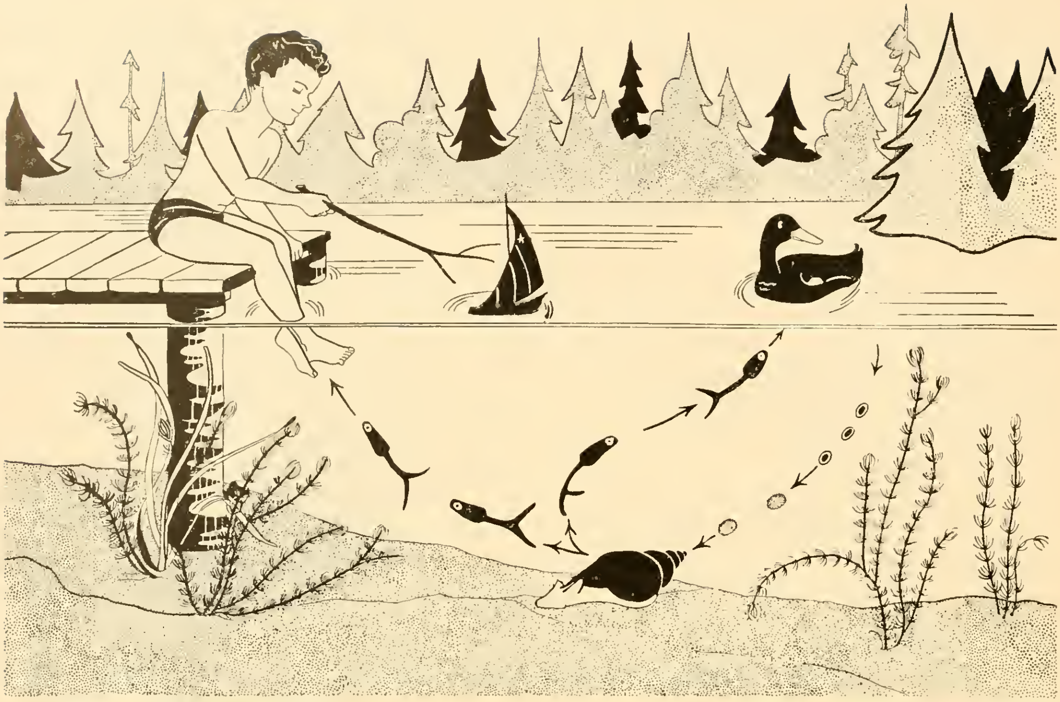


Fig. 9-11. A blood fluke normally infecting water birds occasionally enters human skin, causing "swimmer's itch" (schistosome dermitis).

cidia which penetrate the tissues of snails, and follow stages of development similar to those of *Opisthorchis* with minor variations. Instead of encysting on a fish, the cercaria burrows through the skin of a person who is unfortunate enough to be in the vicinity and makes its way into the vascular system. It passes through the heart, lungs, and liver, eventually maturing in the blood vessels (veins) that drain the intestines and bladder. Here it grows rapidly, feeding on blood, and when sexually mature lays its eggs, thus completing the cycle.

The several species of blood flukes infest the populations of tropical America, many parts of Africa, and the Orient, particularly China. In some irrigated regions the infection runs as high as 90 per cent among the adult males who are constantly in contact with the water, hence exposed to the cercariae. Treatment consists of giving large doses of antimony compounds and, if the patient can stand the treatment, he can be cured. Like all of the complex parasites, blood flukes can be controlled by removing the intermediate host.

Water birds such as ducks, terns, and gulls, have their own varieties of blood flukes which apparently cause them no particular harm. However, if this type of cercaria cannot find its proper final host, it does penetrate the skin of any person who happens to be near, causing a severe itching which has been called **schistosome dermititis,** or just "swimmer's itch" (Fig. 9-11). The cercariae apparently are not able to penetrate the tough thick mammalian skin, but in their attempts to do so enter it and cause intense irritation. There are several different species of cercariae that follow this pattern. Some are found on the sandy bathing beaches in the lake regions of the North Central states, especially Michigan and Minnesota, where they sometimes become such a nuisance that bathing is actually prevented, much to the disgust and economic loss of resort owners. Elaborate methods of treating the beaches with copper sulfate in order to destroy the snails have been developed and this control has had reasonable success.

CLASS CESTOIDEA

These are the **tapeworms**, a group of parasites that the layman has long erroneously associated with lean hungry adolescents. The worm gets its name from its long ribbon-like appearance, a feature that is common to this large and varied group, members of which infect almost all, if not all, vertebrate animals.

The tapeworm is, perhaps, the most degenerate of all animals, a condition indicating that the association with its host is one of long standing. At the same time it is beautifully adapted to its specialized environment, the vertebrate gut. It is indeed the supreme parasite among parasites. It is provided with excellent hold-fast organs to keep it in place in the gut of the host (Fig. 9-12). All nourishment is received from the contents of the gut or from the gut wall directly, so the animal has not bothered to retain even a semblance of a digestive tract. Its nervous and excretory systems are very rudimentary, and its ability to move has been reduced to very feeble contractions. However, it has evolved an extremely elaborate and prolific reproductive system, an essential feature in its survival since the possibility for any individual egg to reach maturity is very small. Although it has degenerated in other respects, it has gone all out in this one phase of its life, and measured in terms of biological success, the shift in emphasis has apparently been satisfactory.

The common beef tapeworm (*Taenia saginata*) of man is a typical example of this group (Fig. 9-13). It consists of two principal parts, the head or **scolex**, and the **proglottids**, sectional pieces attaching to one another, and growing larger as they proceed posteriorly. The scolex possesses hold-fast organs which make it possible for

Fig. 9-12. The scolex of the dog tapeworm (*Taenia pisiformis*). Note the sharp hooks and sucking discs used as attachment organs.

the worm to maintain its position in the gut. The proglottids, which are budded off from the region just back of the head called the **neck**, mature as they move progressively posteriorly. The younger proglottids are therefore anterior to the older. The mature proglottids, gorged with eggs containing young embryo worms, break away from the worm and pass out of the body in the feces. Because of the close association of cattle and their keepers in certain parts of the country, it is not unusual for the eggs to be picked up by grazing cattle. Once in the gut of this host the egg membranes and shell are digested away and the young **six-hooked embryo** (hexacanth) emerges. It soon bores its way through the gut wall into a blood vessel where it floats to the muscles, particularly heart and jaw muscles. Here it develops into a **bladder** and a tiny inverted tapeworm scolex grows from the wall of the bladder. Beef so infected is said to contain "bladder worms" and is usually unmarketable. If such beef is poorly cooked and then eaten by humans the bladder worms "hatch." The tiny scoleces evert and become attached to the soft intestinal wall where they immediately begin budding off proglottids.

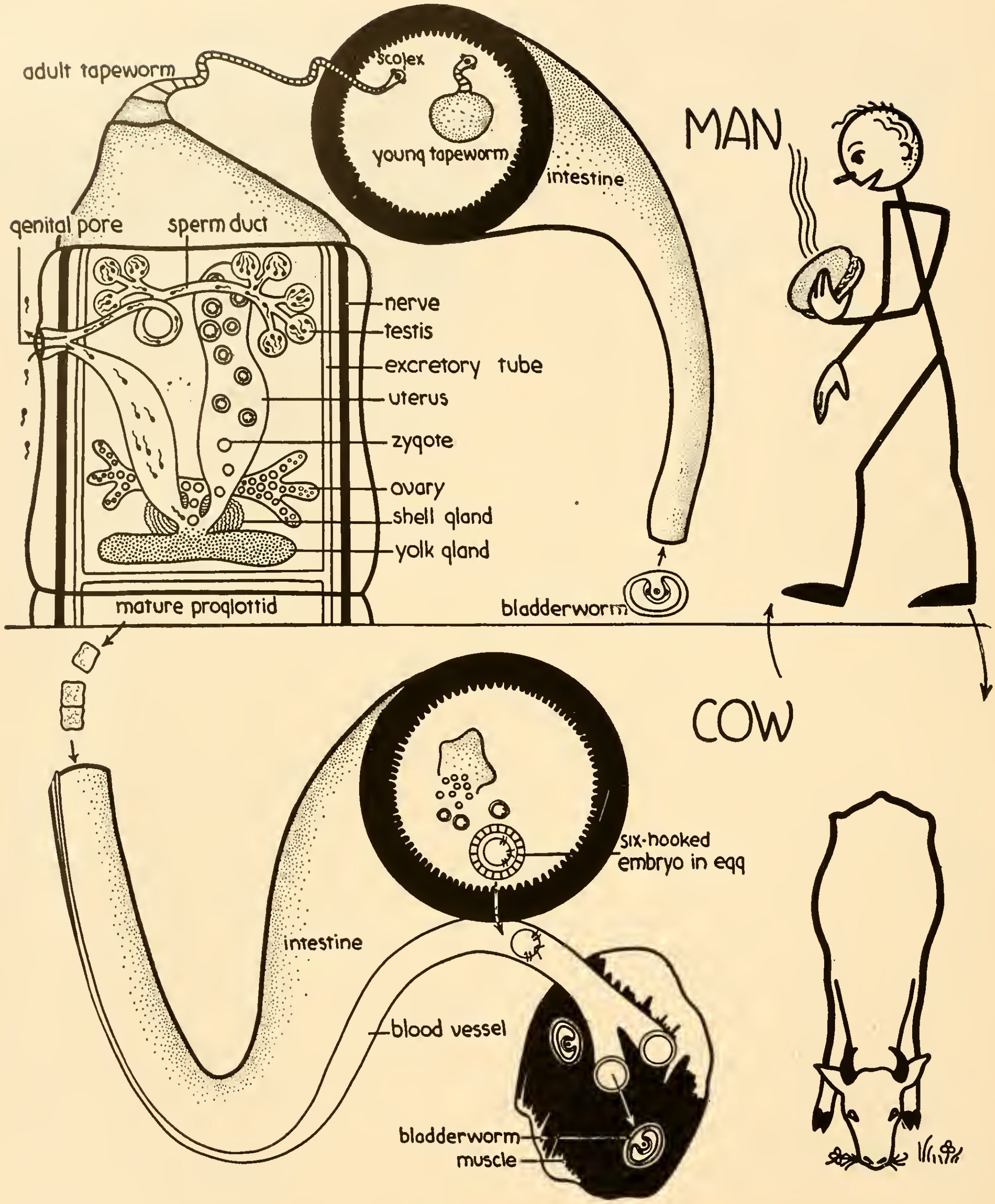


Fig. 9-13. Life history of the beef tapeworm (*Taenis saginata*) of man.

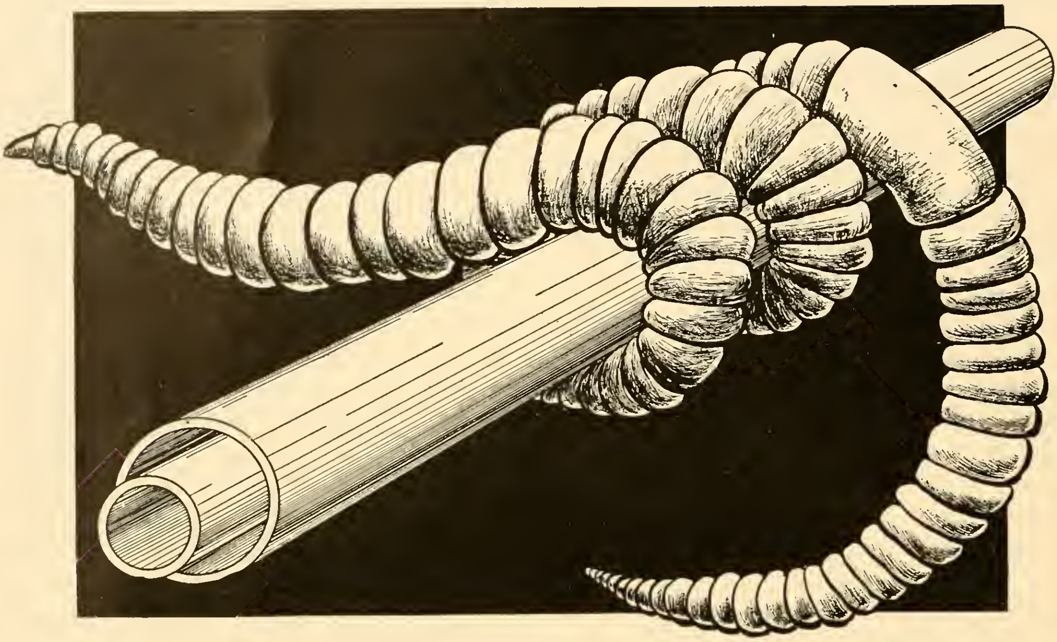
An examination of the proglottid demonstrates the fact that it is almost a complete individual itself. Indeed, the tapeworm is sometimes considered a colony in which each proglottid is an individual, much like the buds in hydra or the polyps in Obelia. Besides rudimentary nervous and excretory systems it possesses male and female sex organs, which are capable of producing prodigious numbers of sperms and eggs. The testes, numerous and scattered throughout the proglottid, are connected through fine tubules to the **sperm duct** which opens to the outside through the **genital pore.** The paired **ovaries** produce eggs which pass through a small duct (oviduct) where they receive sperm from another proglottid, or another worm, via the **vagina.** Here they also obtain the food material called **yolk** from the **yolk gland,** while the **shell gland** secretes material for forming the shell. The fertile eggs then are deposited into the **uterus** which eventually becomes greatly distended as the eggs begin to develop crowding all other structures out of place. Such a **gravid** proglottid (full of developing embryos) breaks off and follows the cycle indicated above.

Meat inspections in this country, together with sanitation among cattle raisers, have greatly reduced the incidence of this parasite. In fact, it has become so difficult to obtain this human parasite that biological supply houses usually have standing orders for them. Control of tapeworms is very simple: merely cook the suspected meat. There is a similar tapeworm in pork (*Taenia solium*) which is also becoming scarce.

A few decades ago during the lumberjack days in this country, particularly in Minnesota and Michigan, the fish were heavily infected with a tapeworm larva that was transmitted to man through his habit of eating raw fish. The worm, *Diphyllobothrium latum,* was apparently introduced by immigrants from the Baltic region of Europe where the infection was known for centuries. The life history involves two intermediate hosts, a small crustacean and a fish. The crustacean receives the infection by eating tapeworm eggs, the fish (pickerel or pike) eats the crustacean, and finally man gets the worm by eating the uncooked fish. This is a giant among tapeworms, having been known to reach a length of 60 feet.

In review, we have seen that with the advent of the mesoderm and with it several important organ systems, the flatworms far outstripped the coelenterates in complexity. They are, however, still small creatures and relatively simple when compared to a mammal, in other words, still further important changes must have taken place in subsequent groups of animals. We shall see what additions are made in the next group of tubular worms.

CHAPTER 10



THE TUBE-WITHIN-A-TUBE BODY PLAN

To this point we have considered animals of such a degree of complexity as to provide for only small bodies, from microscopic dimensions to several inches at most. Since there are animals of great size in the world, the ideas exploited thus far must not have been adequate for the development of such large bodies. Something new, then, must have been added. Undoubtedly, many different ideas were tried in reaching the present great complexity to which the highest animals have attained. By far the greatest majority of these ideas were not successful and were discarded. Some proved satisfactory and these are the ones that are incorporated in the bodies of successful animals in the world today. Success, biologically speaking, means spreading the species over the surface of the earth: the English sparrow is a success in America today, whereas the now extinct passenger pigeon is a biological failure. The new ideas that appear in the next group of animals should be studied to see why they have been retained and how they have pushed the whole mass of living things one step higher on the evolutionary scale.

One of the first things that needed attention was the digestive tract, which in the coelenterates and flatworms is merely a sac, with or without ramifications. All the food makes its way into such a digestive tract through the mouth, and all undigested food comes out the same way. This is a very awkward method of handling such an important function. A distinct improvement would be a tube running throughout the body with the mouth at one end, and a corresponding opening at the opposite end to allow undigested food to pass out of the body. In this way food could be constantly taken in at one end, and progressively digested as it passes backwards, a kind of assembly line method. This would mean the development of a "tube-within-a-tube" body plan.

Another great need was a method of distributing the digested food to all the cells of the body. So far this had been done by simple absorption and diffusion. To be sure, certain provisions had been made to facilitate this process, but at best, such things as the diverticula in the gut of planaria, could suffice for only a very small animal. Such primitive devices for distribution could not supply all the cells fast enough to make it possible for the animal to reach any great size or to move with any speed. A system was required which would carry an ample supply of not only food, but also oxygen to burn it, to every cell. This could be done only with some sort of conveyor belt system. Since digested foods are soluble in water, the system must be made up of a circulating fluid, a series of tubes to confine and lead it to every cell, and some means of keeping it flowing continuously. Only with the development of such a mechanism could animals climb any higher in this scale.

The first of these important steps was taken by the animals found in the phylum Nemathelminthes, the roundworms, and the second step among an obscure group of animals, the Nemertinea. These two groups will be studied from this point of view, and in this order, although in most other respects the nemertines are more primitive than the nematodes.

PHYLUM NEMATHELMINTHES

In numbers of animals the nematodes, which is the name applied to most members of the phylum Nemathelminthes, perhaps exceed all others, with the possible exception of the arthropods and Protozoa. They were once thought to be primarily parasitic. These members first came to the attention of biologists because they were responsible for some of the more serious diseases both in plants and animals. However, it is now known that there are equally as many, if not more, that are free-living. A spadeful of alluvial soil contains literally millions of them. A drop of water, taken from nearly any stagnant pond or the sea, would reveal many of them. Their characteristic whipping movement identifies them to even the casual observer. Most of the nematodes are very small, almost microscopic, although there are a few—the "horsehair worms," for example—that may reach a length of 1 yard. Some of the ascarid parasites of horses may reach a length of 10 to 12 inches.

The most distinct improvement in this group over the preceding is the complete digestive tract, mouth to anus (Fig. 10-1). This is a slender tube, without pockets, running throughout the body length. Digested food is absorbed directly through the gut wall and diffuses into a fluid which surrounds the digestive tract, thence to the body cells. Here again, the animal depends on diffusion to take care of the important matter of getting food and oxygen to the cells, and wastes away from them. This fact, among other things, is probably responsible for the small size of these animals.

A pair of tubes run internally along each side of the body, forming **excretory canals**, but they lack any cells comparable to the flame cells found in planaria. The two tubes unite into a single one, which opens ventrally to the outside through a minute **excretory pore.** Another feature of the nematodes is a complex **nervous system** which consists of several nerves extending the

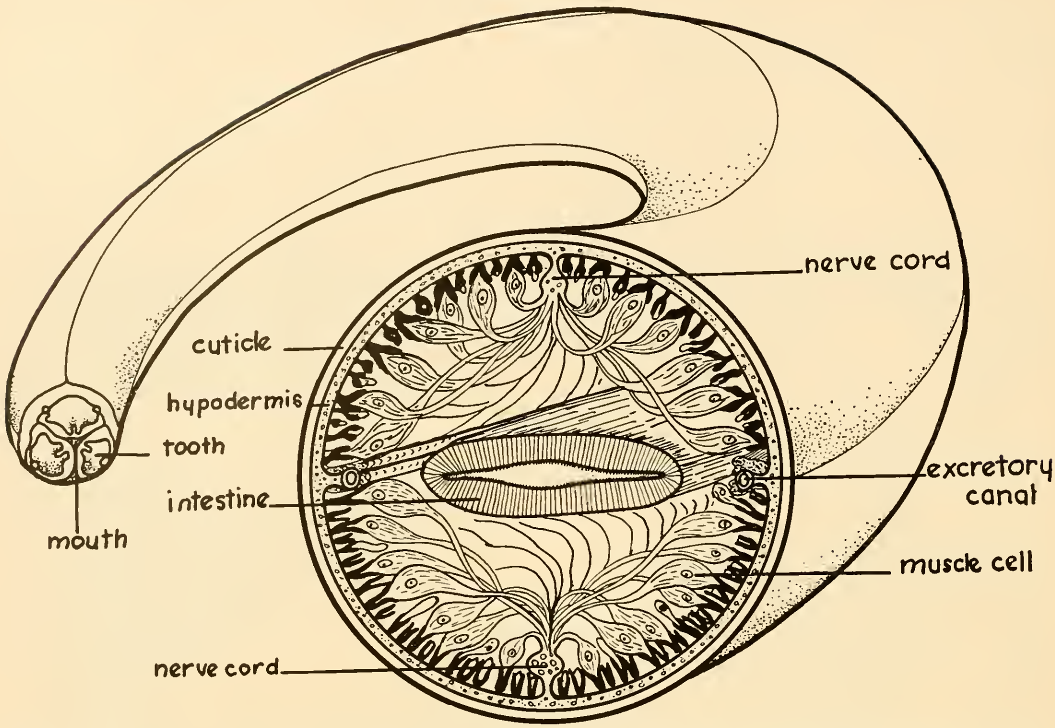


Fig. 10-1. The body plan of the roundworms includes two tubes: one, the gut, within the other, the body wall. This figure shows the anterior end of the worm with its three teeth surrounding the mouth, and a cross-section taken anterior to the gonads.

length of the body and terminating anteriorly in numerous ganglia.

The body wall contains a thick muscular component, separated into four banks of **muscle cells** extending lengthwise, and so attached that the animal can flex its body only in a dorsal-ventral manner, a rather ineffective method of locomotion in the water. In fluids of high viscosity or in soil, however, it is more effective.

The rather elaborate reproductive system lies free in a fluid-filled cavity between the body and gut wall. Since the sexes are separate, only one set of organs is found in each animal. Females, which are usually larger than the males, possess two ovaries in the shape of long coiled tubes. The two ovaries continue into two **oviducts**, which enlarge to form two **uteri** (singular, *uterus*). These join to form a single short **vagina**, which opens externally on the ventral side in the anterior portion of the body. The mature eggs are stored in the uteri. In the male, sperms are produced in a long coiled tube, the single **testis**, which joins the **vas deferens** and then becomes the **seminal vesicle**, the storage place for the sperm. A pair of bristles at the posterior end aid in conducting the sperms from the male to the female during copulation. The opening of the male reproductive system is close to the posterior end of the animal near the base of the bristles.

Parasitic nematodes. Because of the economic significance of the parasitic nematodes we will discuss representative forms, particularly those that attack man. Although over 50 different species are human parasites, a still greater number affect man indirectly by their ruthless destruction of his domestic plants and animals. They invade almost every organ of the body, their damage depending on the kind and number of individuals. Like most parasites, the nematodes tend to remain with a specific host, although they are a little more careless in this regard than some. Occasionally they attack a variety of hosts and may produce a serious disease when they enter a new one. For example, a hog may be riddled with *Trichinella* with no apparent damage, whereas a man with a similar infection is apt to die because he is the "accidental host" while the hog is the normal host. The hog has had trichinella in its tissues so long that it has built up some resistance to the parasite. Since man gets the parasite only occasionally, he has not developed any resistance. Let us consider several common roundworm parasites.

Ascaris lumbricoides (Fig. 10-2) is a common intestinal parasite of many domestic animals as well as man himself. It is an excellent example of the usual life cycle of parasitic roundworms, although there are wide modifications, as will be seen in trichinella, for example. It is not infrequently found in the digestive tract of children, since they are apt to get ascaris eggs on their hands from the soil and transfer them to the mouth (Fig. 10-3). The embryonated eggs pass through the stomach to the intestine where they hatch into tiny worms (0.2-0.3 mm. long). These bore through the intestinal wall into the lymph, then the capillaries, and finally the general circulation. They are carried through the heart to the lungs where they grow somewhat in size. Eventually the larvae break through into the air sacs, migrate up the trachea, and are swallowed, arriving in the intestine for the second time. Here they mature, copulate, and lay eggs which pass out of the host with the feces. The eggs may be picked up directly by another host, or they may become desiccated and blow around in the dust to be engulfed at some later stage.

Fig. 10-2. One of the largest round worm parasites found in the intestine of both man and the pig as well as other animals is *Ascaris lumbricoides*. The male is slightly smaller than the female and it possesses a curved posterior end. The female is about 25 cm. long.

In general, small numbers of ascarids are relatively harmless, but large numbers can cause serious illness. Sometimes they wander away from their usual haunts: they may crowd into the appendix or perforate the gut wall, causing peritonitis; they may even get into the nasal chambers, obstructing the air passages when full grown. When large numbers of larvae move through the lung tissue, they are apt to leave lesions which may give pneumonia an opportunity to gain a foothold. Appropriate vermifuges can be used to remove this parasite.

The adult ascaris probably maintains its place in the intestine by active movements, since it does not possess an attachment organ such as the flukes and tapeworms do. It feeds on the food in the gut by a pumping action of its bulb-like pharynx. To keep from being digested by the enzymes secreted by the host, ascaris, like all intestinal parasites, is protected by a tough cuticle, through which probably is secreted substances that counteract the hydrolizing

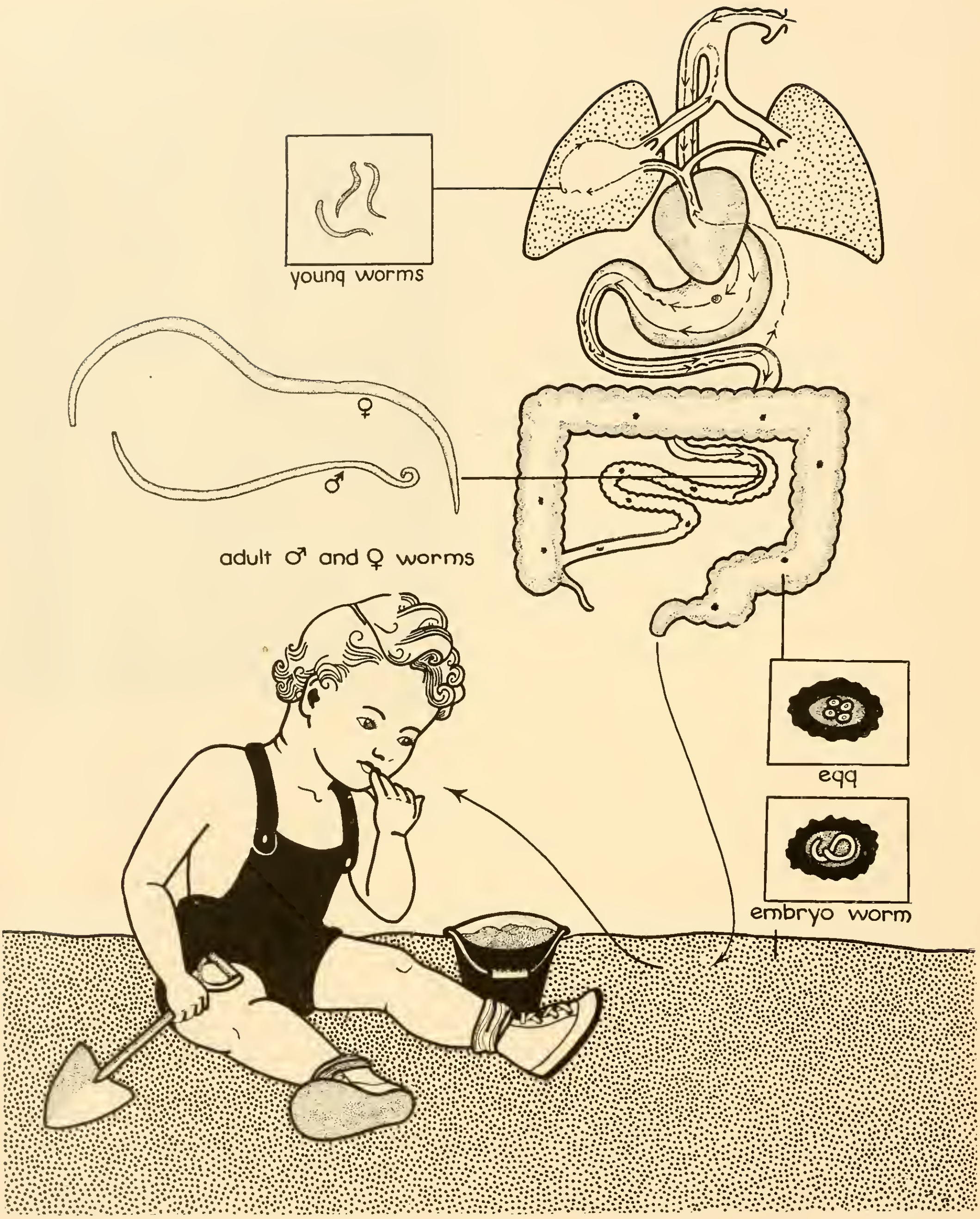


Fig. 10-3. A schematic representation of the life cycle of *Ascaris lumbricoides* as it occurs in humans.

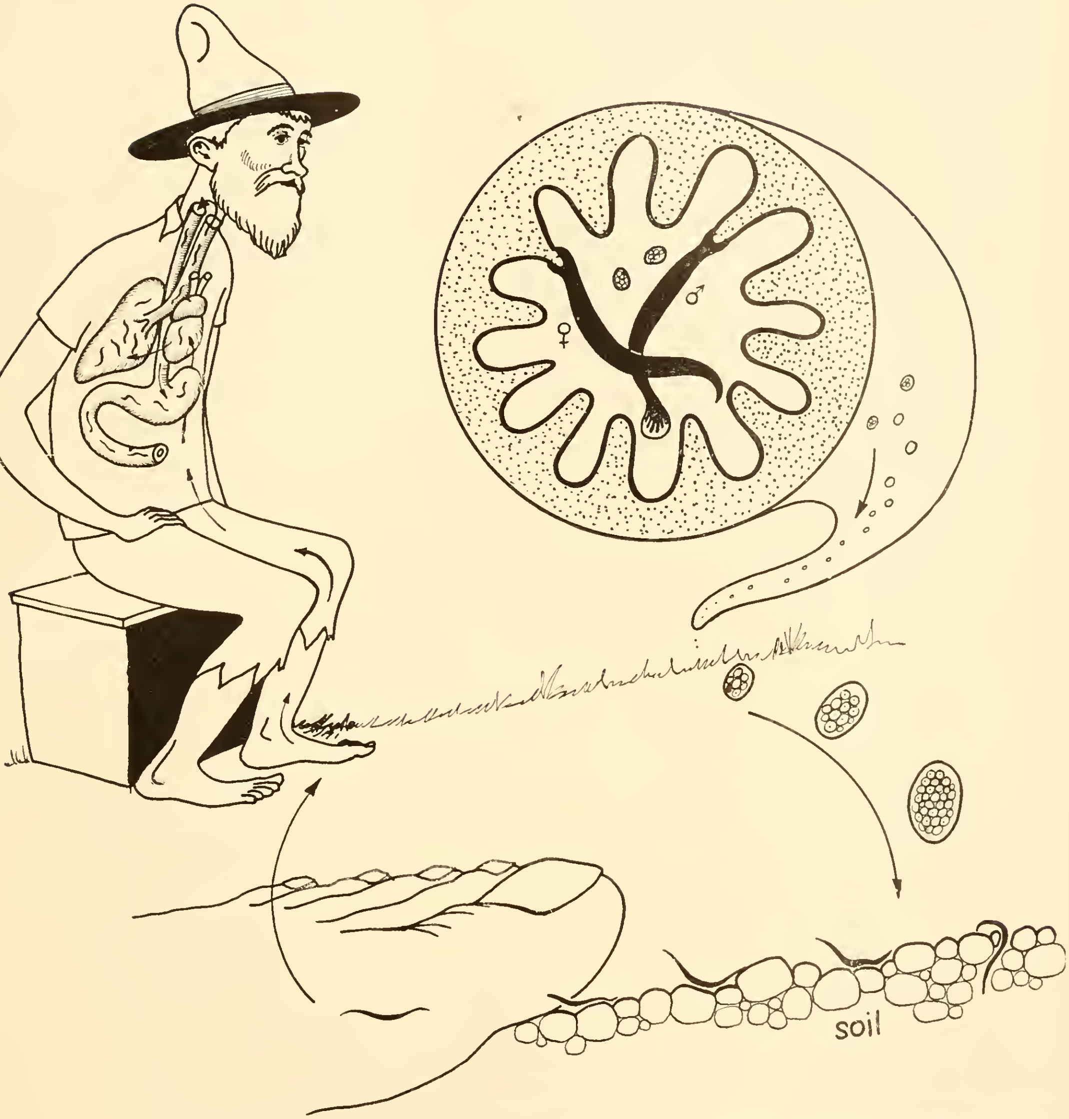


Fig. 10-4. Life cycle of the common hookworm (*Necator americanus*). The adult worms are shown attached to the lining of the intestine. The fertilized eggs begin development while still in the digestive tract. They pass out with the feces and eventually hatch in the soil where they lie in wait for their next host.

power of the enzymes. Oxygen must be obtained from carbohydrate breakdown within its own body, since there is very little oxygen in the gut. The only hope for survival is to produce a great many eggs, which it does most effectively. A large female has been known to contain 27,000,000 eggs, 200,000 of which she lays every day. As in all parasites, the chance for any one egg to produce a mature worm is extremely remote, but by this colossal effort to bring forth potential offspring ascaris has been very successful in the world, as attested by its universal occurrence.

A notorious relative of ascaris is the hookworm (*Necator americanus*), which is directly responsible for untold misery and indirectly for the death of millions of peo-

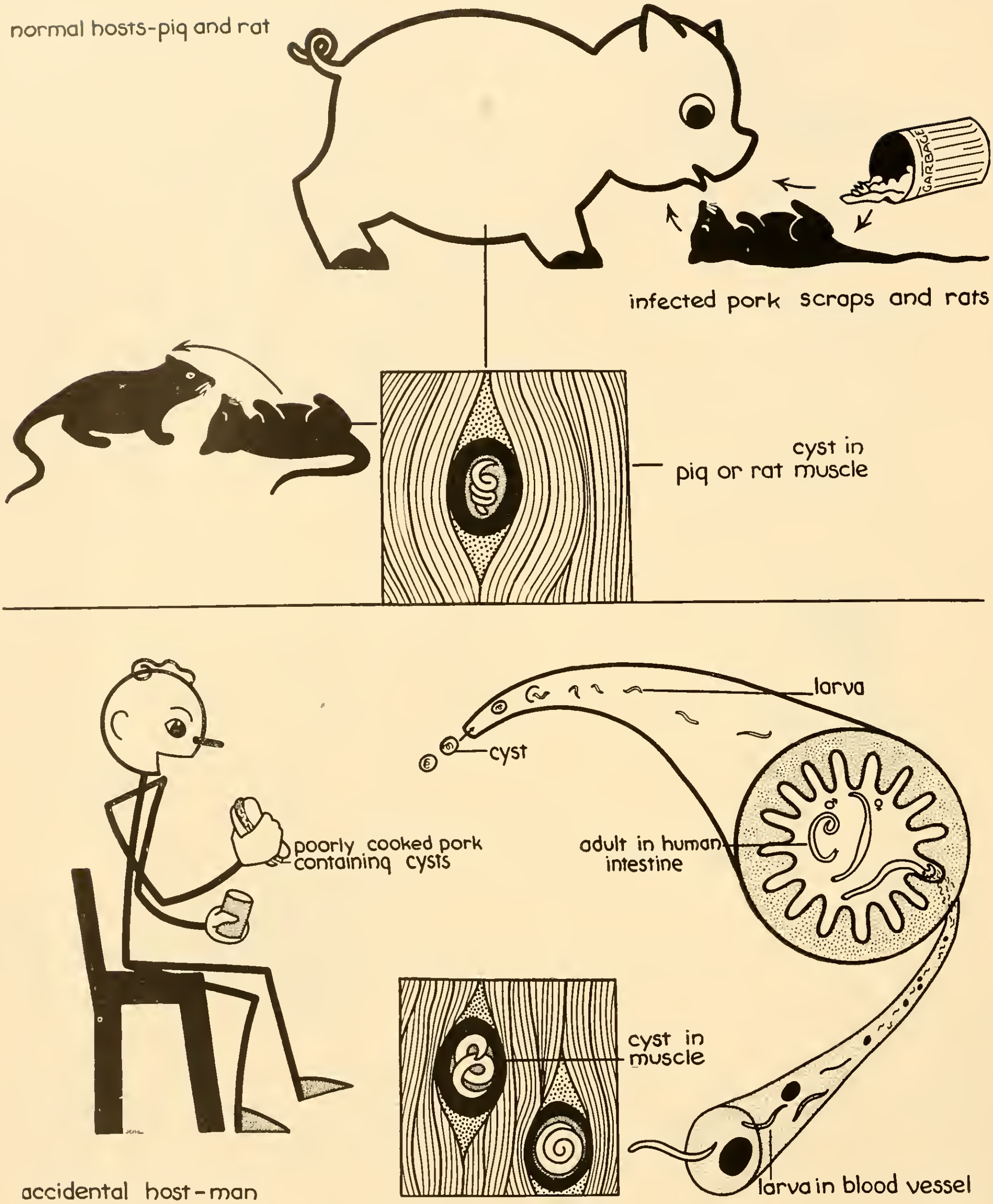


Fig. 10-5. Life cycle of trichina (*Trichinella spiralis*).

ple throughout tropical and subtropical regions of the world. People in certain communities of our southeastern states are heavily infested which, in part at least, is responsible for their "poor white trash." It is little wonder that they are lazy and shiftless when their intestinal walls are teeming with hookworms sapping their strength. Children tend to be retarded both physically and mentally which, coupled with extreme poverty and ignorance, dooms them to a life filled with misery, frustration, and servitude.

The adult hookworm differs from ascaris

in that the mouth is provided with teeth so it can cling to the soft mucosal lining of the intestine from which it withdraws its food, blood (Fig. 10-4). Fertile eggs pass out with the feces of the host and are deposited on the ground where they hatch into larval worms. After a brief growth period the larvae are ready for their next host. They gain entrance by holding on to the foot or any other part of the body of the host, boring in, and finally getting into the blood stream. They then follow the same path described for ascaris, eventually reaching the intestine.

Preventive measures are so simple that one wonders why there are any cases of hookworm at all. Wearing shoes prevents the worms from getting into the host; proper methods of disposing of human excreta would also stop the infection very swiftly. Both of these methods have been tried with reasonable success but the incidence of hookworm disease is still much too high in this country. Perhaps the most important factor is poverty; if all people were gainfully employed and had an adequate education this disease would be completely eradicated. World-wide measures could stamp it out altogether, but such suggestions are only wishful thinking at the present time.

Another roundworm parasite that is of grave importance to man is **trichina** (*Trichinella spiralis*), a worm whose normal hosts are the pig and rat, although it has been found in other vertebrates as well. Man is an *accidental host* and is therefore perhaps even more severely affected by the parasite. The life cycle of trichinella varies somewhat from the two preceding examples of roundworm parasites (Fig. 10-5). The common source of human infection is through the muscle of the pig, which harbors trichina in its infective stage, small **cysts** containing **larvae** (Fig. 10-6). If these are eaten, uncooked, the tiny worms (1 mm. long) emerge in the intestine where they mature and copulate. The very tiny worms deposited by the female bore through the intestinal wall into the blood stream and distribute themselves through the muscles of the body, attacking particularly those of the tongue, eyes, diaphragm, and ribs. It is this migratory period that is dangerous because, in addition to the mechanical injury that millions of worms can inflict, there is also the likelihood of bacterial infections. The disease at this stage is characterized by high fever, intense muscular pains, and frequently partial paralysis. A sufficient amount of infected meat can cause death at this time, but if the infection has been light enough not to cause permanent damage to nervous and muscular tissue, the symptoms will subside and the person recover. Infections are far more common than records indicate. For example, a large Midwestern hospital reported that 27 per cent of its autopsies showed positive trichinosis, although none of the deaths was directly caused by that disease.

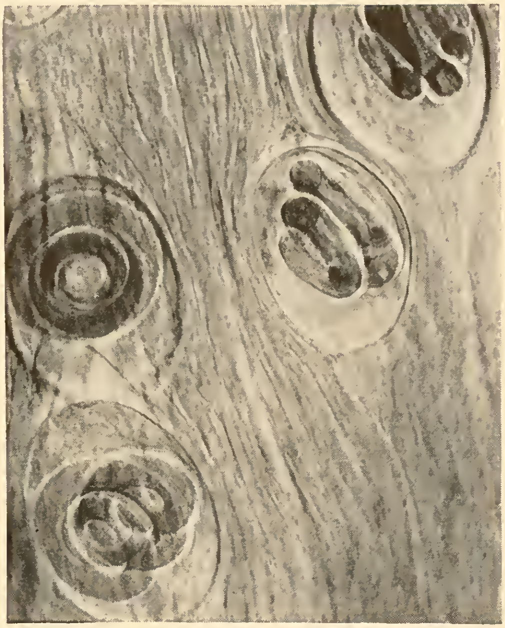


Fig. 10-6. Larval *Trichinella* cysts in the muscles of a rat.

Preventive measures are even simpler than for hookworm: merely cook pork. There is no treatment for the disease once

A

Fig. 10-7. *A.* The microfilariae that cause the disease elephantiasis live in the blood of man and can be seen in blood smears taken at certain times of the day. The tiny worm is clearly visible in this picture and its relative size can be determined by comparing it to the small irregular objects which are the white corpuscles.

B

B. A case of elephantiasis. (From Smith and Gault, *Essentials of Pathology*, 1938, D. Appleton-Century Company.)

an infection has gotten under way. It is also well to remember that meat sold on the market is not inspected for trichina, primarily because it is too difficult to detect light infections. One poorly cooked ("pink") pork chop can contain billons of worms, which are adequate to kill a person. It is true that there are fewer and fewer cases of trichinosis reported, probably because the practice of feeding meat scraps to hogs is less prevalent and also because a general war on rats has cut down the rat-hog cycle which normally keeps the worms going.

There are numerous parasitic nematodes that cause bizarre diseases in the tropics, diseases which are normally known only to parasitologists and medical men who are experts in the field of tropical medicine. However, during World War II the tropics became the battleground for many American men and consequently tropical diseases suddenly loomed as a significant health problem. Among the numerous roundworm parasites the one that causes **elephantiasis** (*Wüchereria bancrofti*) is perhaps the most important. The life cycle of this worm differs from that of other nematodes in that it requires two hosts. The larvae, called **microfilariae,** circulate in the blood of the infected person (Fig. 10-7). An interesting adaptation is that these tiny worms come out in the peripheral blood vessels in the evening, a time when the mosquitoes which are the carriers (intermediate host) are active. The mosquito picks up the microfilaria with the blood as it feeds; inside the mosquito the worm grows and eventually makes its way out through the proboscis of the host. During the biting process the microfilaria slips off the proboscis onto the skin of the next host and immediately bores its way in. Once in the blood stream of the final host it moves into the lymph glands where it becomes mature. The worms become so numerous that they can effectively clog the lymph passages, which results in huge swellings, usually in the extremities. A leg may grow to weigh 100 pounds, hence the name *elephantiasis.*

Preventive measures consist in keeping from being bitten by infected mosquitoes. Light infections are not serious because eventually the body forms new lymph channels so the swelling is reduced to normal. The danger lies in continual infection where the same individual is bitten again and again by infected mosquitoes.

PHYLUM NEMERTINEA

The second step to higher complexity, namely, the development of a circulatory system, first appears in the phylum Nemertinea, representatives of which are sometimes called "band worms" because of their long ciliated flat bodies. The nemertines live primarily in the ocean where they crawl among the rocks. They are highly colored and greatly elongated, sometimes measuring as much as 80 feet in length. If captured, their bodies stretch so that they often break into two parts under their own weight, but regeneration occurs as readily as it does in planaria. They are also able to break their bodies into many parts, a process called **autotomy** (self-cutting), which is not an uncommon characteristic among invertebrates.

In addition to a complete digestive tract, the nemertine possesses a very primitive circulatory system (Fig. 10-8). It consists of three blood vessels that run throughout the length of the body, but which do not break up into tiny capillaries as in higher animals. In these forms oxygen and food still diffuse some distance through fluid before arriving at the cells. Although still inefficient, this method is a considerable improvement over that found in lower forms, where diffusion of digested material and oxygen from sources of intake to cell must pass a greater distance. The circulating fluid (blood) contains red cells in some species, much like those in higher animals. The red color is

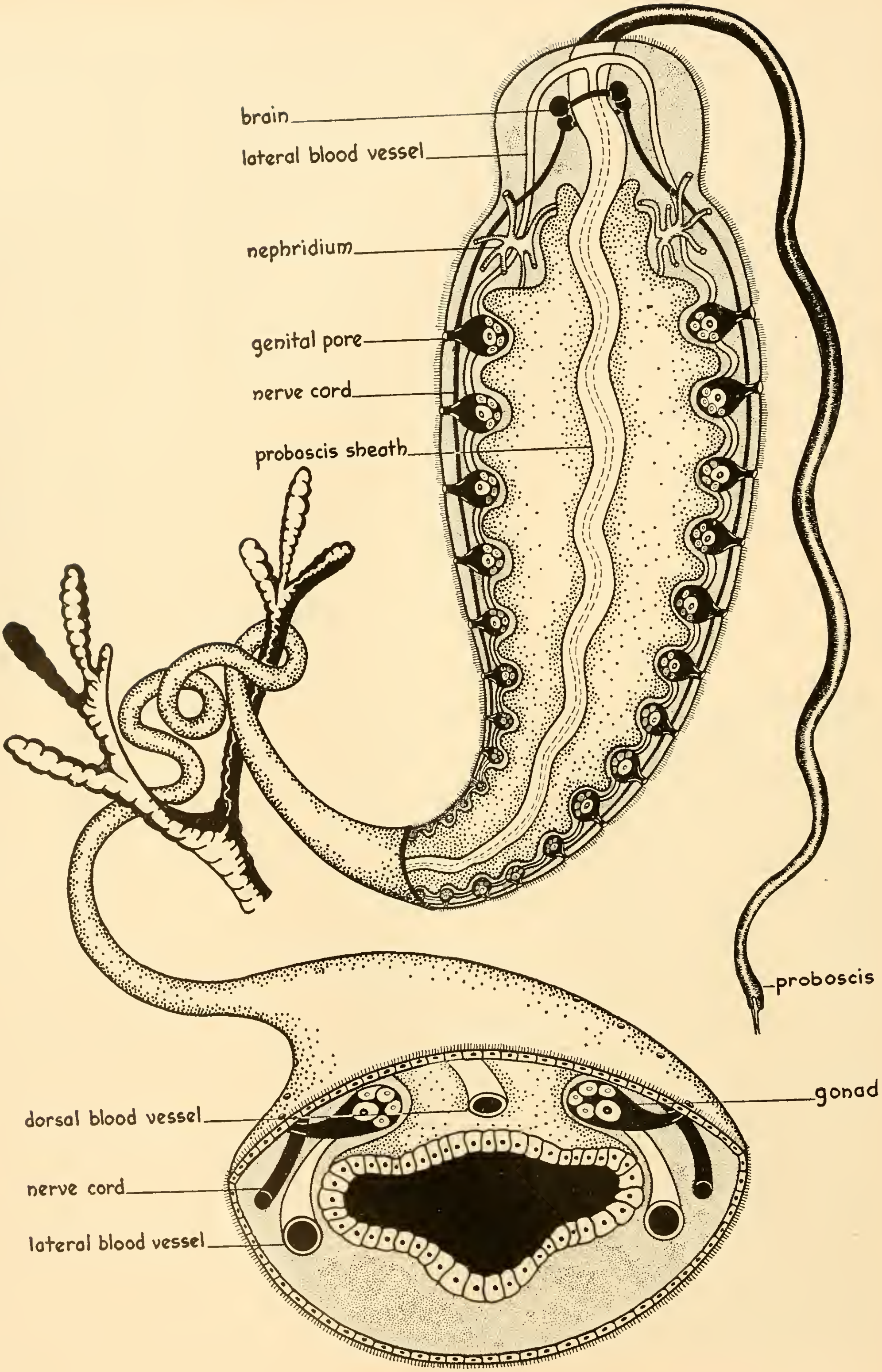


Fig. 10-8. A longitudinal and cross-section of a nemertine showing the tube-within-a-tube body plan and also the beginnings of a circulatory system.

due to **hemoglobin**, which makes up the major portion of the material found in these cells. The affinity of this pigment for oxygen makes it useful in an oxygen-carrying capacity.

Another deficiency of the nemertine circulatory system is the lack of a pumping station. The only propulsive force for the blood is furnished by the contractions of the animal as it swims. This massaging effect causes the blood to flow along in the vessels. These deficiencies of the blood system are very great, which is perhaps one reason why these animals have never achieved greater success. But imperfect as it is, it is a great step forward over the more primitive arrangements for distribution.

PHYLUM ANNELIDA

Not only are the features initiated in earlier phyla further developed in the phylum Annelida, but new features are also introduced. Two principal ones are **segmentation**, or **metamerism**, and the formation of a body cavity, the **coelom**. These two innovations have made it possible for animals to grow larger bodies and to develop more complicated neuro-muscular mechanisms, thus permitting greater and more diversified activity.

The most obvious difference between an annelid and lower forms is its segments. These are serially similar parts, conspicuous both on the outside and the inside of the body. Internal organs are repeated in every segment, each part resembling all others in most respects. There are modifications, however, in certain body regions, as we shall see. There is an intricate connection between the segments, so that the animal is a coördinated whole. Segmentation is retained in higher forms such as the arthropods and the chordates, and is therefore a successful idea that has contributed toward the greater complexity of animal bodies. Just how segmentation came about is conjectural. It may have resulted simply from individuals dividing asexually by transverse fission, remaining attached, and eventually becoming integrated into a coördinated whole. Phenomena leading to support this explanation can be found among some of the flatworms (see p. 79).

The members of the phylum Annelida are mostly free-swimming marine worms. They abound in the oceans and live near the shore and hide in the sand in burrows during their quiet periods. Some biologists believe that the annelids are intermediate between the lowest protozoan forms and the highest vertebrate animals; in other words, they represent the halfway mark up the long path of evolution. Since they form the basis for further development, it is necessary to examine this group of animals carefully, which we shall do by studying two representatives, the sandworm (*Neanthes*), and the common earthworm (*Lumbricus*). Of these Neanthes is more typical because it is aquatic and possesses more of the characteristics of the phylum. The earthworm, on the other hand, is terrestrial and in many respects is quite unlike most annelids.

Neanthes

Neanthes (formerly known as Nereis), the common "sandworm" or "clamworm" (Fig. 10-9), lives in shallow water on the sandy shores of most oceans of the world, where it is found in small burrows with its head and tentacles protruding slightly. When small animals venture too close, the worm suddenly everts its heavily armed proboscis, seizes its prey, and drags it into the burrow to be devoured. When at rest the worm actually "stands" in its burrow and undergoes a constant undulating movement, creating a current of water that flows in and out for breathing. The worm leaves its burrow during the breeding season but only rarely does it leave otherwise.

The segments of Neanthes are conspicuous externally, especially because each one possesses a pair of laterally placed paddles,

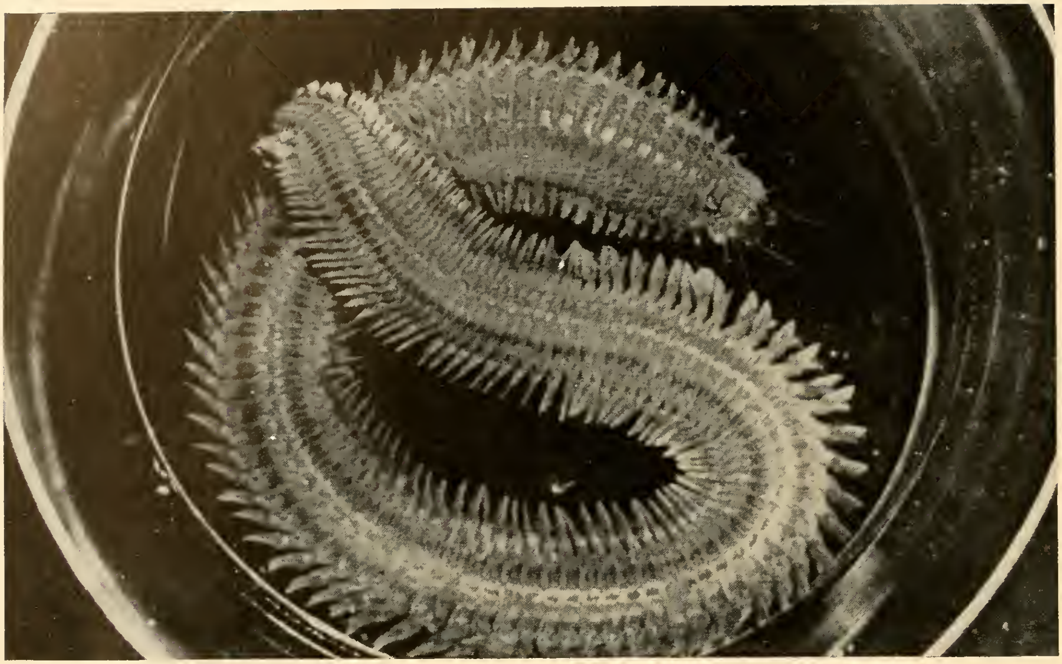


Fig. 10-9. The "sandworm" (Neanthes) is a common inhabitant of our Atlantic Coastal waters. It lives in a burrow in mud or sand from which its head and tentacles protrude. Small animals passing near enough are snatched and devoured. During the breeding season worms leave their burrows and congregate in great numbers near the surface of the sea.

called **parapods**, which function like oars on a boat to propel the animal through the water. In addition, snake-like undulations of the body aid in swimming. Paired bunches of bristles (**setae**), located in the parapodia, hold the animal in its burrow, should an outside force attempt to remove it. The head is a distinct structure well provided with sense organs in the form of four eyes, and two tentacles which appear to be tactile in function (Fig. 10-10). There is a protrusible pharynx which terminates in a pair of fierce-looking jaws. The sturdy muscular body is covered with a cuticle which takes on an iridescent sheen in the sunlight. One is impressed by its unique beauty as it glides through the water with its graceful undulations.

The tube-within-a-tube body plan is conspicuously evident when one studies Neanthes internally (Fig. 10-11). The internal organs are serially repeated in each segment with the exception of the first and the last. The gut, a straight tube passing

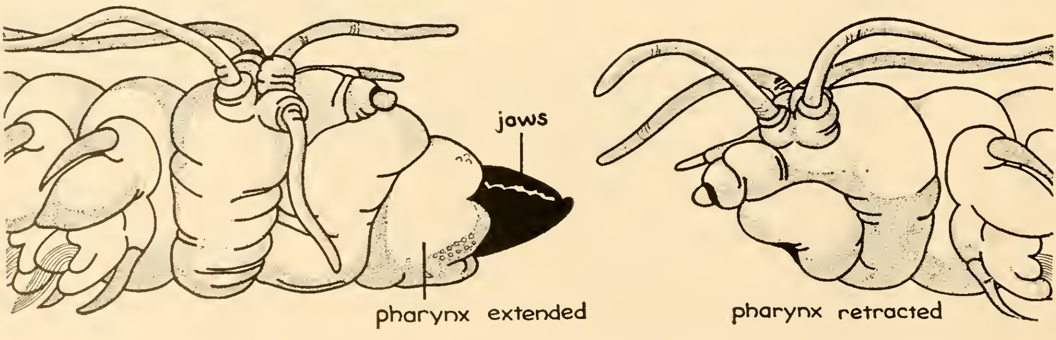


Fig. 10-10. Side views of the head of Neanthes showing the pharynx extended and retracted.

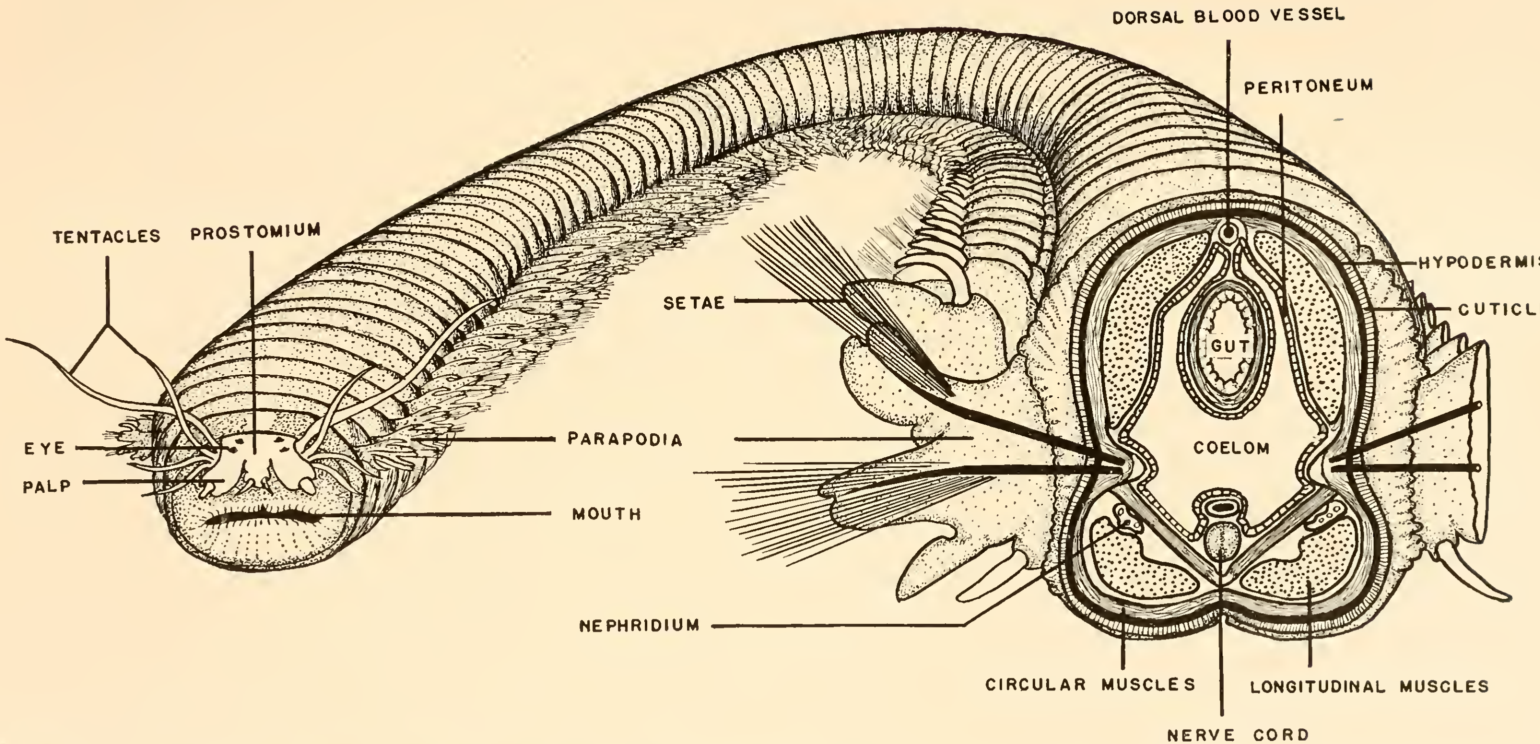


Fig. 10-11. Neanthes in cross-section to show the internal body plan of an annelid. A "head on" view demonstrates how well this animal is equipped with sense organs.

from mouth to anus, is surrounded by a sheet of tissue, the **peritoneum**, which forms the walls of the **coelom**, a very important cavity introduced among the annelids for the first time and referred to earlier. The coelomic cavity in the annelids is decidedly different from the body cavity of the roundworms which had no lining whatever. The coelom functions in nutrition, since a large portion of the food and waste products diffuse into the coelomic fluid and through it reach their ultimate destination.

The circulatory system of Neanthes is far superior to the one found in the nemertines. Tiny capillaries now allow a rapid exchange of oxygen and carbon dioxide, as well as food products. Furthermore, circulation is maintained by contraction of the large blood vessels themselves, rather than by the body as a whole. Here, then, is seen for the first time a contractile portion of the system which serves as a heart to keep the blood circulating continuously. The blood, like that of the nemertines, contains hemoglobin, although it is not confined in cells, but is free in the plasma.

Neanthes receives its oxygen and eliminates its excess carbon dioxide through the thin walls of the parapods. The frequent waving movement of these organs facilitates rapid gas exchange. Each segment has a pair of small coiled tubules with an internal opening, the **nephrostome**, which resembles a tiny ciliated funnel, and an external opening, the **nephridiopore**, at the opposite end, which perforates the body wall. The nephrostomes lie in the segment anterior to the tubule and the nephridiopores. They take in coelomic fluid from which nitrogenous wastes are extracted in the tubule and excreted through the nephridiopore. This excretory system is considerably more complex than the one noted in planaria, although fundamentally it is similar.

Neanthes shows more varied and specific responses to the external world than are found in lower forms. Its four eyes and sensitive tentacles aid the worm in getting around in the dark. The centralization of the nervous system, initiated in planaria, is carried much further in Neanthes. Not only has the nervous tissue concentrated into two large masses, but also each segment has a similar enlarged **ganglion.** With this organization the animal has a well-developed means of coördination, a far cry from the nerve net of hydra.

If Neanthes is placed in a dish of sea water, it keeps up violent swimming movements, but if a test tube is placed in the container the worm backs into it almost instantly and quiets down. This is presumably due to the tactile stimulation from the tube wall, reminiscent of the burrow. Movements during the breeding period also indicate a highly developed neuromotor mechanism.

In the nights of late July and August, Neanthes gather in great numbers along the eastern coast of the United States for the purpose of shedding their eggs and sperms. By illuminating a small area of an appropriate ocean surface, thousands of worms may be seen at this time churning the water by swimming at a rapid, erratic rate, and swirling in apparent frenzy. Suddenly the females seem to split open along their sides, discharging their eggs into the sea water like a white cloud. The males, which are smaller than the females, shed their sperm in a similar manner. Both sexes die shortly after extruding their gonadal products. By dipping up some of this water it is possible to observe the early stages in the embryology of this animal. The eggs undergo segmentation and develop into free-swimming ciliated larvae, called **trochophores,** which promptly settle to the bottom and metamorphose into young Neanthes.

Relatives of Neanthes

There are many close relatives of Neanthes living along the ocean shores, although some are found at great depths. They range from miscroscopic forms to those that reach 10 feet in length. Some are active swimmers and live in the open ocean catching their prey in flight, whereas others such as the sea mouse (Fig. 10-12) crawl over the ocean floor. Many construct burrows out of mucus, such as *Chaetopterus* (Fig. 10-13); others bore into rocks to provide a home for themselves. Some are highly colored, such as the peacock worm (Fig. 10-14) which could easily be mistaken for a flower.

Many of these worms have spectacular breeding habits. One, the **palolo worm** (*Eunice viridis*) of Samoa and Fiji, spawns in a most remarkably regular and peculiar manner. On the first day of the last quarter of the October-November moon, the posterior portion of the worm, heavily laden with eggs or sperms, breaks off from the parent worm and swims to the surface where the gonadal products are discharged. The surface of the sea is milky white with the great numbers of these cells. Natives, who are familiar with the exact time of spawning, collect these worms when they are about to spawn and feast on them.

Fig. 10-13. This annelid (*Chaetopterus*) lives in a tube secreted by its own body. The appendages are used as paddles to keep the water circulating through its tube, thus bringing in oxygen and small animals upon which it feeds. It is luminescent, which seems strange since there is no opportunity for any other animal to appreciate its beauty. This female specimen, which is removed from its burrow, is about 15 cm. long.

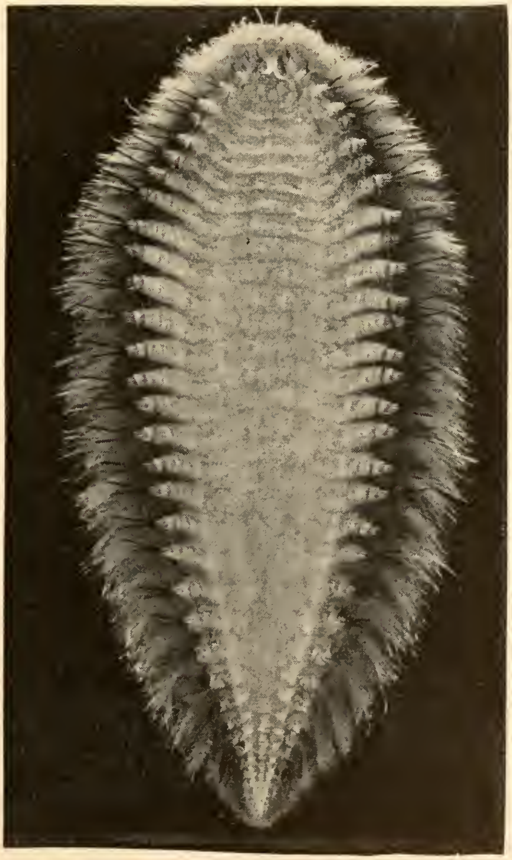


Fig. 10-12. Aphrodite (*Aphrodita hastata*), the sea mouse, from ventral view which definitely establishes it as an annelid. From the dorsal side it resembles a furry animal, hence its name. It is about 12 cm. long.

The earthworm

No discussion of the phylum Annelida is complete without a study of the lowly earthworm, spurned by the squeamish and cherished by the fisherman and robin. It seems striking that this creature, which is so helpless when removed from its burrow, has been able to spread its kind over nearly

Fig. 10-14. This annelid, called the peacock worm (*Eudistylia*), builds its long tube in sand among the rocks. The miniature head, along with many brilliantly colored gills, protrudes from the end of the tube. The gills function in breathing and food gathering, since they are covered with a sticky mucus in which minute sea animals become enmeshed and are then drawn to the mouth by means of cilia. Peacock worms in clusters resemble a bunch of flowers; their real identity becomes apparent when they suddenly withdraw the tentacles into the tube.

the entire surface of the earth. This is even more surprising when it is known that most of its relatives are aquatic forms. It apparently deserted its ancestral watery environment and blazed a trail into a terrestrial habitat of semi-solid soils. In this transition it lost certain of its ancestral parts and acquired others. There are few species of earthworms, while there are many species of aquatic forms.

The industrious robin searching for earthworms is a common sight, but other animals, such as moles, amphibians, small snakes, and fish, also feed upon this form. Some species of earthworms have been found to be intermediate hosts for such parasites as gapeworm and tapeworm of fowls, and lungworms of pigs. Hog influenza is caused by the mutual action of a virus and a bacterium contracted when lungworms borne by the earthworm invade the respiratory tract. They are highly beneficial to man by constantly tunneling the soil, thus permitting a greater circulation of water and air. Charles Darwin noted that their castings on fertile soil amounted to as much as 18 tons per acre per year. This constant elevation of subsoils to the surface tends to cover rocks and gravel, thus making the topsoil more tillable. In this sense, too, the earthworms benefit man substantially.

External anatomy. The large species, *Lumbricus terrestris* (Fig. 10-15), is a good example of an earthworm. Its most conspicuous external characteristic is its segmentation, resembling Neanthes in this respect. Mere vestiges of the parapods remain in the form of four pairs of very short setae located on each segment. These are used for traction in locomotion and their effectiveness in this capacity is easily ascer-

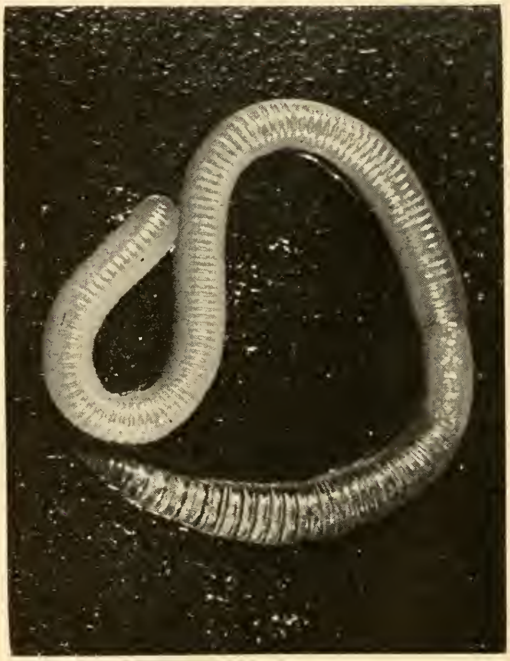


Fig. 10-15. The common earthworm (*Lumbricus terrestris*). This specimen had just projected the head end forward and had contracted the posterior half of its body in its typical crawling movements. Note the clitellum.

tained by catching a worm that has its posterior end partly within its burrow. A slow steady pull removes it, whereas a sudden one leaves the intruder with only a portion of the worm in his hand, the other end securely held in the burrow by the stiff setae.

There are no conspicuous sense organs on the head end, like the eyes or tentacles of Neanthes. Indeed, the animal seems to lack a head, though it does have a protruding "lip," the **prostomium,** which covers the mouth.

The saddle-shaped **clitellum** rests on the dorsal side about one-third of the way from the anterior end. There are also several openings which can be seen by careful inspection. Most noticeable are those of the **sperm ducts,** which open on the fifteenth segment. The fourteenth segment bears the smaller openings of the **oviducts,** and each segment except the first three and the last bears a pair of **nephridiopores.** Finally, the four openings which lead into the **seminal receptacles** are located in the grooves between segments 9 and 10, and 10 and 11.

Internal structures. A section of the body wall (Fig. 10-16) shows the outer thin, tough **cuticle,** which serves as a protective layer for the tall **columnar epithelial** cells composing the bulk of the epidermis. Among these latter are scattered sensory cells, sensitive to light, touch, and chemical stimulation. Other cells dispersed among the epithelial cells are the mucus-secreting cells responsible for the slimy condition of the skin, which is essential both for respiration and locomotion. Beneath the epidermis lie two layers of muscle, the outer **circular** and the inner **longitudinal.** These function in locomotion. Lying beneath the muscle layers and lining the coelom is the **peritoneum.** The digestive tract is as it is in Neanthes, making the tube-within-a-tube plan conspicuous. By removing the dorsal wall throughout the anterior half, the internal anatomy can be studied. The segmentation which is so striking externally is just as conspicuous from the inside. Membranous partitions, **septa,** which wall off each segment, are perforated by the **gut, nerve cord, blood vessels,** and **nephridia.**

Beginning at the anterior end, the digestive tract starts with the **mouth,** which opens almost immediately into the large muscular **pharynx;** this latter organ is used as a kind of pump to draw food into the mouth. Following the pharynx is the **esophagus,** which opens into the **crop,** a storage sac. This in turn leads into the **gizzard,** which functions in the grinding of food, much the same as a similar organ in the chicken. The remainder of the gut is a long tube, the **intestine.** This organ bears a fold along its dorsal side, the **typhlosole,** which increases the surface of the gut without increasing the volume of the animal. A straight tube, from mouth to anus, suffices for small animals, but larger animals require a tube with still greater surface area, both for digestion and absorption of food.

Various gland cells are located throughout the digestive epithelium. Some produce digestive enzymes, while the secretion of others lubricates as well and thus facilitates the movement of food. Lateral to the esophagus and attached to it are three pairs of **calciferous glands,** which function in secreting calcium carbonate for neutralizing any acid soil that may be taken in with the food. The epithelial lining of the gut secretes fat-splitting, carbohydrate-splitting, and protein-splitting enzymes. The gut is surrounded by **chlorogogen cells** which are derived from the peritoneum and probably function in the elimination of wastes from the blood. It is believed that fat is also stored in these cells.

Food for the earthworm consists of leaves and any other available organic matter, even bits of meat. Much soil is taken in with the food and used later in the gizzard for grinding the food in preparation for digestion. Food is temporarily stored in the crop before it passes into the gizzard, where it is ground to a fine mass. It then passes on

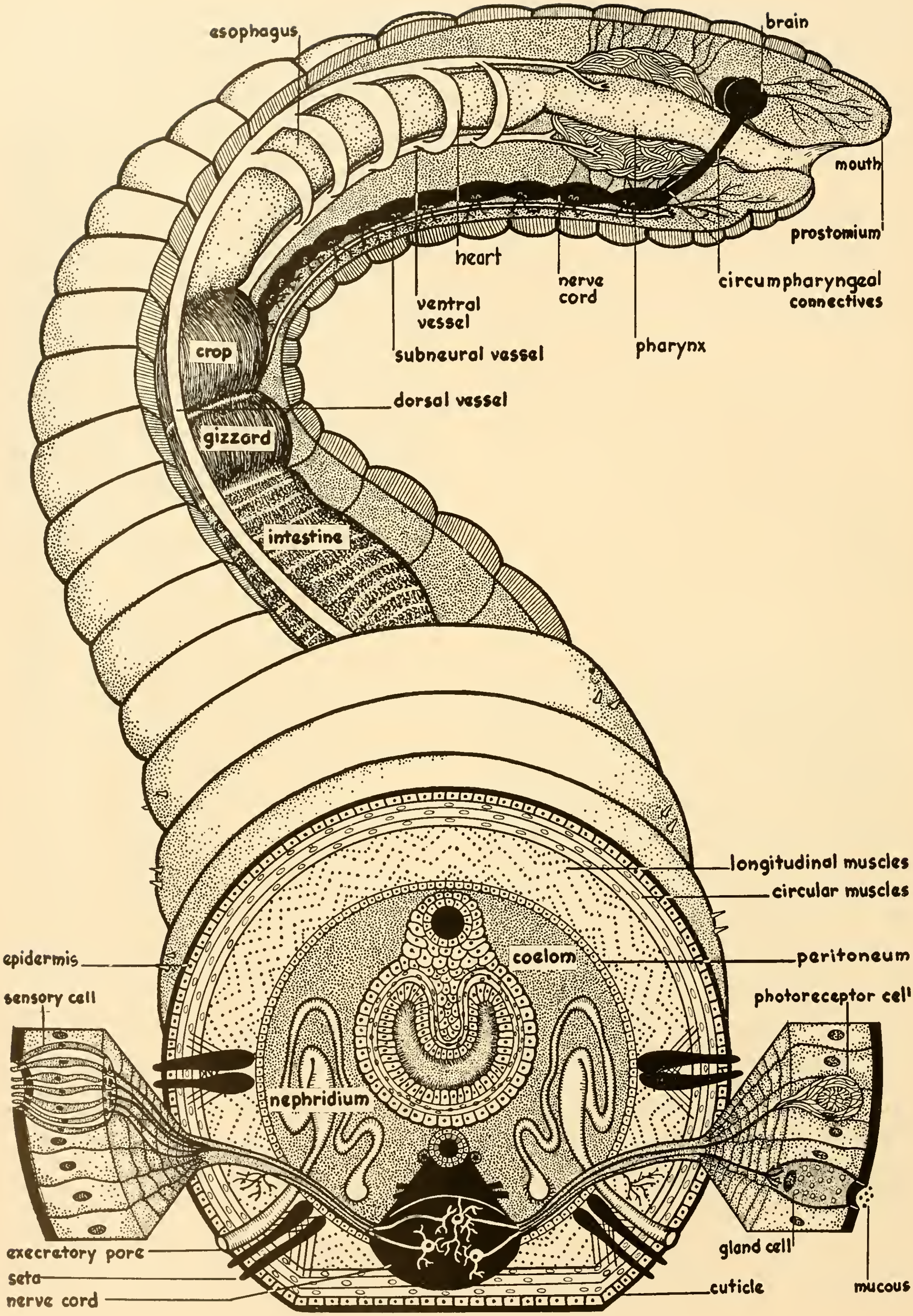


Fig. 10-16. Longitudinal and cross-section of the earthworm.

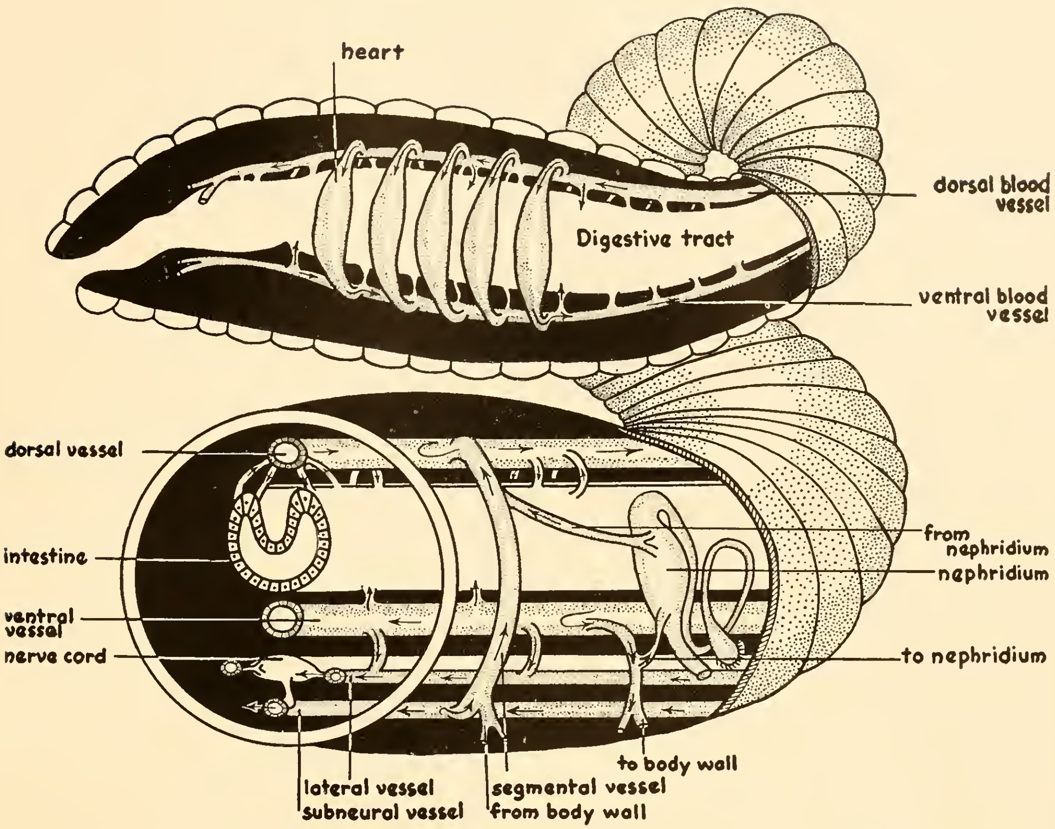


Fig. 10-17. A schematic view of the circulatory system of the earthworm. In the lower portion, one segment has been greatly enlarged in order to show the course of the blood.

to the intestine where digestion and absorption are carried on. Undigested material passes out through the anus. Earthworms deposit their "castings" on the surface of the ground near their burrows. When millions of worms continue this process for centuries in the same areas, the result is a constant inverting of the soil reminiscent of plowing in agriculture. The castings of the worms also greatly enrich the soil.

The **circulatory** system (Fig. 10-17) of the earthworm is similar to that of Neanthes. However, there is an improvement in the pumping system in the form of five pairs of "hearts" which surround the esophagus and connect the **dorsal** with the **ventral blood vessel.** In addition to the peristaltic waves that move the blood forward in the dorsal blood vessel, the "hearts" send it by a rhythmic contraction of their walls to the ventral blood vessel with considerable force. There are five principal blood vessels in the earthworm which convey blood to all parts of the body. The **dorsal** and **ventral** blood vessels are the main vessels that carry blood to and from the "hearts." The **laterals,** located on each side of the nerve cord, receive blood from the ventral vessel and carry it to the **subneural vessel** via the nerve cord. The blood then passes into the **segmental** vessels which convey it up to the dorsal blood vessel, picking up blood from both the nephridia and the body wall on the way. Short blood vessels extend from the dorsal vessel and convey blood to and from the intestine; blood also enters the intestine from the ventral vessel. A careful study of Fig. 10-17 shows the plan of the

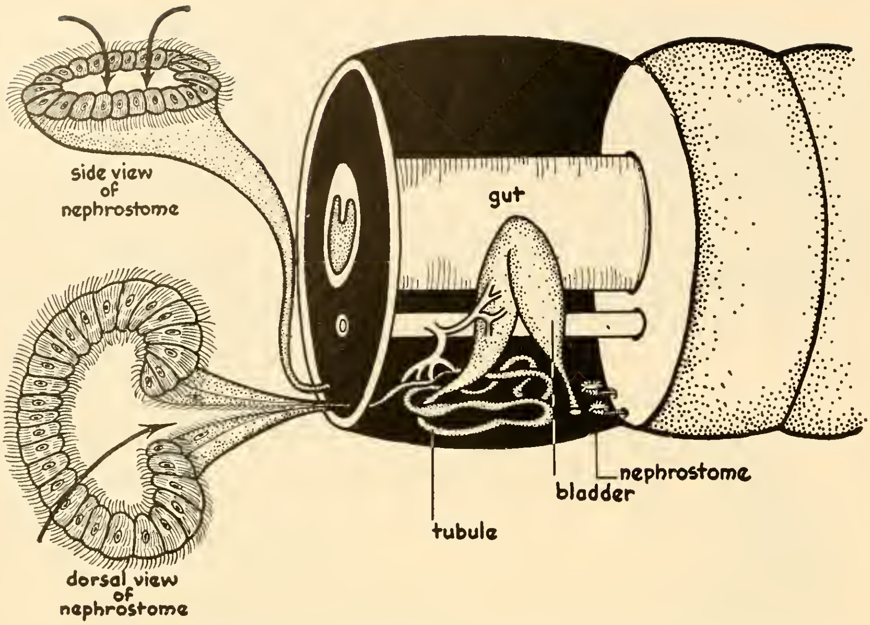


Fig. 10-18. A schematic side view of one segment of the earthworm showing the details of the nephridium. The nephrostomes have been greatly enlarged.

system, namely, five principal vessels running the length of the worm, with numerous cross-connections and branches supplying blood to all parts of the body. These are the first animals to possess a complete circulatory system. All animals above this group also have well developed circulatory systems.

The blood of the earthworm contains many white blood cells (**leucocytes**) floating in the fluid **plasma.** The respiratory pigment is hemoglobin, which is carried free in the plasma, not in corpuscles. The gas exchange takes place where the capillaries come close to the surface of the epidermis. For this reason the surface of the animal must be moist at all times, for a dry membrane will not allow the gaseous exchange to take place.

The arrangement of the nephridia is similar to that in Neanthes. The nephridium consists of a small ciliated funnel, the **nephrostome,** which opens into a tiny coiled tubule (Fig. 10-18). This penetrates the septum of the next segment, where it coils, gradually becoming larger and finally expanding into a bladder-like sac before opening to the outside through the **nephridiopore.** Nephridia are found in all of the segments except the first three and the last. The actual excretory process is carried on by the beating of the cilia of the nephrostome and the lining of the tubule, which causes waste products from the coelom to enter the tubule and be discharged from the body. Waste materials in the blood are picked up by the glandular portion of the tubule and excreted directly. The chlorogogen cells may also aid in this process.

Behavior. As might be expected, the behavior and hence the nervous system are more complex in the earthworm than in the lower types. The center of the nervous system is a bilobed "brain," located in the anterior region dorsal to the digestive tract (Fig. 10-16). The **circumpharyngeal connectives** connect to the **ventral nerve cord** which consists of a series of **ganglia** much the same as in Neanthes. There are a few nerve fibers extending into the prostomium, suggesting that this organ is probably sensitive to touch.

Research on the nervous system of the earthworm has revealed that it possesses the components of reflex arcs very similar to those of man (Fig. 10-16). Impulses come in from the external world through the sense organs on **afferent,** or **sensory,** fibers, pass to **association neurons,** and from these to **efferent,** or **motor, fibers,** which run out to muscles or glands. Thus in a form as low as the earthworm, there is an intricate nervous mechanism which enables the animal to carry out complex operations.

It is of interest to biologists as well as psychologists to know when the nervous systems of animals become complex enough to permit the storage of response patterns which we call memory. In other words, how far up the tree of animal life must we go to find animals that can profit by experience, or learn? One experimentalist (Swartz, 1929) found that an earthworm which at first would enter either branch of a Y-shaped tube could learn, after several hundred trials, to avoid one branch of the tube if an electrode were placed in it and the worm received a shock each time it entered that branch. This is perhaps the first animal so far considered that can profit by past experience.

There are no obvious sense organs present on the earthworm's body but microscopic examination of the epidermis reveals several kinds of sensory cells scattered among the ordinary epithelial cells which connect directly to the nervous system and function as sense organs (Fig. 10-16). Such cells are located in the parts of the body that are most likely to come in contact with the environment: the prostomium, the portion of largest diameter in each segment, and the mouth cavity. Some of these cells are specialized for light reception, while others respond to chemical and tactile stimulation.

The earthworm responds readily to light. If removed from the burrow, the worm becomes very active and immediately attempts to get away from the bright light and crawl into a crevice or burrow. If sought for at night with a flashlight, as is the habit of those who search for the so-called "night crawlers," the moment the light strikes, the worm retracts into its burrow with almost lightning-like speed, so fast that one must be very agile to catch it. It appears, then, that light is readily perceived and interpreted.

If an earthworm is experimentally placed near any volatile chemical, such as acetic acid, it responds violently and moves in the opposite direction. Likewise, it moves toward bits of meat or decaying vegetation, which, of course, are its food. In this case the sense organs appear to be located in the mouth cavity.

Since the earthworm is dependent on being able to find its way around underground in completely dark passages, it must rely on the sense of touch perhaps more than any other. The tactile end organs (Fig. 10-16) are bundles of modified epithelial cells with tiny protruding hair-like bodies that are in contact with anything that touches the body wall. They probably also function as a sort of hearing device, since any vibration on the earth near the burrow, as in the case of footsteps, causes the worm to respond readily. They do not respond to air-borne vibrations which affect our ears.

The earthworm is sensitive to temperature; it avoids cold and hot areas and seeks out moderate temperatures. In its natural environment it lies near the surface in its vertical burrow with the "head" uppermost when the temperature is moderate, receding if it is too cold or too hot. In winter it burrows down below the frost line and remains inactive throughout the cold season; it does likewise when the soil becomes dry during a drought. It cannot tolerate desiccation and therefore responds positively toward moisture, but only to a certain point, since it cannot withstand immersion in water for a long period of time. After a rain it is common to see on sidewalks earthworms which have been "drowned" out of their burrows. The apparently fantastic stories of earthworms falling from the skies during storms are perhaps founded on the same basis as the stories of frogs and other animals having "rained." This usually follows a tornado where masses of water have been carried into the air, resembling a water spout in the ocean, and these animals are taken along in the water and released many miles away.

The bristle-like setae are the earthworm's chief organs of locomotion. While the animal is in its burrow the setae in the posterior end project out and are imbedded in the wall of the burrow. This is done by contraction of the muscles at the base of the setae. Those at the anterior end then relax and the circular muscles contract, thus elongating the worm. The anterior setae then secure their end of the animal and the longitudinal muscles contract, bringing the posterior end forward. In such fashion the animal moves through its burrow. Since the setae are located on the ventral sides as well as the lateral walls, the animal is able to crawl slowly over a surface when removed from the burrow. If the anterior segments containing the brain are removed, the worm seems to move in a normal fashion, which means that the nerve centers for crawling movements are located in the ganglia and not centered in the brain.

Reproduction. In order to survive in its terrestrial habitat, the earthworm has been forced to undergo some drastic adaptations in its reproductive system. It will be recalled that most annelids discharge their sex products into water where union of the eggs and sperms is purely fortuitous. On land, obviously, some other means must be provided to bring about this union and to insure adequate conditions for the developing embryo. A most unique method has been devised for this purpose. In the first place, the sexes, which are separate in other annelids, are united in the earthworm, that is, it is **monoecious**, or **hermaphroditic**. This has the advantage of making it unnecessary for worms of different sexes to unite; any two worms can exchange sperms. This is important because the chances of animals meeting are less than would be the case in water where seasonal aggregations occur.

The **ovaries** and **testes** are located in the anterior end of the worm where ducts provide the proper exit for eggs and sperms (Fig. 10-19). There are two pairs of tiny testes located in the tenth and eleventh segments, surrounded by large sac-like bodies, the **seminal vesicles**, which are storehouses for the sperm cells. Funnels direct the sperm into the sperm ducts which open to the outside on the fifteenth segment. A pair of ovaries cling to the posterior wall of the septum in segment 13, and small funnels catch the eggs and direct them into a sac where they are temporarily stored. Eventually the eggs pass to the outside through the oviduct in segment 14.

The process of exchanging sperms occurs at night, usually following a rain. Two worms become attached along their ventral sides, as shown in Fig. 10-19; this usually occurs while the posterior ends of the worms remain in the burrows. Some, however, crawl some distance away from the burrow until contact is made with another worm. A slimy material is then secreted mutually by the worms which, as it hardens, encases both animals together in a temporary sheath. Small tubular passageways form between the sheath and the body walls, thus providing a pathway for the sperms, which are forced from each worm along these channels until they reach the **seminal receptacles** of the other worm. After this exchange of sperm cells the animals separate.

At some later period when the eggs are mature, the clitellum secretes a mucous sheath which slips forward like a tight sweater over a man's head. In the vicinity of the fourteenth segment eggs are forced into the mucous ring, and as it slips over the ninth and tenth segments sperms pass

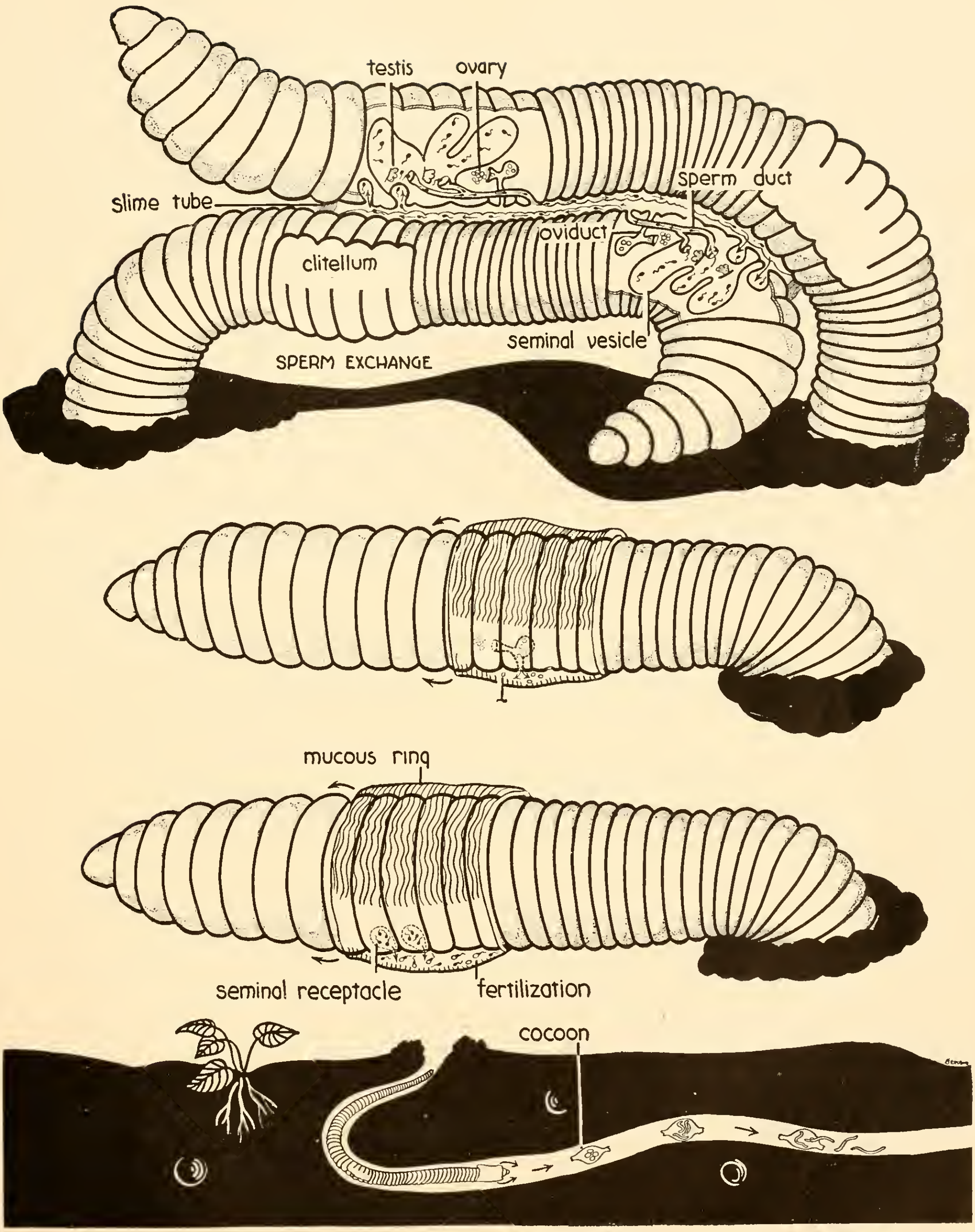


Fig. 10-19. Copulating earthworms, showing the various steps in the fertilization of the eggs and subsequent cocoon formation.

out of the seminal receptacles and unite with the eggs. After the mucous ring slips over the anterior end, the ends contract, forming a closed capsule, or **cocoon**, full of fertilized eggs, which is left behind in the burrow. There is no larval stage and the eggs hatch into small earthworms which penetrate the wall of the mucous capsule and begin to shift for themselves.

Relatives of the earthworm

Earthworms have many relatives which range in size from microscopic forms to species which may reach 10 feet in length. There are well over 2,000 species and most of them are smaller in size than the common earthworm. Although nearly all live in damp soil, some are found in fresh or polluted waters. One form, *Tubifex,* is encouraged to grow in filter beds of sewage disposal plants in order to keep the filter open. They are considered very valuable for this purpose and specimens are often shipped to new filters to start the "culture" going. The common blood worm, which is a species of Tubifex, is found in tubes at the bottom of fresh-water ponds where it feeds on the muck and perhaps aids in the purification of such waters when they are polluted. Another small form, *Enchytraeus,* is sold in pet shops as a source of food for small fish.

Certain of the small forms, such as *Chaetogaster,* reproduce asexually by transverse fission and sometimes several cling together, resulting in a chain of individuals. In some species this method has apparently replaced the sexual method altogether.

Leeches

After a swim in the old swimming hole, boys often find small black leeches that cling tenaciously to the skin. When removed, they leave a stream of blood flowing from the wound. It is also common for the fisherman to see a large (12 inches long) leech, *Haemopsis grandis,* swimming in beautiful undulating movements near the surface of the water. Another leech, *Hirudo medicinalis,* was once cultured in Europe for the specific purpose of bloodletting when that practice was in vogue. It is interesting to note that during the last century, and before, it was considered beneficial to remove blood in certain illnesses. Today the procedure is the reverse, as is indicated by the many blood banks over the country.

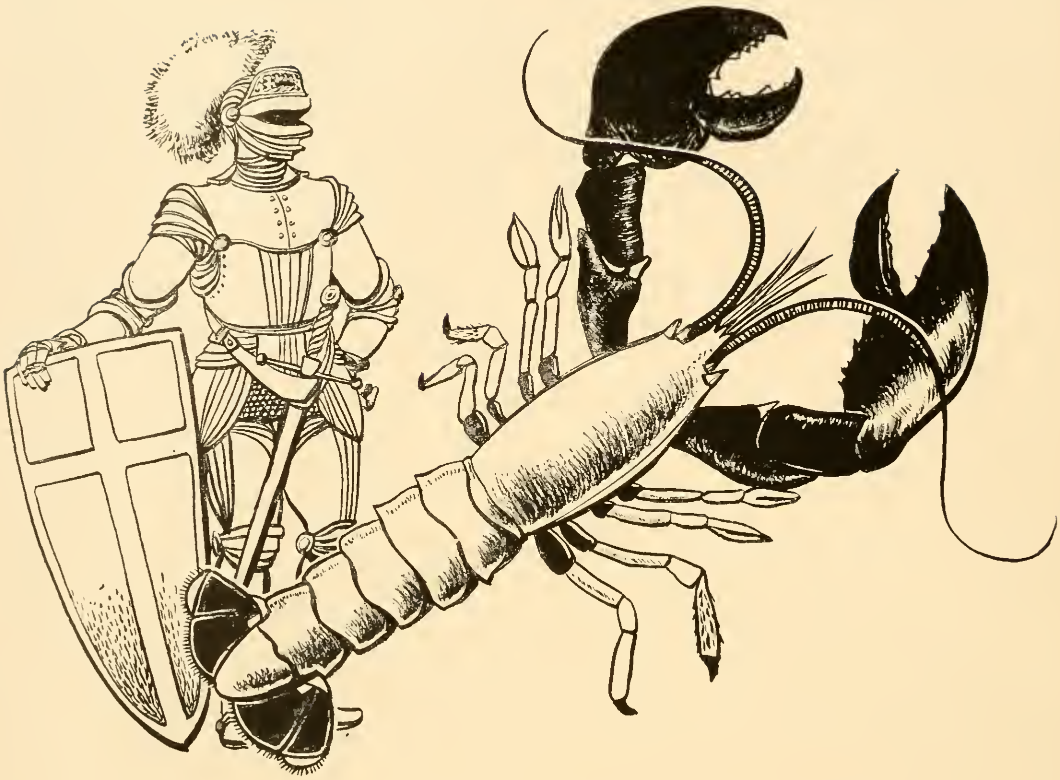
In some regions, particularly the tropics, leeches live in watering places where large vertebrates come to drink. They attach themselves to the buccal cavity, sometimes in such numbers as to cause serious injury to horses as well as other animals, including man. Some leeches live on land and are occasionally so numerous that they are a serious hazard to human beings. Army commanders have been known to provide their men with leech-proof stockings in order to get through such infested areas.

The leech has many of the annelid characteristics, but it lacks setae, and it possesses copulatory organs, which other annelids lack. What appears to be segmentation externally does not correspond with the actual segments, for there are fewer segments internally than appear from the outside. The body has remarkable powers of extensibility and contractibility, enabling it to move like the measuring worm. The hold-fast organs are two suckers, one on each end, which are used both in locomotion and in feeding. In the center of the anterior sucker is the mouth, which is usually provided with three small cutting teeth that inflict a wound when the leech is feeding upon its victim. The anus is located in the center of the posterior sucker. The digestive tract is sacculated so that it can retain a large meal of blood. Apparently this is provided because meals are usually few and far between, some leeches being able to live a year between feedings.

When securing a blood meal the leech becomes attached to the skin, which it pierces with its teeth. An enzyme (hirudin) is secreted by the salivary glands, which prevents the blood from clotting. Blood is sucked by the pumping action of the pharynx and stored in the large sacculated crop to be passed on into the intestine for digestion a little at a time.

In review, we have seen in this chapter the advent of characteristics of key importance to the development of more complex animal bodies. The acquisition of a coelom and segmentation, together with the "tube-within-a-tube" body plan, have laid the foundation for higher forms. Perhaps the features that have appeared so far in the animal kingdom are more important than any that follow, because later groups, while adding some new characteristics, actually become complex by elaborating features that are already established in the annelids. Let us keep these fundamental characteristics in mind as we examine the next groups of animals.

CHAPTER 11



ANIMALS WITH JOINTED FEET—THE ARTHROPODS

The body plan of the arthropods is sufficiently plastic and flexible to permit members of the phylum to fit into most of the niches of the earth. Although the arthropods resemble the annelids in many respects, they show important innovations. One of these is the hard outer skeleton, the **exoskeleton**, which functions as a rigid coat of armor. It is as if the cuticle of the annelid had become thick and rigid. This means that the muscles can be attached to the inside of this material and function more efficiently in moving the body. The exoskeleton supports the entire animal, much like the framework of an airplane or automobile. One can well realize the difficulty of trying to fasten the engine of an airplane to a soft fuselage. For the same reason the plan of the exoskeleton as an over-all superstructure is apparently a very good one. It is composed of a protein substance, **chitin**, which is impregnated with more or less lime, depending on the species. Some arthropods, like the lobster, have a high percentage of lime in the exoskeleton, whereas the insects have smaller amounts. The greater the lime content, the harder the skeleton. For the land dweller, exposed to rapid desiccation, a waterproof outer covering becomes essential. Since the exoskeleton of these air breathers is practically waterproof, one may assume that this condition made it possible for the animal to invade land.

One rather serious disadvantage to this external plate of armor is concerned with growth. As the animal increases in size, this suit becomes tighter and tighter, until finally the animal must rid itself of the old suit and secrete a new one. During the time of transition, however, the arthropod finds itself in a very precarious situation. Having shed the old suit, it must wait for its body size to enlarge and for the new skeleton to harden before its muscle can again be effective. This procedure may take several hours and during this time the body is very soft and nearly immovable. The animal is, therefore, unprotected at such times and takes special precaution to conceal itself from its enemies. The process of shedding the skeleton and growing a new one is called **molting**.

Another important difference between the annelids and the arthropods is the presence in the latter of feet with joints. This conspicuous character gives the phylum its name. The feet and legs of animals with a hard exoskeleton need joints for the purpose of movement. In the arthropods many appendages have lost their original locomotor function and have become radically modified into organs of defense, offense, and even sense organs. The exoskeleton and the jointed appendages thus have distinct advantages and have contributed much to the success of this group.

The nervous system, while similar in plan to that of annelids, is considerably more centralized. There are fewer ganglia, and more independence of all parts of the body. This increased integration has resulted in an animal that is swifter, more agile, and better able to cope with its environment.

The coelom is much reduced in size, being replaced to a large extent by a system of blood spaces called the **haemocoel.** There are certain modifications in other systems also, but these will be discussed in the various groups, as they occur.

The arthropods include such a wide variety of forms that it seems as though they had explored nearly all the possibilities. There are more species in this group of animals than in all others put together, in fact, several times as many. Furthermore, the number of individuals exceeds all other Metazoa. The arthropods literally encompass the earth; they invade the soil, the water, the air, the frigid polar zones, and the torrid equatorial latitudes. Since they feed on the same foods as man, they have become his most serious competitor, indeed, it has been said that the main struggle for survival today is between the arthropods, particularly the insects, and man. This might be true if man does not destroy himself first by his own cunning. Insects are carriers of some of the most serious diseases which affect man and his domestic animals, and although some species are beneficial, it is doubtful that the benefit to man of some outweighs the damage done by the others.

THE ONYCHOPHORA-PERIPATUS

The phylum Arthropoda is divided into several classes (Fig. 11-1), of which only four warrant discussion in an introductory text. The first is a very small group, the **Onychophora**, composed of about 70 species, all of which bear the name of *Peripatus.* These small animals are as interest-

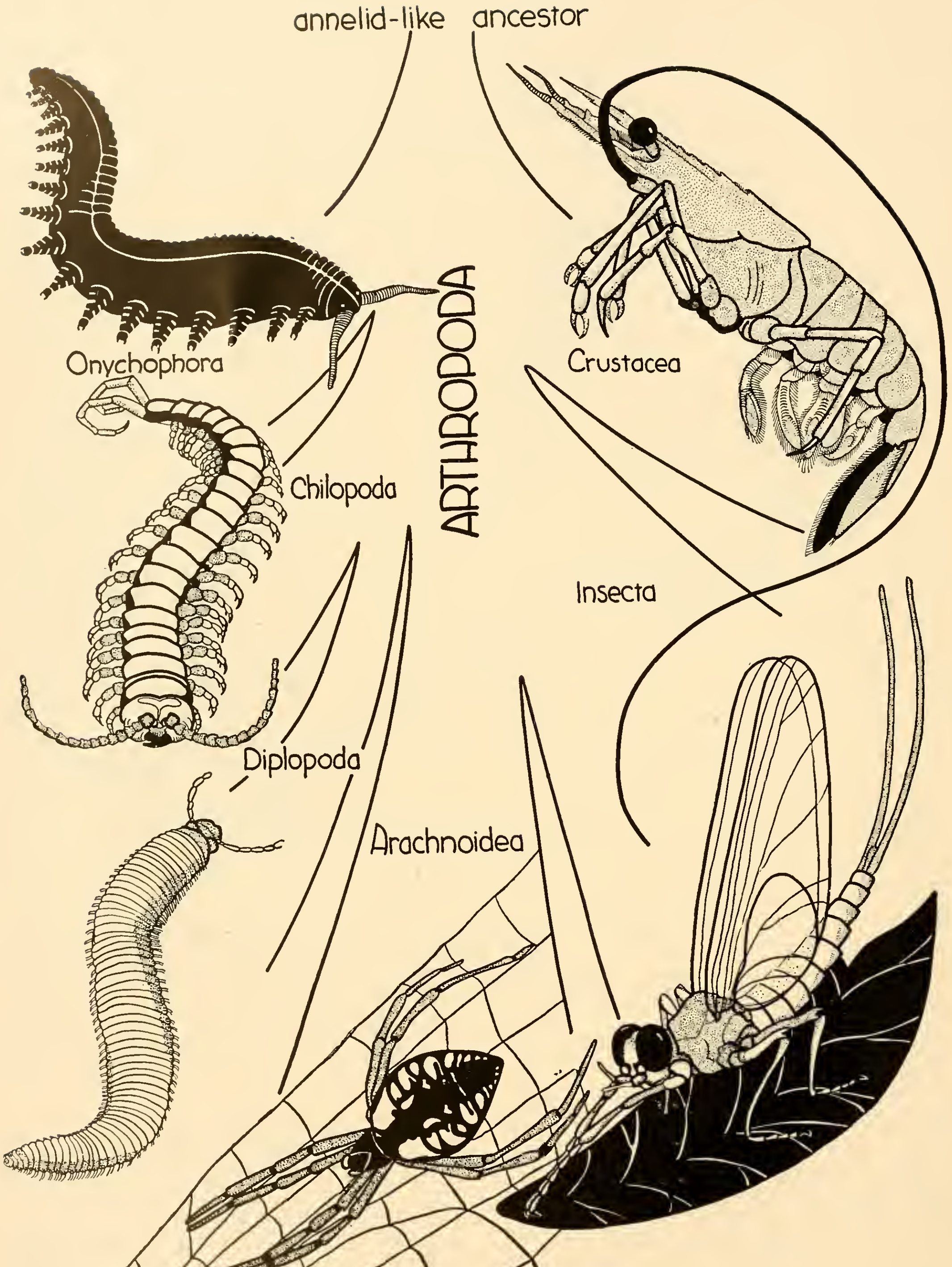


Fig. 11-1. Classes of arthropods.

ing as they are rare, being found only occasionally in widely separated places—in Africa, Australia, Asia, and the two Americas. Because they are limited to widely scattered, isolated places, they are thought to have come from the annelid-arthropod stock at a very early period in biological history, subsequently dying out in the areas between. Peripatus lives in the dense, tropical forests, in damp places under logs and other objects found on the forest floor. The inexperienced observer would mistake it for a caterpillar because of its long, many-appendaged soft body with anteriorly protruding antennae (Fig. 11-2). Like annelids, Peripatus has a pair of appendages for nearly every segment. These have clawed feet but they lack joints, hence unlike the typical arthropod appendage. The exoskeleton is also very thin, like the cuticle of annelids and very unlike the usual arthropod.

The excretory system is definitely annelid-like, while the nervous system is even more primitive than that found among the annelids. The occurrence of cilia in the reproductive tubules is also an annelid character, since such structures occur nowhere else among the arthropods. On the other hand, its circulatory system and coelom are similar to those found in other arthropods. The respiratory system resembles that of the arthropods but is sufficiently different to be thought of as having arisen independently.

It is apparent that Peripatus is, in many ways, intermediate between annelids and arthropods. This evidence seems to point unmistakably to the annelids as the arthropod ancestor. Of course, Peripatus is not identical with the early arthropod, since it must have gone through changes itself during this very long period of time. However, it seems to have changed but little by comparison to other present-day members of the phylum, and it seems safe to say that it probably resembles the early arthropod more than any other living form.

(Photo by Ralph Buchsbaum)

Fig. 11-2. ***Peripatus*** **is a rare animal that shows both annelid and arthropod characteristics and for that reason is of considerable interest to zoologists.**

Peripatus is thus a most remarkable animal. Some zoologists now place it in a separate phylum. It is a pity that it cannot be studied in the beginning zoology laboratory, but it is scarce, hence costly.

THE CRUSTACEA

The Crustacea make up a large and successful class of arthropods. They live on land, in fresh water (Fig. 11-3) and in the ocean (Fig. 11-4). They include such common forms as fresh-water fairy shrimps and crayfish (Fig. 11-5), seashore crabs (Fig. 11-6), lobsters, and barnacles (Fig 11-7). The group is of considerable economic significance to man. It is a valuable source of food, as demonstrated by the fact that around $10 million worth of shrimp, crab, and lobster are marketed annually in this country alone. The large leg muscles and the choice abdominal muscles of the

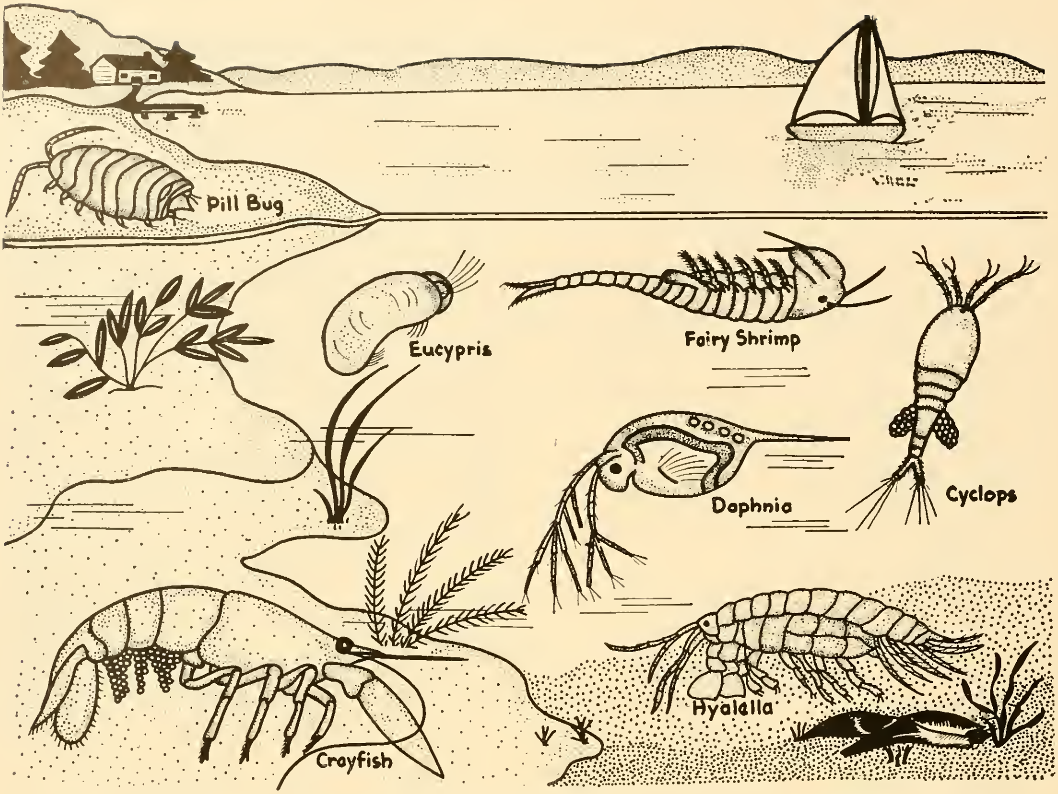


Fig. 11-3. Fresh-water and terrestrial crustacea. Although primarily aquatic, the pillbug lives on land.

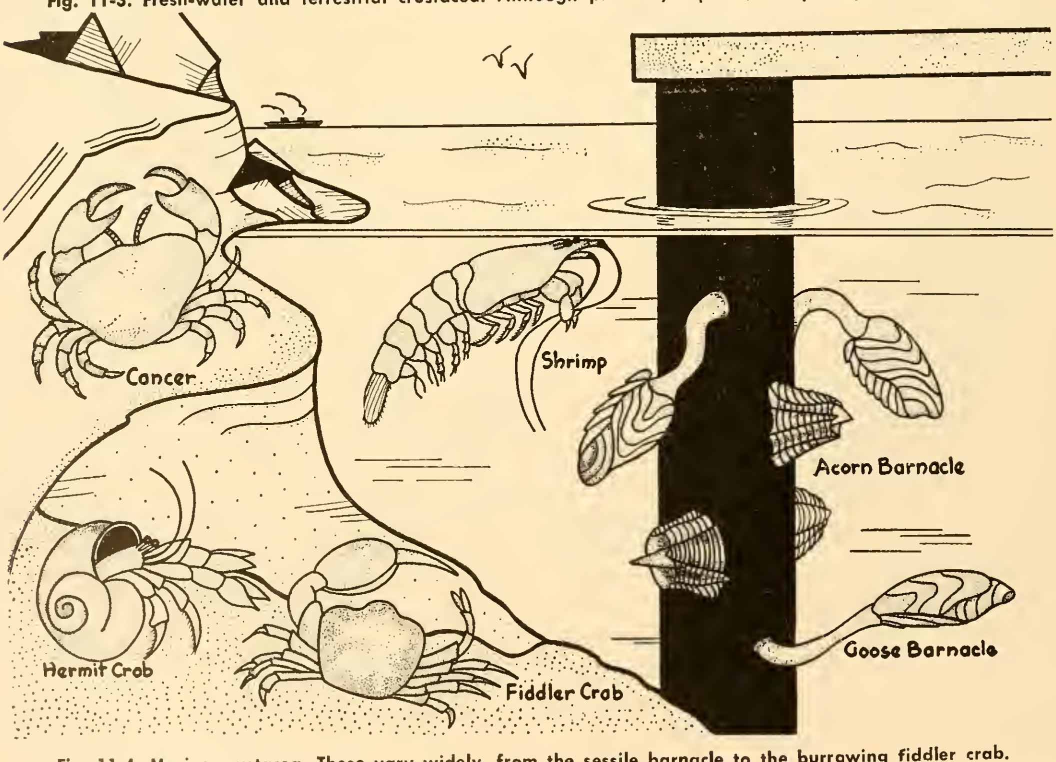


Fig. 11-4. Marine crustacea. These vary widely, from the sessile barnacle to the burrowing fiddler crab.

Fig. 11-5. The common crayfish (*Cambarus*) found over most of the United States. They live in ponds and streams where they feed on small fish or any other animal, dead or alive. Note the great area of the expanded tail (uropods and telson). This is very effective in locomotion. When disturbed, the animal contracts its tail powerfully, thus sending it darting backwards. The crayfish is much like its marine cousin, the lobster.

A

B

Fig. 11-6. The large edible blue crab of the Atlantic Coast (*Callinectes*). *A.* This crab is agile even on the sandy beach. It is moving rapidly toward the ocean in its typical side gait. When out of the water it is extremely pugnacious. *B.* Ventral view of the same animal, showing the large egg mass which is carried about until the young hatch.

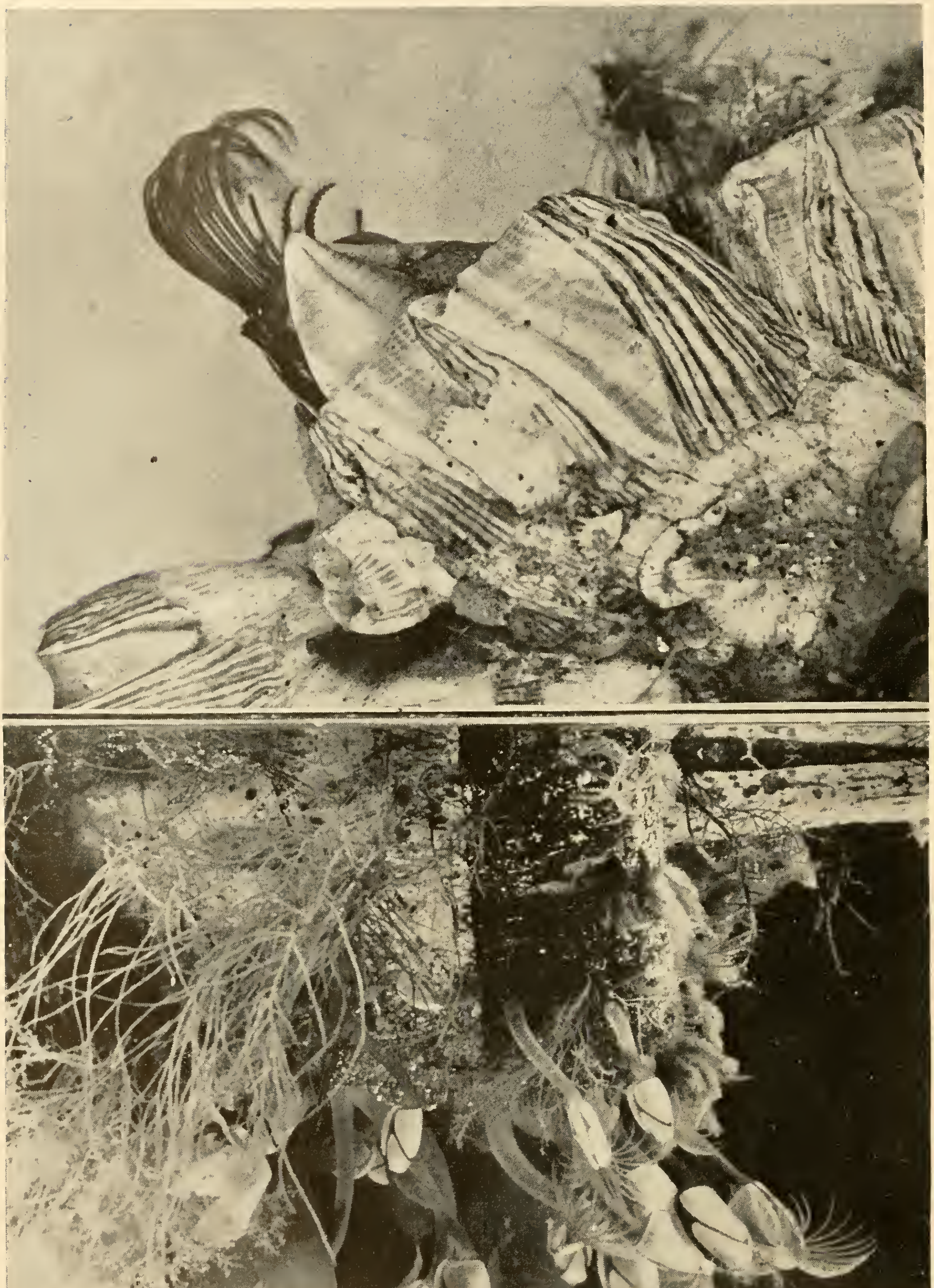


Fig. 11-7. (Upper picture) A rock-encrusting acorn barnacle (*Balanus tintinnabulum*). Its arthropod characteristic is indicated only by the jointed appendages which protrude between the valves of its shell. These are used to strain the water for tiny sea animals that make up the diet of this strange arthropod.

(Lower picture) The goose barnacle (*Lepas anatifera*) attached to a lobster pot buoy. The long stalks make it possible for them to sample larger areas in search of food than is possible for the stationary acorn barnacle.

lobster and shrimp are the parts usually eaten. The fresh-water crayfish (Fig. 11-5) and other Crustacea are generally not eaten in this country, although in certain parts of the world they are considered excellent food. In addition, the Crustacea play an important rôle in the food chain of fishes (see p. 95). There is a stage in the development of all fish when they must feed on some form of Crustacea; this may be the larval stage of some larger form, such as the crayfish, or it may be a minute adult crustacean, such as **cyclops** or **daphnia** (Fig. 11-3). If it were not for these small animals, fish would never get through the early part of their life. Some Crustacea, on the other hand, act as intermediate hosts for certain dangerous parasites of man, such as the human lung fluke, *Paragonimus westermani.* On the whole, the group is important both economically and biologically.

Let us consider a representative member of the Crustacea in some detail. The lobster and crayfish are excellent examples and because of their universal distribution are readily available for study.

The lobster and the crayfish

These two closely related animals live in different environments, the lobster in the sea and the crayfish in fresh water, yet their bodies have much the same appearance. In fact, a description for one also fits the other fairly well. This discussion is confined largely to the lobster, although frequent references will be made to the crayfish.

The lobster is a bottom dweller, spending its life seeking food, which consists of other Crustacea, small fish, and mollusks. It feeds as a scavenger whenever it finds dead animals on the ocean floor. It is a secretive animal, hiding by day in any cavern that affords enough space for its body, and sallying forth at night, crawling forward along the sea bottom, alert to any stimuli that may mean food is in the vicinity. If in danger of attack by other predators, it can swim backward with darting speed by powerful strokes of its abdomen. In so doing, it stirs up the mud at the bottom, thus forming a "smoke screen," which confuses the intruder and allows the lobster an opportunity to gain distance to a safe place. The crayfish employs the same methods in defending itself, and it seeks the same type of food in much the same manner.

Structure. The animal is enclosed in a **chitinous exoskeleton,** containing considerable quantities of lime and sclerotin which make the skeleton rather heavy and bulky, but a very excellent armor plate (Fig. 11-8). Since the animal is suspended in water, most of its weight is taken care of by buoyancy, and it is still a very agile creature. The **chitin** thins out at the joints, allowing maximum flexibility. The anterior portion of the body is covered by the **carapace,** and each posterior abdominal segment by an arched dorsal **tergum,** two lateral **pleura,** and a ventral **sternum.** Tiny holes perforate the entire skeleton, being particularly numerous in the appendages and tail region. Set into these are bristles, which make the animal extremely sensitive to its surrounding world through tactile stimulation.

The appendages of the lobster or crayfish demonstrate a very interesting series of adaptations and modifications for a particular mode of life (Fig. 11-9). There are nineteen pairs of appendages in all, one pair on each segment. The **antennules** and **antennae** are modified for tactile and chemical stimulation; the **mandibles,** or **jaws,** for chewing; the next five, **maxillae** and **maxillipeds,** chiefly for food manipulation; the next pair, the enormous **chelipeds,** for grasping food and for defense; the next four for walking; and the last six for swimming and various other functions. All of these appendages, with their variety of form and function, come originally from a simple appendage with a single function, namely, locomotion (Fig. 11-10).

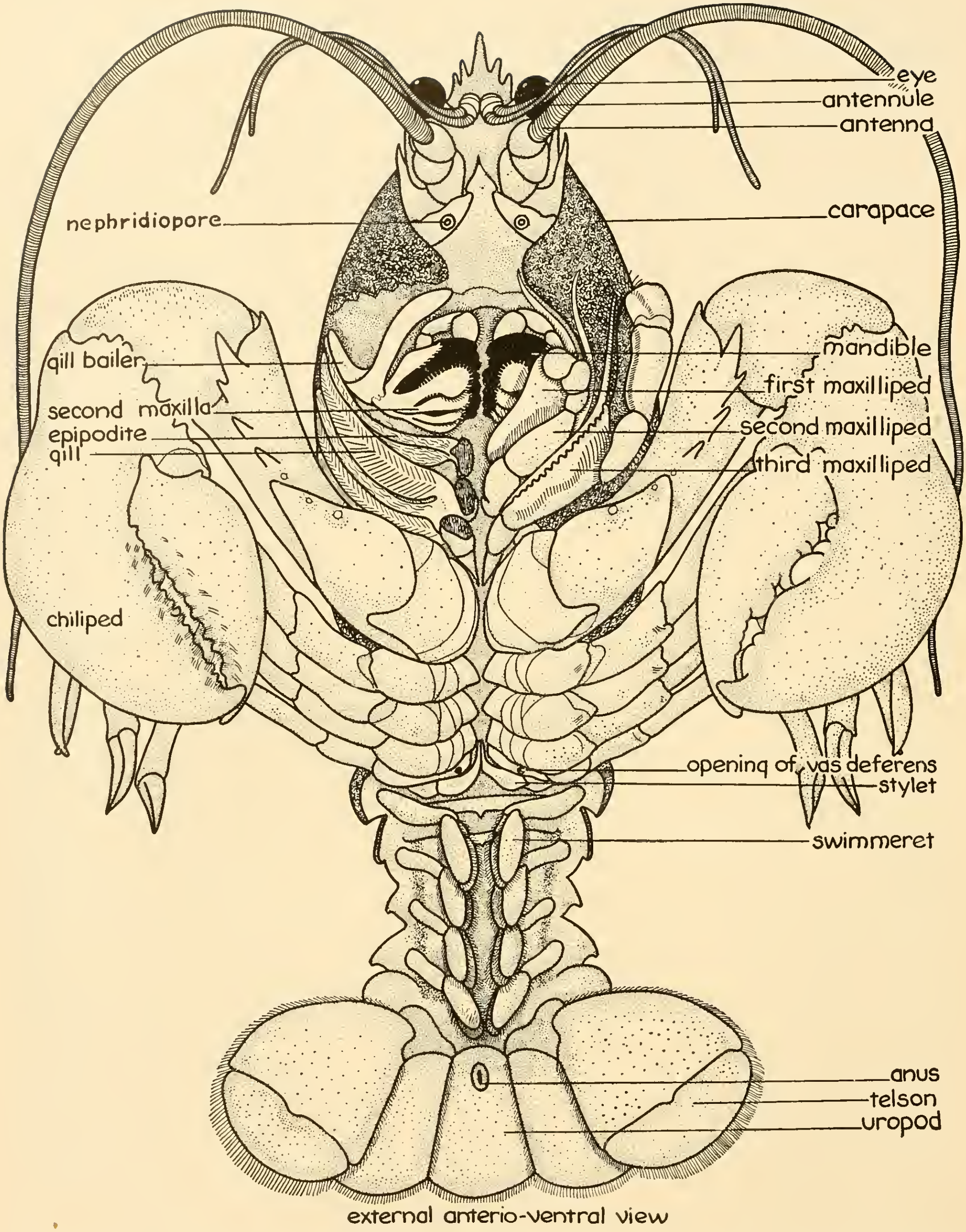


Fig. 11-8. Lobster, ventral view. A part of the carapace on the right side is cut away so that the underlying appendages can be seen.

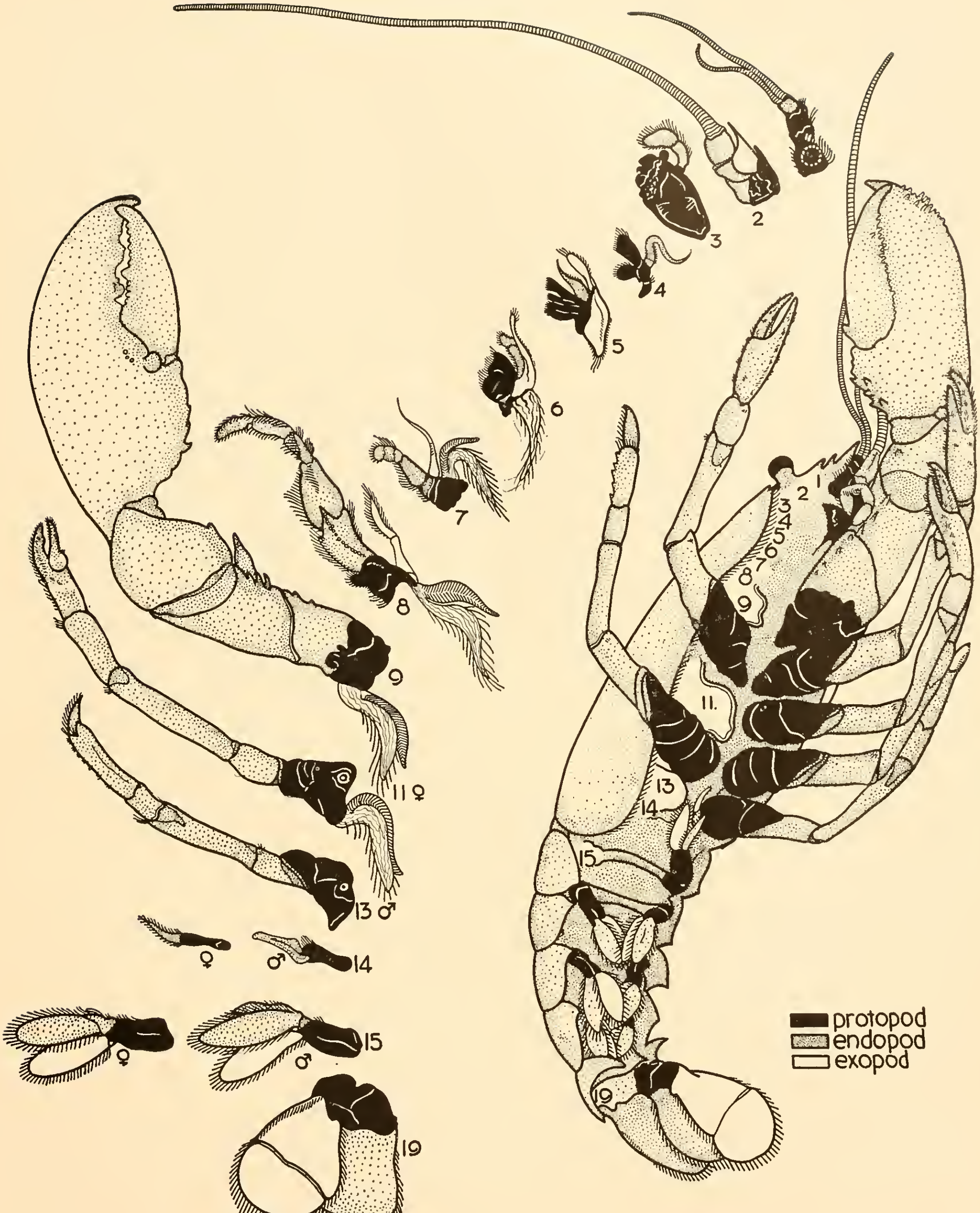


Fig. 11-9. Lobster appendages. Most of the right appendages have been removed for comparative purposes. Each retains parts of the original larval appendage, but here it is drastically modified to perform specific functions. This is an illustration of serial homologies among the invertebrates.

The primitive appendage, one which appears in the early embryology of all Crustacea, is said to be **biramous**, because it branches into two parts. It persists in its primitive condition in the **swimmerets**, located on the underside of the abdomen. The single basal portion, the **protopod**, is attached to the body and two branches extend from it, the **endopod**, toward the median line and the **exopod** away from it. The original function of such an appendage was locomotion (swimming), and all of the primitive Crustacea, such as the fossil trilobites, possessed just this type and nothing more. Through the ages it became modified in a most versatile manner in all of the appendages except the swimmerets. For example, the antennules and antennae are receptors for tactile and chemical stimuli and resemble the swimmerets very little. One of the most radical departures is the mandible, or jaw, where there is almost no hint of its progenitor. Among the walking legs, as well as other appendages, the exopod has been greatly reduced or lost entirely.

Structures that have a common origin, such as in the case of these appendages, are said to be **homologous**, and when they are on the same animal they are said to be **serially homologous**. This introduces the principle of **homology** which is illustrated throughout the animal kingdom and is very important in determining animal relationships. Homologous structures have a common embryological origin, therefore when two animals show such structures, even though they may not have the same function in the adult form, the animals are known to be closely related. The more nearly the structures are alike the closer the relationship, which means that they came from a common ancestor. We shall discuss this topic again in the last chapter of this book.

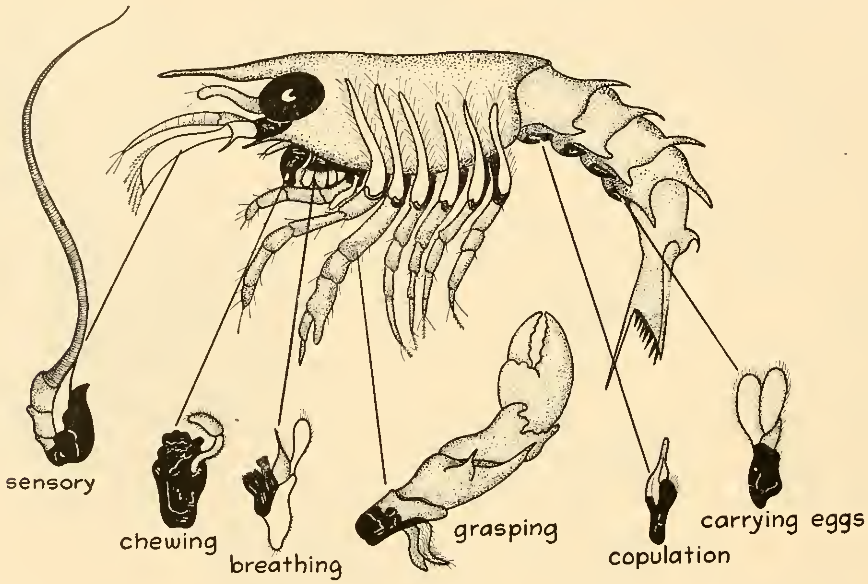


Fig. 11-10. Young lobster, showing the undifferentiated appendages, together with the appendages as they will appear in the adult animal. Note how they are modified for specific functions. In the young form the appendages are designed primarily for locomotion, in the adult they take on a variety of functions.

Upon cutting through the body wall, among the first and most obvious structures noted are the muscles, particularly in the

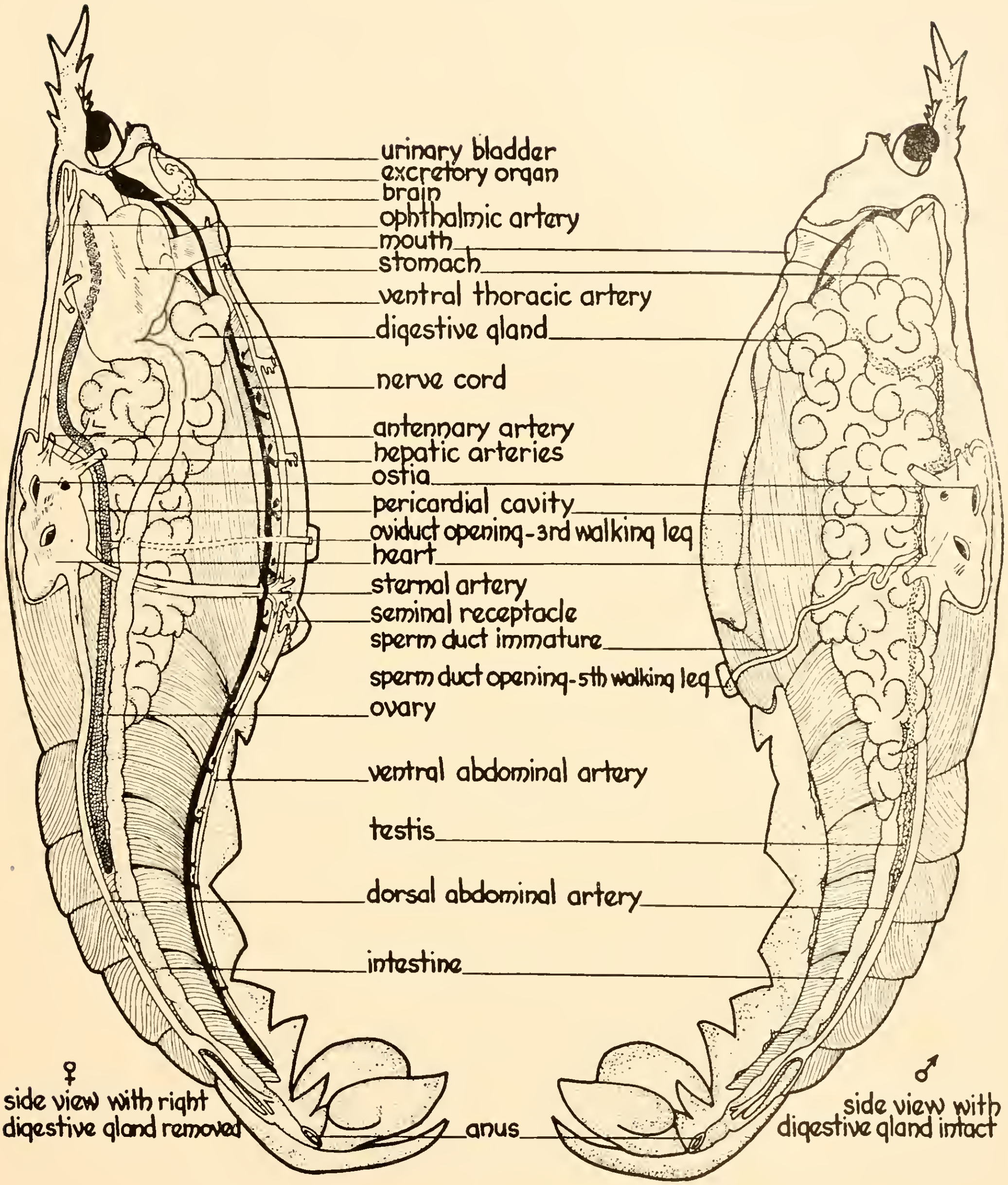


Fig. 11-11. Internal anatomy of the lobster, both male and female.

abdominal region. The muscles are attached to the internal side of the exoskeleton, where they are always in pairs, and oppose one another in action. One muscle pulls an appendage or any other part of the body in one direction, whereas the other pulls it back again. The principle is followed by all higher animals with skeletons, including man.

Digestive system. The **chelipeds** catch and crush the food, then pass it to the **mouth** with the aid of the **maxillae** and **maxillipeds** (Fig. 11-8). The **mandibles** break the food up still further, before it is swallowed through the short **esophagus** and taken into the large **cardiac stomach**, which functions more as a storehouse for food than as a digestive organ (Fig. 11-11). At the posterior end of this organ is the **gastric mill**, which is composed of three small tooth-like bodies called **ossicles**, two in a lateral position and one in the mid-dorsal line. These fit tightly together and the grinding movement is brought about by muscles attached to the outside of the stomach. Before food can pass on into the second stomach, called the **pyloric stomach**, it must pass through the gastric mill, which grinds all the food fine and renders it digestible. In addition, the two stomachs are separated by filtering "hairs" which act as strainers, allowing only fine particles to pass through. Foods that cannot pass through, such as parts of skeletons, are regurgitated through the mouth. Once the food is in the pyloric stomach some of it passes into the two large multi-lobed **digestive glands**. The enzymes necessary for the complete digestion of the food are secreted by these glands. Digestion occurs for the most part in the upper end of the **intestine**, although some apparently goes on in the digestive glands themselves. Absorption also takes place here, and in the intestine. All undigested food in the intestine passes out through the **anus** as feces.

Circulatory system. The circulatory system of the lobster varies markedly from that of the annelids. Instead of several pairs of hearts, the lobster possesses a single pulsating vesicle that lies on the dorsal part of the body, surrounded by a thin membrane and cavity, the **pericardium** and **pericardial cavity**, respectively (Fig. 11-12). The **heart** has three pairs of tiny valved openings, called **ostia**, which allow the blood to enter from the pericardial cavity. Seven arteries lead away from the heart and convey the blood to all parts of the body.

From this point on, the system differs even more radically from that of the earthworm. The blood leaves the tiny arterioles and passes out into spaces, called **sinuses**, where it bathes the tissues. This type of system is called an **open blood system**, in contrast to the closed system of the earthworm. Once the blood leaves the tissues, it seeps into the ventral portion of the **cephalothorax**, then through a set of **afferent vessels** (to the gills) where gas exchanges take place. It then makes its way to the pericardial chamber of the heart, through **efferent vessels** (away from the gills), thence through the ostia, and out into the body again. Valves located in the walls of the ostia permit the blood to pass through the ostia in one direction only, namely into the heart.

The blood contains colorless leucocytes as well as a respiratory pigment, **hemocyanin**, which has a slight bluish color when oxygenated and serves the same oxygen-carrying function as the hemoglobin does in other forms. The blood has remarkable clotting properties. If an appendage is removed forcibly, there is hardly any noticeable loss of blood, the clot forming almost at once, and filling the large opening.

Breathing system. When the lateral walls of the carapace are cut away, large feather-like delicate gills are exposed. These are the breathing organs of the animal. While the crayfish lies quietly in running water, the water moves over the gills without any help from the animal. However, when the demand for oxygen is greater or when the oxygen content of the water is low, a special modification of the second maxilla, the **gill bailer** (scaphognathite), waves up and down, like a gondolier sculling a boat, causing the water to flow over the gills in a posterior-anterior direction. This can easily be demonstrated by placing a crayfish in a shallow white pan and allowing a small amount of India ink to be placed near the posterior end. Great clouds of the carbon particles will issue from the anterior end, indicating a flow of water. Since the openings of the excretory organs, which lie at the base of the antennae, are in the

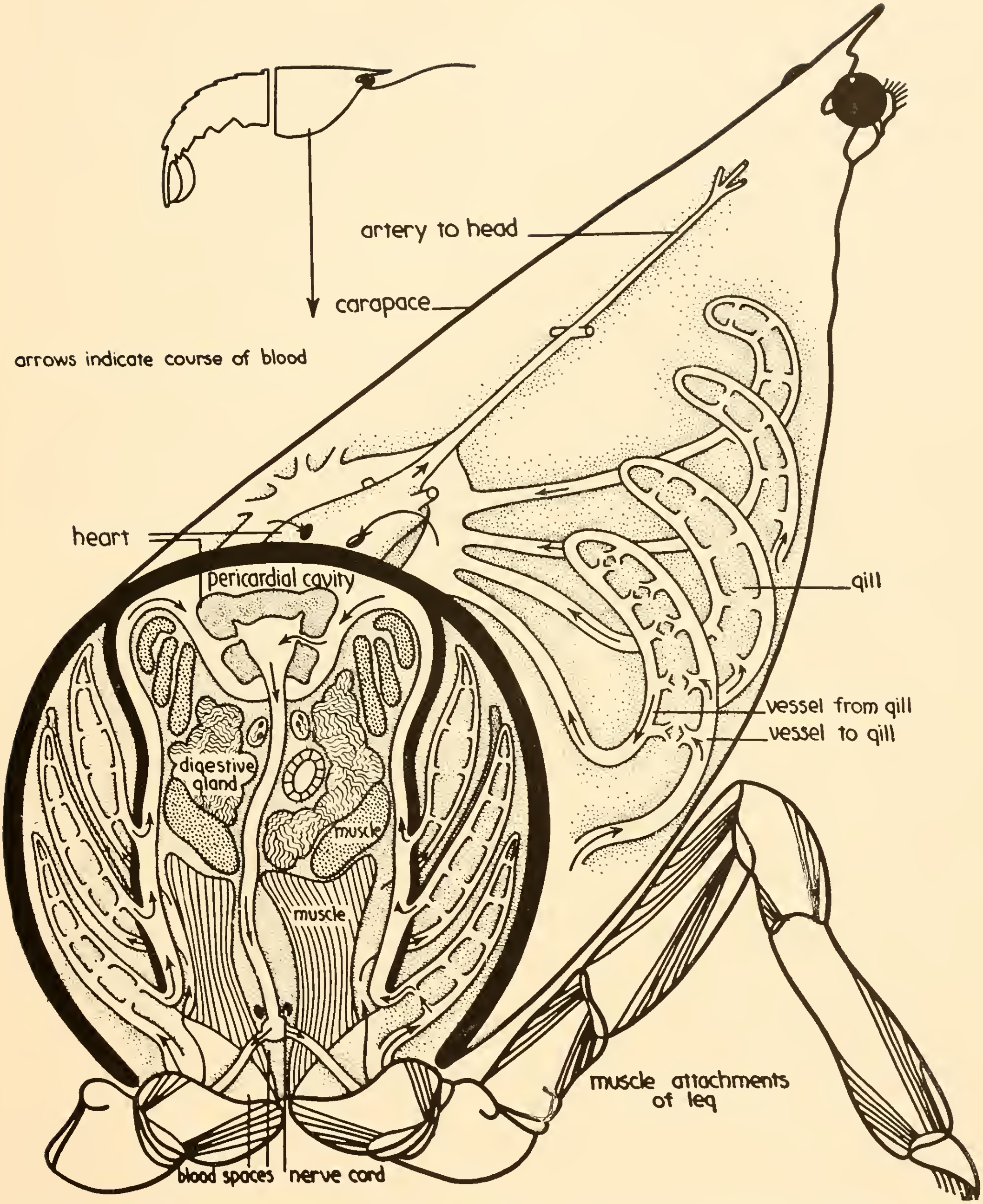


Fig. 11-12. Cross-section and partial side view of the lobster to show the internal organs, circulatory system in particular.

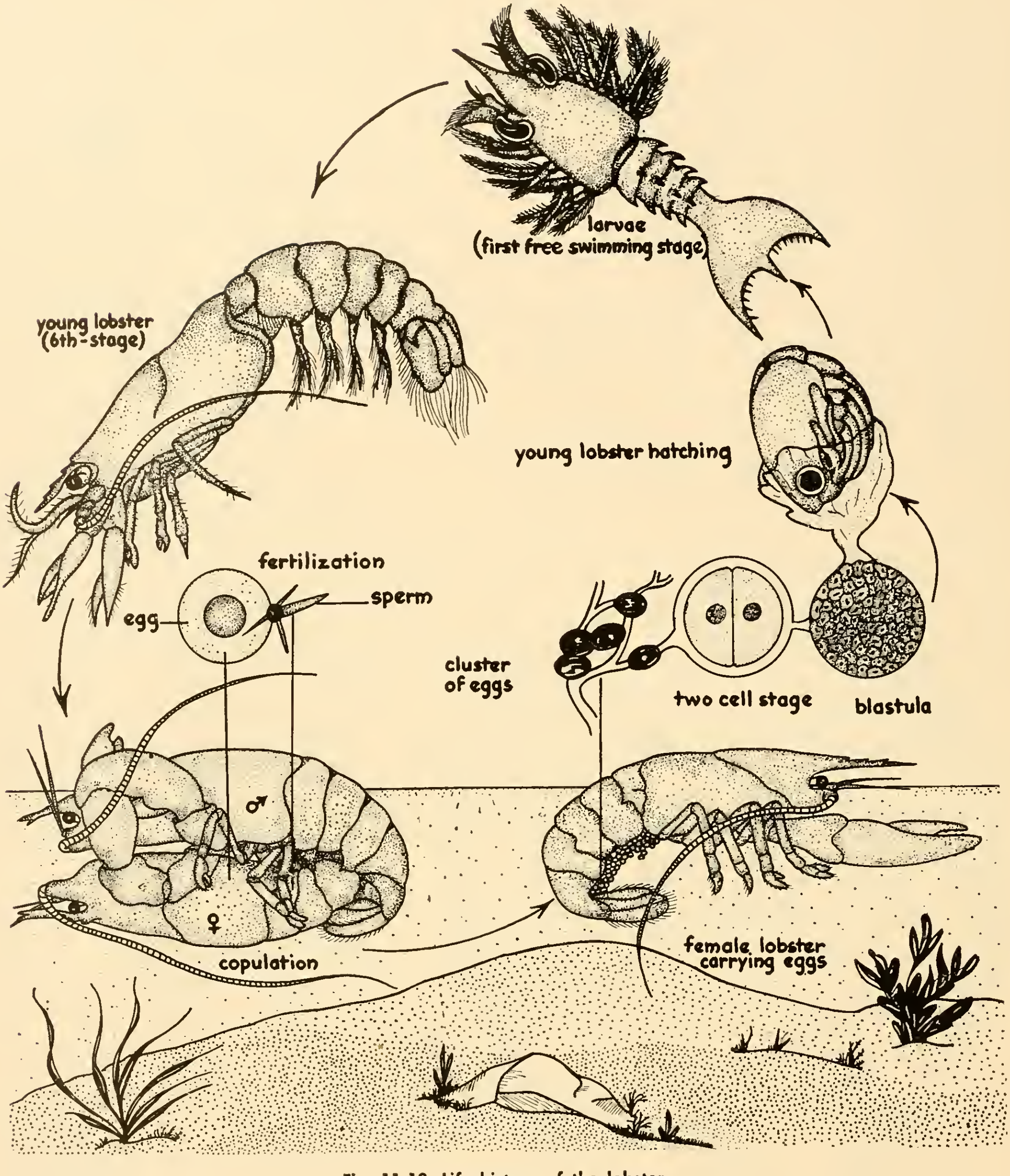


Fig. 11-13. Life history of the lobster.

path of this outgoing water current, the waste products from these organs are also carried away.

Excretory system. Nitrogenous wastes are withdrawn from the blood and body fluids by a pair of **kidneys**, called the **green glands** because of their color. They are located beneath the antennae in the body and consist of a **glandular** portion and a **bladder** (Fig. 11-11). The bladder stores waste material until it is released through the opening at the base of the antennae, already referred to.

Reproductive system. The gonads differ slightly in shape in the lobster and the crayfish; they are longer and thinner in the former and fused into a three-lobed gland in the latter (Fig. 11-11). Sperm cells are

Fig. 11-14. A female crayfish carrying her eggs attached to the swimmerets. The eggs are about ready to hatch because close observation will reveal the embryos just under the shell of the egg. As a matter of fact, these did hatch the following day.

produced in a tubular **testis** and pass through the **vas deferens** to an opening at the base of the fifth (considering the chelipeds as the first walking legs) walking legs. An ejaculatory duct toward the end of the tube aids in removing sperm during mating. The first pair of swimmerets is modified in the male to form a **copulatory organ** for transfer of the sperm to the **seminal receptacle** on the ventral side of the female. The ovaries of the female produce eggs which pass through a straight oviduct to the opening at the base of the third walking legs. Her first pair of swimmerets is rudimentary.

At the start of copulation the male lobster grasps the chelipeds of the female with his pincer-like appendages and turns her over on her dorsal side (Fig. 11-13). The two ventral sides then come together. The first pair of swimmerets of the male is placed near the opening of the seminal receptacle of the female and the sperms are discharged. The female receives the sperms in packets or **spermatophores**.

The female lobster lays eggs only once in two years, usually at the time when the water has reached its summer temperatures (from about mid-June to September 1st). The male, however, is unable to discern the sexual condition of the female and copulation often occurs long before the maturation of eggs in the ovary. In such cases the sperm cells, which are stored in the seminal receptacle of the female, must maintain their vitality for a long time, very often for several months. Eggs are fertilized after their ejection from the oviducts. As the eggs are extruded, a mucous material is produced by glands in the swimmerets which glues the eggs to the many bristles on these appendages. The eggs are thus carried by the female from ten to eleven months (see Fig. 11-14 where a crayfish is carrying her nearly hatched eggs) and usually do not hatch until the summer following that in which they were laid. This condition has resulted in much confusion concerning the laying of eggs by the lobster.

When the lobster hatches as a free-swimming larva, the period of fosterage is over for the female lobster. By fanning movements of the swimmerets the young are driven away from the body of the mother. Young lobsters, however, tend to keep together in a cluster.

Growth. Molting is an important process for the crayfish and lobster, as it is for all of the arthropods. This is necessary in order to provide for increase in the animal's size, although a small amount of growth can occur under the rigid exoskeleton. Just before the molting process begins, some of the lime is withdrawn from the exoskeleton, softening it somewhat. Simultaneously, a new skeleton is secreted beneath it, arising from the epithelium, called the **hypodermis.** The muscles and body bulk then shrink a little and the old skeleton splits on the dorsal side, between the abdomen and carapace. The animal backs out slowly, leaving behind a replica of itself, complete in all details, except for the actual body. This shedding is so thorough that even the facets of the eyes, and the lining of a part of the gut are included. Once the old skeleton is cast off, the animal grows rapidly for a period of time as a result of taking in a great deal of water. For several days during the hardening period the animal remains in hiding, and it becomes aggressive again only after its skeleton is well hardened.

Another interesting characteristic of many crustaceans, associated with growth and reproduction, is **autotomy,** the power to throw off appendages at will. The fiddler crab affords a most striking example of this phenomenon. If one of its posterior legs is held with a forceps, it will drop it off readily (Fig. 11-15). As other legs are pinched, they too are dropped but with increasing reluctance, until but three remain. Then it must be stimulated rather drastically before it will leave these behind. It seems to sense the danger of being legless, even though it will later acquire a new set through **regeneration.** The value of autotomy is obvious; it enables the animal to escape with the loss of a single appendage, whereas without this ability it might not escape at all. The break always occurs at a certain place near the base of the leg. There is a constriction of the wall at this point so that the loss of the appendage is followed by only a minor loss of blood.

The lost parts are replaced by the slow regeneration of a new appendage. This occurs more readily in young animals than in older ones, although the ability to regenerate seems to remain throughout life. Perhaps due to the greater specialization of these animals regeneration is limited to the appendages and to the eyes, and thus much less pronounced than in the lower forms of animals. This is as might be expected, since the greater the integration of parts, the more dependent each one is on the other, and the less possibility there is for any part to replace the whole animal. The ability to regenerate is reduced still further in the vertebrates.

The nervous system. In contrast to the rather meager sensory equipment of flatworms and annelids, the lobster and crayfish are well supplied with sense organs. If a small bit of liver is dropped in one end of an aquarium containing a crayfish, very shortly the animal will orient itself in the proper direction and move directly toward the food. The soluble parts of meat diffuse through the water and touch tiny hairs on the chelipeds, antennules, antennae, and mouth parts, causing impulses to pass to the central nervous system. This sensitivity to chemicals is equivalent to man's senses of taste and smell.

The animal's ability to move about satisfactorily in total darkness indicates that it must have senses that guide it under such

Fig. 11-15. (Upper picture) A "head-on" view of a fiddler crab (*Uca*), showing the great difference in the size of the first pair of legs. The large claw is present only in the male and he brandishes it in a peculiar manner in the presence of a female who has no such adornment. This peculiar activity is probably responsible for the name. These animals live in burrows near the water's edge where they go to feed on any dead and decaying matter.

(Lower picture) The same crab is shown after it has been stimulated to release its appendages (autotomy). Each appendage was grasped with a pair of forceps and squeezed until the crab threw it off. It released its first appendages readily, but no amount of pinching would force it to throw off the last three. It apparently was aware of the necessity of keeping a few legs.

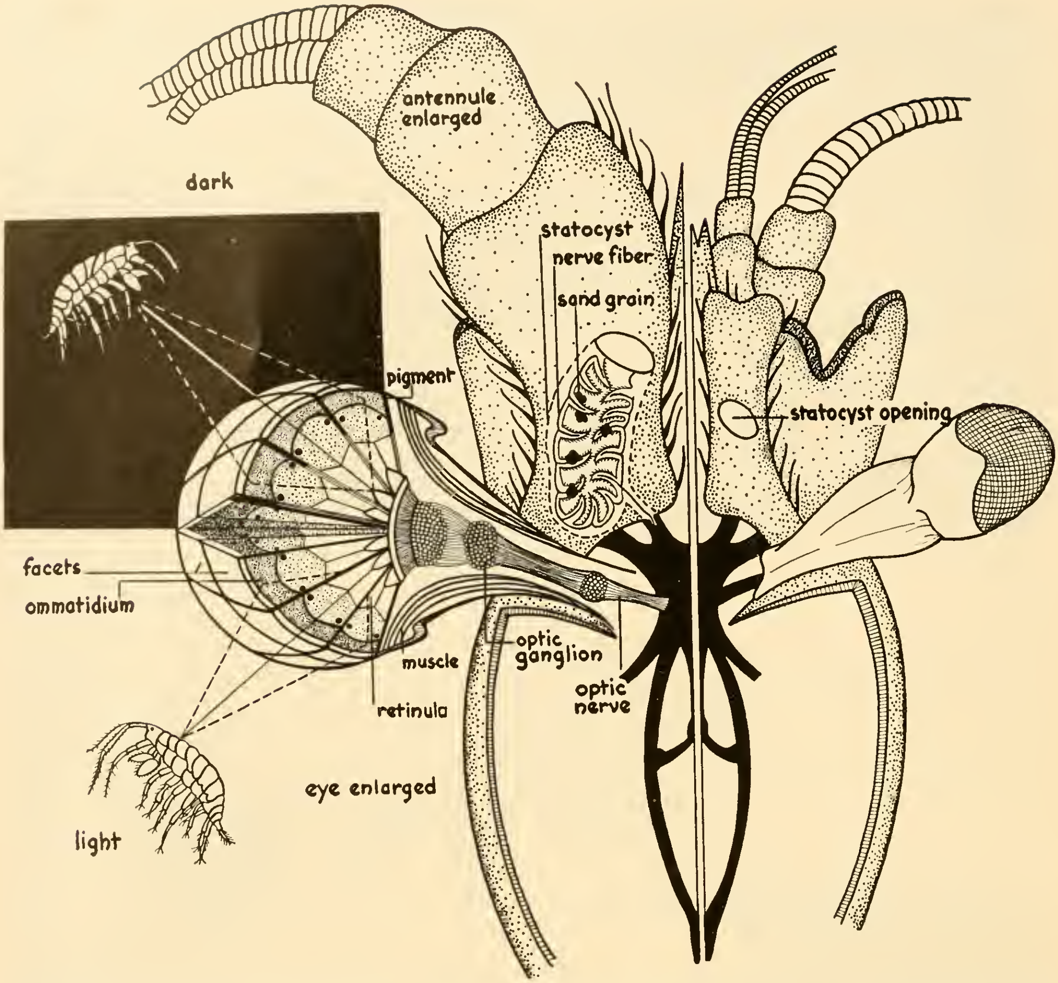


Fig. 11-16. Nervous system of the lobster, dorsal view. The eye and statocyst have been greatly enlarged and simplified in order to show their manner of function. The eye is further divided into two parts: the upper portion shows how it functions in the dark; the lower portion, how it functions in the light.

conditions. The sensory structures involved here are the tactile hairs which are stimulated whenever any part of the body comes in contact with an object. Tactile hairs are particularly abundant on the chelipeds, at the end of the telson, on mouth parts, and underneath the body. They may also be sensitive to vibrations in the water, thus providing the animal with a "hearing" mechanism which functions somewhat like the ears of vertebrates.

The animal is continually responsive to gravity, even when swimming freely, which means that it must have organs of equilibrium. These organs are the **statocysts**, located at the base of the antennules. They consist of small cuticular sacs, containing tiny grains of sand, which are glued to small sensory hairs (Fig. 11-16). The nerve fibers from these sensory hairs join to form a large nerve leading to the brain. The proof of the function of these statocysts can be determined experimentally. During the molt the cuticular lining of the statocysts, together with their grains of sand, are lost, so that the crayfish must replace its sand grains (**statoliths**) after each molt. Shortly after molting, the crayfish buries its head in the sand and thus fills the statocysts through its opening on the dorsal side of the antennule. A biologist working with a marine shrimp, *Paleomonetes,* allowed the animal to molt in a clean aquarium, then supplied iron filings which it promptly added to its statocysts. When the animal was placed in a magnetic field, it oriented itself with respect to the pull of gravity and the pull of the magnet. The special function of the statocysts is their ability to respond more promptly to the pull of gravity than would be the case if only the tiny hairs were present.

The visual mechanism has become very complex in the arthropods. While arthropod eyes vary considerably, a description for the crayfish eye will convey a general idea for the entire phylum. The eyes are located on long movable stalks and can be protruded or retracted in order to improve the vantage point of the observer. The eye itself differs markedly from any vertebrate eye (Fig. 11-16). It has an outer rounded transparent surface called the **cornea,** which is divided into at least 2,000 tiny sections, or **facets.** The facets merely indicate the outer limits of the units or **ommatidia,** which make up the eye of the crayfish. Each ommatidium is composed of the outer facet, which functions as a **lens,** a series of cells below which make up a sensitive portion, the **retinula,** and heavily pigmented regions at the outer and inner ends of this cylinder (Fig. 11-16). The sensory cells of each retinula terminate in nerve fibers, which lead directly to the brain, and the fibers from all the retinulae form a nerve equivalent to the **optic nerve** in vertebrates.

The eye functions as a very efficient organ for photoreception. Light falling upon the lens of a given ommatidium at the proper angle is focused on the sensitive region below and stimulates the sensory cells. Since the ommatidia are long cylinders, the animal sees tiny points (one for each ommatidium stimulated) which are parts of objects that come within its vision. The image is thus a **mosaic** in which the slightest movement is readily detected. This is true, however, only in bright light when the pigmented walls of each ommatidium are spread over the entire cylinder. In dim light the pigment recedes toward the two ends of the cylinders, so that the rays of light pass readily from one ommatidium to another. The animal then sees the image superimposed, so that movement is not easily discerned. The image may be more distinct in reduced light, however, than when seen as a mosaic pattern (Fig. 11-16). Thus the animal has a means of seeing under varying light conditions.

It is obvious that the Crustacea are well supplied with sense organs that make the animals aware of the outside world. How they interpret the incoming sensations and respond to them depends on the development of the nervous system.

The crayfish and lobster possess a bilobed **brain,** relatively large when compared to that found in lower forms. The brain lies between the eyes and is connected with the **ventral nerve cord** by means of a pair of **circumesophageal connectives,** very similar to the arrangement found in the earthworm (Fig. 11-11). There is a large **subesophageal ganglion,** made up of six fused ganglia, followed by a series of ganglia, one for each segment. Large nerves extend out from the ganglia to the appendages and to other parts of the segment.

In addition to its well-developed nervous control the crustacean also possesses **hormones,** chemical regulators that are produced by one part of the body and affect other parts. This has recently been demonstrated in connection with the **chromatophores,** located beneath the epidermis, which move to the surface and may either spread out or contract into a tiny mass. The alternate expanding and contracting by thousands of these bodies have the composite effect of changing the color of the entire animal. In some invertebrates this is so well developed that an animal may match its background almost perfectly (see p. 430). It was once thought that the chromatophores were controlled by the nervous system, but it is now known that they are controlled by the secretions from a tiny gland, the sinus gland, located in the eye stalk. If it is removed, the spread of pigment granules in the chromatophores is affected so that the crustacean fails to show normal color change as a result. If the sinus gland is replaced in the body of the crustacean, the normal action of the chromatophores is restored. The same hormone also regulates the molt and affects the deposition of calcium salts in the exoskeleton; others affect heart action and carbohydrate metabolism. Research reveals that hormones are produced by the central nervous system as well as the sinus gland.

THE INSECTA

Stories concerning the ravages of insects are as old as man himself; such stories found their way into the earliest writings including the Bible. This was primarily because of the competition existing between man and the insects, for the insects consume the food man intended for his own use. They have caused devastating famine in many parts of the world, and even today they torment man as well as other animals. A trip through a boggy or swampy region on a humid summer evening will bring anyone to the sudden realization that the insects appear to have a rather secure place even in our modern civilization. Despite constant war upon them, they still persist and the cost of keeping insects under control is nearly one and a half billion dollars each year. A traveler who crosses a state border is often subjected to inspection in order to determine whether or not he is carrying any insect which might add to the long list of "bed fellows" that the state already harbors. It has been truly said that man's big battle today is being fought against the six-legged little beast which, if left unhampered, could soon overwhelm man and his civilization.

There are over 700,000 species, several times more than all other species of animals put together. How is it, that these small animals have so outstripped all other forms of life? First of all, their rigid exoskeleton has enabled them to invade the air and support themselves outside of water. This waxy covering prevents desiccation, an essential feature for an animal that divorces itself completely from an aquatic existence. They have become so successful in their air environment that they have conquered all possible regions—the only invertebrates that have taken to the air. They burrow in the ground and have returned to both fresh and brackish waters, but avoid the sea. They live on and in the bodies of plants and animals, becoming in some instances serious parasites. They suck the juices of plants and the blood of animals, and often feed upon other species of their own group. This is nature's way of maintaining a balance among animals. This has been hailed and encouraged by man as a method of biological control. For example, certain ladybird beetles are grown by the million and planted on citrus fruit trees that are infested by the destructive cottony cushion scale insect. The beetles feed upon the pests, thus keeping them under control.

The wings of the insects have made it possible for them to travel long distances, thus not only increasing their ability to find food but also to spread themselves to new areas where they might thrive more successfully. Fortunately, present-day insects have never attained any great size, although certain fossil forms did reach a wing spread of more than 2 feet. Most present day species range between one-eighth to one-and-a-half inches in length. There is a South American beetle which is about 5 inches long and some tropical moths have a wing

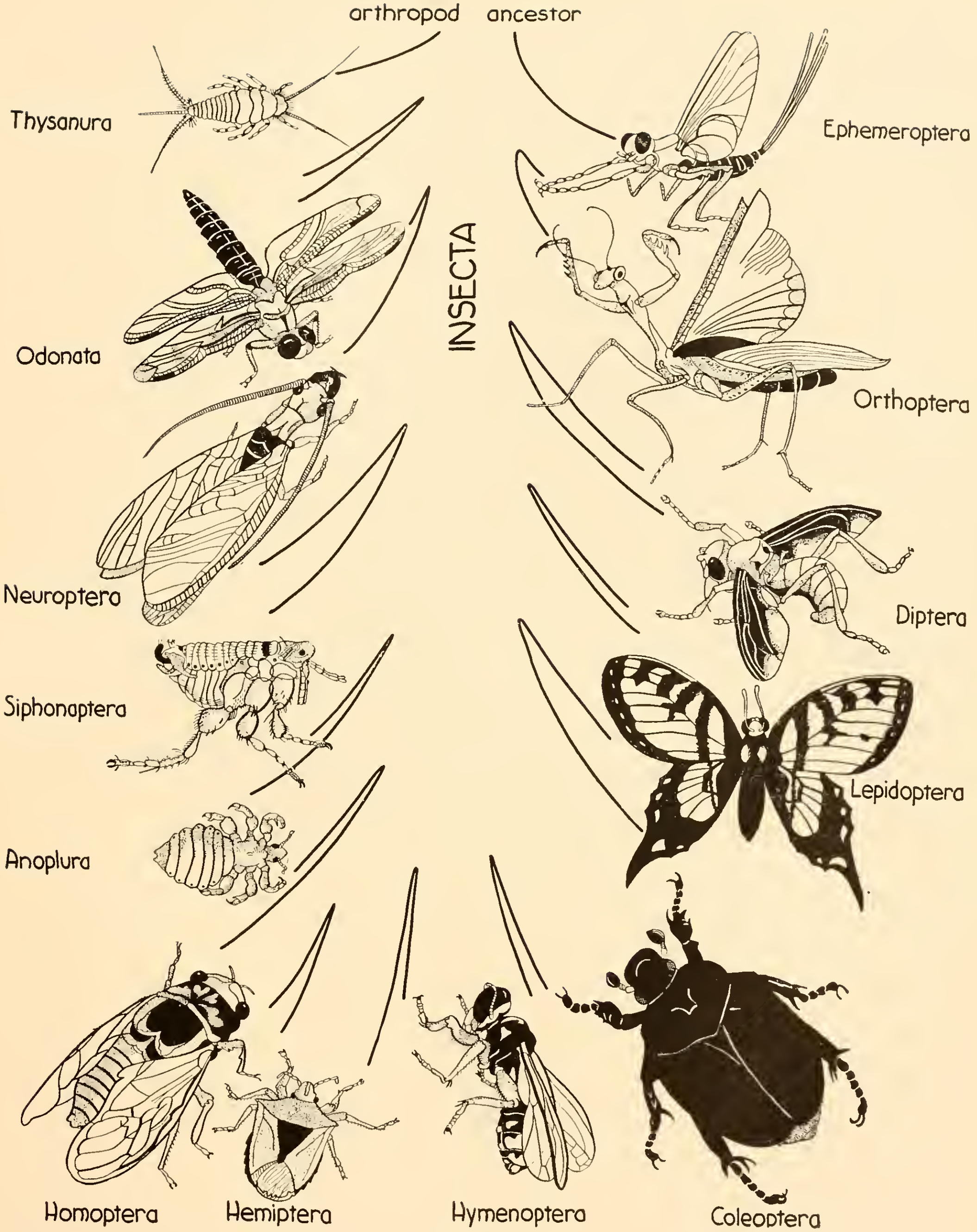


Fig. 11-17. The common orders of insects.

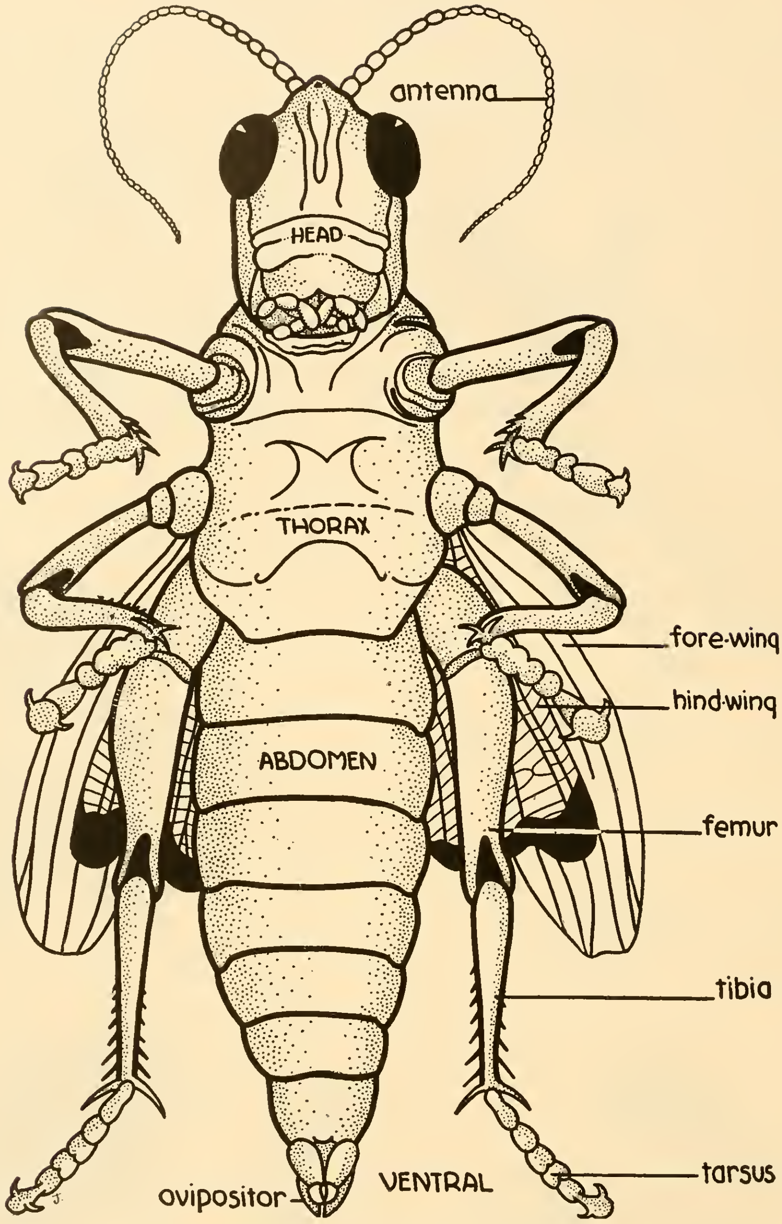


Fig. 11-18. External ventral view of the grasshopper.

spread of 9 inches. Insects as large as cats and dogs would increase man's problems considerably.

Entomologists (specialists on insects) have grouped this vast array of insects into about 26 different orders, the more important of which are shown in Fig. 11-17. Let us study in some detail two representatives, the grasshopper and honeybee.

The grasshopper

A study of this representative insect will throw some light on the reasons why the insects have reached the pinnacle of the

Fig. 11-19. The lubber grasshopper (*Romelea microptera*), common in our Southern states, demonstrates insect parts clearly and with a minimum number of modifications. It is commonly used in zoology classes. This is a male.

invertebrate world. The grasshopper is selected because of its relatively large size and because it is well known to everyone. Furthermore, it shows certain primitive insect characteristics that make it easier to understand than other members of the group. Its many species are world-wide in distribution, living in and feeding on grass or any other available leafy vegetation. It sometimes increases in such numbers that it becomes a serious pest, great hordes devouring almost everything of plant origin, except wood, that lies in its path. Grasshoppers have been known to stop trains from climbing grades because their crushed bodies caused the wheels to slip on the rails, and to cause cars to skid on the roads at places where the insects cross, as their bodies are crushed beneath the tires. Corn fields through which they pass are sheared to the ground and left in desolation.

Structure. Externally, like all insects, the grasshopper is divided into three parts, the movable **head**, the **thorax**, and the **abdomen** (Figs. 11-18, 11-19). There is a considerable amount of fusion of segments when compared to the crayfish. For example, the head appears as a single structure, but it is made up of six segments. Likewise, the thorax is composed of three segments, and there is a variable number of segments in the abdominal region, usually eleven. A pair of legs is attached to each of the three thoracic segments, and a pair of wings to each of the last two. The legs have several parts which named from the body outward are the **coxa, trochanter, femur, tibia,** and **tarsus.** The hind legs are long and well

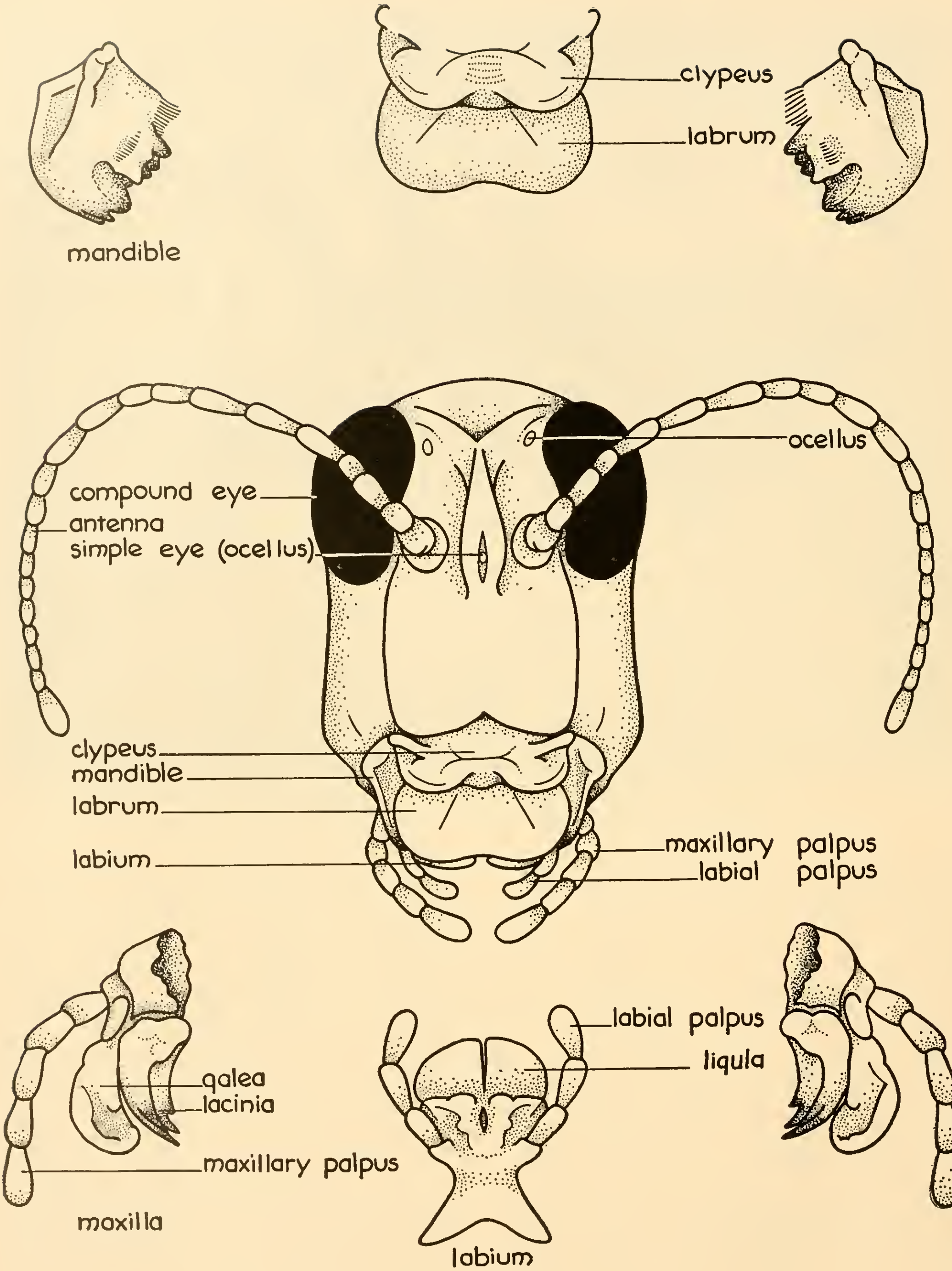


Fig. 11-20. Grasshopper head and mouth parts.

developed for jumping, whereas the other four are used in walking. The outer wings are leathery and rigid, serving as protective covers for the more membranous underwings. When the insect is at rest, the underwings, which are the propelling wings during flight, are neatly folded under the outer ones.

The **compound** eyes of the grasshopper are securely integrated into the head skeleton, but in other respects resemble those of the crayfish (Fig. 11-20). In addition, three small simple eyes, or **ocelli**, are located between the compound eyes. The ocelli function perhaps only in detecting light and dark, which seems unnecessary because the large eyes are so sensitive to varying light intensities. The single pair of antennae vary in length in different species of grasshoppers and function as tactile as well as olfactory organs. Although most of the head is encased in a solid **epicranium**, the several mouth parts can be traced back to modifications in the crayfish appendage plan. There is a broad upper lip, the **labrum**, which is attached beneath the **clypeus**. A pair of lateral, dark colored **mandibles** oppose one another in chewing in such a way as to make it convenient for the animal to bite the edge of a leaf without turning its head. Lying outside the mandibles are the **maxillae**, which are composed of several parts, called **palpi** (singular, *palpus*), and used in manipulating the food as it enters the mouth. The lower lip, the **labium**, possesses two small **palpi**, resembling the larger ones attached to the maxillae. Lying in the center of all these parts is the **tongue**, or **hypopharynx**. Together, these make an efficient chewing mechanism for handling the kind of food that is eaten by the grasshopper.

Digestive system. As food is taken in, it is copiously mixed with colorless saliva, secreted by several **salivary glands**. The food moves through the **esophagus** to the **crop** where it is stored, until it passes into and through the gizzard where it is ground

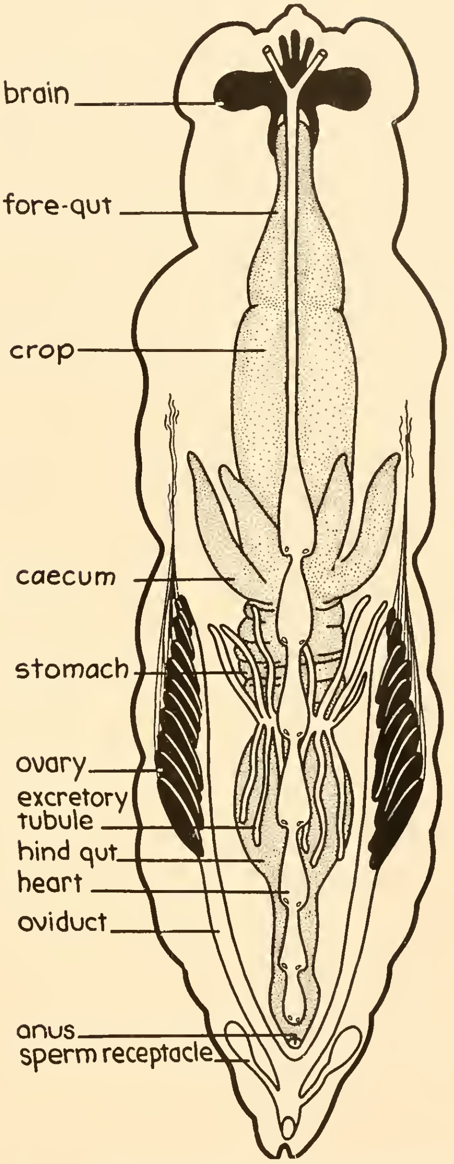


Fig. 11-21. Internal anatomy of the grasshopper, dorsal view.

to a fine consistency (Fig. 11-21). The food then enters the **stomach** where digestion occurs by the action of **enzymes**, which are secreted by eight double **digestive glands** or **caeca**. Finally the digested food passes into a large and then a small **intestine**. Small excretory tubules, the **Malpighian tubules**, empty into the anterior end of the large intestine. The gut opens into the **rec-**

tum, and then to the outside through the anus.

Circulatory system. The body cavity of the grasshopper is the **haemocoel**, or blood cavity, not the coelom, as was the case in the earthworm. This is formed by a continued expansion of the vascular system until the entire coelom is obliterated, with the exception of the cavities of the gonads. The cavity is filled with a colorless blood which contains only leucocytes. Since the blood does not function as a conveyor of oxygen, it has no oxygen-carrying pigment as the blood of most other animals has. The blood is kept in motion by the action of the dorsal tube-like **heart**, composed of a number of chambers into which small **ostia** open (Fig. 11-21). The heart is surrounded by a **pericardial sinus**, which holds the blood before it enters the heart, much the same as in the crayfish. As the heart beats, blood moves forward and out into the haemocoel again. The heart has no occasion to be as active an organ as it is in many other animals, since respiration is carried on in another fashion.

Breathing system. The respiratory system of insects is unique in the animal world. It seems strange that it should have appeared in this one group of animals and nowhere else. Air, with its oxygen, is carried directly to the cells through a system of tubules called **trachea** (Fig. 11-22). This very complex system consists of tiny tubes which must remain distended so that the air can pass freely in and out of them. Small chitinous **spiral threads** give support to the tubules and control their diameter. There are several openings into the trachea along the thoracic and abdominal walls; these are called **spiracles**. A valve covers the opening so that the spiracle can be opened and closed during the breathing process (Fig. 11-22). Leading in from the spiracles, the tubules become smaller and smaller until they are as small as capillaries and lie directly against the cells, supplying them with oxygen and carrying away the excreted carbon dioxide. The grasshopper also possesses several large air sacs which may be contracted to aid the movement of air through the many small tubules. The grasshopper contracts and enlarges its body, particularly the abdominal region to facilitate the air flow and the anterior spiracles open and close alternately with the posterior spiracles, so that the air makes a one-way passage.

The nervous system. While the grasshopper has many of the sense organs that the crayfish possesses, it lives in an air environment and therefore needs somewhat different methods of maintaining contact with its outside world. For example, the eyes and the tactile hairs which cover the various parts of its body resemble those of the crayfish, and it has organs of chemical sense on its antennae and mouth parts. However, the grasshopper and many other insects have the means of making and receiving sound vibrations. In the grasshopper the organ for hearing is on the first segment of the abdomen. In several respects this resembles the ears of higher vertebrates, in that it is composed of a stretched membrane, the **tympanum**, to which is attached a slender process that is connected to a nerve. The animal makes its characteristic clacking sound by rubbing its roughened hind tibias against a wing vein.

As a result of the fusion of three head segments, the grasshopper possesses a rather large **brain**. Nerves extend directly from the brain to the eyes, the antennae, and to a ganglionated cord running through the body. The first ganglion in the cord, the **subesophageal ganglion**, formed by two great nerves or connectives proceeding from the brain around the esophagus, is followed by three large ganglia in the thorax and five in the abdomen, where some fusion has gone on. Nerves go out to all parts of each segment and to the legs and wings, and there is also a fine network of nerves beneath the epidermis. The nervous system

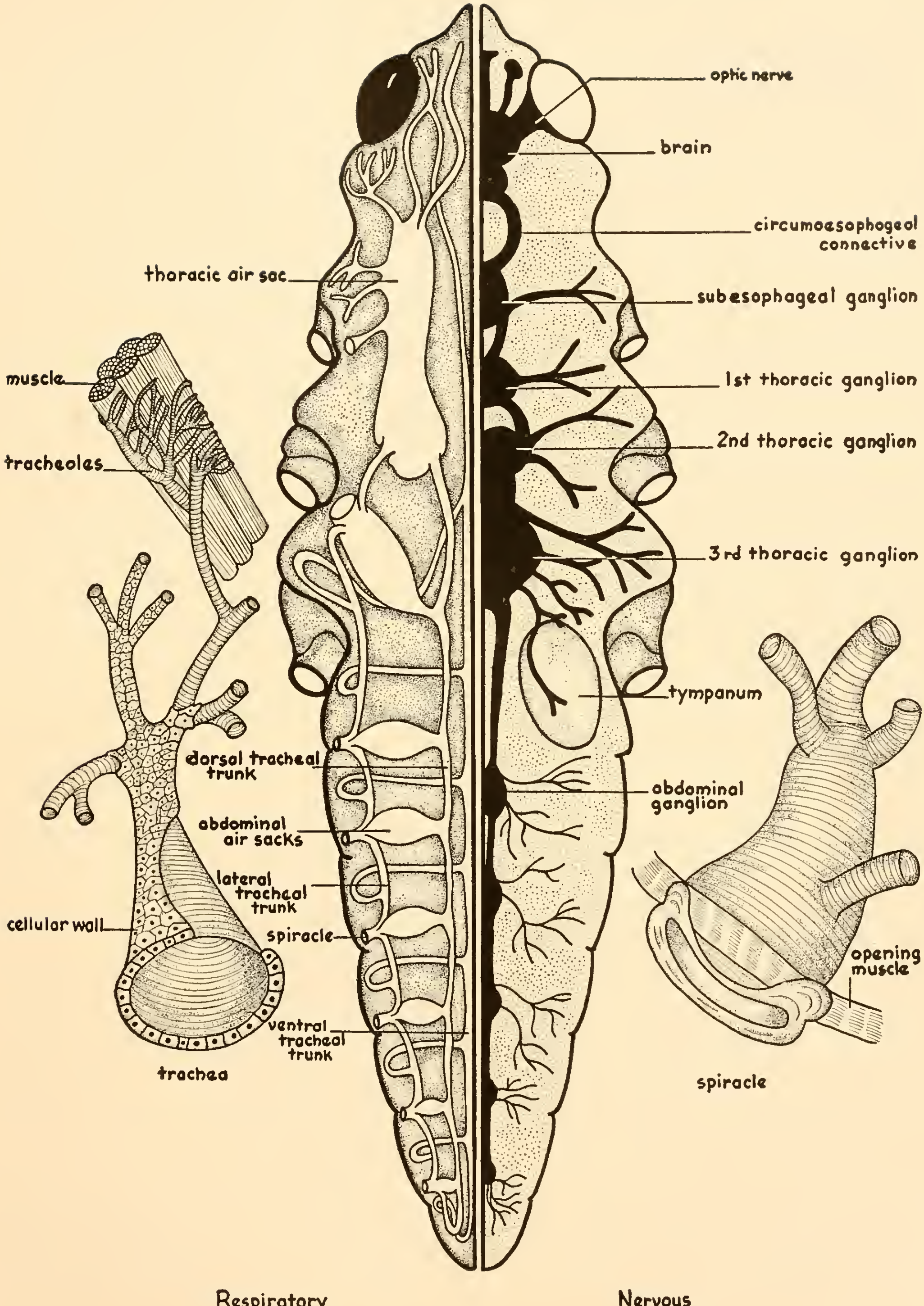


Fig. 11-22. Dorsal view of the respiratory and nervous systems of the grasshopper. Trachea and a few muscle fibers are drawn in detail at the left; the spiracle and end of the trachea to the right.

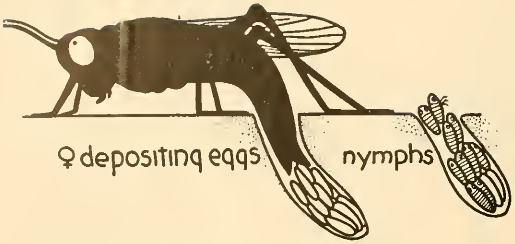


Fig. 11-23. Grasshopper depositing its eggs, and the larvae hatching some time later.

is somewhat better developed than that of the crayfish, as is indicated in both its structure and function.

Excretory system. The excretory organs, the **Malpighian tubules**, have already been mentioned in connection with the digestive tract. Insects are the only animals whose **excretory** glands (**kidneys**) open directly into the intestine (Fig. 11-21). The long, coiled tubules lying in the haemocoel are bathed in blood so that suspended nitrogenous wastes are easily removed. Uric acid has been found to be the end product of nitrogenous metabolism in insects.

Reproductive system. On late August days it is common to see grasshoppers copulating. Some days after fertilization the female grasshopper lays her eggs (Fig. 11-23). She uses her powerful pointed **ovipositors** for digging a hole in the soil where the eggs are deposited, together with a mucous substance which cements them into a packette, known as a **pod**. She lays about 20 eggs at a time, and may deposit as many as ten pods before death overtakes her some days after the egg laying is accomplished. The eggs begin to develop as soon as they are laid and become well-formed embryos before cold weather sets in. The embryos then undergo a rest period, the **diapause**, in which they pass the winter. In the warm spring days, development is resumed and the embryos hatch in early summer as **nymphs** (Fig. 11-23), which resemble the adult grasshopper without wings. Nymphs undergo several molts during their subsequent rapid growth, the wings appearing and becoming longer at each shedding period. It is during this period of rapid growth, when their bodies demand so much food, that the animals are so destructive to crops. The summer is spent leisurely, feeding and growing, until the breeding season begins.

The sex organs of the grasshopper consist of a pair of **testes** and **ovaries** (Fig. 11-21). The testes are made up of several small tubules or follicles, which are joined to the **seminal vesicle** by means of the **vas deferens**; the latter then join to the ejaculatory duct and copulatory organ, the **penis.** A pair of accessory glands secrete a fluid in which the sperms are suspended. The large ovaries are composed of several egg tubes in which the eggs develop; two oviducts extend from the ovaries and join to form the **vagina.** A pair of accessory glands is also present in the female, which contributes to the eggs during their formation.

The honeybee

The honeybee has been associated with man as a domestic animal for many thousands of years and stories about this animal have found their way into the writings of poets and historians as well as naturalists from very early times. Aristotle described the parthenogenetic development of the drone bee, even though he had no microscope with which to verify his statements. The bee offers excellent material for the study of social behavior in lower animals and is a remarkable illustration of adaptation. The more scientists study the social life of this little animal, the more remarkable does it appear.

Bees have learned to live in colonies where all members work for the community in a rigid *caste system.* There is one **queen** which lays all of the eggs for the colony, a number of **drones** (males), one of which fertilizes each newborn queen, and thousands of sterile females, called **workers,** which do all the work of the colony (Fig.

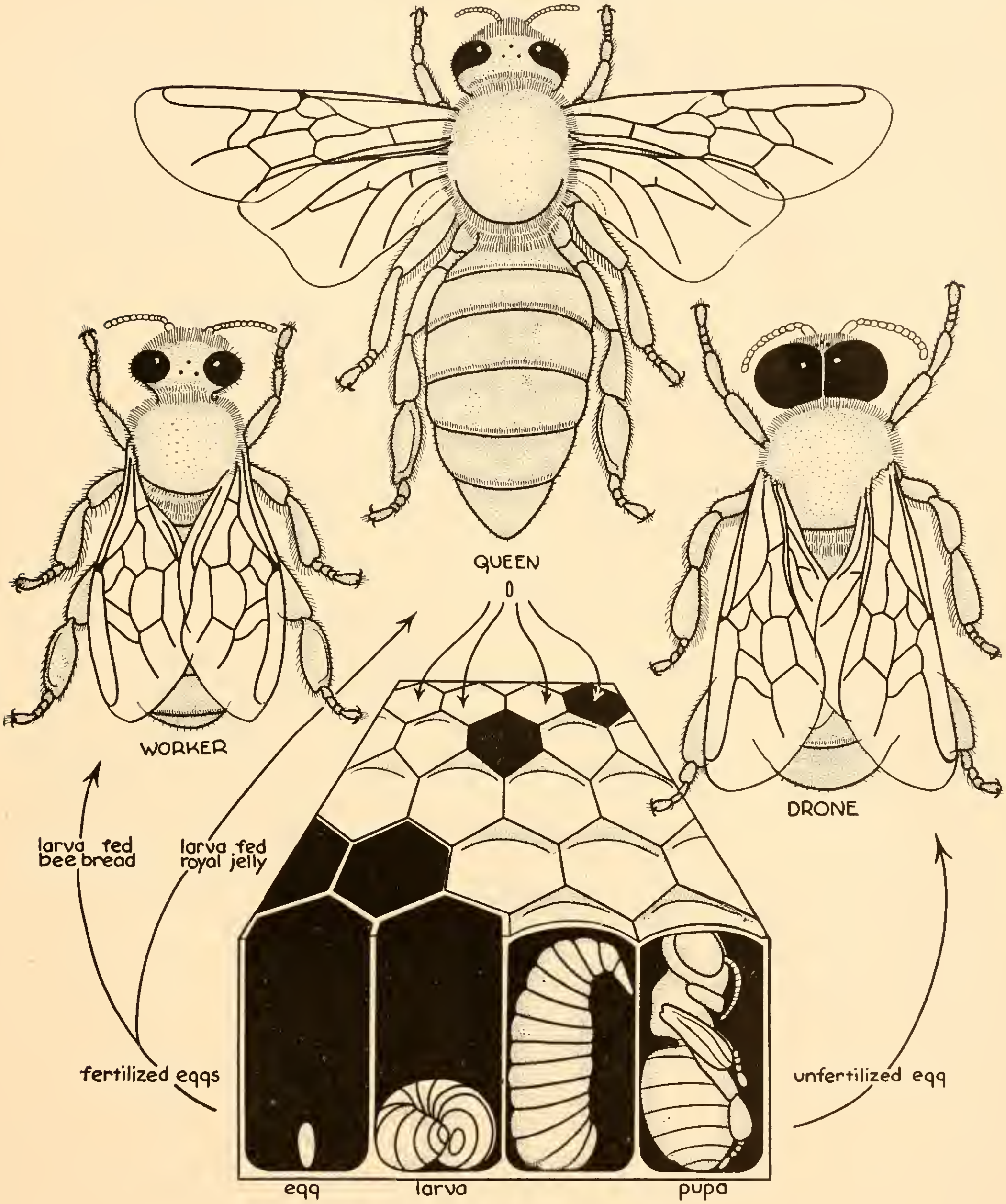


Fig. 11-24. Life history of the honeybee.

11-24). All is sacrificed, even life itself, to the welfare of the colony.

Anatomically, the bee differs from the grasshopper in many ways, although fundamentally their bodies are alike. Since its diet consists of both fluids and solids, the mouth parts of the bee are modified for sucking as well as for chewing. The ovipositors of the females have been modified into an organ of defense, the *sting*. The appendages which serve as walking legs are adapted for carrying pollen and for a variety of other highly specialized but essential functions in addition to locomotion.

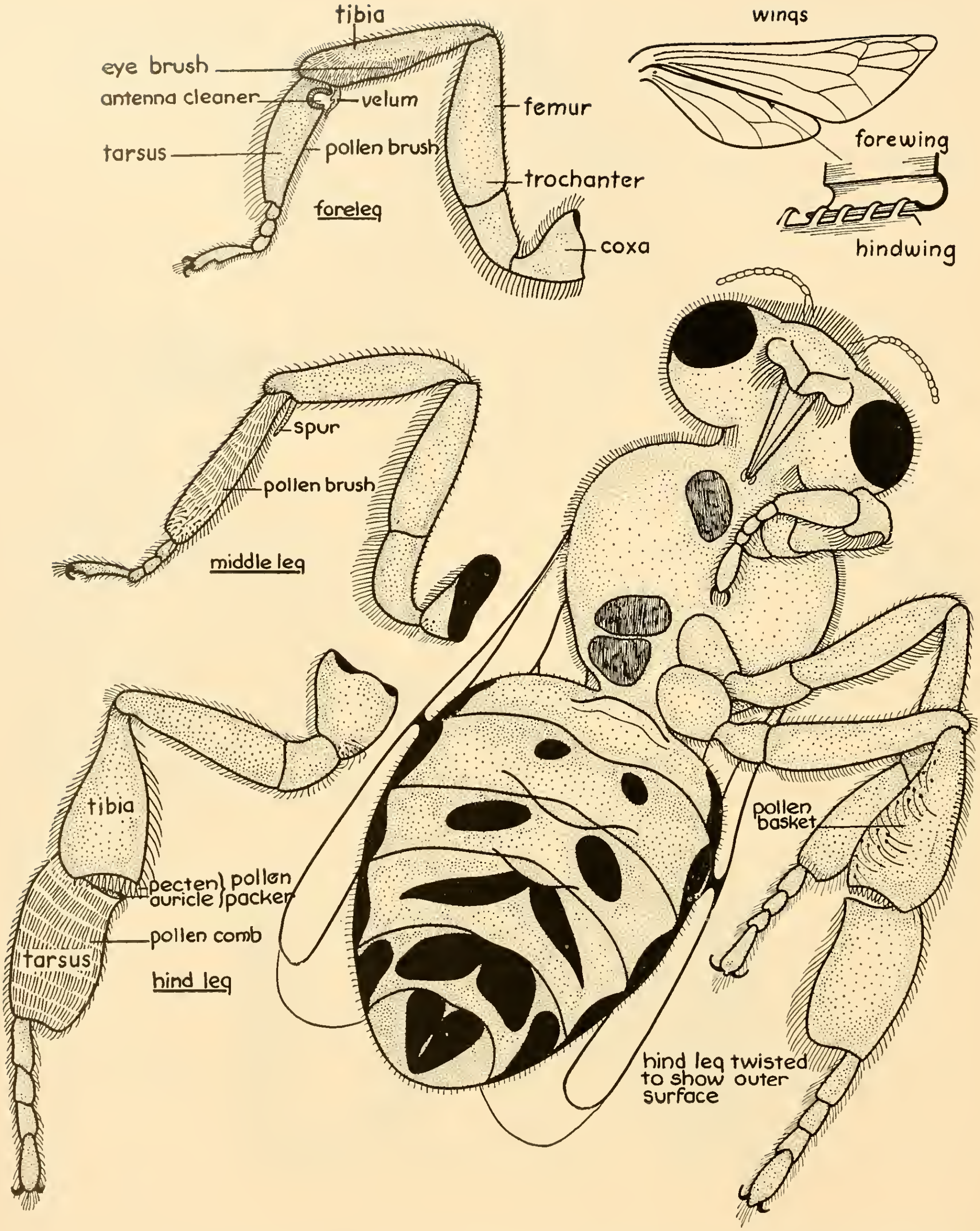


Fig. 11-25. Ventral view of the honeybee to show modification of the legs for carrying pollen. In the upper right corner a small portion of the fore and hind wings are drawn to show how the wings may be hooked together during flight.

The external surface of the bee is covered with "hairs." Those over the eyes are straight and unbranched, whereas those over the remainder of the body are branched, thus affording a place for pollen to cling. During a visit to a flower, the bee gathers some pollen with its mandibles and moistens it with honey. Pollen is also obtained from the action of the **pollen brushes** on the front two pairs of legs which clean the anterior portion of the body (Fig. 11-25). These brushes pass the sticky pollen mass back to the middle legs which rub it upon the pollen combs of the hind legs. The pollen is then rubbed from the right hind leg onto the left and from the left onto the right, and thus carried to the **pollen packer,** which is composed of two parts, the **auricle** and the **pecten.** Once the pollen has reached this position, the tarsus is flexed on the tibia, packing the pollen from the bottom into the **pollen basket** (Fig. 11-25). A great quantity of pollen may be collected in this way so that when the bees fly home in the late afternoon the huge balls of pollen cause the hind legs to dangle much lower than when they are not so loaded.

The anterior pair of legs has two cleaning mechanisms, an **eye brush** and an **antenna cleaner,** which the bee uses to remove pollen from these organs. The antenna cleaner is composed of a **velum,** a small flexible projection from the tibia, and a crescent-shaped depression on the proximal end of the tarsus, lined with short bristles. The antenna is brought into this depression and pulled through several times to clean it. In addition to the pollen brush on the middle pair of legs, there is also a **spur,** which is used in picking and transferring wax in the process of comb-building.

The bee has two pairs of delicate membranous wings which can operate either separately or locked together by means of a row of hooks that fasten into a groove in the posterior margin of the forewing (Fig. 11-25). During a straight flight, where speed is essential, the wings are locked together and the bee flies as if it had only two wings. The question of flight in insects has been a puzzling one, not only to biologists but to engineers as well. The latter claim that, according to aerodynamics, a bee cannot fly! Aside from speed, flight in insects exceeds anything the engineer has been able to devise so far, yet aircraft designers have so far been unable to apply the principle employed by these little animals. Flight in insects is brought about in a peculiar manner, namely, not by wing muscles, as in the case of birds, but by powerful muscles which cause the thorax to vibrate and this in turn forces the wings to flap up and down. In Fig. 11-26 this is illustrated. As the anterior-posterior thoracic muscles contract, the dorsal wall of the thorax (ter-

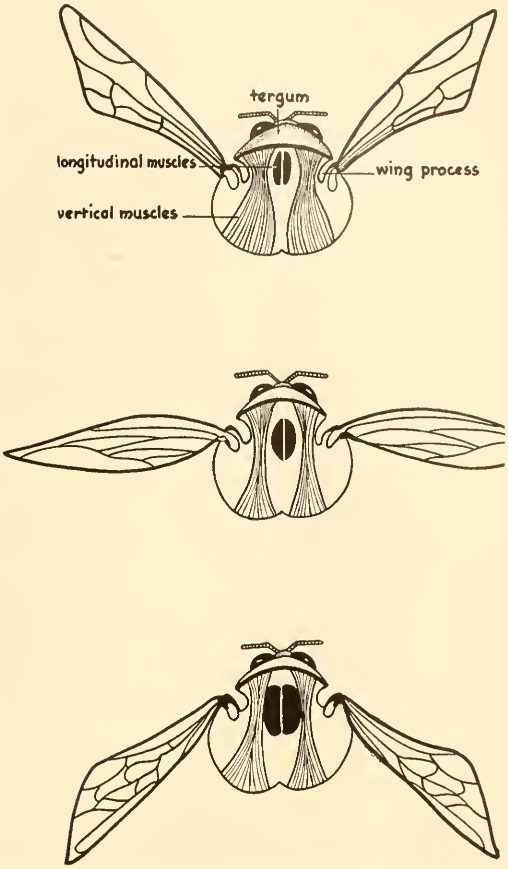


Fig. 11-26. Cross-section of the bee showing how the wings function during flight.

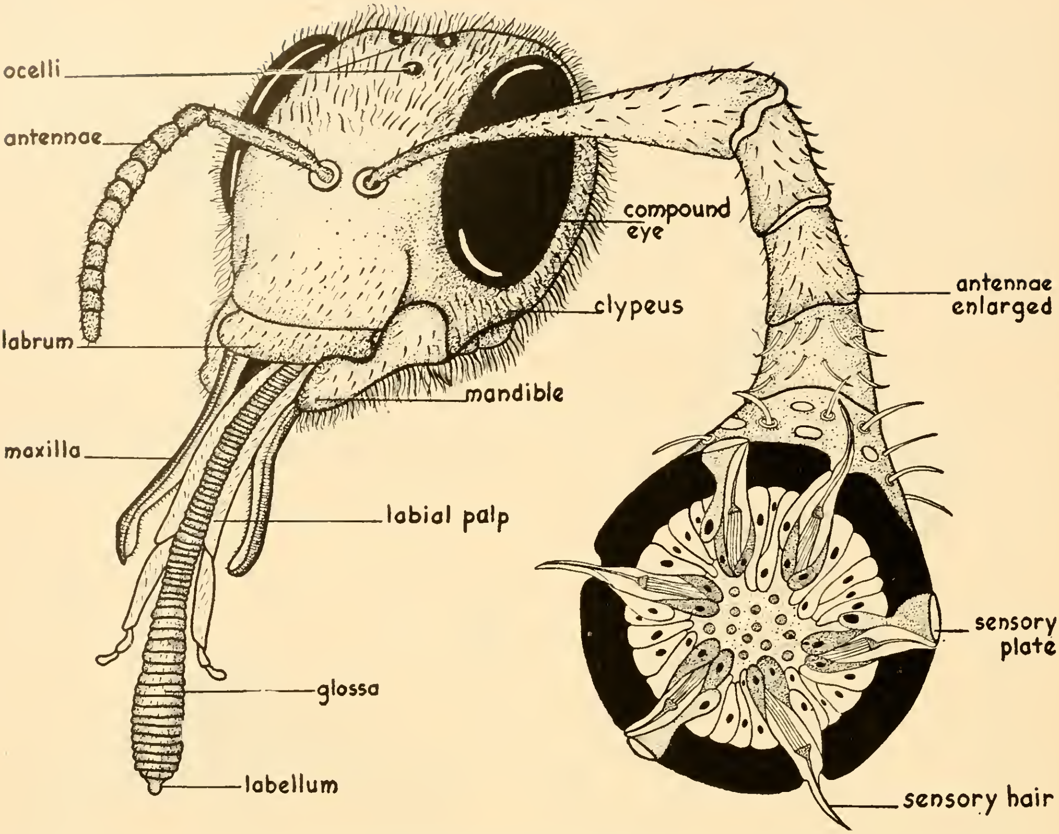


Fig. 11-27. The head of the bee, showing the mouth parts. An antenna has been enlarged in cross-section to show the details of the sensory end organs.

gum) is forced upward. This pulls the dorsal basal edge of the wing upward, causing the wing as a whole to be forced downward with considerable force; the body wall acts as a fulcrum. The upstroke is accomplished by the sudden contraction of the dorsal-ventral muscles in a similar manner. Thus the wings move up and down by the throbbing of the thorax and not by any effort on the part of the wing itself. Its pitch can be altered so that the bee can hover, fly forward, or fly backward with ease, something man has had great difficulty in duplicating mechanically. In the helicopter this has been accomplished to a certain degree. Bees are capable of long flights, sometimes as long as 10 miles, although usually much shorter distances are covered in their routine work.

Another interesting modification of the bee's appendages is the sting. This is found only in the females, workers and queen, because it is homologous to the ovipositor. The organ has become a complicated apparatus, retaining the muscle system which made it possible for the grasshopper to deposit its eggs in very hard soil. In the sting these muscles enable the bee to force sharp-grooved **darts** into the tough skin of an intruder. A pair of **feelers** on either side of the darts "selects" the spot where the sting is to be released. This prevents the bee from stinging inert bodies. Lying between the upper ends of the darts is the **poison sac** which is in contact by means of ducts with an **alkaline** and an **acid gland.** During the stinging procedure the poison sac is squeezed, and its product is forced into the

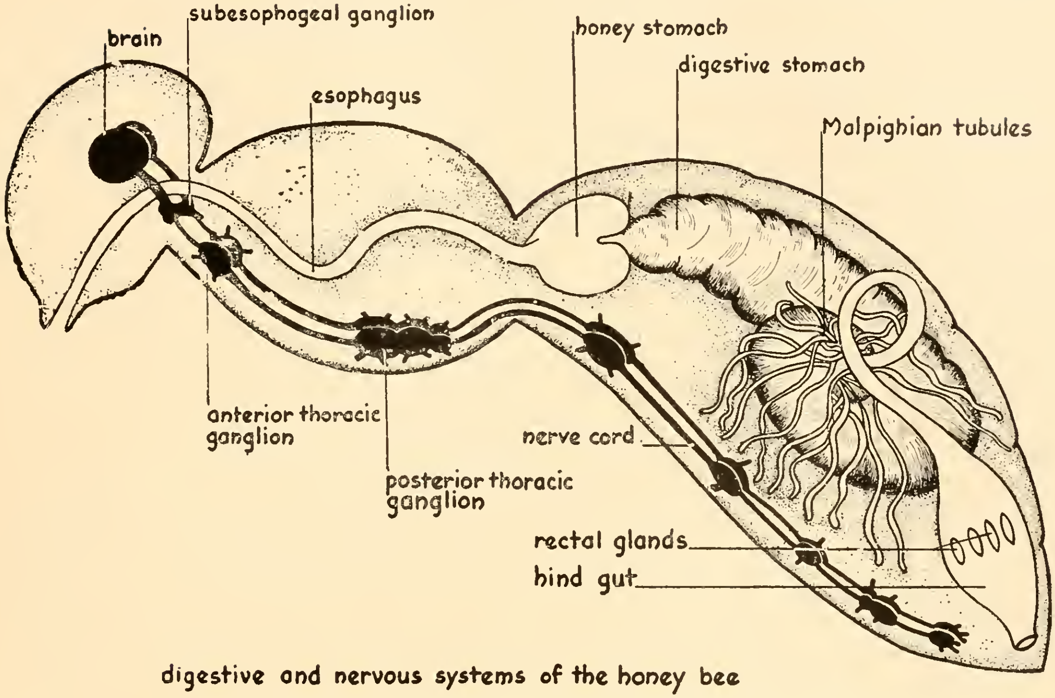


Fig. 11-28. Side view showing some of the internal anatomy of the bee.

wound made by the darts. This substance causes much of the pain and swelling associated with the sting of the bee. Once a worker stings, its darts become firmly fixed in the skin of the recipient so that the entire apparatus and sometimes other internal organs are torn out when the bee leaves. A day or two later this results in the death of the bee. Queens use their sting in battle with other queens, but are able to use it over and over again without the injury which results to workers.

The diet of the bee consists chiefly of nectar from flowers, which is essentially a solution of sugar. Although the mouth parts noted in the grasshopper are also found in the bee, they are greatly modified for sucking liquids (Fig. 11-27). The **mandibles** are much like those of a grasshopper and are used in wax manipulation and comb-building. The **maxillae** and **labium**, together with their **palps**, however, are extended and grooved on the inside so that when they are brought together they form a tube or **proboscis.** The greatly elongated tongue (**hypopharynx**), which lies in the groove made by these mouth parts, acts as a pump. When the bee feeds on colored honey it is possible to observe the food make its way along the tongue with considerable speed until it disappears in the mouth, thence moves to the **honey stomach**, which is a crop for storage (Fig. 11-28). Between the crop and the **true stomach** is a small valve, controlled by the bee, which makes it possible for the bee to take as much nectar as it needs for use in its own digestive tract. The rest is regurgitated into a wax cell in the hive for storage as honey.

The nectar undergoes chemical change while in the crop. The most significant difference noted is a reduction from the disaccharide, **sucrose**, to the monosaccharide, **glucose**, and the possible addition of other substances in small quantities. This watery substance is placed in the open comb cells of the hive, and allowed to undergo evaporation to remove a large portion of the water. When this is complete the resultant honey is covered and sealed by a thin layer of wax. Evaporation is hastened by "air conditioning," which is brought about by certain workers detailed to keep the air in constant motion by beating their wings. After a particularly busy day, when large amounts of nectar have been brought in, the hives can be heard "singing," due to the intense activity of the ventilator bees. This also provides a constant flow of fresh air through the colony, which probably contributes to the general health of the colony. As previously mentioned, this same lively beating of wings is also used as a means for raising and maintaining the temperature above freezing during the winter. In this case the activity contributes heat from the burning of sugar in the bodies of the bees themselves.

While the nectar supplies carbohydrates for the bee's diet, nitrogen is provided in the form of pollen. The method of collecting and transporting pollen to the colony has already been described. The pollen, or "**bee bread**," is packed in cells for future use in feeding the larvae as well as the adult bees during the winter. Bees also collect "**bee glue**," or **propolis**, which is pitch found around the base of buds. It is used as a varnish for mending and stopping up cracks in the hive to make the hive as tight against the elements as possible.

The **wax glands**, located on the ventral side of the abdomen, secrete the material for building the wax cells of the comb. Cells of various sizes are constructed for specific purposes. The smallest are the worker cells, which are used to rear the workers and also to store pollen. The drone cells are somewhat larger than the worker cells and are used not only to rear the drones but may also be used for the storage of honey. Usually, however, the honey cells slope upward to prevent the honey from being lost by running out. The largest and most elaborate cells are those provided for the rearing of the queen. Various generations of bees are sometimes reared in the same cells, and the old cocoon cases can be found in them lying one on the other.

The respiratory, excretory, and nervous systems are much the same as those already studied for the grasshopper. Reproduction in the bee is somewhat different, however, and a discussion of this system is necessary. The male or drone bees possess two kidney-shaped **testes**, from which a pair of vasa **deferentia** conduct sperms to the large **seminal vesicles.** The vesicles, as well as a pair of large **accessory glands**, enter a single **ejaculatory duct**, all of which then connect with the large, complicated copulatory organ, the **penis.** The major part of the abdominal cavity of the queen is filled with a pair of large **ovaries**, which resemble those of the grasshopper. Oviducts connect with a single **vagina.** A dorsal evagination of the vaginal wall results in a sac called the **spermatheca**, the storage place for sperms received from the male during copulation.

Soon after the advent of spring the queen lays many eggs. This brings about such a great increase in the number of bees that the hive is soon overcrowded and a change in arrangement becomes necessary. The workers build new queen cells and a new queen is produced, who promptly proceeds to drive the old queen out. The latter gathers a substantial portion of the workers and "swarms" to a new home. Such a large mass of bees may be observed clinging to a tree branch, where they rest until scouts find a new home. The queen who is left behind kills any other queen larvae that may be developing and flies out on her "nuptial flight." At this time she copulates with one of the drones and receives sufficient sperm in her spermatheca to last the rest of her life, which may be as long as 15 years. A small "sperm pump" makes it possible for her to fertilize or withhold sperm from eggs. Since she allows only three or four sperms to be deposited on the **micropyle** (small opening at one end of the egg) of an egg as it passes out of the oviduct, she

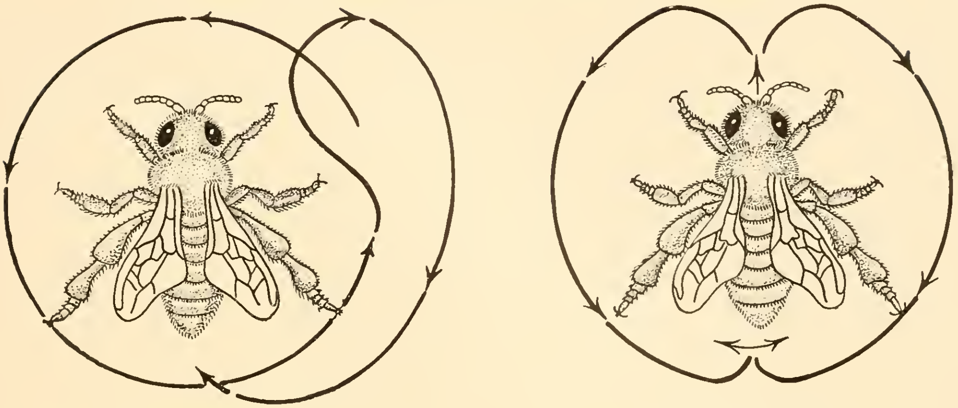


Fig. 11-29. Behavior of the bee during its circle and wagging dance.

may lay over a million fertilized eggs in her lifetime. Such eggs develop into females, workers or queens. But unfertilized eggs also develop and these become males or drones.

The eggs hatch in three days into tiny larvae which are fed at first on a rich secretion from the queen's pharyngeal glands, the "royal jelly." Later the workers and drones are fed on honey and pollen, but the queen larva is retained on the royal jelly diet and thus becomes large and fertile. When full grown, the larvae are enclosed in a cell and pass into the inactive **pupa** stage, to metamorphose into the adult bee. Within two to three weeks, depending on the caste that is produced, the adult emerges by cutting its way out of the cell. The cell is then cleaned and another egg laid in it, starting the process over again. The number of bees produced depends to a large extent on the available pollen and nectar. When bees are raised commercially, the hives are always placed near a good source of food, so that the colonies grow fast and the honey produced is as much as 100 pounds per hive per season. At the close of the season, most of the colonies are destroyed, only a few being carried over to start new colonies the following spring.

Implemented by their remarkable sense organs, bees exhibit highly complicated behavior. Their eyes are much like those of crayfish, with about 4,900 ommatidia in the eye of the queen, 6,300 in the worker, and 13,000 in the drone. Bees distinguish the colors of our spectrum, except red, which they confuse with black. They can also detect ultra violet. They have an excellent sense of smell which is made possible by some 1,600 (queen), 2,400 (worker), or 18,900 (drone) sensory endings on the antennae (Fig. 11-27). This aids bees in finding their way about with exceeding precision. Coupled with these well-developed sense organs is the size of the **brain**, which is much larger proportionately than for other invertebrates.

When bees return to the hive after finding a rich source of nectar or pollen they go through a kind of dance in which they walk forward, wagging their abdomens rapidly, then circling and repeating the process (Fig. 11-29). At other times they simply walk in circles. Von Frisch, the brilliant Austrian zoologist who first worked out this amazing behavior, called these the "wagging" dance and the "circling" dance, respectively. The dances are closely followed by other bees in the hive, who then set out and very shortly are able to find the source of food. Soon a large number of bees is taking nectar and pollen from the spot. By a series of experiments with moving the source of artificial

Fig. 11-30. The rat flea, carrier of bubonic plague.

food for bees, von Frisch discovered that the circling dance meant that the source was less than 100 meters away, whereas the wagging dance meant that it was beyond that distance. Direction is determined by the position of the sun. If a bee is caught and then released very soon, it finds its way home without any difficulty. If, however, it is caught and placed in a dark box for two hours and then released, it will fly along the path that it would have taken when the sun was in the position it had been two hours earlier. Thus the bee is able to measure the angle of the sun and use it as a guide in returning home. It is able to do this even on cloudy days or when it sees only a small portion of the sky. Hence this little animal seems to possess powers of response never dreamed of in lower animals. Perhaps there are many more, equally as extraordinary, awaiting our discovery.

Insects unlimited

Insects are so widespread and numerous and touch upon man's life in so many ways that no one is entirely free from their influence, from the housewife who fights the ubiquitous fly and cockroach to the flea- and louse-bitten beggar who is constantly struggling to rid himself of these pests. On the other hand, there are those who operate a million dollar industry and profit by the labors of the honeybee or the silkworm. Moreover, there are vast fertile areas of the globe that are denied occupancy by man because of the presence of insects which carry deadly diseases. The competition that is going on between man and these tiny beasts is quiet and not too apparent to the ordinary person, but it is a deadly battle and it is not at all certain that man will always be the victor as he is today. He might better employ his efforts to fight this enemy, rather than to fight his fellow man.

Perhaps the most benefit derived from insects is from their work as pollinators of flowers. Many trees would bear no fruit if it were not for various insects, and the same is true of such crops as clover and figs. Shellac is made from a secretion produced by certain lac insects in India; others produce a dye called cochineal. The cocoon of the silkworm is unwound and spun into silk thread used to make the fine silk cloth familiar to everyone.

On the debit side are those insects which carry disease, such as the mosquito (malaria, yellow fever, filariasis), the body louse (typhus), and the flea (Fig. 11-30) (bubonic plague). In the past and still today these diseases are the cause of a vast amount of human misery. Bubonic plague alone wiped out from one-half to three-fourths of the population in vast areas of the world several centuries ago. Today approximately one-sixth of the population of the world is made wretched by malaria. With the eradication of the mosquito alone, much suffering would cease.

Domestic animals also are harassed throughout their lives by numerous insects. The botfly causes most serious damage to the stomachs of horses, while the ox warble fly larvae bore holes in the hides of cattle

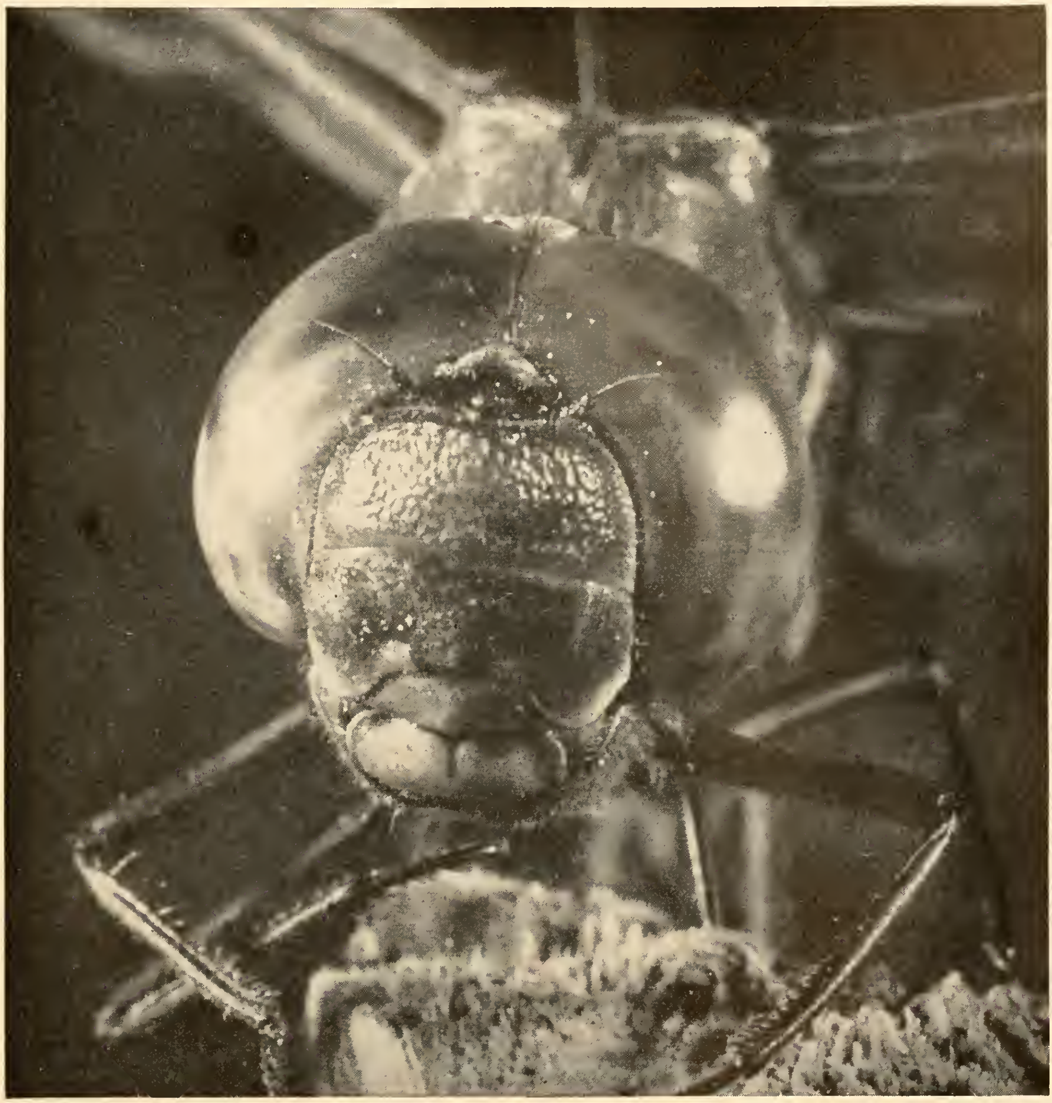


Fig. 11-31. The dragonfly (*Aescha*) is noted for its excellent powers of flight and its enormous eyes. It captures mosquitoes and other insects while in full flight. Its two large eyes may possess as many as 30,000 ommatidia, and for that reason are probably excellent photoreceptors. Its antennae are rudimentary and are probably of little importance to the animal.

causing them distress, as well as making the hide valueless for leather. Finally, there are the millions of gnats, flies, mosquitoes, and bugs that can be rated merely as having a high-grade nuisance value, but do no special harm.

In addition to transmitting important human diseases, insects attack man's food and either destroy or actually consume it. Cereal grains both in the storage bins and in the fields are injured or destroyed by various types of insects. Clothes, furs, and upholstered furniture are eaten by the clothes moth. Not only the furniture, but the house itself can be tunneled and destroyed by termites.

Modifications in form and function

Although all insects, with few exceptions, have body parts similar to those of the grass-

Fig. 11-32. The larval dragonfly is equipped with mouth parts that are adapted for catching other insects in the water, where it lives until it becomes an adult. The upper picture shows the parts thrust out in the striking position; in the lower picture they are retracted where they are held except when in use.

hopper and bee, there are wide modifications in these parts in different species. Starting at the anterior end of the insect and working posteriorly, some of the modifications are as follows: The antennae may be very short, as in the dragonfly (Fig. 11-31) or they may be very long, as in the long-horned grasshoppers, in each case performing a specific function that requires the particular type of antennae in question. The eyes may be extremely large, as in the dragonfly (Fig. 11-31), where they detect the flying mosquitoes which the airplane-like insect pursues. Or they may be absent, as in the termites which work in the dark.

The mouth parts vary even more widely than the differences between the grasshopper and the bee would indicate. The larval dragonfly has a formidable weapon for catching its prey (Fig. 11-32). The butterfly has a long tube which is carried in a coil under its "chin" when not in use, but, when stretched out during the process of taking nectar from a flower, it may be as long as the animal itself. The cicada possesses a stiff beak which is used in penetrating plant tissues to obtain the juices on which it feeds (Fig. 11-33). The deerfly has fierce, biting mouth parts which make a deep incision in the skin when it obtains a meal. In fact, when disturbed, it often departs with a small fragment of the skin between its mandibles. There are also the thin dart-like mandibles of the mosquito which can pierce the skin very delicately and withdraw its meal of blood, at the same time injecting a small amount of saliva to prevent the blood from clotting. The mouth parts of all insects are homologous, yet witness the variety of functions they perform.

The thorax bears two pairs of wings and three pairs of legs, all of which are variously modified in different insects. The wings are formed as thin sacs, by evaginations from the thoracic wall, through which trachea make their way. Eventually the sacs collapse and the walls unite and harden, the "veins" being formed by the trachea. Some

Fig. 11-33. The mouth parts of the cicada (*Magicicada*) are modified to form a stiff beak, which it uses in piercing twigs in order to obtain the sap, its chief source of food. Note the three simple eyes; the one directed anteriorly is particularly conspicuous.

Fig. 11-34. The wings of insects are highly modified. Those of the butterflies and moths are covered with scales. Some moths, such as this one, possess long scales that resemble fur. Note the long feather-like antennae and the heavily pigmented eyes.

Fig. 11-35. The forewings of beetles are hard and without veins, and the hindwings are membranous. This is clearly demonstrated in the familiar potato beetle (*Leptinotarsa decemlineata*) which is destructive to potatoes as well as other crops throughout the United States and Europe.

insects, such as the moth (Fig. 11-34), have wings which are large and covered with scales, while others, like the beetle (Fig. 11-35), have hard anterior wings (**elytra**) that fold over and protect the soft posterior membranous wings. In the flies the wings have been reduced to two—the anterior pair only. The posterior pair has been reduced to two short stumps called **halteres**, which serve as sensory organs to maintain balance during flight.

The legs may all be the same size and used for walking or running, or they may be modified for jumping, as in the case of the grasshopper. Other modifications include the paddle-like feet for swimming, in aquatic forms (Fig. 11-36), the digging legs for excavating, as in the mole cricket, and the pincer-like legs for grasping prey, as in the praying mantis (Fig. 11-37). Certain insects have large, hairy surfaces on their long legs which make it possible for them to walk on water, where they bend the surface tension without breaking it (Fig. 2-2). Some legs are modified for making a sound, as in the case of the cricket, in which the posterior legs are rubbed against the wings to make the characteristic chirp of this in-

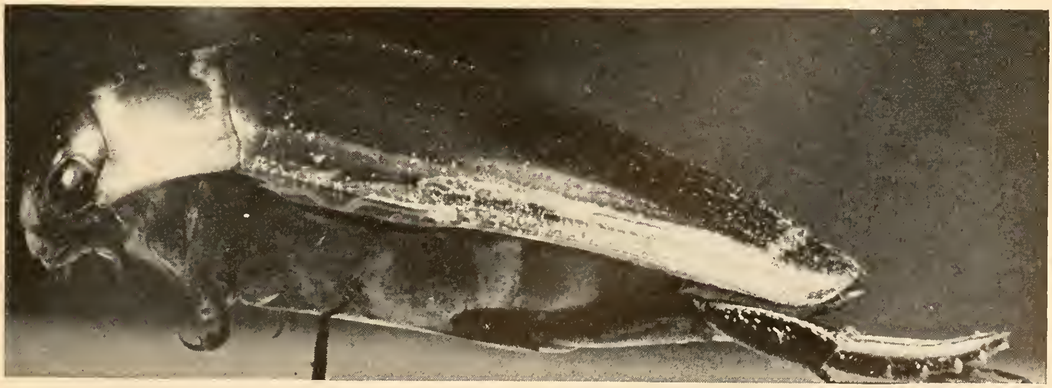


Fig. 11-36. Aquatic insects are modified in many ways for life in the water. The predaceous diving beetle (*Dytiscus*) shown here has its hind legs fringed with hair-like bristles which serve to increase the effectiveness of these appendages when used in swimming. As a result, it is an excellent swimmer. The insect also stores reserve air under its wings for use while submerged.

Fig. 11-37. The praying mantis (*Stagmomantis carolina*) has its anterior legs modified into grasping appendages. It gets its name because of its manner of posture while waiting for some unwary insect to approach within striking distance. It is one of the larger insects, reaching a length of 4 inches in some of the larger specimens.

sect (Fig. 11-38). The cicada has special organs to make its shrill song (Fig. 11-39).

The chief modification in the abdominal region is the ovipositors of the female. These have been described for the bee and the grasshopper. In some insects, however, the ovipositor is developed in a most extraordinary fashion. Thus in the Ichneumon fly, it is several times as long as the body and can drill a hole in wood an inch or more deep. Since this insect lays its eggs in the body of the larval wood beetle, such an apparatus is essential.

The over-all color of insects varies as much as it does in birds, from the brilliant iridescent green Japanese beetle and highly colored butterflies to the inconspicuous drab color of the housefly and the camouflaged walking stick. The colors are either in the exoskeleton or they are produced by differential interference of light impinging on regular minute depressions and elevations in the cuticula. Some insects resemble other insects or parts of their environment. One species of fly, for example, resembles and even acts like a bee, thereby taking advantage of the protection of the bee's sting, even though it has none itself. This is called **mimicry**. The mimic takes advantage of the weapon carried by other insects, simply by resembling it in both coloration and in action, and is thus able to discourage its normal enemies. Other insects, such as the walking stick, resemble the twigs and leaves of the bush upon which they rest to such a great extent that they are not easily seen and when discovered even become stiff like a leaf petiole.

There are numerous modifications in the respiratory systems. Although most of the insects breathe air, some, such as caddis fly larvae, receive their oxygen by means of thin gills and can get along perfectly well under water. These gills are not, however, in any way homologous to the gills of the Crustacea. It is clear that the insects became air-breathing arthropods and that only a few have secondarily gone back into the water during their larval life. It is also interesting to note that they have taken only to fresh water and not to salt water. This would be expected, since the osmotic pressure of the tissues of insects is quite different from that of the sea today, although it may have been the same when the insects, or their progenitors, left their marine life long ago. It must be mentioned, however, that some vertebrates, such as turtles, seals, and whales were able to overcome this difficulty and returned to the sea. Finally, some insect larvae can survive in the mud at the bottom of bodies of water where oxygen is absent. They receive their oxygen by breaking down organic matter there, just as many anaerobic bacteria (bacteria that live without free oxygen) do.

The digestive systems of insects vary con-

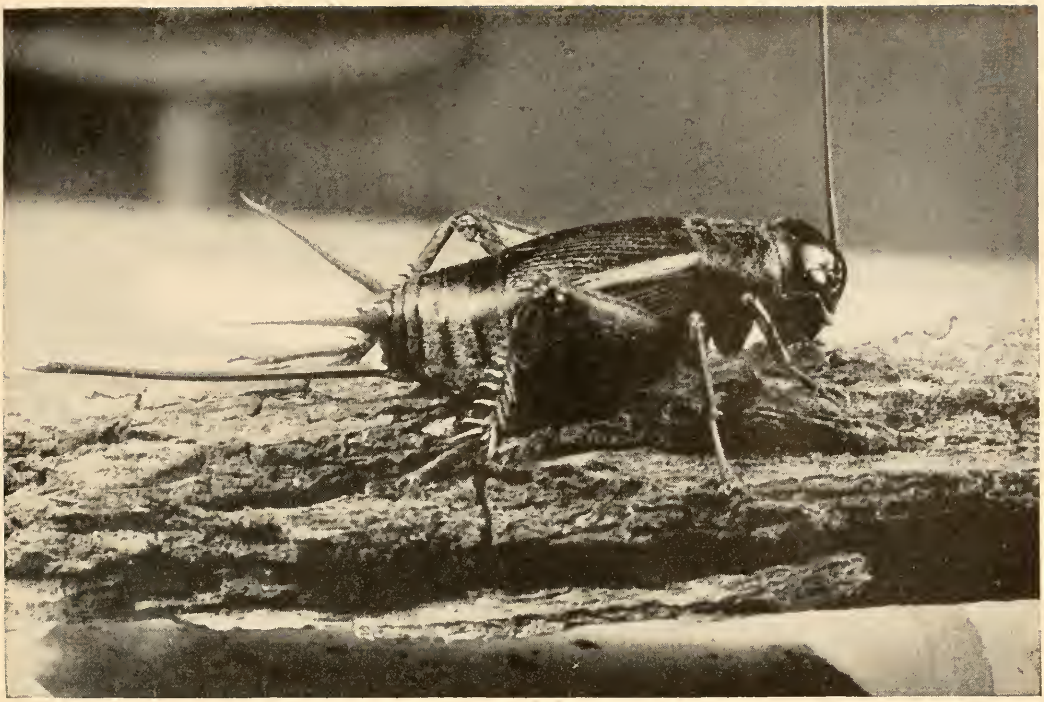


Fig. 11-38. In some insects the appendages are utilized in making sounds. The common field cricket produces its familiar chirp by rubbing its posterior legs against its wings. This is a female; note its long ovipositors.

Fig. 11-39. The cicada produces its shrill song (only the males sing) by a specially designed sound-making apparatus. It consists of two sets of vibrating plates located on the ventral side of the abdomen. The right one can be seen opposite the tibia of the posterior leg in this photograph.

siderably, depending on their type of diet. Furthermore, the diet may differ widely during the larval and adult stages: the butterfly, for instance, feeds on leafy vegetation as a larva, and on nectar as an adult. Feeding may be confined to certain stages of the life cycle and absent in others. Such insects as the May flies and fishflies feed only as larval forms, the adults living but a few days during which time food is unnecessary. The adult stage is devoted to mating and egg-laying. Among mosquitoes, the males mate and die, never feeding at any time on blood, whereas the females of some species must obtain a blood meal before her eggs will mature. She has a voracious appetite and is able to take a meal of blood equal to several times her body weight.

Some insects, such as certain species of termites, feed entirely on wood, a carbohydrate, apparently never taking in any nitrogen. They are able to exist on this diet because of the action of the Protozoa (flagellates) which inhabit their intestinal tract. Neither the Protozoa nor the termites can survive without the other, a case of perfect mutualism, as was pointed out earlier (Fig. 5-9).

Some insects, like the adult dragonfly, are carnivores (meat eaters), others, like the grasshopper, are herbivores (vegetable eaters), and still others, like the cockroach, are omnivores (both meat and vegetable eaters). However, almost any one of them can be forced to change its usual dietary habits when it is confronted with starvation.

The sense organs and nervous systems have become greatly modified among the insects. The central nervous system of some of the lower insects does not differ greatly from that found in the earthworm, while in others, like the honeybee, there has been a great deal of fusion of ganglia and an apparently higher or more closely knit coördination of parts developed.

Insects have developed better means of communication than is found among the lower forms. Their ability to produce and to hear sounds has already been described in some forms. Another means of communication is illustrated by the firefly, which is able to produce a light which seems to bring the sexes together at the mating season. How this light is produced is an interesting problem, and one which biologists have studied for a long time. It will be discussed under the topic of bioluminescence. Most insects are remarkably sensitive to chemicals, especially in the air, greatly exceeding man in this respect. Some leave a faint scent which is detected by other members of the species, usually of the opposite sex. It is a common schoolroom experiment to place a female Cecropia moth, as she emerges in the spring, on the inside of a window screen. Very shortly a great many males, detecting her presence either by odors or by the production of sound, will collect on the outside of the screen. The male mosquito has a very large feathery antenna with which he can detect aerial vibrations coming from the female as much as a quarter of a mile away.

The social insects represent a very high development of the nervous system, perhaps the highest in the invertebrates. There is a long series of gradations from the solitary insects to those which aggregate during hibernation or migration, like some grasshoppers and the monarch butterfly. Out of something like this gregarious behavior may have come the parental care in guarding the eggs and later the young. From such species have come the true social forms which live together in large numbers and have developed various castes, as already described in the honeybee. The change in the various castes has been fundamental because it involves hormonal changes which in turn alter the anatomy of the caste, as, for example, the development of the large mandibles of certain of the soldiers among some species of termites. In this group, in addition to the soldiers which protect the colony, there are the workers, the males, and the queen. In some ant colonies there are as many as 27 different types of individuals, not all present at once but occurring at some time during the history of the colony. Each type performs certain duties and fits into the harmonious operation of this complex venture.

Ants seem to have followed the food habits of man, at least in their methods of providing a food supply. The more primitive ants merely feed as carnivores, but pastoral ants take aphids into their nests and feed them, gathering the honeydew (an excretory product) from them in repayment for their efforts. The harvester ants show further development by carrying cereal grains into their burrow to supply them with food during the winter. Finally, the most advanced are those ants which gather a certain species of fungus and plant it in underground gardens, tending it even to the point of adding humus as a fertilizer. Such behavior represents a very complex interrelationship of instincts, to say the least.

Experiments seem to indicate that insect behavior consists entirely of instincts built up through millions of generations. Instincts are inherited behavior patterns. They are presumably inherited like other traits, and subject to the laws of natural selection. In order to speak of intelligence among insects, there would have to be evidence not only of memory but of ability to choose, and while there is a little of the former in some species, the latter has never been observed. Complex integrated patterns of instincts which make an animal fit perfectly into its environment are oftentimes mistaken for intelligence, but careful analysis will show that such an interpretation is not justified.

Fig. 11-40. Some insects, such as certain braconid flies (not a fly but a relative of the honeybee), lay their eggs inside the body of other insect larvae as shown here. The large sphinx-moth caterpillar in this case supplies the food for the developing fly larvae, which finally break through the skin and spin their white cocoons. The attack usually means death to the caterpillar.

In the reproduction of insects, fertilization is internal. Most insects lay eggs (oviparous) and deposit them in a place where

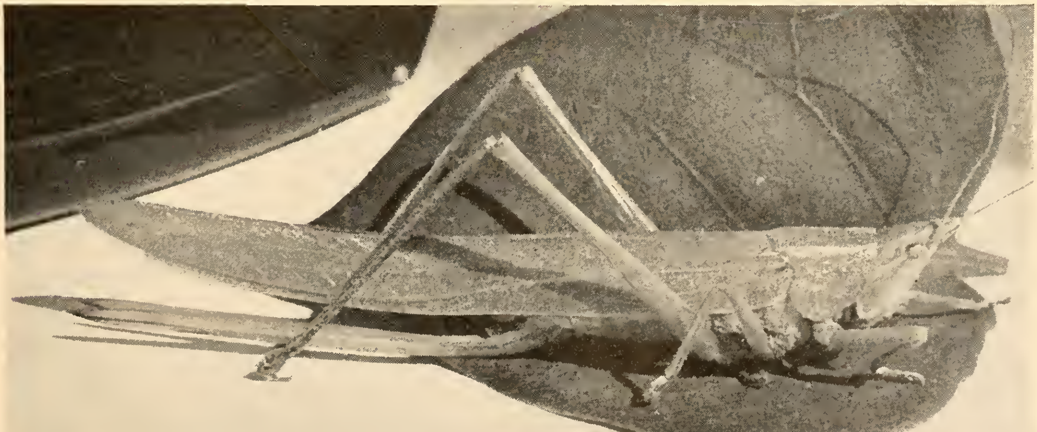


Fig. 11-41. Insects lay their eggs in a variety of places. The katydid (*Microcentrum*) digs a deep hole in the ground where she deposits her eggs. Note the long ovipositors.

Fig. 11-42. Insects vary a great deal in the length of time they remain in the different stages in their life history. The periodical cicada (*Tibicina septendecim*) is interesting because it is thought to remain as a larva in the ground for seventeen years, hence its name "seventeen-year locust" (locusts are grasshoppers). Most cicadas are larvae a much shorter period of time. Here is the case of one clinging to the bark of a tree after the adult emerged. Note the slit along the dorsal side through which it made its way.

development of the larvae is most apt to succeed. This may be in the body of another insect (Fig. 11-40), the tissues of a plant, the ground (Fig. 11-41), or the water. In some species the eggs hatch very soon, as in the housefly, while in others many weeks or even months are required (Fig. 11-42). Certain flies and all of the aphids bring forth active young (ovoviviparous).

The eggs of some insects develop without fertilization by a sperm. Such reproduction is called **parthenogenesis,** or **unisexual reproduction.** This has already been observed in bees, but it is also commonly found among the aphids, where the females lay eggs all through the summer months which hatch only into females. As fall approaches, the eggs produce both males and females. Fertilization then occurs and the resulting eggs remain over winter and hatch into females again in the spring. This process seems to de-emphasize the importance of males, and one begins to wonder why males are necessary at all! However, they do bring in the possibility of variation which is impossible with only one sex. Parthenogenesis is thus a regressive step, and genetically is more akin to the asexual budding that was observed among the coelenterates. Obviously this is a step backwards in evolution.

There is a wide variety among different species of insects with respect to the number of offspring produced by one individual. Some of the viviparous flies, for example, produce only a few offspring, whereas the queen bee may lay a million eggs in her lifetime. Under optimum conditions the housefly, if unchecked, could increase in one summer to such proportions as to cover the earth completely, for it goes through its entire life cycle in eight days if the temperature is high enough (80-90° F.).

The manner of development from egg to adult is widely variable among many animals and is particularly striking among the insects. The term **metamorphosis,** which means change in form, is applied to any animal that undergoes more or less marked changes of form between the time of hatching and of reaching the adult state. A few primitive insects merely increase in size after hatching, showing no metamorphosis (Fig. 11-43). Others, such as the grasshopper, hatch into a **nymph,** which resembles the adult fairly closely except for the wings which are acquired much later (Fig. 11-44). Such change is known as **gradual metamorphosis.** Some, such as the dragonfly, hatch into a **naiad** (Fig. 11-32), which resembles the adult to some extent, but not as much as the nymph resembles the adult grasshopper. This type of change is called **incomplete metamorphosis.** In the case of the housefly or June beetle, the larval stage does not resemble the adult in any way (Fig. 11-45); the larva is worm-like and usually its diet varies radically from that of the adult. Moreover, between the larval and the adult stage there is a "resting" stage, known as the **pupa,** during which time the larval body is transformed into the adult body. This type of change is known as **complete metamorphosis.** Other aspects of

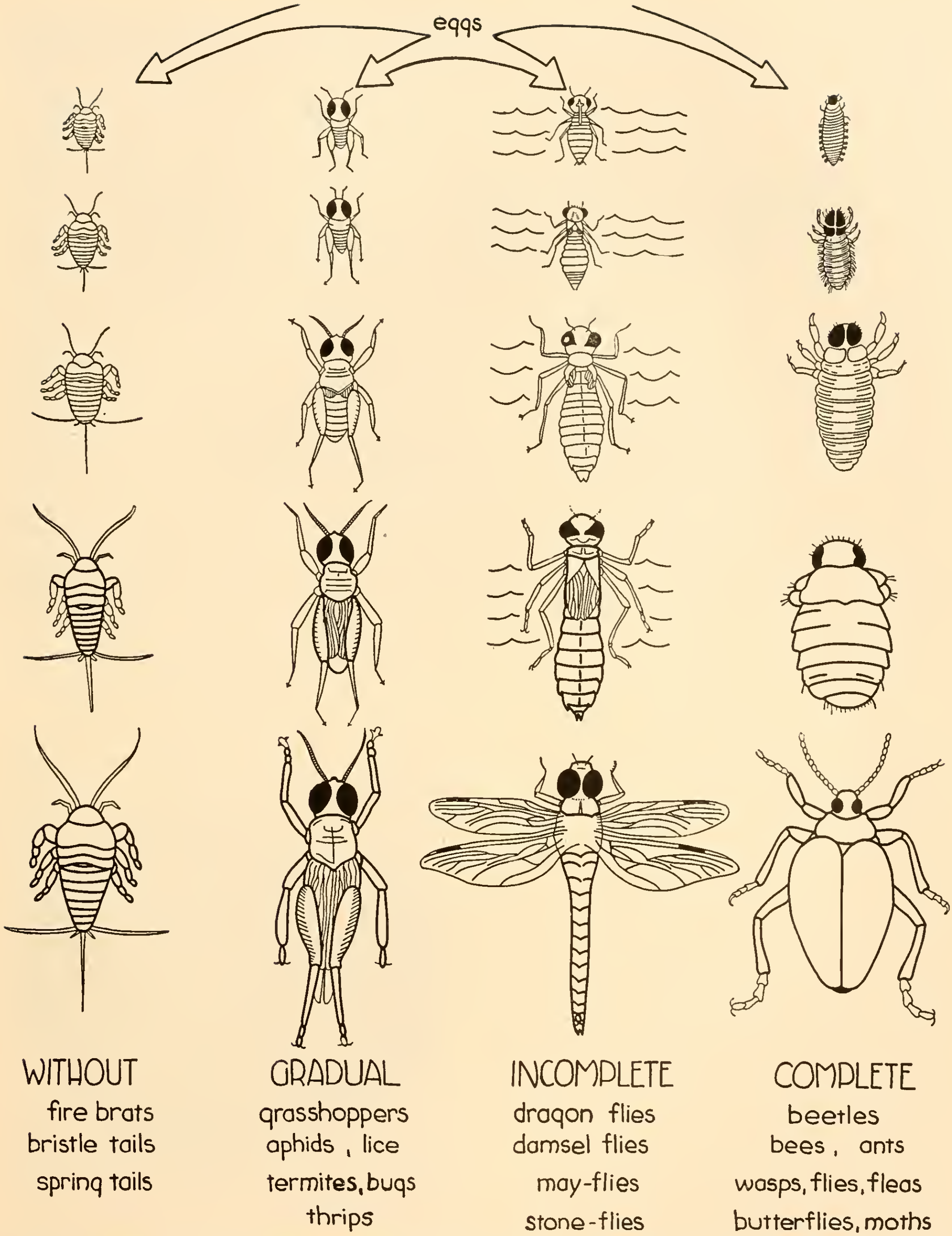


Fig. 11-43. Various types of metamorphosis, together with the names of some of the insects that undergo each type.

Fig. 11-44. Insects show wide variation in the manner in which they develop from egg to the adult. The grasshopper shows one type, namely, gradual metamorphosis. Note that the young resemble the parents in most respects when hatched. As they grow, however, they acquire adult structures such as functional wings.

metamorphosis as it appears in other animals will be discussed in a later chapter.

It has recently been learned that insects as well as Crustacea possess certain hormones that influence development and probably profoundly affect other phases of their lives. It has been demonstrated that a gland, the **corpus allatum,** lying behind the brain, is hormonal in function. When it is removed from the bug *Rhodnius*, molting does not occur. If the gland is transplanted to other distantly related insects, it is still effective, hence the substance secreted is apparently non-specific.

OTHER ARTHROPODS

There are several other groups of less important arthropods which will be considered briefly: the spiders, ticks, and scorpions (Arachnoidea); the centipedes (Chilopoda); and the millipedes (Diplopoda). Of

Fig. 11-45. Insects such as beetles undergo complete metamorphosis during their development. The larva shows no resemblance to the adult and frequently lives in quite a different environment. This is a larva, "grub worm," of the June beetle which matures in the soil, feeding on underground vegetation. Note the nine dark spiracles.

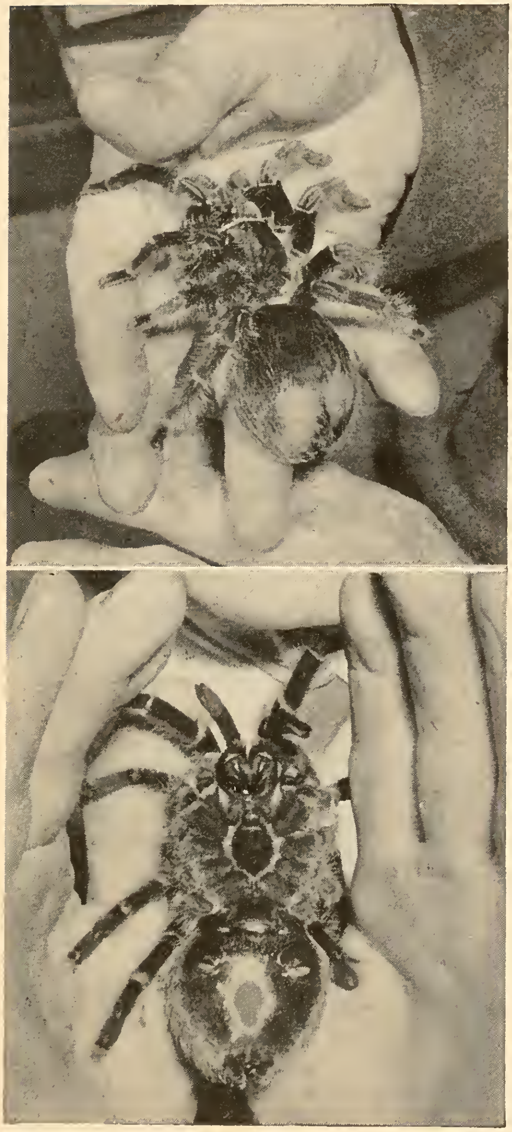


Fig. 11-46. American tarantula (*Eurypelma*), one of the largest of all spiders. They are harmless if properly handled and live to a ripe old age in captivity. This specimen is 26 years old (estimated) and has been in the possession of Mr. Robert Baird for 22 years.

The dorsal view is shown in upper picture. Note the eight pairs of legs and the "hairy" body.

In the lower picture, the ventrol view, the large powerful nippers are seen which are used in stinging the prey. The spinnerets con be seen on the tip of the abdomen. The silk glands lie just inside the abdominal cavity and the secretion is forced out through the tiny openings, solidifying into thread when it contacts the air.

The food of this spider is other arthropods, usually insects, although it will kill a small bird and feed on it. Its sting is relatively harmless to man.

these the first group is the most important.

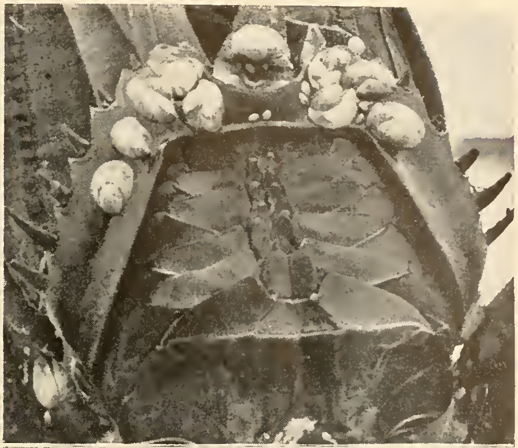
The acquired fear of spiders and scorpions is almost as characteristic among people as is the fear of snakes. In either group of animals, however, only a small number is actually harmful to man; most of them benefit him in one way or another. The spiders, for example, feed almost entirely on insects, many of which are pests to mankind; their efforts in keeping the insect population down is probably considerable. The spider's persistence has become legendary through the story of Robert Bruce and the spider.

Passing through the woods or sometimes in the open in the late summer, all of us have no doubt had to brush cobwebs from our brows. These are made by the famous "ballooning spiders," which are recently hatched spiders that seek some high place from where they can float, clinging to their tiny thread. Even in the most feeble breeze these tiny spiders float great distances, sometimes far out to sea. It is their method of dispersal, which makes it possible for the species to find new and fertile places to hunt for food. Others build very delicate webs in which flying insects are captured and sucked dry by the owner of the web. Watching a spider spin such a web is indeed a fascinating adventure. Other spiders chase and catch their prey; still others leap upon it and kill it by piercing the body with their sharp nippers (Fig. 11-46) and injecting a small quantity of poison that simply paralyzes the insect, until it is consumed by the spider. Such a paralyzed insect may stay in a fresh condition for a long time—a kind of room-temperature refrigeration. Some of the tarantulas may feed voraciously when food is available, but when it is scarce they may go for months without food and remain in good health. Although most spiders live only a year or so, tarantulas have been kept in captivity for as long as 26 years.

The bite of most spiders is harmless, even the bite of the large tarantula being no

Fig. 11-47. A female black widow spider (*Lactrodectus mactans*) with her egg case.

Fig. 11-48. The common scorpion (*Vejovis*) of the Southwest is an arachnid like the spider. It hides by day and hunts spiders and insects at night. The sting at the tip of the tail is an effective weapon against predators and is useful in capturing prey. It sucks the body fluids from its prey. Its sting is painful to humans but not fatal.



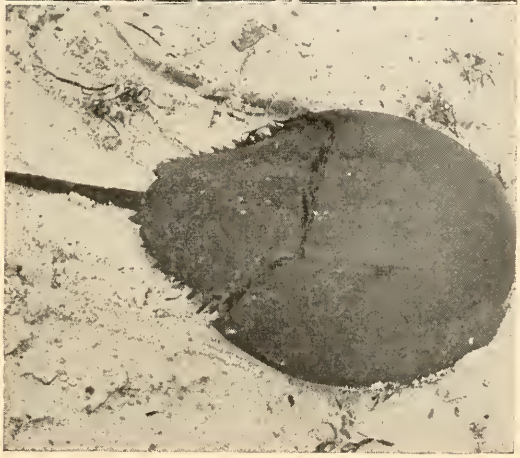


Fig. 11-49. The king crab (*Limulus*), or horseshoe crab, is a distant relative of the spiders and scorpions and is not a crustacean at all. It is a "living fossil" whose close relatives have all become extinct many millions of years ago.

Note the leaf-like flaps just back of the legs. These are the book gills, so called because when in use the flaps wave in the water like the pages of a book. The snails (*Crepidula*) find it advantageous to "hitch hike" on the crab, thus affording them a much more extensive feeding area than they could ever attain under their own power. When out of water note the track it makes in the sand. While clumsy on land *Limulus* moves effectively along the ocean floor where it shovels in the mud searching for worms of various kinds that make up its diet.

more serious than a bee sting. There is one species, however, which is very common in the United States, particularly in California, which can cause serious illness and death in some cases. This is the black widow, *Lactrodectus mactans* (Fig. 11-47), which is three-fourths of an inch long, and glistening black. On the ventral side is a bright red hour-glass shaped figure, which is a positive means of identification. It lives normally in piles of rocks, lumber, and more recently around buildings, particularly garages. It has been known to cling to the underside of automobiles, thus being transported to all parts of the country. The bite causes severe abdominal spasms and general restlessness, and the mortality is about 5 per cent. An anti-venom has been developed which protects the victim from the more serious effects of the toxin. In spite of the relatively small amount of harm done by this one species of the group in our country, spiders are generally set upon and killed by the ordinary person. This is unfortunate, for these friends, rather than enemies, of man should be protected.

The life history of the spider is rather unique in some respects. The male is always smaller than the female and in some cases, such as the black widow, he is hardly recognizable because of his proportionately minute size. He spins a web upon which he deposits his sperms in a mass, which is then picked up by his specially formed front appendages and carried while searching for a female. Once he has found a mate, he usually performs a rather weird kind of dance and then deposits the sperm bundle

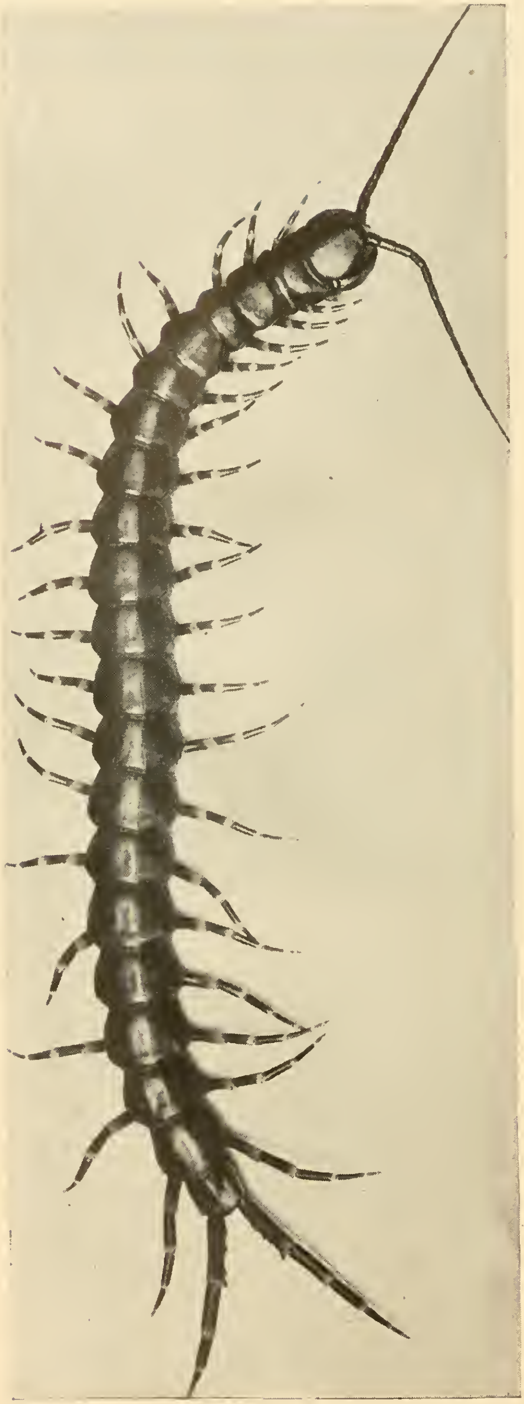


Fig. 11-50. Centipedes have numerous jointed legs. Some tropical forms are nearly a foot long and can inflict a painful wound in a man. This is a smaller form common in the U. S.

into her genital pore. Sometimes the female proceeds to devour her unsuspecting mate, but such is not always the case, and he may succeed in escaping. She then spins a tiny ball in which the eggs are laid and often carries it around with her. It is with considerable difficulty that this ball of eggs can be removed from the female spider. She takes it with her everywhere and guards it very closely. But after the young have hatched, they are on their own.

The scorpion (Fig. 11-48) is an elongated relative of the spider, with large, fierce-looking pincers held out in front. The long abdomen also terminates in a sharp-pointed sting which inflicts an irritating wound on man and a fatal one for the insects and spiders which make up its primary diet. It is active at night and hides by day under logs and rocks. The "mating dance" of the scorpions has been described in detail by many observers and is a very interesting event.

The horseshoe or king crab (Fig. 11-49) another arthropod, is of interest because it belongs to a very ancient group and is therefore sometimes referred to as a living fossil. It inhabits our Atlantic coastal waters from Maine to Central America and its molt is a common sight, if not the animal itself. For some strange reason, this surviving species of the arthropods which lived long ago (Cambrian period) has been able to continue down to the present, while its millions of relatives have become extinct.

The many-legged centipedes (Fig. 11-50) are commonly found under stones and logs where they remain inactive during the day. At night, however, they move swiftly about in search of their favorite food, earthworms and insects. They possess a pair of poison claws on the first segment which are effective instruments in securing prey. Some of the tropical centipedes reach a length of 10 inches, and their bite, while not dangerous to man, is certainly painful. In temperate zones the most common is the house

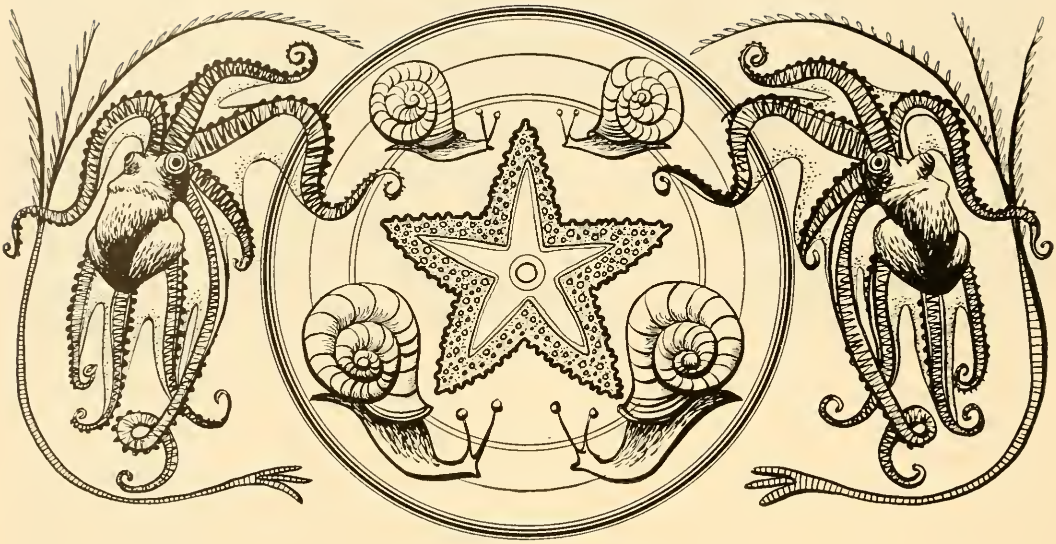
Fig. 11-51. The millipede (*Spirobolus*) possesses two pairs of jointed appendages on most of its segments. These numerous legs move in a rhythmic manner as can be seen from this photograph. Millipedes live in decaying vegetation upon which they feed.

centipede, which is not only harmless to man but actually beneficial because it feeds exclusively on some of his prime enemies, the insects.

Millipedes (Fig. 11-51) occupy habitats similar to those of the centipedes and resemble them in having many legs, except that they possess many more as the name implies. Some have over 100 segments with two pairs of legs on each. When the millipede crawls the legs move in a wave-like manner, the wave seemingly moves in a posterior-anterior direction. They are slow, crawling creatures, not at all like the centipedes. They feed on plants and decaying organic matter. When in danger some species roll into a ball, whereas others secrete an offensive fluid which serves them well as a protection against their enemies.

In summary we have seen that the arthropods have acquired a body plan so beautifully designed that it has permitted the group to penetrate almost every available type of land and fresh-water environment, and to become the most successful of all animals alive on earth today. The body plan limits the group in only one respect, that of size. All arthropods (with few exceptions) are small animals and to produce successful larger forms an entirely different design had to be evolved. This is beautifully accomplished in the chordates, the last group to occupy our attention. However, before going on with this very important group we must discuss two peculiar groups of animals that appear to represent digressions from the phylogenetic sequence, the mollusks and echinoderms. Their aberrant body plans, though strange when compared to others studied so far, have been sufficiently satisfactory to permit them to spread their kind over much of the earth's surface, both in the water and on land.

CHAPTER 12



ABERRANT ANIMALS—THE MOLLUSKS AND ECHINODERMS

All of the animals considered so far have followed a series of rather logical steps, in which increasingly complex physiological needs have been satisfied by the development of new parts supplementing the basic plan of the lower phyla. Two very large groups of animals, the mollusks and the echinoderms, have solved these needs in a manner quite different from the other groups. Since they have not followed the trend that has been obvious from amoeba through the arthropods, they are known as aberrant animals. Both groups are biologically successful: not only are there several thousand species of mollusks and echinoderms, but they are spread over a great part of the earth.

PHYLUM MOLLUSCA

The soft-bodied animals that compose the phylum Mollusca include the snail and clam, which are familiar to nearly everyone, as well as the lesser known squid, chiton, and octopus. These animals are scattered through the oceans and fresh waters of the world, their large fleshy bodies providing an abundant source of food for man and other animals. There are over 70,000 species of mollusks which vary rather widely in external appearance but have similar basic body plans. Perhaps the most notable and striking thing about the mollusks is the lack of segmentation. Even the chitons (Fig. 12-1), which appear externally to be segmented, show no true metamerism when the internal anatomy is studied. It seems rather strange that this group of animals ignored or failed to acquire a body arrangement which is so successful among the annelids and arthropods and becomes even more so among the chordates.

In considering the ancestors of the mollusks it is necessary to go back a very long way, into prehistoric times. Fossil records indicate that mollusks were present in some of the earliest rocks and have continued, uninterrupted, to the present time. However, even in the rocks there is little evidence to determine their ancestry. It is generally believed that they were derived from "worm-like" ancestors, although these were not the annelids known today. Larval studies indicate that there is a close relationship to the annelids, but that relationship must go far back since the larval stage of the mollusk, the **trochophore**, does not show segmentation in the mesoderm (Fig. 12-2). This means that the annelids and mollusks split off and went their separate ways before segmentation was introduced. The trochophore larva is common to both annelid and mollusk and remarkably similar in both. The coelom is formed by a depression in the mass of mesoderm, which arises from a single cell.

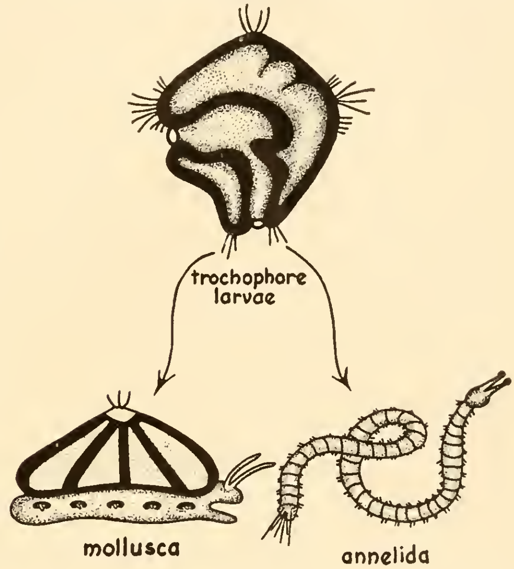


Fig. 12-2. The ancestral trochophore larva from which both the mollusca and annelida are thought to have been derived.

Fig. 12-1. Chitons are primitive mollusks and probably resemble the ancient forms that gave rise to our modern mollusks. Note the eight overlapping shells on the dorsal side. Chitons live among the rocks on the seashore and are active at night.

The molluscan body plan has certain characteristic features that appear consistently in all of the species in the group. One of these is a muscular organ, the **foot**, an organ which serves for several types of locomotion. The snail and chiton crawl on it, the clam digs a wedge-shaped path with it and also walks on it, while the squid uses it to capture prey as well as to crawl over the ocean floor (Fig. 12-3). Another new character is the **mantle**, which is an envelope of tissue covering the entire animal. The mantle gives rise to the **shell**, common in so many members of this group. The original shell appears in the larva as a product of the mantle epithelium and gradually expands as the animal grows.

Those mollusks that possess shells use them as an abode which is readily available

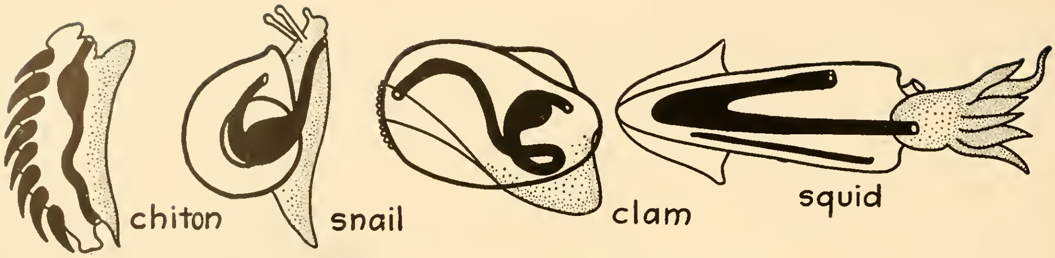


Fig. 12-3. Modifications in the body plan of various kinds of mollusks.

for a retreat in case of danger. Although a clam is usually safe in its tightly closed shell, it is nevertheless preyed upon by the starfish, which has the ability to open the shell and devour the soft body parts (Fig. 12-24). Some members of the phylum have no shells, such as the slug and octopus. They are protected only by their coloration, their habits, or the ability of some to discharge a cloud of inky material into the water which totally obscures them.

The digestive tract is tubular, much the same as in the annelids, although it is coiled in various ways in the different groups of the mollusks (Fig. 12-3). Many of these animals are provided with a peculiar rasping tongue, the **radula,** which is found nowhere else in the animal kingdom. It is used in loosening algae from surfaces, and in tearing bits of plants loose as the animal feeds. The radula is a long ribbon of tough tissue, to which many sharp teeth are attached. Muscles are arranged so as to pull the radula back and forth over a projection which is thrust out through the mouth while feeding. It is an interesting and clever device to facilitate feeding.

The clam

The fresh-water clam, although differing in some respects from other molluscan forms, is a familiar representative of the entire phylum. It is a bilaterally symmetrical, "headless" animal, enclosed in a double shell, usually found partly buried in the sand of lakes or streams. By means of its hatchet-shaped, muscular foot, which protrudes from the shell, it is able to plow slowly along, feeding on microscopic forms of life.

When the clam "walks" the foot is thrust forward between the two valves of the shell. This permits blood to flow into the many **sinuses** of the foot, causing it to swell and thus form an anchor. As the retractor muscles contract, the clam is drawn for-

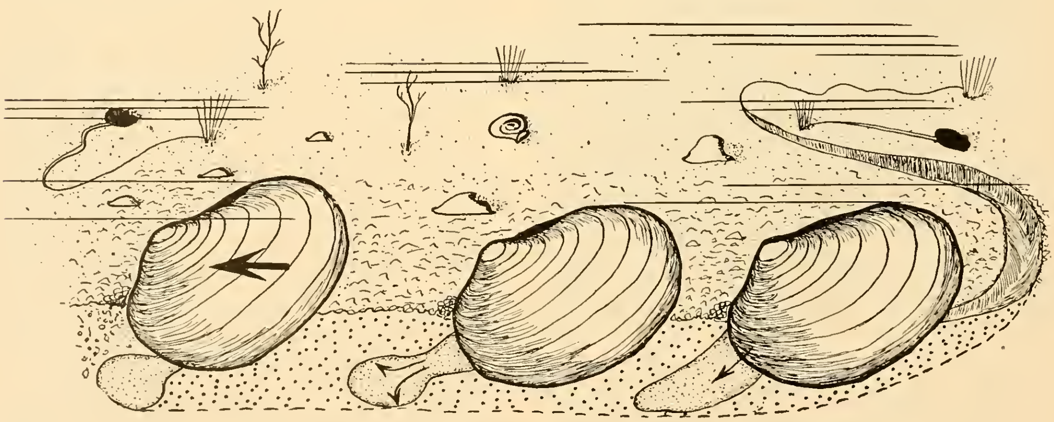


Fig. 12-4. Locomotion of a clam.

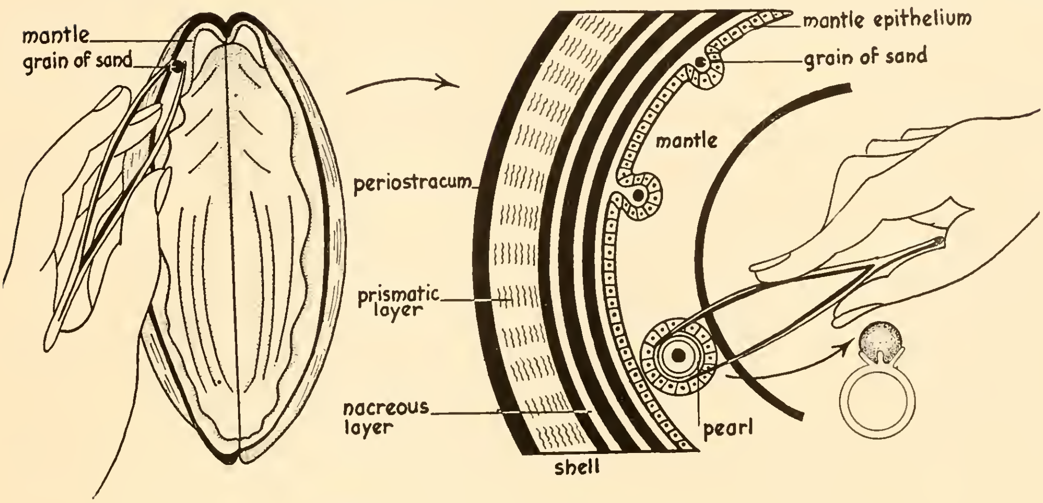


Fig. 12-5. Artificial production of pearls.

ward an inch or so. The blood then is forced out of the foot so that it thins down again and can be withdrawn from the sand. The process is repeated with each step (Fig. 12-4) and a wedge-shaped path is left behind.

If a clam is molested, its foot is hastily withdrawn into the shell by the **anterior** and **posterior retractor muscles**, and the valves are slowly and tightly shut by two powerful muscles, the **anterior** and **posterior adductors**. This is the only means the clam has of barring its door from intruders. To attempt to pull the valves of the shell open is a nearly hopeless task, unless a thin-bladed knife is first inserted through the edge of the shell to sever the large adductor muscles. The starfish, however, has a novel way of opening the valves. It circumvents the clam, attaches its tube feet to the two valves of the shell, and exerts a steady pull. The pull is resisted by the clam for some time, but finally the muscles are exhausted and begin to relax (Fig. 12-24).

The two valves of the clam are hinged dorsally by a ligament, which can be observed when the adductor muscles are cut. The shell itself is usually oval in shape, with a blunt anterior end. Along the dorsal surface is the **umbo**, a bulbous structure which is the oldest part of the shell. From it appear the **concentric lines of growth**, indicating successive stages of development.

The outer layer of the shell, the **periostracum**, is produced first, then the **prismatic** layer, and finally the innermost part, the **pearly** layer. The periostracum is rough and can resist the weak acids produced by the dissolved carbon dioxide in the water. The prismatic layer, which gives strength to the shell, is produced from crystals of calcium carbonate lying perpendicular to the outer layer. The pearly layer, the portion that interests the shell collector, is also composed of calcium carbonate crystals that are arranged parallel with the shell, resulting in an extremely smooth iridescent layer. The mantle deposits this layer over any irregularities that occur, either in the shell or loose particles that may lodge in the mantle itself. This is the origin of pearls. Foreign bodies, such as grains of sand or the eggs of certain parasitic worms, sometimes become attached to the mantle or lodged between the mantle and the shell. In such a case, layer after layer of calcium carbonate (pearl) is secreted over the particle, eventually resulting in a pearl. The Japanese produce pearls

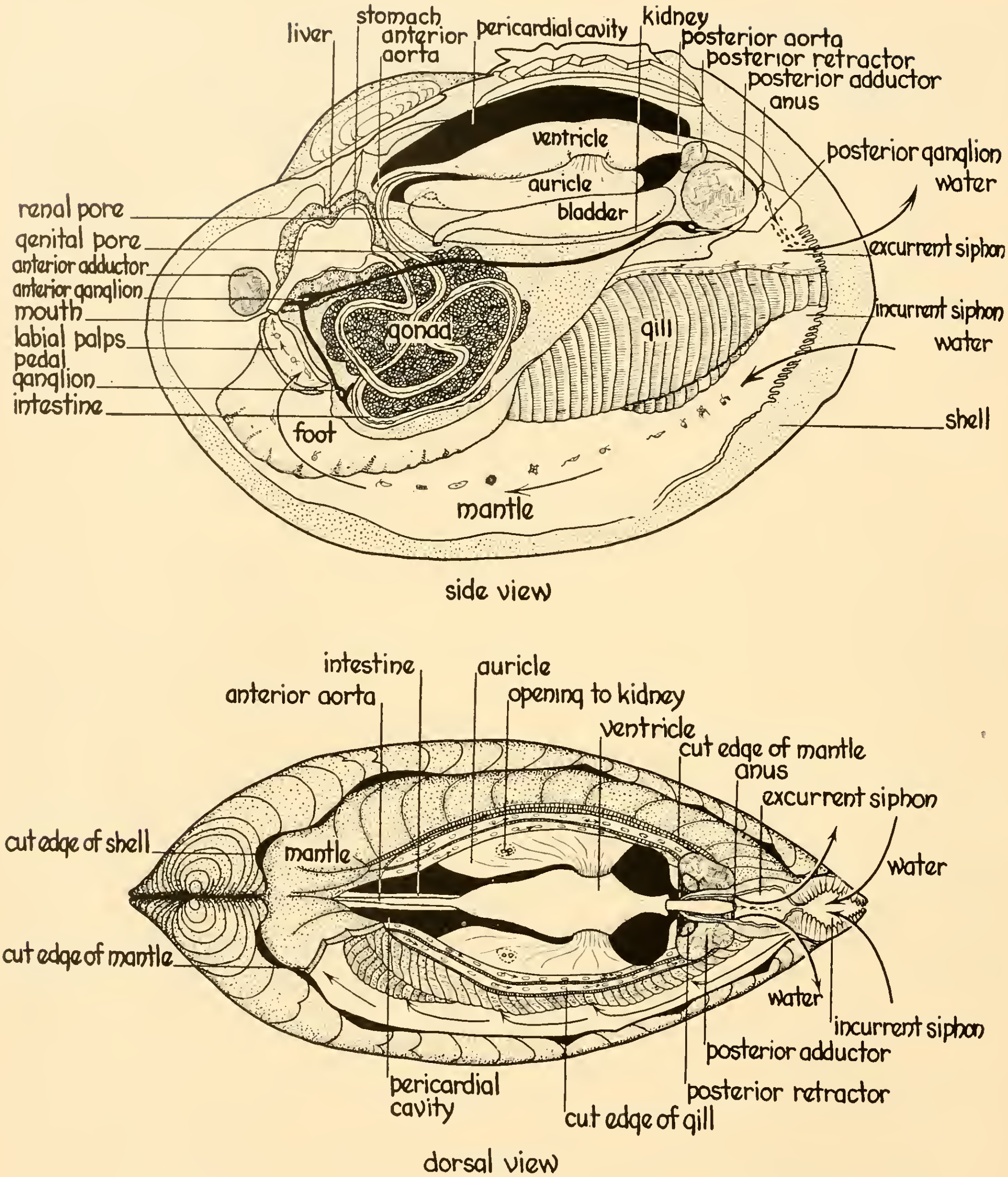


Fig. 12-6. The internal anatomy of the clam shown from the side and dorsal views.

arificially by inserting glass beads into the mantles of clams or oysters. After several years the pearls can be removed and sold on the market. These are true pearls artificially produced (Fig. 12-5).

Once the valves of the clam are opened, a soft body enveloped in a mantle is exposed. The mantle simply consists of two thin sheets of tissue, or **lobes**. The posterior free ends are muscular, and come together to form the **ventral incurrent** and the **dorsal excurrent** siphons, which permit water to move in and out by ciliary action of the inner mantle cavity (Fig. 12-6). Each side of the mantle adheres to the inner nacreous surface of the two valves. At these points of

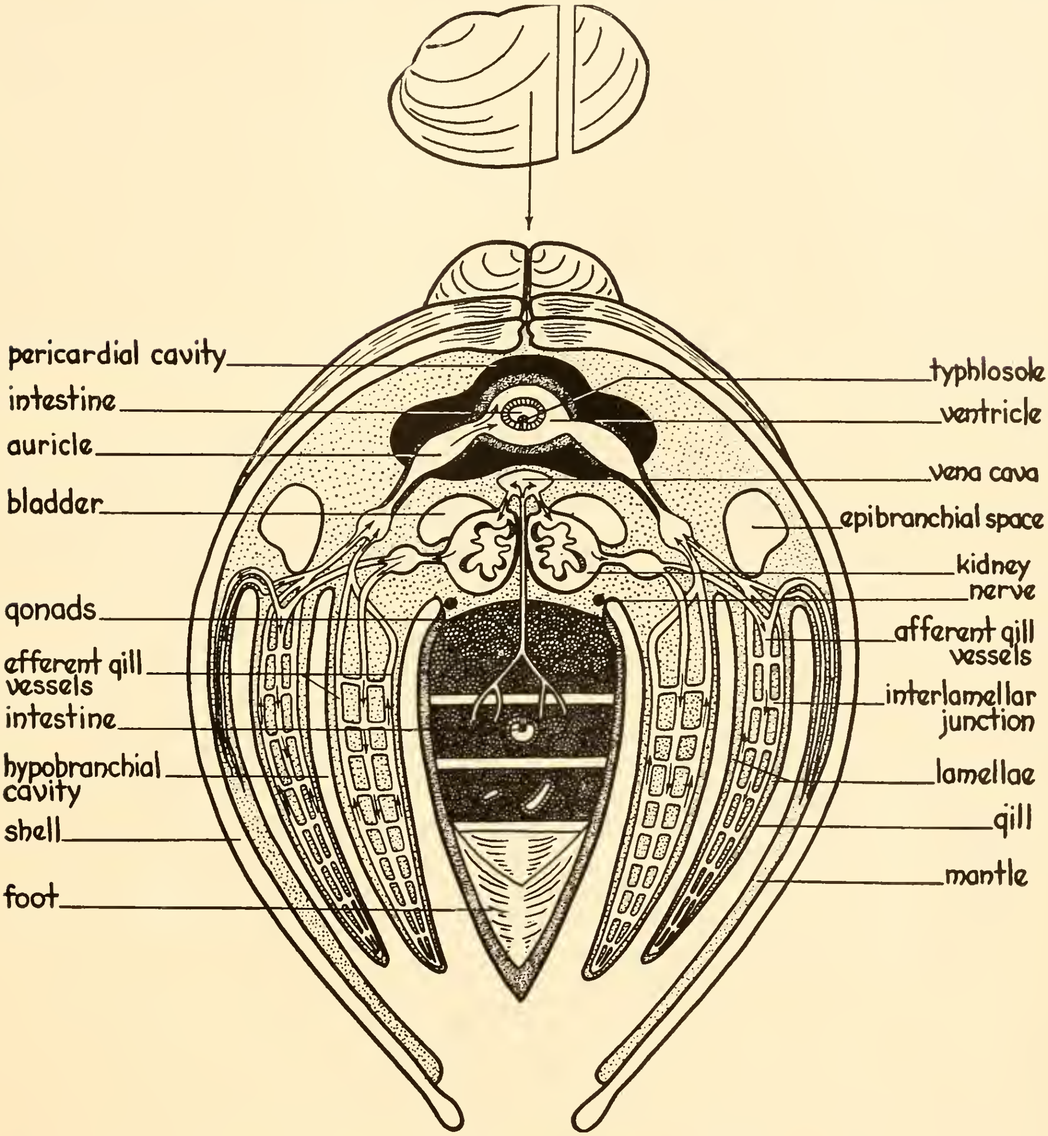


Fig. 12-7. Cross-section of the clam through the region of the heart.

adhesion, the **pallial line** is formed on the shell. The heavy muscular foot lies directly beneath the mantle and extends anteriorly from the mid-portion of the body. Just posterior to the foot and beneath the mantle are two pairs of **gills.** The dorsal portion of the body, directly above the muscular foot, contains the internal organs of the animal and is called the **visceral mass.**

The four plate-like gills are attached from a point between the siphons to the region just opposite the umbo (Figs. 12-6, 12-7). They hang freely beween the mantle and the visceral mass. Each gill is made up of two plates, the **lamellae,** which are held together by bridges of tissue. The cavity between the lamellae is divided into separate **water tubes.** The lamellae are thrown into vertical folds called **gill bars** and are reinforced by chitinous rods. In addition horizontal rows of ciliated pores, or **ostia,** perforate the lamellae through which water enters the gill. The water tubes lead to a dorsally situated **supra-branchial chamber** that continues to the posterior portion of the gill and opens into the excurrent siphon. Blood from the veins circulate through tiny vessels within the gill to be aerated before returning to the heart. In this manner the constant stream of water flowing through the gills supplies the animal with oxygen.

The beating cilia of the gills and the mantle draw water and food into the mantle cavity through the incurrent siphon. The siphon opening serves to strain out all but very minute food particles such as algae, Protozoa, and bits of debris. Mucus secreted by the gills catches these particles which are borne anteriorly by cilia to two pairs of triangular, ciliated **labial palps.** Here a separation takes place (Fig. 12-6), the edible particles being carried into a groove between the palps and then to the mouth, and the debris passing out through the excurrent siphon. In the buccal cavity more mucus is secreted and the food is carried through the short **esophagus** to the dorsally located, sac-like **stomach.** A pair of **digestive glands** joins the stomach through ducts. Digestion occurs both in the stomach and in the glands themselves. In some species of clams the **crystalline style,** a gelatinous rod resembling a pouch or caecum of the stomach, secretes a starch-digesting enzyme. The intestine, leading from the stomach, coils several times through the visceral mass, much of which is the yellow-colored, branched **gonad,** before it turns dorsally to pass through the **pericardial cavity** and the heart. Absorption takes place throughout the length of the intestine, particularly in the portion of the rectum which passes through the **ventricle** of the heart. The **typhlosole** is a longitudinal fold in the rectum, a structure very similar to that found in the intestine of the earthworm. Posteriorly, the intestine opens through the **anus,** located within the excurrent siphon, where the feces are carried away with the out-going current of water (Fig. 12-6).

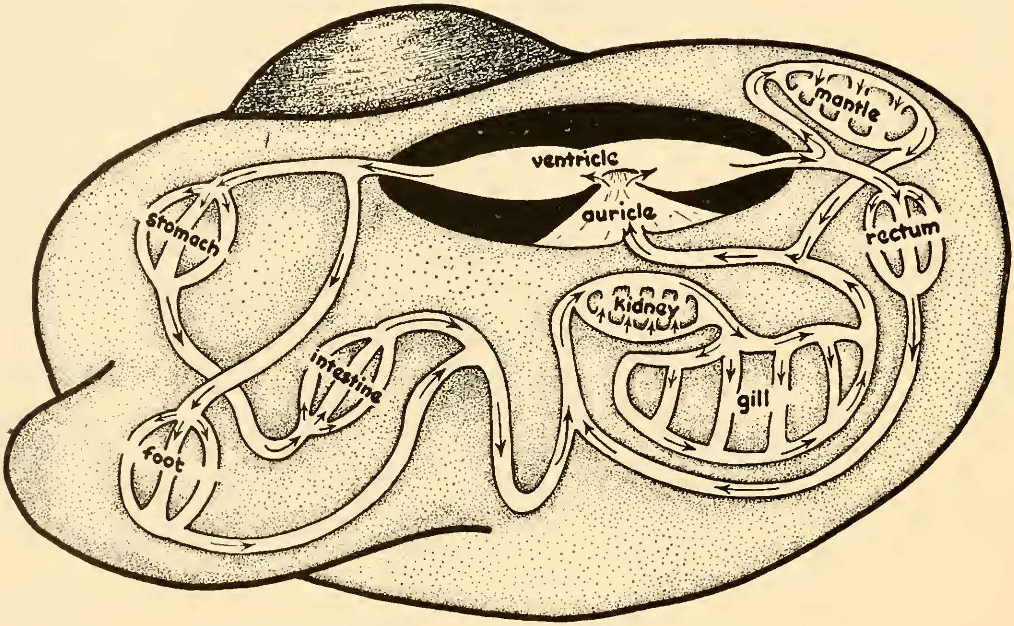


Fig. 12-8. Schematic drawing of the circulatory system of the clam.

The **heart,** lying in the dorsal pericardial cavity, forces the blood through the circulatory system of the clam (Figs. 12-7, 12-8). The **ventricle**, which is joined by two laterally situated **auricles**, pumps the blood forward into an **anterior aorta**, supplying the muscular foot and viscera, and posteriorly, through the **posterior aorta**, supplying the rectum and the mantle. Blood from those parts of the body supplied by the aortas, with the exception of the mantle, is returned through a vein to the **nephridia**, or

to absorption through diffusion. This is particularly true in the region of the foot where blood sinuses are numerous.

Two U-shaped kidneys lie ventral to the pericardial cavity (Figs. 12-6, 12-7). These function in the removal of wastes from the blood and other fluid of the pericardial cavity. Each is a tubular organ, folded upon itself and divided into **glandular** and **bladder-like** parts. A ciliated opening from the pericardial chamber into the glandu-

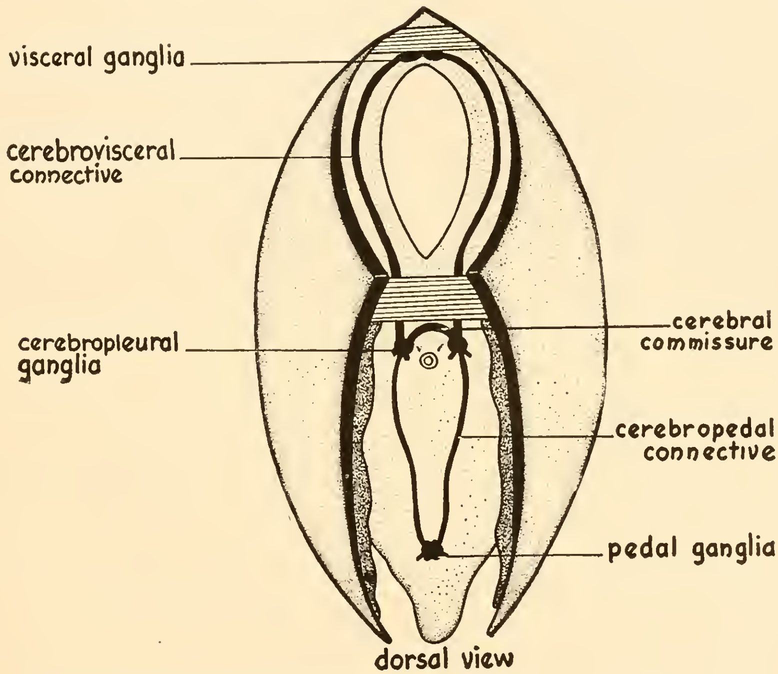


Fig. 12-9. Anterio-dorsal schematic drawing of the nervous system of the clam.

kidneys, for the elimination of waste products. It then moves to the gills to pick up oxygen and eliminate carbon dioxide. Oxygenated blood is returned from the gills on each side of the clam to the corresponding auricle. The mantle also returns oxygenated blood to the auricles. Unlike the circulatory system of some other animals, some of the arteries and veins of the clam are not joined by capillaries, but end in sinuses, without cellular lining. Food and oxygen carried directly to these sinuses can pass into intercellular spaces and are not restricted

lar portion drains this region, while the bladder region opens into the path of the excurrent water, thus carrying wastes out of the body.

Three pairs of ganglia and their connecting nerve cords constitute the nervous system of the fresh-water clam (Fig. 12-9). Each pair of ganglia controls the body region in which it is located: the **anterior** or **cerebropleural ganglia** on either side of the mouth; the **pedal ganglia** in the foot; and the **posterior** or **visceral ganglia** ventral to the posterior adductor muscle. Each

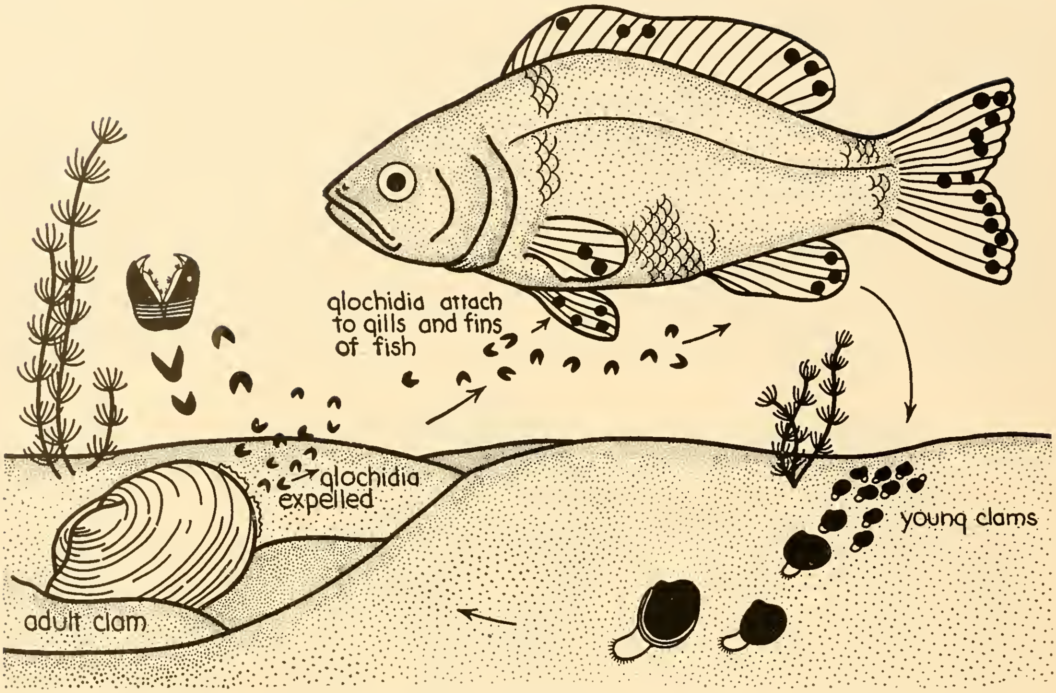


Fig. 12-10. Life cycle of the clam.

pair of ganglia is connected by a **commissure** and by two **connectives**, the **cerebrovisceral** and **cerebropedal** to the other ganglionic pairs. Small nerves extend from the ganglia to the body surface and the muscles. Although the clam is a highly specialized animal in many respects, its nervous system is comparatively primitive. First of all, there is little evidence of a brain. Furthermore, the connectives that surround the esophagus are highly reminiscent of the circumpharyngeal connectives of the earthworm. The sensory apparatus is limited to sensory cells on the siphon margins, tactile organs on the mantle, and some areas which are believed to be sensitive to chemicals. Most of these structures resemble similar parts of lower type animals. Clams are slow, sluggish animals and the sensory system required is relatively simple.

Fresh-water clams, for the most part, are dioecious, but some are hermaphroditic. The **ovaries** and **testes**, yellow in color and surrounding the intestine, constitute much of the visceral mass (Fig. 12-6). The sperms of the male are liberated from the testes through the **genital pore**, just ventral to the aperture of the bladder portion of the kidney. From here they are carried through the body to be discharged through the excurrent siphon. As water is carried into the incurrent siphon of the female it may, purely by chance, carry sperm cells with it. These then enter the **suprabranchial chamber** of the gills where the **ova** discharged from the ovary await fertilization. After fertilization, the eggs are drawn into the water tubes of the gills and attached to them by mucus. While the tubes are carrying eggs they become enlarged and are called **brood chambers**. After a period of development, the zygotes become small larval **glochidia** (singular, *glochidium*), complete with two valves and a larval thread (Fig. 12-10). Many species develop a hooked valve. At this stage they are discharged into the water through the excurrent siphon of the female where they may

Fig. 12-11. The knobbed whelk (*Busycon carica*) laying its string of egg capsules. This large whelk inhabits the eastern coast of the United States. This one was taken at Woods Hole, Mass.

float through the currents or sink to the bottom. There is no free movement of the glochidium at this time, other than the opening and closing of its valves. Hooked forms try to attach themselves to any fish with which they may come in contact, whereas the hookless forms grasp the gills of fishes by means of their valves. In time, the epithelium of the fish encases the glochidium in a cyst-like case. During this period the young clam is entirely parasitic, receiving nourishment from its host through absorption. After the adult organs have developed, the glochidium bursts out of the cyst and sinks to the bottom as an independent free-living animal.

Most pelecypods (from the class name —Pelecypoda) are bottom dwellers, some species of clams even burrow far down into the sand and push their siphons up into the water. Other forms, such as the **oyster,** are permanently attached to rocks or similar objects beneath the water. The **shipworm** (*Toredo navalis*) has such a slender shell that it can burrow into the wood of ships and wharves, where it does extensive damage. The scallop can swim freely in the water by flapping its shells together.

Other mollusks

Members of the class **Amphineura** are the most primitive forms among the mollusks. In this group are the chitons, which most nearly resemble the probable wormlike ancestors of the phylum (Fig. 12-1). Their dorsal covering of eight calcareous plates has led some biologists to believe that this may be the remnant of segmentation. The ocean-inhabiting chitons attach themselves so securely to rocks that it is almost impossible to pry them loose. If they are dislodged they promptly curl up into a ball. Much like the annelids, chitons live under rocks. They are principally "vegetarians," feeding on various kinds of marine algae.

In most forms the sexes are separate. One investigator, Grave, found that the

Fig. 12-12. Gastropoda. Two oyster drills (*Urosalpinx*) and one periwinkle (*Littorina*) are crawling over a rock encrusted with barnacles (*Balanus*). These marine snails are very common on our coasts.

sexual activity of one species of chiton was influenced by moonlight. It is generally believed that periods of moonlight are preferred by this animal because the tides are low, a condition most favorable for successful spawning. Coloration in chitons varies, ranging from turquoise and slaty blue to gray and white. Most of the Amphineura are "shy" animals and tend to avoid daylight, although there are some species with furry mantles that do sally forth in the daytime.

The class **Scaphopoda** includes several "headless" species, the best known being *Dentalium,* the "elephant's tooth." It has a muscular foot which is modified for burrowing into the sand and is therefore quite sharply pointed. Its elongated body is encased in a tapering shell. Unlike most mollusks, this animal bears no gills and the mantle alone takes care of respiration.

Some of the most interesting and varied forms of the mollusks belong to the class **Gastropoda**. They range in size from microscopic forms to the large whelks (Fig. 12-11). Although most members of this class possess some kind of shell, forms that are entirely without a shell also appear. Some have adapted themselves to terrestrial life as well as the usual aquatic habitat. The most common form is the snail, an animal familiar to almost everyone (Fig. 12-12). The snail is often observed wending its way slowly on the leaf of a water plant or along a sandy-bottomed pool. It moves by gliding over a secreted mucus path, using its flattened muscular foot which forms the ventral surface of its body. The movement of the snail closely resembles the gliding movement of planaria. In some species the foot is actually ciliated to aid the gliding motion; in others movement occurs by rhythmic muscular contraction of the foot. The land snail (Fig. 12-13) has a definite head which bears two pairs of tentacles, one short pair, supposedly the center of the sense of smell, and a longer pair with a simple eye at the tip of each. In water forms the eyes are situated at the base of the tentacles.

Judging from its coiled shell, one would expect the snail to have an asymmetrical body. This is only partly true, however, for the head and the elongated flattened foot are bilaterally symmetrical, whereas the remainder of the body, which composes the visceral mass, is asymmetrical, parts of the digestive and circulatory systems being coiled. The shell of the gastropods is univalved, that is, one piece, but the single valve may vary in shape from tiny flattened spirals to long spindle shapes or even turban or slipper-like forms.

Originally snails were aquatic forms, but as some species migrated to land one of the two gills was lost and the mantle was gradually modified until one fold of it appeared as a primitive **lung.** These animals, possessing one lung and one remaining gill, belong to the order **Pulmonata.** The more primitive marine forms that have retained the two gills are members of the order **Prosbranchiata,** while the fresh-water forms with the right gill remaining are in the order **Opisthobranchiata.** Some of the land snails have returned to fresh water, but the lung has remained. Such forms must come to the surface of the water occasionally for a supply of oxygen, particularly during hot weather.

Snails occur in nearly all parts of the world, with the possible exception of extremely cold climates, although one species, *Vitrina glacialis,* is found living high in the snow-covered Alps. Some of the fresh-water snails, such as species of *Lymnaea* and

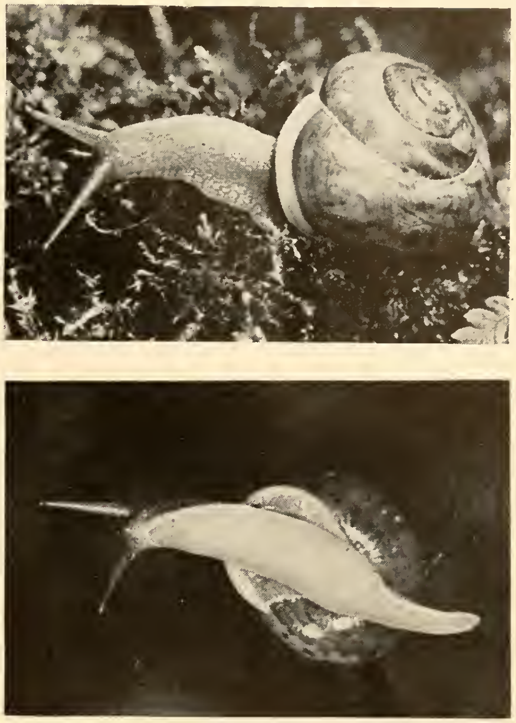


Fig. 12-13. Land snails such as this one (*Helix aspersa*) have a part of their mantle modified into an air breathing organ so they are at home on land. In the top picture of the dorsal view, the eyes appear at the tips of the two large tentacles. The ventral view of the snail crawling up a glass plate is shown in the bottom picture. Note the second pair of smaller tentacles and the mouth at the anterior end.

Helisoma, are able to survive for several weeks in cakes of ice, providing they are frozen gradually. Movements of these species may be observed through the ice. For the most part, water snails are active throughout the four seasons of the year. Land snails, on the other hand, are active only during the warmer parts of the year and are most active at night or immediately following a light rain. As cold weather approaches they seek a protected place for hibernation. During this period, a membrane is formed, covering the aperture of the shell to protect the animal.

In general, snails are harmful to man. The herbivorous land snail, for example, often damages vegetation considerably. Some forms serve as intermediate hosts for parasitic flatworms, while others are para-

Fig. 12-14. The nudibranch gastropods are without gills and breathe through their skin, which is often thrown up into papillo-like structures that function somewhat as gills do. Those pictured here (*Hermissenda crassicornis*) are yellow-green in color and are about an inch long.

The two specimens in the top picture are feeding on hydroids which they are able to do without discharging the nematocysts. In fact they incorporate the stinging cells into their own body to be used sometime later for their own defense. Just how they do this is unknown.

Another specimen, pictured below, is laying its long strings of eggs.

sites themselves. In former times snails had some value as a source of food, but this is negligible today.

The slugs are gastropods that do not bear shells. The nudibranch, prosaically called the sea slug, does have a shell during the larval stage but the adult form appears to be a snail without a shell (Figs. 12-14, 12-15). The name *slug* was apparently given to the lifeless preserved laboratory specimen, which takes on a dingy collapsed appearance after it has been exposed to light and preservative. When observed in its natural habitat on rocky coasts, however, these colorful animals are found to be most inappropriately named.

Although the gastropods were of economic significance to ancient man, the pelecypods serve modern man to the greatest extent. Clam chowder, sautéed scallops, and oyster cocktails have become favorite forms of sea food all over the world. The shells of the bivalved animals are also used by man. Most cherished are pearls, the rare jewels secreted by the mantle of the stationary fresh-water clams and pearl oysters. The bits of shell that are cut and polished into buttons are products of fresh-water bivalves, the clams.

Members of the class **Cephalopoda** are the most highly organized of the mollusks and include the largest species of the invertebrate animals. The head region, as the name implies, is large and well developed, unlike most of the preceding groups. Most forms of this class bear two large complex eyes, resembling the eyes of vertebrates. Some have continuous shells, such as the shell of the *Nautilus* (Fig. 12-16), a member of the group immortalized by Oliver Wendell Holmes in his poem, "The Chambered Nautilus." In others, such as the

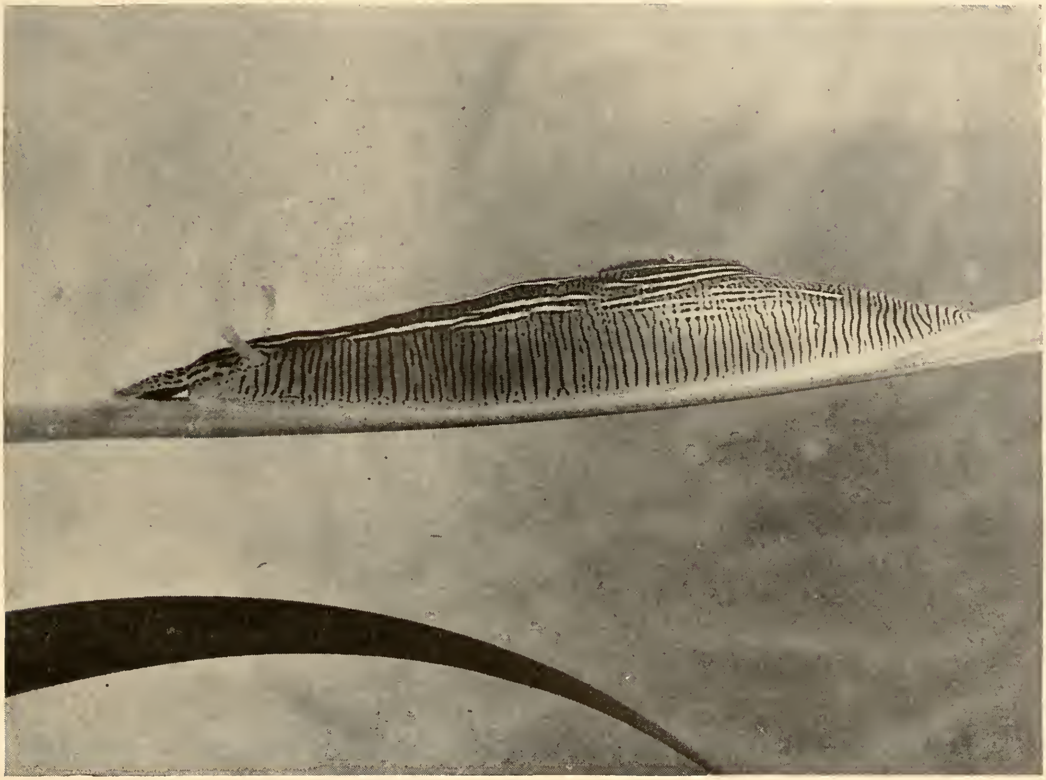


Fig. 12-15. This is another beautifully colored naked gastropod (*Phyllaplysia taylori*) found in the oceans. Note the delicate lines and the two tentacles that protrude like horns.

cuttlefish (*Sepia*) and the **squid,** the shell is located internally. In addition to a generally large, fleshy body, the cephalopods usually have long muscular arms, or **tentacles,** which are modified portions of the foot.

Fig. 12-16. The chambered nautilus, a cephalopod mollusk, lives in the deep waters (1800 ft.) of the South Pacific. Its shell, shown here, is made up of many chambers, the last and most spacious being occupied by the animal.

One cephalopod, the squid, is not only unique in organization but also in the wide range of sizes in which it occurs (Fig. 12-17). Different species of squids vary from miniature animals 1 inch long to giant forms of 18 feet, or twice that length when the arms are stretched out. Fossil remains show that the squid was one of the most prominent animals during prehistoric times. The tapering body of this mollusk, which suggests an arrowhead or rocket, enables it to shoot through the water with lightning-like speed, either forward or backward, changing its direction simply by directing its ventral siphon toward or away from the anterior arms (Fig. 12-18). This and the medusa are the only animals to use jet propulsion in locomotion. The squid is also equipped with fins to aid in swimming and directing its course through the water.

Even though the squid is a rapid swim-

Fig. 12-17. Members of the class Cephalopoda are conspicuous by their many tentacles or arms and their large complex eyes. The squid (*Loligo*) is a common member of the class. This one is resting on the bottom of an aquarium. Note the siphon just below the eye which controls the squid's direction of movement. Also note the contracted chromatophores which cause the animal to appear light in color.

mer, it is often pursued by large fish and by some whales. When it is hard pressed by its enemy, it can resort to another method of defense. Near the base of the siphon is a sac filled with inky fluid which can be discharged into the excurrent siphon, thus spreading a cloud of murky water which obscures the vision of the enemy and hides the squid. Here again this animal has employed a defensive device which man has only recently used in warfare. Other interesting adaptations of deep sea squids

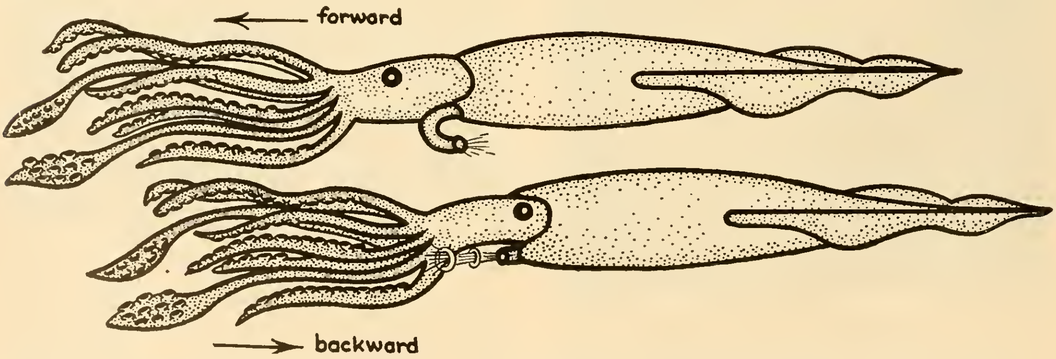


Fig. 12-18. Locomotion in the squid. In order to go forward the siphon is directed backwards; to go backward the siphon is swung around so that it directs the water forward.

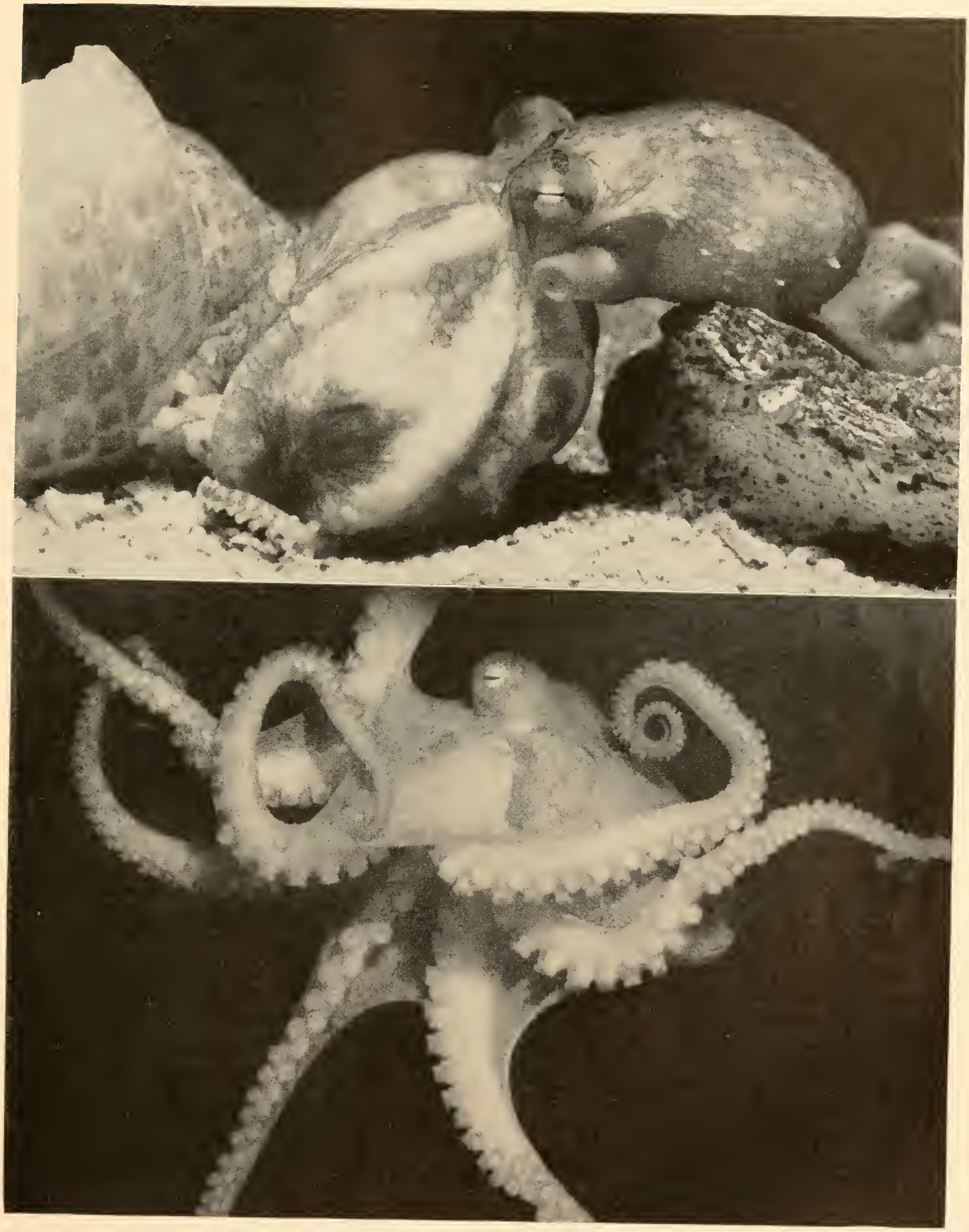


Fig. 12-19. Cephalopoda. The octopus or devilfish (*Octopus*) is completely naked and has eight very long powerful arms, well provided with suckers, which aid the animal in crawling over rocks in search of crabs which are its main source of food. Its heavy horny jaws are used in cracking the shells of crabs and the radula tears the flesh in tiny bits that are eaten. Most octopi are small and relatively harmless, although they continue to maintain their diabolical reputation.

In the top picture the animal is resting. Note the large siphon which is effective in swimming.

The same specimen is swimming in the bottom picture. Note that it is only slightly more awake than when completely at rest.

Fig. 12-20. The common starfish (*Asterias*), like most starfish, is found along rocky shores crawling over the hard surfaces in search of mollusks, particularly clams, which constitute its main food. This one is crawling over the shells of clams, many of which are empty because their soft bodies were sacrificed to satisfy the hunger of this and several other starfish.

are the luminescent organs, the value of which is not entirely known. It may be to attract food to the animal or to keep enemies away.

Stories of the dangers of the devilfish, or **octopus** (Fig. 12-19), may be considered practically fictional, at least in respect to the grasp of its tentacles being deadly to man. Actually the octopus is harmless to man, with the possible exception of the giant devilfish, which reaches a length of 28 feet. The bulbous and flexible body of the octopus possesses muscular tentacles that are well armed with suckers. The animal usually lurks in shady underwater caverns awaiting its prey, which it seizes by extending the tentacles. A siphon, similar to that of the squid, enables the octopus to swim, but it more commonly crawls over rocks on the bottom of the ocean.

PHYLUM ECHINODERMATA

The second group of higher invertebrate animals that possess remarkable and unique characteristics is the phylum Echinodermata. Members of this group deviate from the direct line of ascent to higher forms even more than the mollusks and occupy their own isolated position in the animal kingdom. Although they have acquired the complex organs of the higher types, they have reverted to radial symmetry, a predominant characteristic of the coelenterates. For this reason they were once classified with the coelenterates but, because of

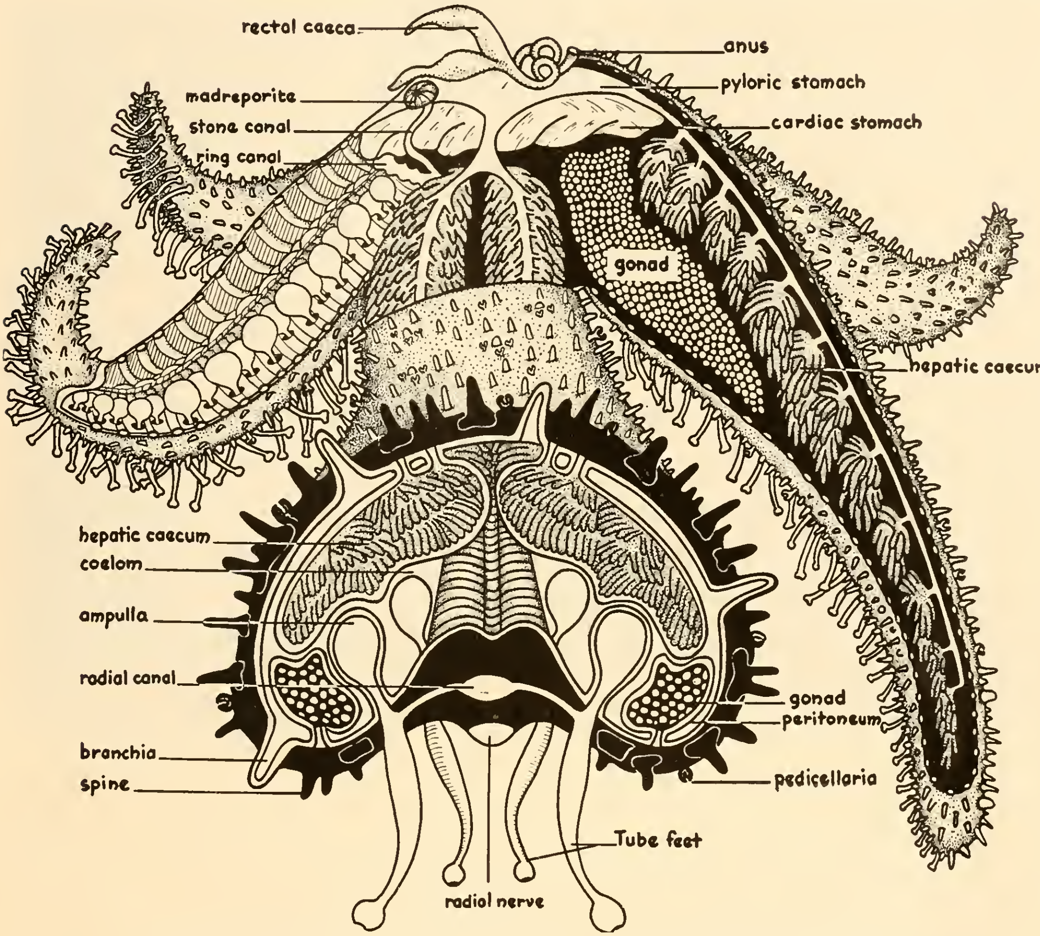


Fig. 12-21. Starfish cut in such a manner as to show the internal anatomy.

their calcareous spiny exoskeleton and complex water vascular system as well as other more advanced systems, they have been placed in a separate and much more advanced group.

The echinoderms are marine animals, mostly free-living but slow-moving. Some are permanently attached forms living at the bottom of the sea; others are commonly found along the seashore, in the sand or on rocks. Very often starfish, which are the most common members of the group, invade oyster beds and cause a great deal of damage because these choice morsels are among their chief sources of food. At one time the damage to commercial oyster beds was so great that the problem was indeed menacing and costly. Men working in the oyster beds tried in vain to remove the starfish and destroy them by cutting them in two. This was no solution to the problem for, like lower forms of animals, the starfish has tremendous powers of regeneration. Thus, instead of being destroyed by these measures, the starfish were actually increasing; in place of one starfish, the two pieces grew into two new individuals.

The echinoderms are characterized chiefly by their spiny outer covering, the spines varying from those of microscopic size to the large movable spines found on such animals as the sea urchin. They resemble the next phylum, the chordates, by the presence of a mesodermal endoskele-

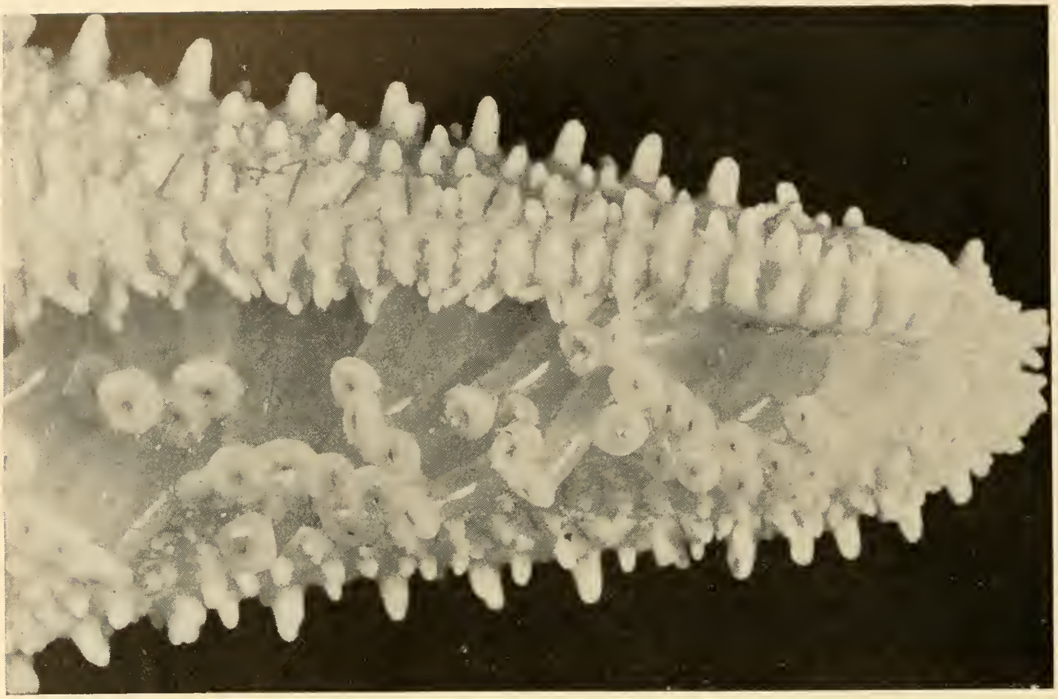


Fig. 12-22. A close-up of the tube feet of the deep sea red starfish (*Hippasteria phrygiana*) to show the nature of the sucking disc at the tip and the circular muscles in the tube that aid in its action.

ton. In addition, the larvae of some forms resemble some chordate larvae (Fig. 13-4).

The starfish

Starfish, found in abundance along most seacoasts, vary greatly in size from tiny species about one-half inch in diameter to the giant starfish, which measures about 18 inches. The common starfish, *Asterias vulgaris* (Fig. 12-20), is found chiefly upon rocky seashores and bottoms where mollusks, its main food, are also most abundant. Starfish resemble the conventional five-pointed star pattern, the five radiating arms rising from a central disc. Unlike the higher invertebrate forms already studied, the starfish is headless, similar to some mollusks. It is able to move itself in any direction that one of the five rays may point. However, it usually moves forward with two particular arms, namely, the **bivium,** which consists of the two arms adjacent to the **madreporite,** a sieve-like structure through which water enters (Fig. 12-21). The upper portion of the body, the **aboral** surface, is covered with **spines,** and between these projections are **gills,** or **papulae,** which function as respiratory organs for the animal. Along the bases of the spines are small pincerlike structures, the **pedicellariae,** which serve to keep the body free from foreign material. Because the animal is so well armored with various types of sharp projections, it is little wonder that it is not chosen as food by other animals. The **oral** side, or under surface, on which the mouth is centrally located, serves two main purposes, locomotion and food collection.

An outstanding feature of the echinoderms is the appearance of a unique device, the **ambulacral system,** consisting of two rows of tube feet which extend from the mouth down the oral side of each of the five rays (Fig. 12-22). The tube feet enable the animal to move slowly over rocks or along the ocean floor, to twist and turn its

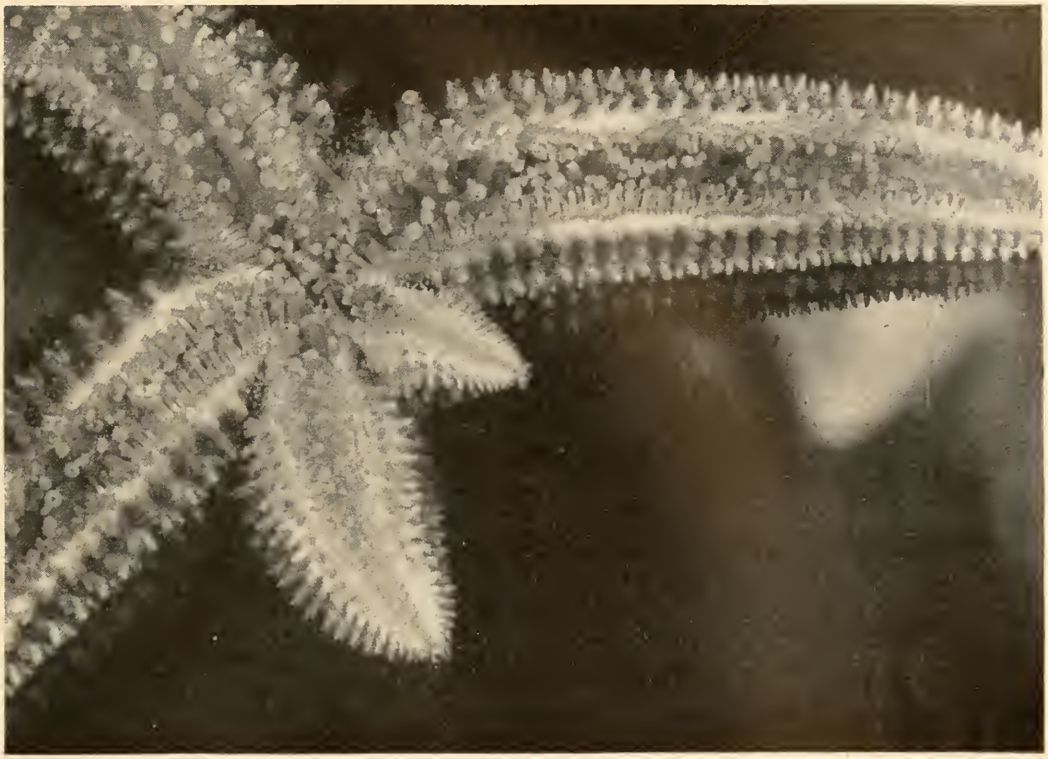


Fig. 12-23. Regeneration in a starfish. It required six weeks for this starfish to accomplish the regeneration of the two arms seen here.

body, and to capture food. If a single foot is examined, the portion that protrudes externally from the oral surface is found to be an elongated tube. Internally, at the opposite end, a bulbous structure, the **ampulla**, joins a central tube, the **radial canal**, which extends up the ray of the animal to join a central circular tube, the **ring canal**. A short tube, the **stone canal**, is joined to the ring canal and runs up to the dorsal surface of the disc, opening externally into the madreporite plate (Fig. 12-21).

Water enters through the madreporite plate, passes into the stone canal, then the ring canal, and to the ampullae. At the margin of the ring canal are located the **Tiedemann bodies** which produce the **amoebocytes** found in the fluid of the ambulacral system. When the ampulla contracts, the fluid is forced into the tube foot, which is thus elongated. If the sucker-like tip (Fig. 12-22) of the foot touches and attaches to an object, the muscular wall of the foot contracts, forcing the fluid back into the ampulla, thus causing the foot to be shortened. Since the foot adheres to the object it has touched, the shortening of the foot draws the body forward. In this manner the starfish is able to move. It also uses this mechanism to obtain food, but instead of the alternating "push-pull" system of locomotion, a steady contraction of the tube foot is exerted to produce a constant pull.

The endoskeleton, which is produced by the mesoderm, is a calcareous framework composed of many ossicles, most of which are arranged in a definite pattern. Even though the starfish has this strong endoskeleton, it is capable of autotomy. Thus it can break off an arm and readily regenerate the lost part, in a very short time (Fig. 12-23). An arm may live briefly after it has broken off the central disc, but it does not usually regenerate a new animal unless a portion of the disc has been removed with it. Experiments have been tried in which all five arms were removed from the disk, and in some cases the disc was able to regenerate the five rays.

The **ossicles** of the endoskeleton are joined together by a network of connective tissue and muscle fibers. Lying within the skeleton and extending through all portions of the body is the **coelom.** It contains the internal organs and a lymphlike fluid which carries free amoebocytes, thus resembling the fluid of the ambulacral system. In certain regions the coelom comes close to the external epidermis which forms a tiny finger-like extension, and in these structures, called **dermal branchiae,** the respiratory exchange of gases takes place. The amoebocytes gather waste materials and escape from the body through these same branchiae.

When feeding, the starfish seizes the victim with its arms and secures its grasp by attaching the tube feet (Fig. 12-24). The sac-like **stomach,** which consists of a large lower portion, the **cardiac stomach,** and the smaller upper region, the **pyloric stomach,** is then everted through the mouth. If the captured animal is small enough, the stomach may completely surround it. Retractor muscles in the arms, just below the digestive glands, draw the everted stomach back into the body to complete digestion. If the animal is large it is digested in portions while the stomach remains everted. The digestive juices flow from the pyloric region of the stomach and the **hepatic caeca** (paired digestive glands of each ray) until the remaining food is small enough to be withdrawn into the pyloric stomach. Very often partially digested food enters the hepatic caeca, as well as other portions of the digestive system, and absorption takes place in these various organs. The digested food passes into the coelomic fluid where it is distributed. Attached to the dorsal portion of the pyloric stomach is a short intestine with rudimentary **rectal caeca** and a small **anal opening** on the aboral surface of the disc.

The circulatory system of the starfish is reduced to such an extent that it can scarcely be called a circulatory system at all. There are vessels encircling the mouth and extending down into each ray, but they are too inadequate to transfer the digested material to all parts of the body. Instead, the fluid of the coelomic cavity transports the food to various parts of the body.

The nervous system of the starfish shows the same radial symmetry seen in the other parts of the body and is, in general, simple. It consists of a nerve ring surrounding the mouth, giving off five branches, one to each arm, called **radial nerves** (Fig. 12-21). Two other systems lie internally, one on the oral side and another near the aboral side. Each part of the nervous system seems to function independently. The starfish has only a few sense organs. An **eye** and a **tentacle** are located at the tip of each ray, and the **pedicellaria** function as dermal sense organs.

Experiments show that the nervous system of the starfish is sufficiently organized to exhibit definite responses. A hungry starfish, placed in a pan of sea water containing bits of pulverized mollusk, will move toward the food. This is a distinctly positive chemical response.

Through its eyes the starfish reacts positively to light. This response is best shown by removing the eyes of four rays, allowing one to remain. With but one eye, the starfish will continue to react positively to light, but if the remaining eye is removed, orientation to light is lost.

Professor H. S. Jennings tried memory experiments on starfish to see whether the animal is able to learn. He found that, after subjecting a starfish to 180 lessons over a period of eighteen days, it could be trained to use a particular arm to right itself after it had been turned over on its aboral side. After a lapse of one week, however, only one of the many animals tested remembered its training.

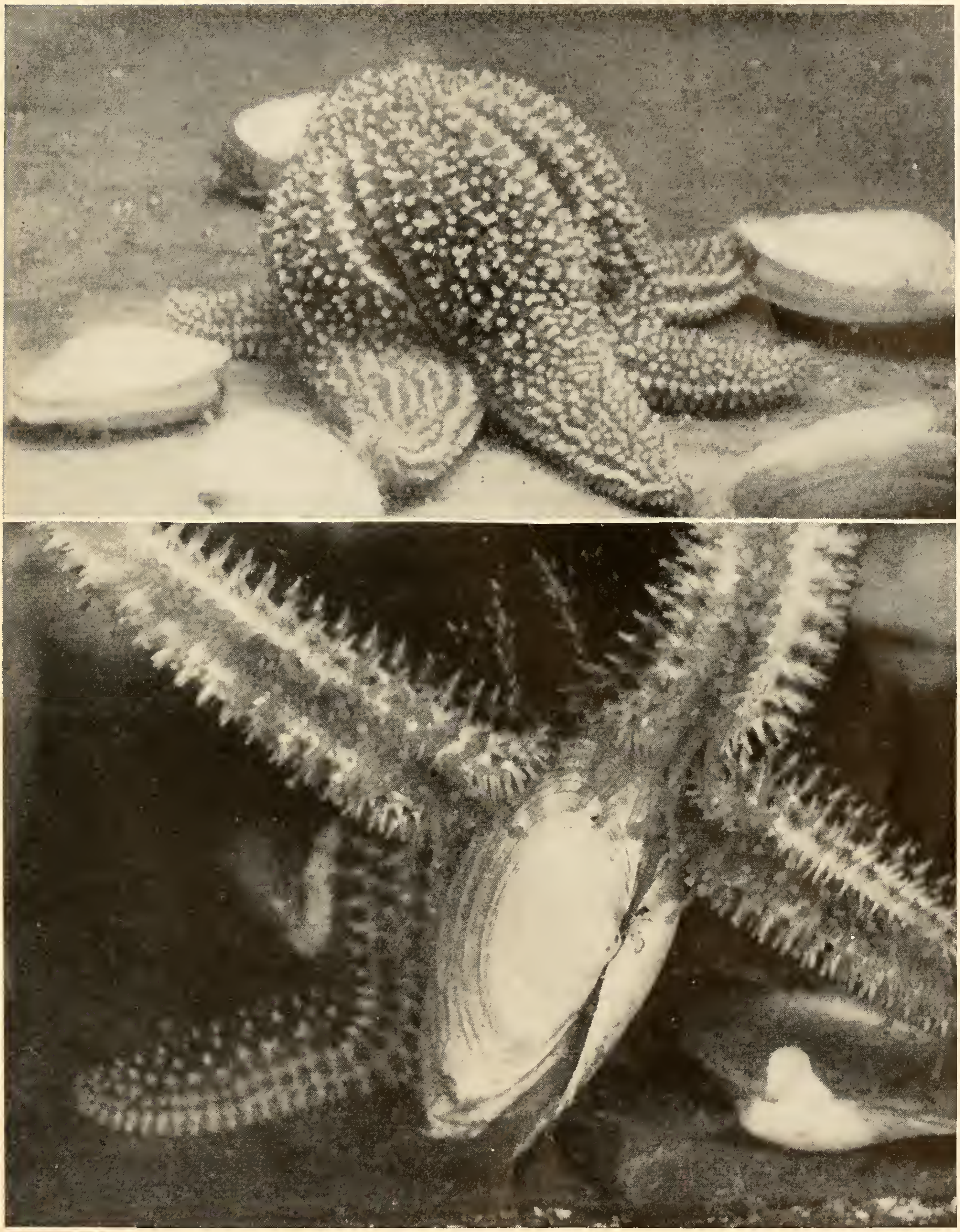


Fig. 12-24. Starfish frequently feed on clams. In the top picture the starfish is huddled over the clam. In the bottom picture the starfish has been turned up on one side. Note the long tube feet attached to the two valves of the clam. Their continued pull eventually weakens the clam so that it gapes open, allowing the starfish to consume its soft body.

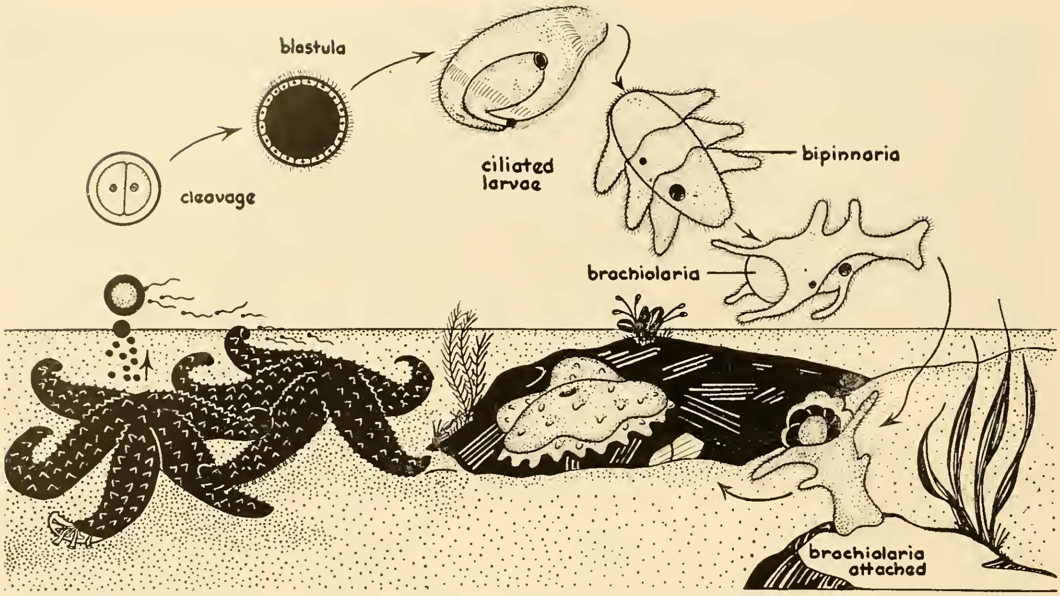


Fig. 12-25. Life cycle of the starfish.

Sexes of the starfish are separate. The reproductive system consists of five paired gonads, lying close to the hepatic caeca and attached in the angles between the arms where their external openings are located (Fig. 12-21). Ova and sperm cells are discharged into the sea water, where fertilization occurs (Fig. 12-25). The larva, or **bipinnaria**, is at first bilaterally symmetrical; later, as the pentagonal shape of the adult form appears, radial symmetry becomes evident. Larval forms are partially ciliated and free-swimming. After a period of swimming near the surface of the water, sometimes for several weeks, the larva finally drops to the bottom of the sea, where it undergoes metamorphosis into the adult starfish.

Other echinoderms

While the starfish is the best-known echinoderm, there are other forms belonging to different classes that show some in-

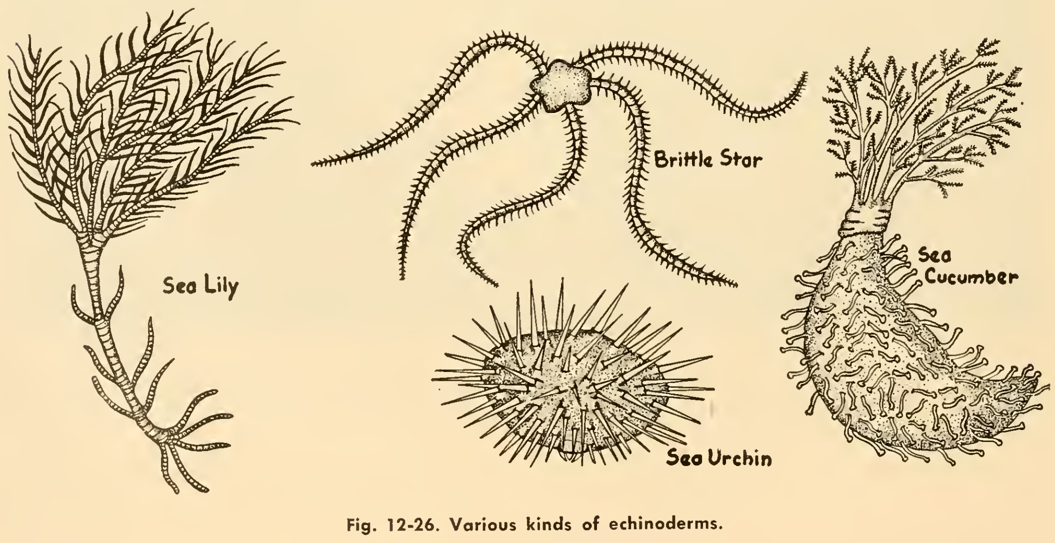


Fig. 12-26. Various kinds of echinoderms.

Fig. 12-27. A basket star (*Gorgonacephalus articus*) taken in 420 feet of water. The five principal arms are subdivided into a great many smaller branches. This is a ventral view.

teresting adaptations. The **sea cucumber** (Fig. 12-26), for example, is quite unlike the starfish in its general appearance, although its fundamental structure is similar. These animals are like cucumbers with a fringe of tentacles on one end. While their habitats vary widely, a common species of our Atlantic coastal waters lives in the mud, just below low tide, exposing only its tentacles above the muddy bottom. It will serve as an example.

The surface of the body seems to be devoid of calcareous plates, but microscopic examination reveals tiny plates embedded in the soft tissue of the body wall. The branched tentacles are located at the anterior end, surrounding the mouth; the anus is at the opposite end of the animal. There are five rows of tube feet, the two dorsal ones functioning as respiratory and tactile organs, while the three remaining rows on the ventral side aid in locomotion, much the same as those of the starfish. The animal is able to crawl in worm-like fashion, by contracting the rather heavy muscles which make up the body wall. It feeds by allowing the tentacles to become covered with detritis from the muddy ocean bottom and then pushing them, one at a time, into the mouth. Organic material is separated from the mud and carried into the digestive tract where it is digested.

Respiration is carried on by means of a pair of **respiratory trees** which extend from the lower end of the digestive tract anteriorly in the body cavity. Water is taken into the cloaca through the anus and circulated through these ramifying tubes. It is likely that excretory wastes find their way to the outside through these organs as well.

The sea cucumber has a nervous system equivalent to that of the starfish. The animal's sensitivity to light is easily demonstrated. If it is suddenly placed in a bright

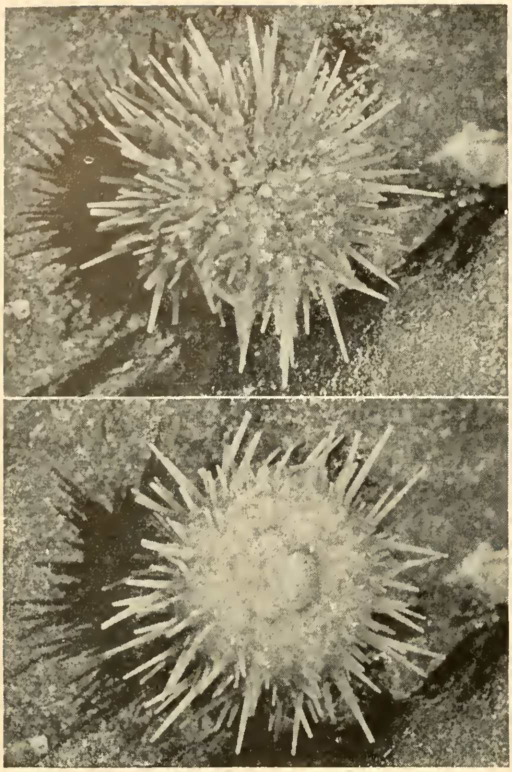


Fig. 12-28. The sea urchins are covered with long spines which aid the long, slender tube feet in moving slowly over the ocean floor. By means of a set of five sharp teeth they are able to tear vegetative and decaying matter to tiny bits which they consume. The aboral and oral views of a young sea urchin (*Arbacia*) are shown here.

light, it will contract at once. If given a choice, it will seek out moderate illumination.

This animal possesses remarkable powers of autotomy and regeneration of lost parts and, in fact, even employs this behavior as a mechanism of defense. If disturbed by an intruder who persists any length of time, the sea cucumber suddenly contracts its muscular walls until considerable pressure is built up within. Then it splits open, almost explosively, near the anus, everting the respiratory trees which secrete a mucous fluid that becomes stringy and tough when it contacts sea water. The unfortunate enemy, usually a lobster, thus becomes hopelessly enmeshed in this mass of threads so that it is no longer concerned with the sea cucumber as a prospective meal. The sea cucumber is able to break the trees loose at their base and regenerate a complete set within a short time.

Another interesting group of echinoderms includes the **brittle** stars and the **basket** stars (Fig. 12-27). Both forms possess small discs and long, slender, motile arms, the arms of the basket star being branched to

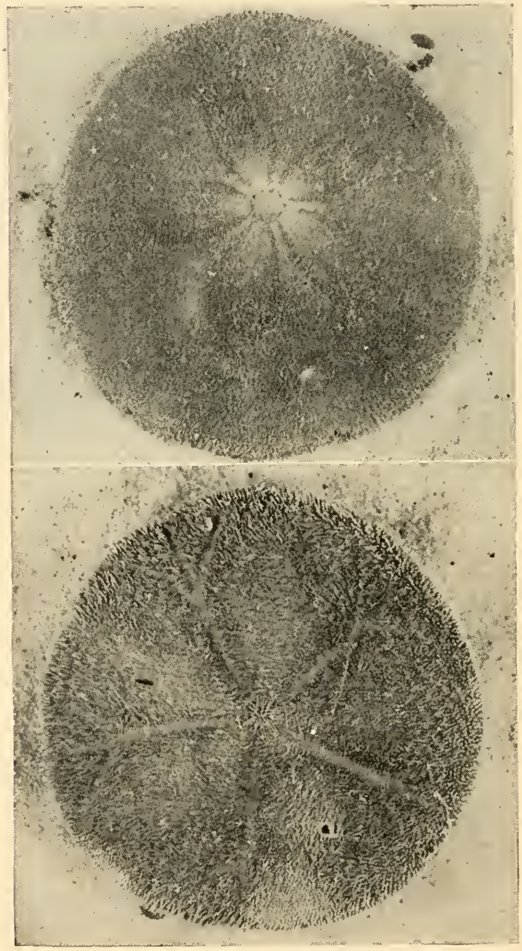


Fig. 12-29. Sand dollars are close relatives of the sea urchins but are much flattened and the spines are much smaller. Both the tube feet and spines make movement possible in the sand where they live. They feed on the organic matter that is present in the sand.

The typical five-arm arrangement of the openings on the aboral side through which the tube feet pass is shown in the top picture. These dorsal tube feet are long and are modified for breathing.

The oral surface in the bottom picture shows the mouth opening in the middle and the anal opening near the edge.

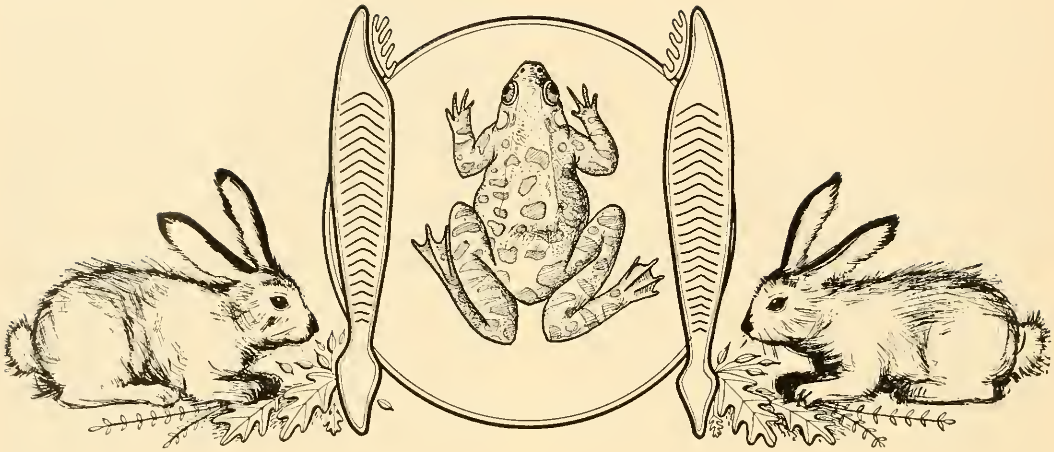
form a kind of basket. The brittle stars, characterized by five long, serpentine arms, can move more rapidly than any other echinoderm. Their tube feet are few in number and are used primarily as touch receptors rather than for locomotion. These animals do not "mind" losing an arm; mild stimulation can cause an arm to be snapped off immediately. The rapid regeneration of a new member makes this a valuable means of escape for these animals.

The sea urchin (Fig. 12-28) and sand dollar (Fig. 12-29) are also seashore oddities. A common species of the former is usually purple in color and often found lying in the small pockets of rocks, in homes that may be occupied for many years. It has remarkably long spines that are used in locomotion as well as in securing prey. The tube feet which cover the rounded body are also used in locomotion. An interesting organ, characteristic of this animal, is **Aristotle's lantern**, a complicated arrangement of teeth in the mouth that is used for picking food apart. Even small fish are captured and torn to pieces by this effective instrument. In most other details the sea urchin resembles the starfish. The sand dollar is extremely flattened dorsal-ventrally, so that it resembles a flat disc. Otherwise, it possesses the organs common to other forms already described.

The least known of all the echinoderms is the **sea lily**, or **feather star**. It is composed of five greatly branched arms and found only in very deep water, attached to the bottom by means of a stalk. Food is carried down to the mouth by cilia contained in the ambulacral grooves. Its tube feet resemble tentacles and are probably sensory in function. There are relatively few species in this class today, although ancient rocks show that there were once a great many more, a fact which indicates that they are probably on their way to extinction.

With the echinoderms and mollusks we have concluded the study of the invertebrate animals, although some of the primitive members of the next group are without vertebrae or backbones and may rightly be considered invertebrates. For the next few chapters we shall be concerned with the last phylum, the chordates, which is the most important of all groups not only because it is a very successful phylum but because it includes man and nearly all of his domestic animals, and that alone is sufficient reason for a careful examination of the group as a whole.

CHAPTER 13



THE ANIMAL CLIMAX—THE CHORDATES

The last and most diversified group of animals is the phylum Chordata, to which man himself belongs (Fig. 13-1). These animals have struck off on a new line of development which has resulted in maximum size and adaptability. Not only are the chordates the largest animals in existence today, but they have adapted themselves to more modes of existence than any other group, including the arthropods. They are found in the sea, in fresh water, in the air, and on all parts of the land from the poles to the equator. They range in size from the tiniest fish to the great whales, which reach a length of nearly 100 feet and a weight of 100 tons and more (Fig. 13-55). In order to penetrate the cold climates and remain active, the birds and mammals maintain a constant temperature (homothermal). Those animals without a constant temperature (poikilothermal), such as the amphibians and reptiles, are forced to spend periods of low temperature in a relatively inactive condition. Since fish remain in the water where the temperature does not vary greatly, they have no need for a temperature-regulating mechanism.

All chordates possess at some time in their life cycle three characteristics which are not found among the invertebrates (Fig. 13-2). The first is a **dorsal tubular nerve cord,** which varies from a more or less undifferentiated tube extending through the entire length of the body of the lower chordates, to a shorter, highly differentiated tube, with a greatly enlarged anterior portion, the **brain,** in the higher forms. In some chordates the nerve cord is proportionately about the same as in the invertebrates, while in others, such as man, it assumes greater prominence, both in size and importance. In invertebrates the nerve cord is solid, but in all chordates it is tubular or hollow.

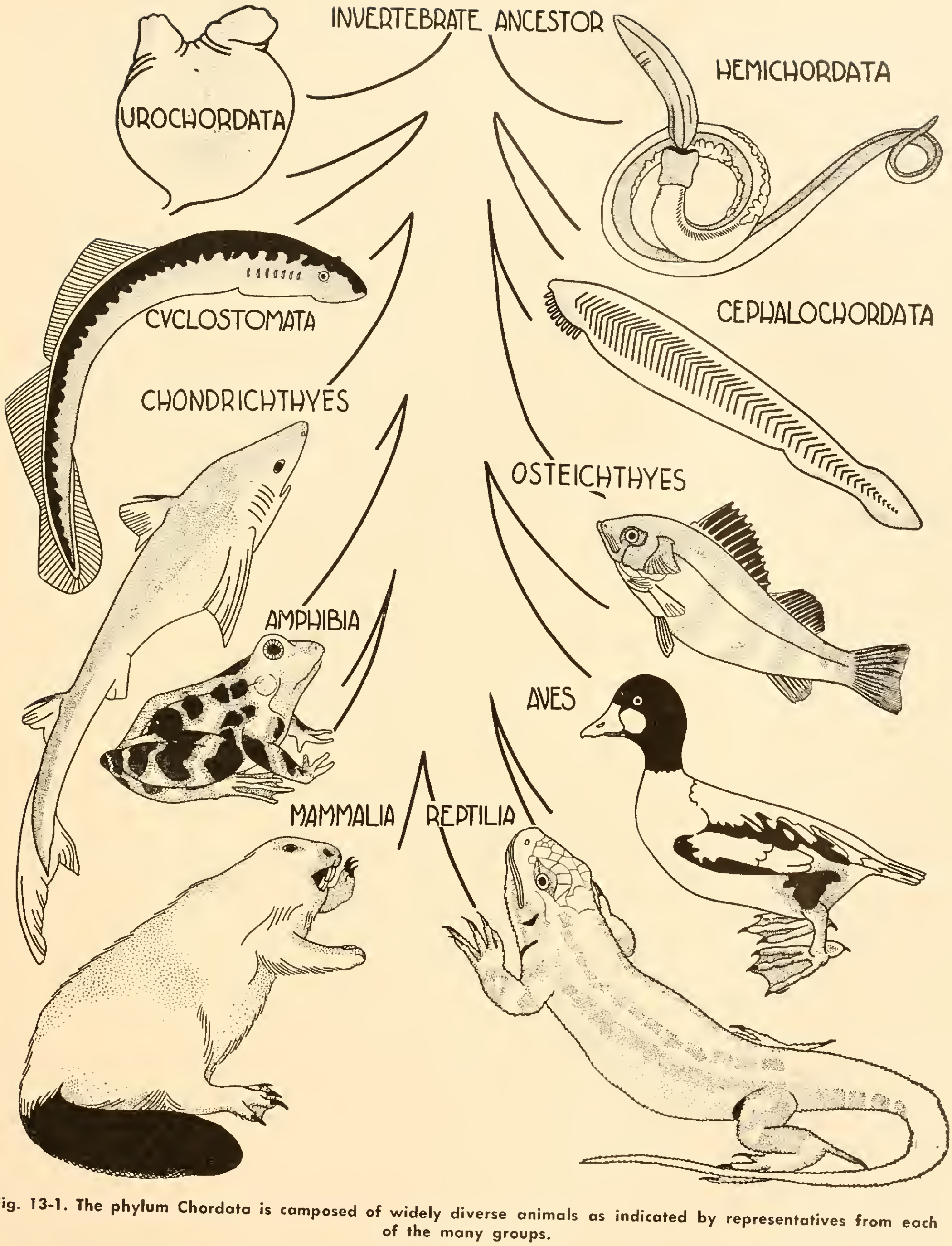


Fig. 13-1. The phylum Chordata is camposed of widely diverse animals as indicated by representatives from each of the many groups.

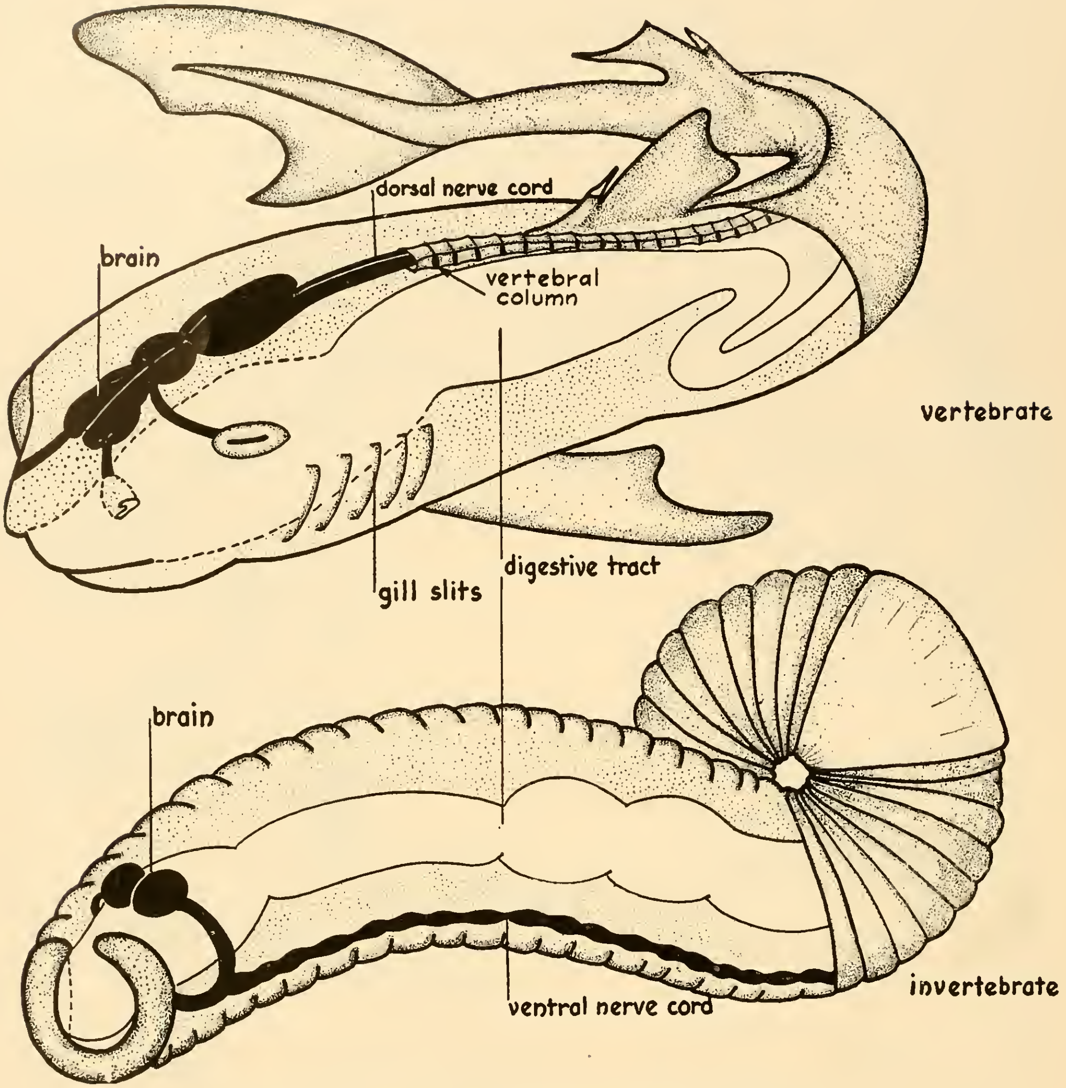


Fig. 13-2. Comparative study of the vertebrate and invertebrate.

A second characteristic of the chordates is the presence of an internal supporting rod, or skeleton, the **notochord.** This may be thought of as a precursor to the vertebral column in vertebrates, but it must not be considered identical. Although the notochord is found in the embryos of all vertebrates, it persists only in the adults of the most primitive. The notochord is made up of a gelatinous matrix, surrounded by a tough, outer sheath, which is inadequate to support a large animal in water, much less on land. In all higher forms, therefore, it is replaced by the more rigid **vertebral column.** As a change from an aquatic to a terrestrial environment took place, provision for support had to be even more elaborate, for the weight of the body formerly supported by buoyancy in the water now had to be borne entirely by the skeleton.

The third charateristic is the presence of

Fig. 13-3. Acorn worms (*Dolichoglossus kowalevskyi*) from the sand flats of Cape Cod. Note the long proboscis for burrowing in the sand and mud.

pharyngeal gill slits. It is obvious that adult land animals have no gill slits, but during embryological development gill slits do appear at some stage. The structures which originally produced functional gill arches in fish, produced other structures in higher forms, such as the sound-making apparatus (larynx) and the sound-receiving apparatus (middle ear bones) (Fig. 25-11). These fitted the animal better for a terrestrial existence and gave it a greater chance of success. As already noted, the arthropods have also been able to divorce themselves from water and have likewise developed a new means of communication by employing old structures to perform new duties. Legs and wings are employed in making sound; antennae and legs in receiving sound.

However, the chordates are set off from all other animals by the possession of these three characteristics noted and these must have been important in contributing to the success of this most important of all groups of animals. Let us consider some members of this phylum.

CHORDATE BEGINNINGS

Scientists have been perplexed about the origin of the chordates and have been unable to determine which lower forms gave rise to this last and perhaps most specialized group. Fossil remains have provided us with a great deal of information about other animals, but man's digging into the earth has failed thus far to reveal any substantial remnants of the early chordates. The reason for this is that these soft-bodied animals did not remain intact sufficiently long to become fossilized. In spite of the lack of evidence concerning the early progenitors of the chordates, there has been a great deal of speculation as to their origin.

The **acorn** or **tongue worms** (Fig. 13-3), which are considered by many zoologists to be very low chordates, were at first classified among the worms. Although they have the three cardinal characteristics that identify them as chordates, they resemble the annelids more closely than any of the great variety of chordate forms. At first

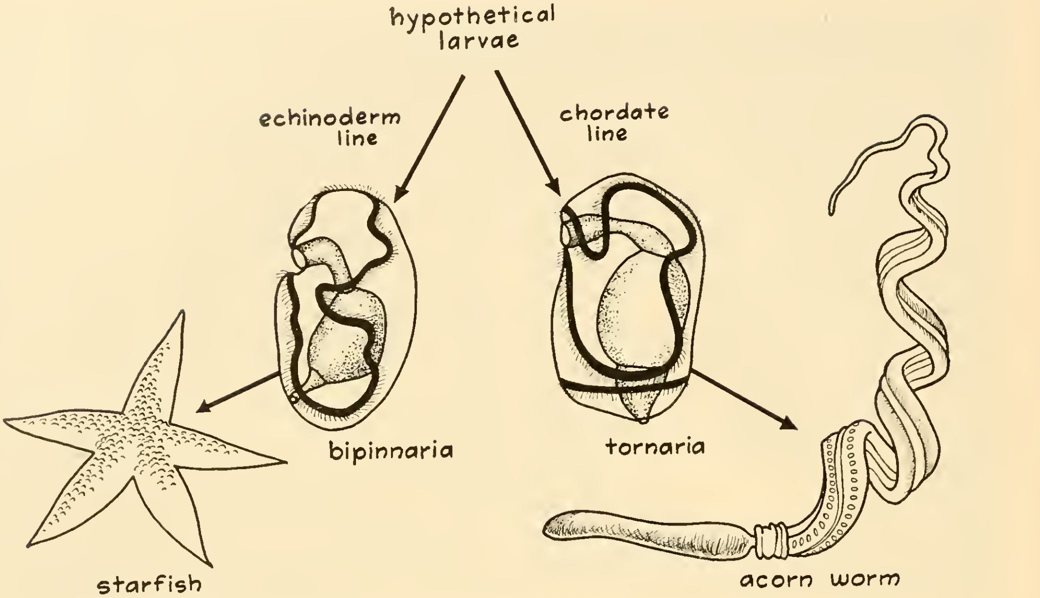


Fig. 13-4. A study of the larval stages of the acorn worm and echinoderms has lent support to the idea that both came from a common ancestor.

glance it thus seems plausible to conclude that some annelid forerunner might have given rise to the vertebrates. There are, however, a great many anatomical features in the annelid that are impossible to correlate even with the acorn worm. For instance, the annelid has a ventral instead of a dorsal nerve cord, and it has no gill slits, and no notochord. In addition there is nothing in the embryology that would lead one to believe they are related. Embryological development repeats the history of the race and thus indicates similarities of even distantly related forms.

Some biologists look with favor on the theory that the chordate ancestor stemmed from the same stalk that gave rise to the echinoderms. Remarkable similarities have

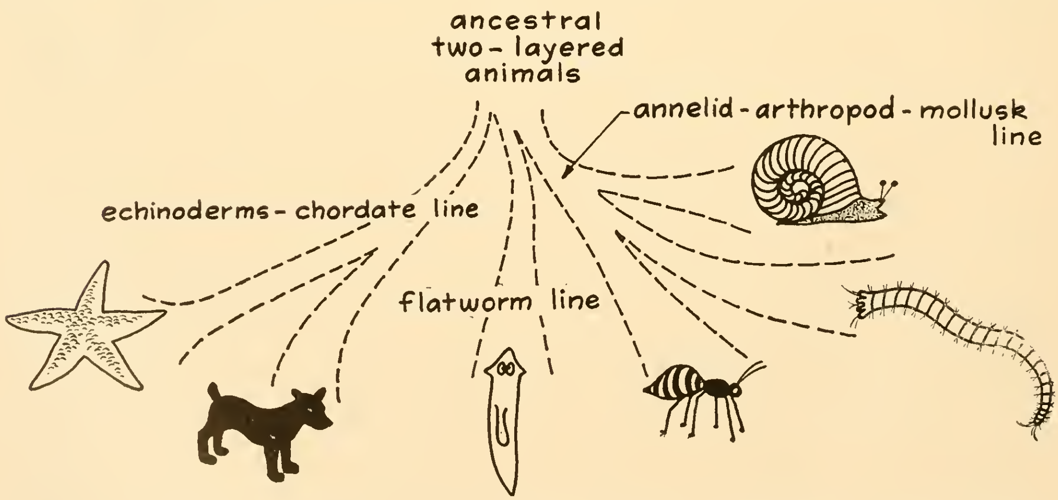


Fig. 13-5. The coelenterates probably gave rise to the echinoderm-chordate line, the flatworm line, and the annelid-arthropod-mollusk line.

been found in comparing the embryos of the echinoderm (bipinnaria) with that of the acorn worm (tornaria) (Fig. 13-4). In fact, they are so similar that it is very difficult to distinguish between them. They are simple, bilaterally symmetrical, free-swimming forms. The bipinnaria sits down and develops radial symmetry to become an echinoderm, whereas the tornaria grows into the acorn worm. Still further back it is generally believed now that the coelenterate type gave rise to three great groups: the echinoderm-chordate stock, the flatworm stock, and the annelid-arthropod-mollusk stock (Fig. 13-5).

THE PROCHORDATES

The **acorn worm** (sub-phylum Hemichordata) (Fig. 13-3) is here considered as the first member of the phylum Chordata, although some zoologists believe it so divergent as to warrant a phylum by itself. This earthworm-like animal lives buried in the mud, using a protrusible proboscis to move about as it feeds on organic matter. It fulfills the required characteristics of chordates by the presence of numerous gill slits, a dorsal as well as a ventral nerve cord, and a small anteriorly located notochord. There are only a few (60) species in the world, but individuals are rather common on both the Atlantic and Pacific coasts of the United States. Although they have no apparent economic significance to man, they are of interest to the zoologist.

The **tunicates,** or **sea squirts** (sub-phylum Urochordata) (Fig. 13-6), are also grouped with the chordates, although after looking at the adult form one would scarcely expect them to be classified here. Commonly attached to rocks along the seashores, they live by forcing water in and out of their sac-like bodies through **siphons,** resembling the clam in this respect. The water passes into a large perforated pharynx which strains out the tiny food particles that are carried into the digestive tract. Gills line the many openings in the pharynx wall, but aside from this one chordate characteristic, it appears to have no claim to membership among the chordates.

However, a careful look at the larval form demonstrates at once its true chordate relationships, for the larva possesses a notochord and dorsal tubular nerve cord, in addition to the gill slits. As an embryo, the animal is tadpole-shaped and swims actively in the sea water (Fig. 13-6). Late in embryonic life, however, it settles on a rock and metamorphoses into the sessile adult, which is a degenerate form compared to the active, free-swimming, fish-like chordate from which it came. Tunicates are very numerous in the oceans of the world and range from microscopic size to more than 12 inches in diameter. They may live in shallow or deep water and are commonly found by the bather who is sufficiently curious to examine the rocks along the coast. The group as a whole has no economic significance.

There is another tiny animal (2 inches long) that cannot be mistaken for anything but a primitive chordate and, moreover, it possesses body structures that force us to believe that some such form might have given rise to the vertebrates. This animal is known as **lancelet,** or **amphioxus** (sub-phylum Cephalochordata) (Fig. 13-7). It is an ocean dweller, found in relatively few though widely separated regions, and reaches such numbers along a part of the shore of China that it is utilized as a source of food. Not only does it possess the three chordate characteristics exhibited by the two preceding groups, but it also has a body plan that closely resembles that of the vertebrates.

Amphioxus has a general shape not unlike that of a slender fish, with two longitudinal folds of skin extending throughout most of its length, which may be forerunners of appendages (Fig. 13-8). Its notochord functions as a semi-rigid supporting internal skeleton, extending from one end

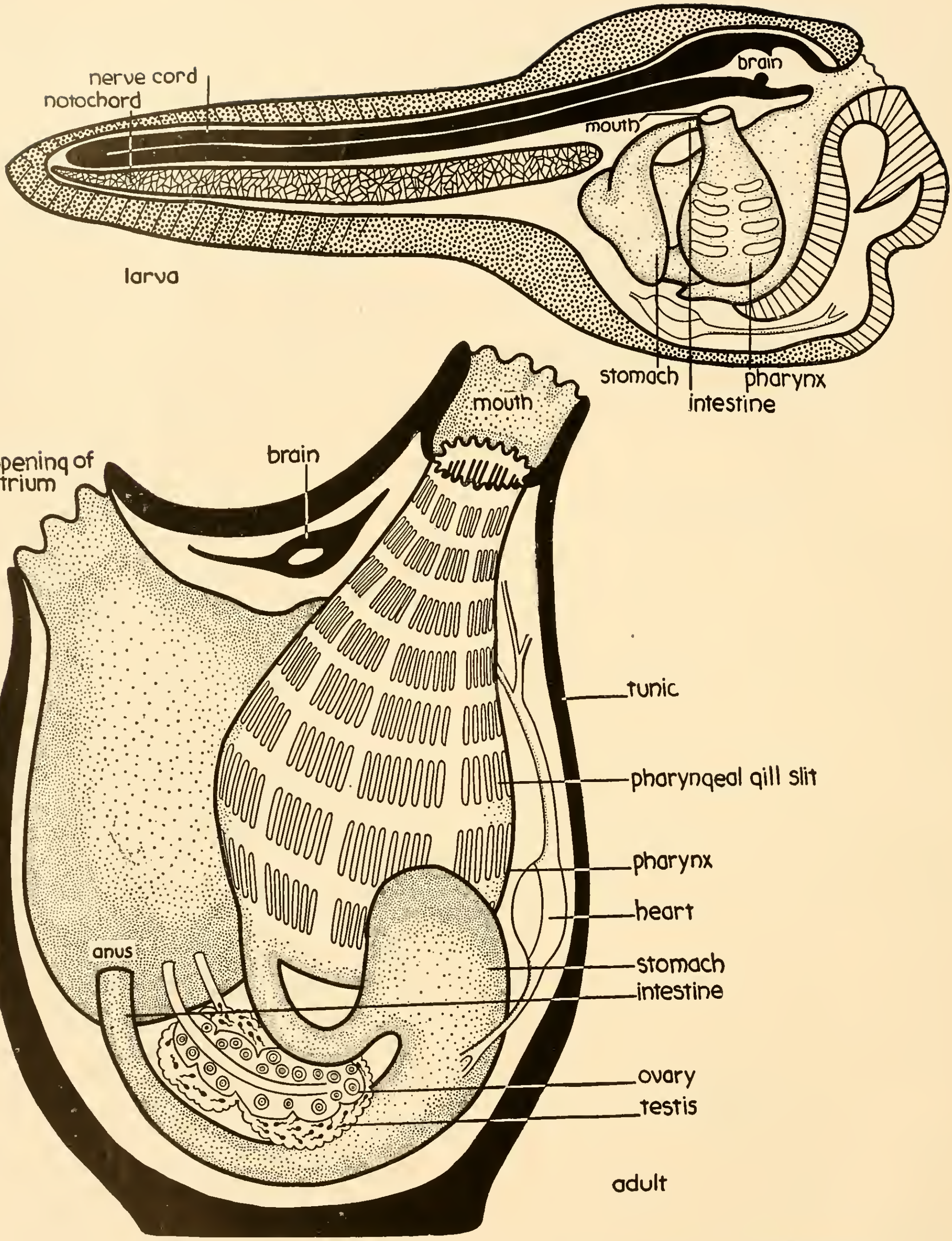


Fig. 13-6. Tunicate. The larval stage in the upper figure and the adult in the lower figure

of the animal to the other. The muscles are segmentally arranged and by their rhythmic contractions make possible lateral undulations of the body used in swimming. Immediately above the notochord is the hollow nerve cord which terminates anteriorly in a light-sensitive end organ, the eyespot. Numerous gills function in breathing. Its digestive and circulatory systems are relatively simple and add nothing to what we have already seen among the invertebrates. In fundamental plan, however, these organ systems, like so many other features of this little animal, show great similarity to the vertebrates and thus point to the possibility that the vertebrates may well have come from a form not greatly unlike it.

THE FIRST ANIMALS WITH BACKBONES—VERTEBRATES

It was not until the chordates somehow acquired a rigid internal skeleton that they became important. There were other factors, of course, but certainly if the group was to advance it needed a substantial internal support upon which a body could be built that would succeed not only in an aquatic environment but also on land. This was accomplished in the development of the vertebral column, or backbone. Let us examine a few typical examples of this highly successful group of the vertebrates.

The first members of the sub-phylum Vertebrata that show the beginnings of a backbone are the **cyclostomes**, the "round-mouthed" eels (class Cyclostomata—round mouth). Typical representatives of this class are the lampreys. They have no appendages and no jaws, only a circular mouth lined with denticles, small tooth-like structures that aid in clinging to prey. When the lamprey seizes a bony fish, its usual prey, it first attaches itself with the sucking mouth and then proceeds to remove small bits of tissue with its rasping tongue. If the point of attachment happens to be in the abdominal region a perforation

Fig. 13-7. Amphioxus (*Branchiostoma californiensis*), partly emerged from its burrow along the California coast.

is made through the body wall and the internal organs injured so severely that the fish usually dies shortly. However, if the injury occurs on the dorsal side over the large muscles, the effect is usually not fatal. The common sea lamprey, *Petromyzon,* has invaded rivers and streams where it has become a formidable foe of fish populations (Fig. 13-9). These ravages have been particularly severe in the Great Lakes region where in many areas commercial fishing has all but ceased on this account. Efforts are being undertaken to destroy them during their nesting period, which takes place in small streams. Thus far, however, little progress has been made against them.

Internally as well as externally the lamprey shows its lowly origin (Fig. 13-10). It retains a notochord similar to amphioxus, but also has the beginnings of a spinal column and other internal skeletal parts which, however, are composed of cartilage. There is a well-developed brain, together with an olfactory organ, a pair of poorly

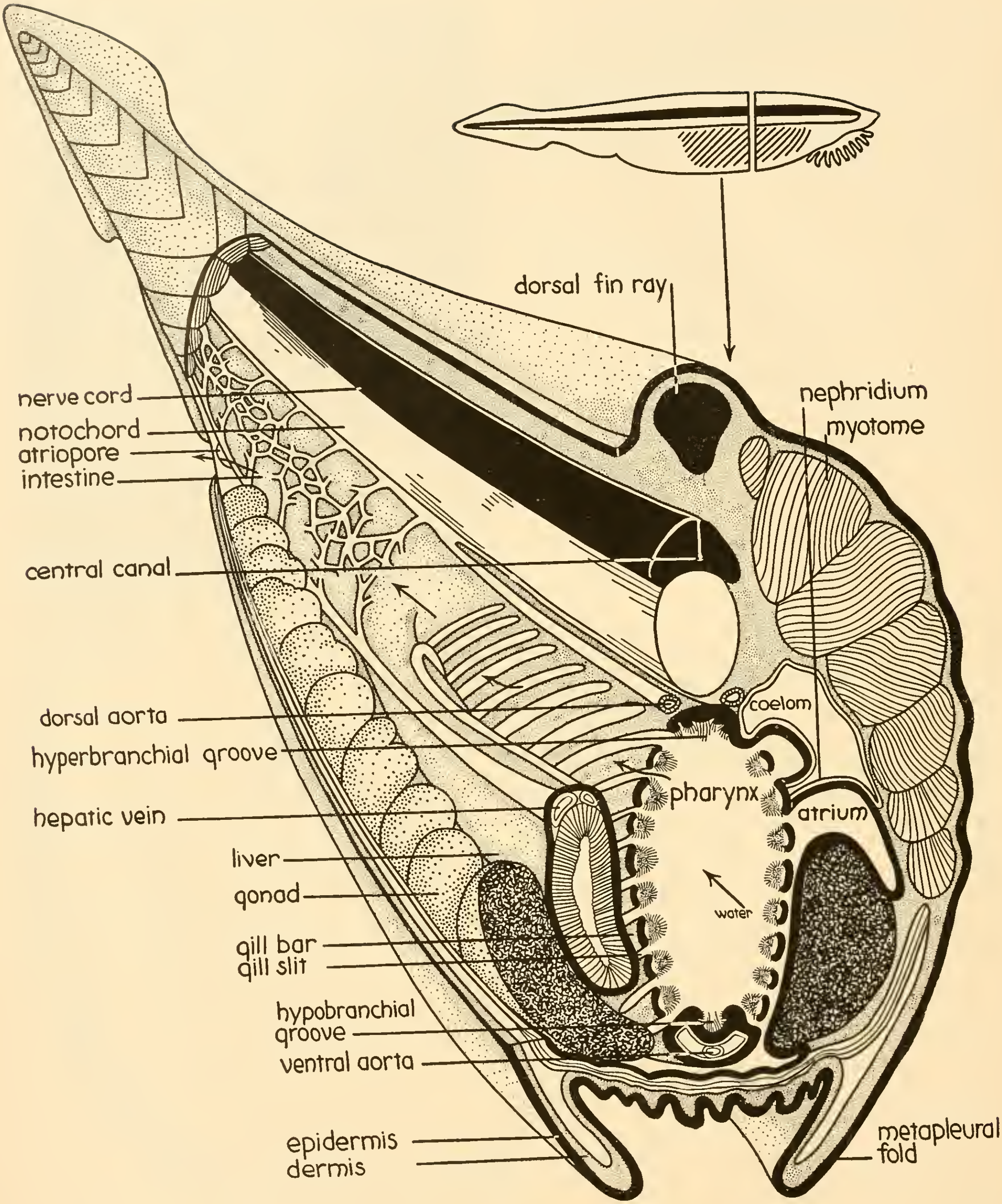


Fig. 13-8. Amphioxus in longitudinal and cross-sections.

Fig. 13-9. Sea lampreys (*Petromyzon marinus*), attacking a fresh-water fish. Note the scar from a previous injury on the dorsal side just above the fore-fins.

developed eyes, and a pair of simple semicircular canals on each side of the head, used in balancing. It has five pairs of gills —less than amphioxus, but more than the common bony fish. Internally, also, the complexity of its body structures far exceeds that of amphioxus in all respects.

Studying fossil records in an effort to determine whether any cyclostome-like forms occurred in the past, paleontologists have been rather successful. A group of animals called **ostracoderms** (Fig. 13-11) that lived about 400 million years ago (Silurian Period), resembled the present-day cyclostomes in many respects. They developed heavy armor plates on their external surfaces, possessed a ventral mouth, and were without appendages. Their heavy exoskeletons were essential to survive the onslaughts of their invertebrate enemies, the water scorpions (eurypterids). It is pretty well agreed now that later descendants of the ostracoderms lost their plates as these enemies disappeared. With the development of jaws, it became possible for them to pursue and capture their prey. Under these circumstances a heavy exoskeleton only hindered rapid progress, and perhaps this was a factor in its disappearance. At one time, the cartilage of the lamprey skeleton, as well as that of the sharks and skates, which came later, was considered a precursor to bone and therefore a more primitive condition. More recently this has been interpreted as a degenerate condition. It is now thought that the cyclostomes and sharks probably descended from forms that possessed not only internal skeletons of bone but also heavy outside bony plates, which degenerated into the cartilage found in these animals today. This appears to be true, since the early fossil remains present so many forms of bone or a hardened bone-like substance.

THE FIRST APPENDAGES AND JAWS

The lower forms such as the cyclostomes do very little free swimming in the water and get along satisfactorily with a broad fin in the tail region and a dorsal fin to aid in locomotion. The even more primitive amphioxus manages to steer itself with paral-

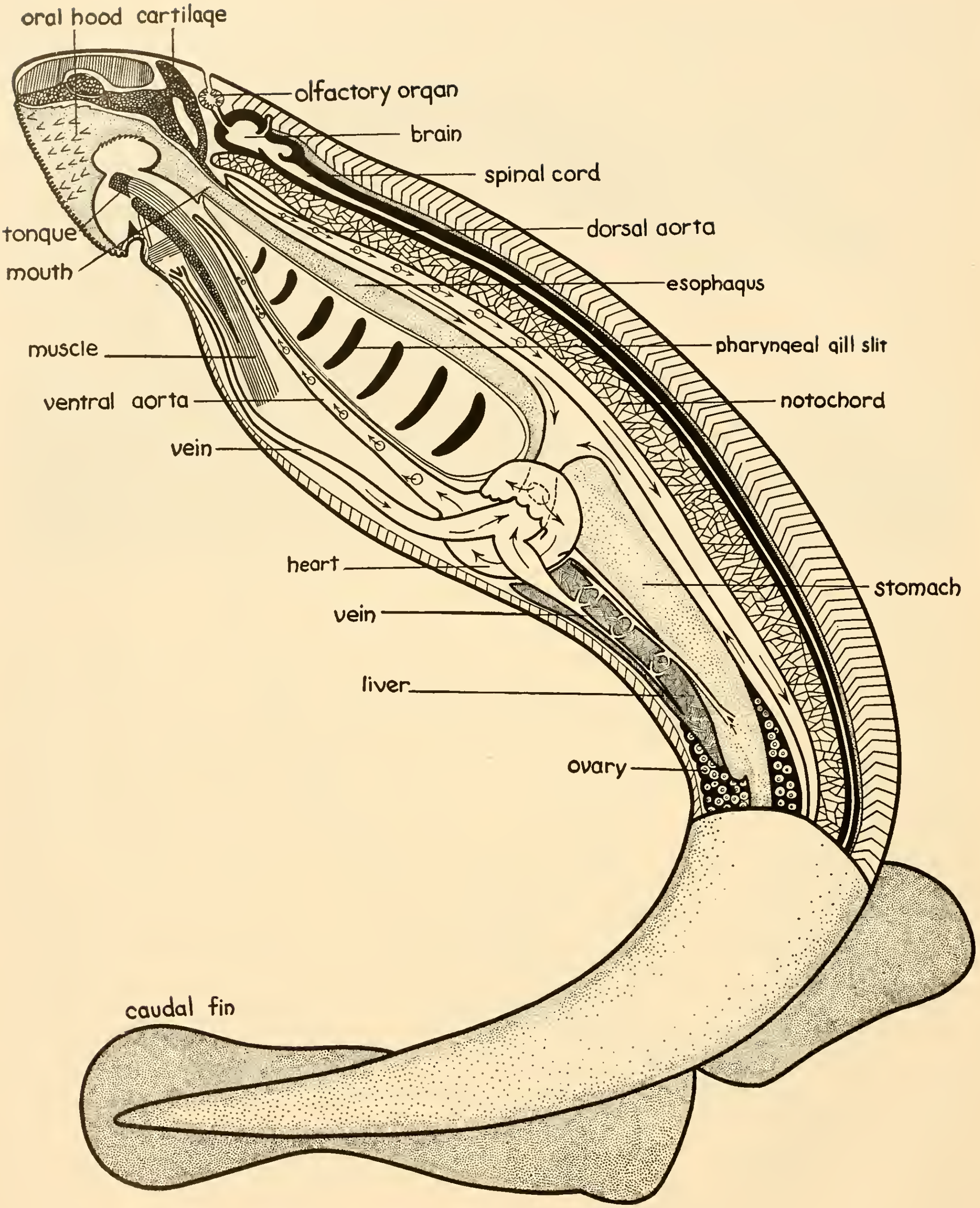


Fig. 13-10. Cyclostome in partial longitudinal section.

lel ventral folds, a dorsal fold, and a tail fold which is perhaps extensive enough to be called a fin. In order to be more maneuverable in their search for food, animals gradually developed more elaborate appendages. Shark-like fossil remains of forms possessing many paired fins (Fig. 13-12) seem to indicate that they "had not quite decided" how many pairs of appendages were of the greatest utility, and, according to Romer, only later did they settle down to the orthodox two pairs, the pectoral

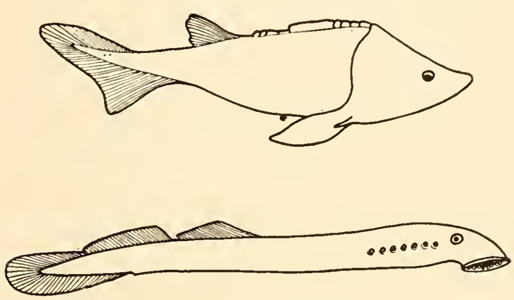


Fig. 13-11. The oldest vertebrates are the ostracoderms shown in the upper figure. They had many features of modern cyclostomes shown in the lower figure.

(chest region) and pelvic (hip region). From these two pairs of fins, which became so prominent in the early sharks and all later fishes, evolved the appendages of land forms (Fig. 13-13).

The prehensile jaws of the early primitive fish were another important acquisition, making it possible for them to become free swimmers and predators, searching out and capturing their prey. This, of course, went hand in hand with the evolution of better appendages to aid in swimming; both were essential if the animals were ever to become very important, and, what is more, be able to get out of the water and onto the land. A clue to the development of the jaws can be found from a study of the shark's gill arches. These differ but little from the jaw itself, and in fact, they are so much alike in this animal, as well as in many fossil forms, that it is generally agreed that the jaws have developed from the first gill arch. As will be shown later, other important organs also develop from these same primitive gill arches.

The teeth found in the shark's jaw occur in never ending rows and show a remarkable similarity to its scales. It is thus clear that the scales in the region of the mouth opening merely enlarged and became the teeth of the shark. These teeth simply grow

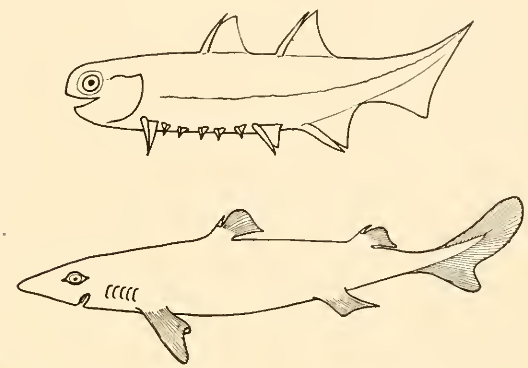


Fig. 13-12. Primitive sharks had many paired appendages extending throughout the length of the body, as shown in the above figure. The two conventional pairs (pelvic and pectoral) appeared in later forms and in all present-day vertebrates.

over the edge of the mouth and are continuously shed as they wear out. Later it will be shown that all teeth are modified scales, including those of man (Fig. 14-4).

The sharks and their close relatives, the rays, cannot match the success of the bony fish when it comes to number and variety of forms. There is, however, some diversification in body form among the group, which becomes obvious when the ray is studied. It is greatly flattened, with enormously developed pectoral fins that look more like wings (hence the name, sea bat) as they undulate in the sea (Fig. 13-14). The tail is drawn out to a long whip-like structure, which, in the sting rays, bears a spine at the tip. When annoyed, the ray can inflict a painful wound. Some of the rays have gone so far as to produce another form of energy in considerable quantity and employ it as a mechanism of defense, namely, electricity, found in the electric

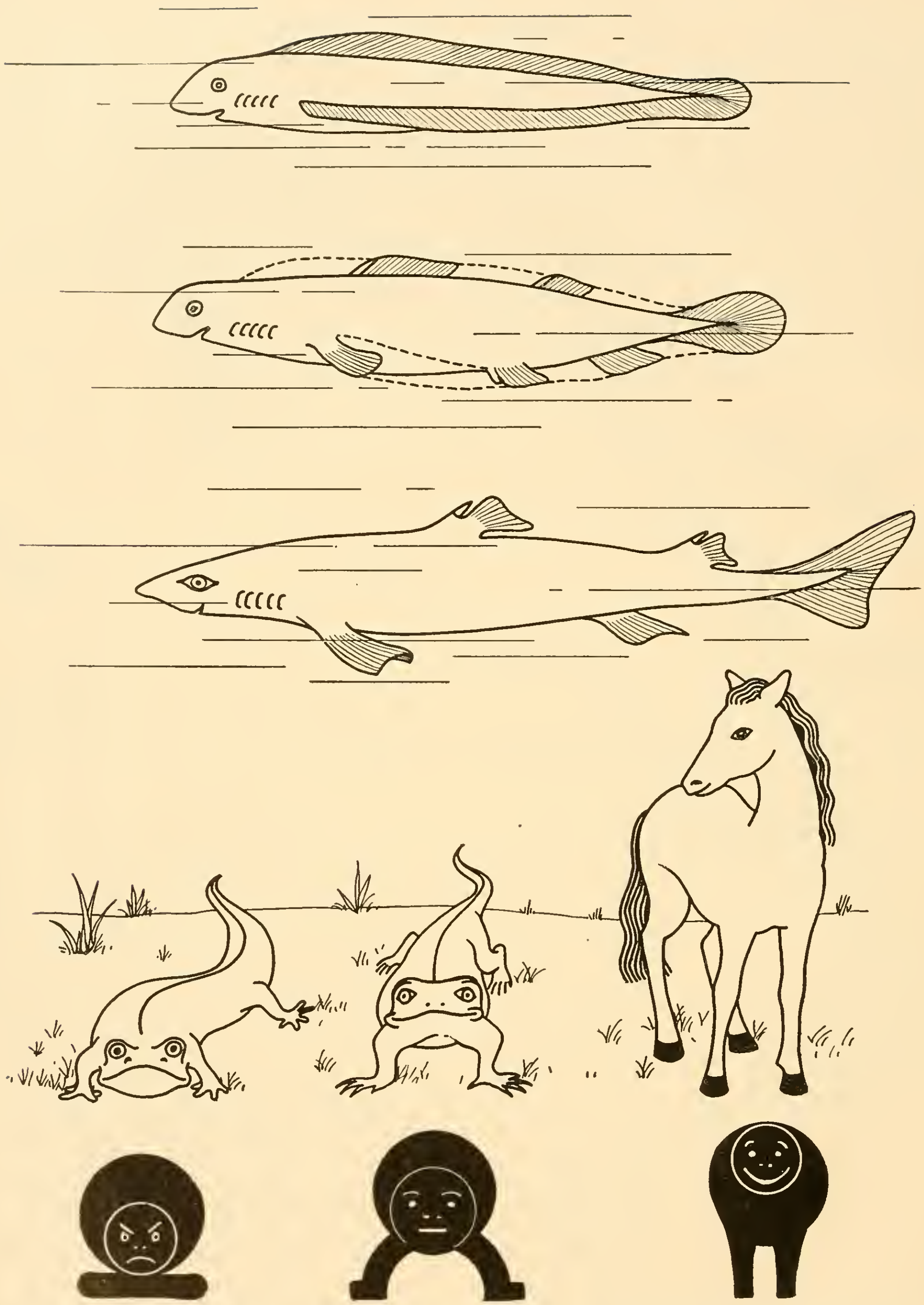


Fig. 13-13. Primitive vertebrates, according to some zoologists, had fin folds much like amphioxus (upper figure). Portions of these folds were retained in the pectoral and pelvic regions to become the paired appendages; other parts became the other fins (middle and lower fish figures). Coming out on land necessitated greater development of the appendages, as is seen among the amphibians, reptiles, and mammals. At first they dragged their bodies over the ground, later the appendages supported the body above the ground, which made it possible for the animal to move more swiftly. This reaches its peak in such cursorial animals as the horse.

Fig. 13-14. Sea bat (ray) lying on the deck of the *Albatross*. Note its huge pectoral fins that give it the appearance of flying when it swims.

ray. Modified muscles are so constructed as to produce an electrical potential sufficiently high to stun lower forms and to cause a good deal of pain in larger animals. Shocking devices are not confined to the rays alone, but are also found among a few higher fish, namely, several species of eels and catfishes. The mechanism of this device has not been completely worked out.

THE MODERN BONY FISHES

The cartilaginous fishes, the sharks and rays (class Chondrichthyes), developed appendages and true jaws as important adjuncts to success in the water. Once these became established as a permanent part of the anatomy of aquatic vertebrates, a great deal of "experimentation" apparently ensued. The result was the modern bony fishes (class Osteichthyes) which have gone "all out" in exploring possible body shapes, sizes, and colors that best suit them for their particular aquatic niches. They range from ordinary fish such as the common perch (Fig. 13-17) to the vicious garpike (Fig. 13-15) and bizarre sea horse (Fig. 13-16). Obviously they have been highly successful, for they have penetrated virtually every aquatic environment. They are found in the oceans of the world—from the surface to great depths, where they have attained the most weird shapes and have developed extraordinary luminescent organs. In fresh water they are found in swift moving streams as well as stagnant pools. Some, such as the salmon and eel, can survive satisfactorily in either fresh or salt water and migrate seasonally from one environment to the other in connection with their breeding cycle.

Structurally, the bony fish are similar to the sharks with a few minor exceptions. For example, they have reduced the number of

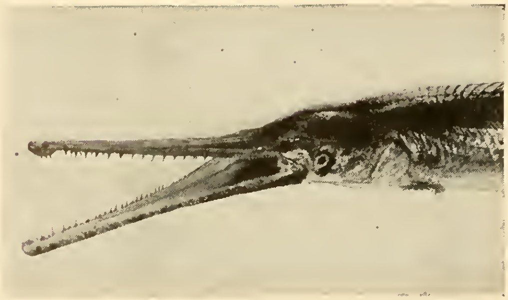


Fig. 13-15. The long-nosed gar (*Lepidosteus osseus*), a vicious carnivore which feeds on other fish. This fish inhabits the Great Lakes and most of the streams of the Mississippi Valley.

gills to four pairs and have covered them with a thin bony cover, the operculum (Fig. 13-17). Their bodies are covered with large overlapping scales arranged like the shingles on a house. The fins, while in general of the prototype, are highly variable both in position and in size among the different groups of fish. There is nothing strikingly different about their internal anatomy with the possible exception of the swim, or **air bladder**, which occupies a large part of the body cavity in many species (Fig. 13-17). We shall discuss its origin later. Its function is to regulate the buoyancy of the body. As the fish moves to different depths the gases (CO_2, N, and O_2) increase or decrease in the swim bladder automatically, adjusting the specific gravity of the fish to the corresponding depth, but if a fish is suddenly pulled from great depths to the surface the expanding bladder may force the stomach out of the mouth.

Most present-day fish possess bony skeletons, a very ancient character. Finally, compared to the ancient bony fish, present-day forms show a tendency toward reduction of the massive head bones and toward a reduction in the number of bones generally through fusion. There are never more, and frequently fewer, bones in later fishes.

The retention of hard internal skeletons made it possible for the fish to begin their long migration onto land, to a new type of life outside of water. Although this movement began with the fish, it was not completely accomplished until the advent of the reptiles, many millions of years later. The hard bones made it possible for appendages to become sufficiently strong to support a body in the air, a feat which the degenerate cartilaginous skeleton of the sharks could never have accomplished.

Among the ancient fish there were some that had a fleshy portion, or "lobe," which extended some distance out into the fin. This contained certain skeletal elements that have been found to correspond directly with similar bony elements in the appendages of true land forms, even to the appendages of man himself. Descendants of these fish undoubtedly were able to migrate onto land at a later time to give rise to the great array of land vertebrates. "Lobe-finned" fish were long thought to be

Fig. 13-16. The sea horse (*Hippocampus kuda*) swims in a vertical position by means of its dorsal fin. Note its prehensile tail, used to cling to vegetation. The male has a pouch under the tail where the eggs are brooded until they hatch.

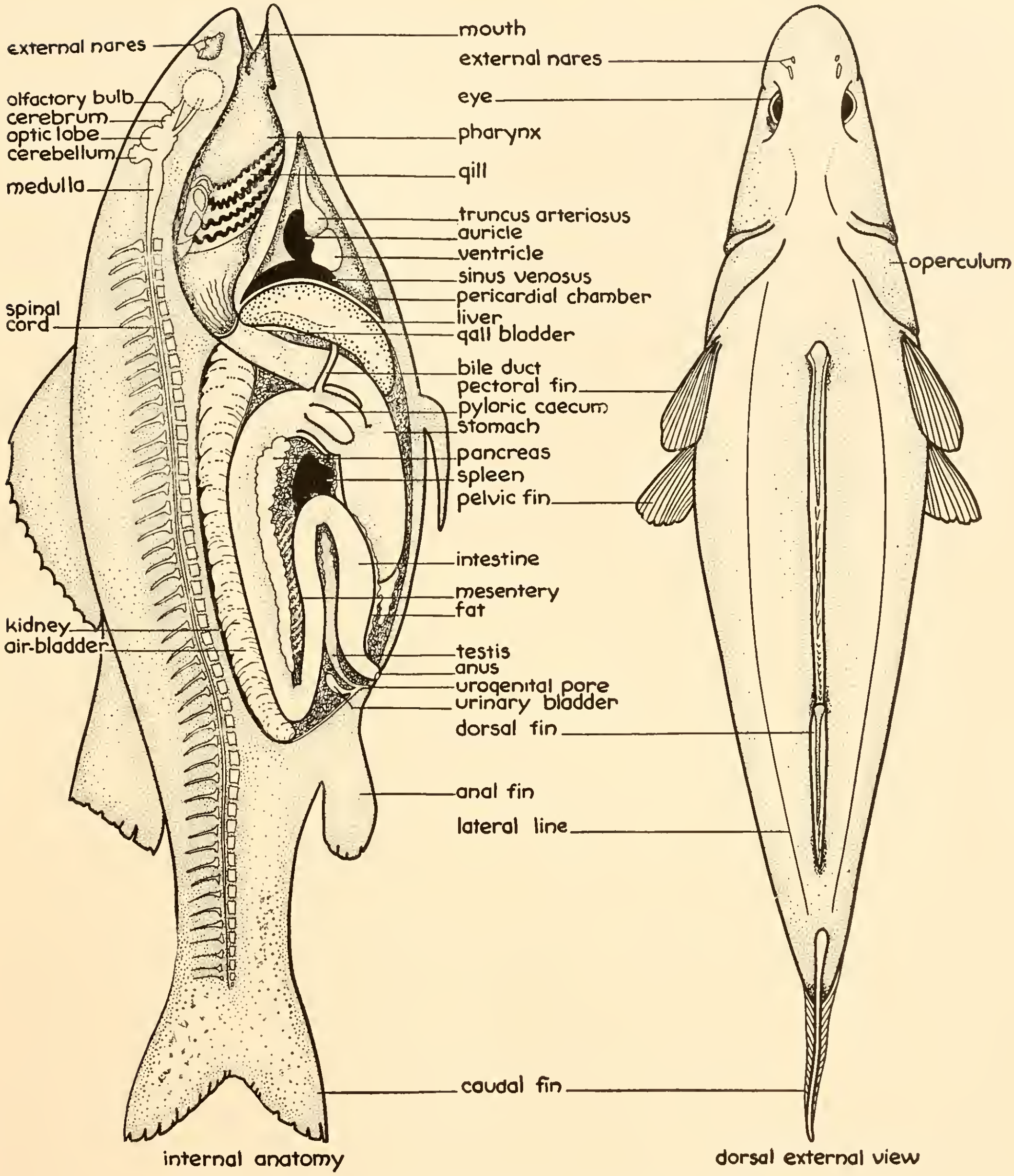


Fig. 13-17. Teleost fish in longitudinal section and dorsal view.

extinct until a fisherman off the coast of South Africa hauled one in (*Latimeria*) in 1939. Unfortunately the true value of the find was not discovered until the body was destroyed, although the skin was mounted (Fig. 13-18). Relatives of the "lobe-finned" fish are not uncommon today. The **lungfish,** for example, inhabits certain tropical parts of the earth where frequent droughts occur. Since this form followed a different path of evolution, it does not possess well-developed appendages and, in spite of the fact that it has lungs, probably did not give rise to the land forms.

One other absolute essential had to be achieved if fish were to live outside of

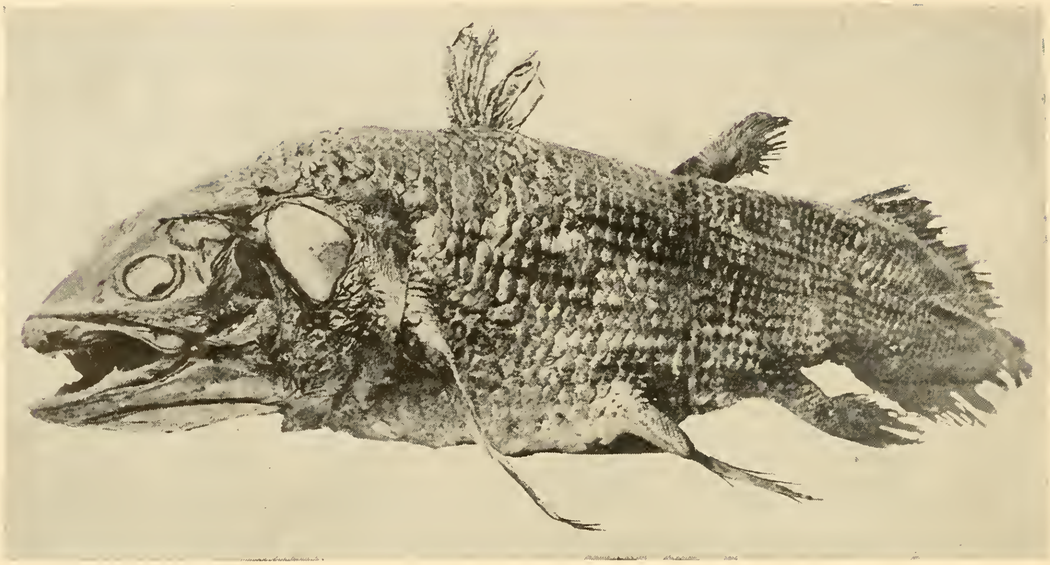


Fig. 13-18. Ancient lobe-finned fish (*Latimeria*) found off the coast of Africa in 1939, supposedly extinct for millions of years.

water, and that was some means of utilizing the oxygen of the air. The "lobe-finned" fish of the past, as well as the lungfish of today, accomplished this rather satisfactorily. Apparently these fish lived in regions where nearly all the water dried up for extended periods during the year, and in order to survive such arid periods, they found it necessary to come to the surface of drying pools and take in air, since there was little oxygen in the water. These animals developed a pair of sac-like lungs from the ventral side of the pharynx which allowed them to gulp air during periods when their gills were useless. This, it must be remembered, is a primitive condition. Its counterpart is found in present-day fishes in the form of a swim bladder which functions as a hydrostatic organ rather than a lung, since these fish have no need for a lung-like structure at any time during their lives. It is therefore easy to see that once this lung-like structure developed among the "lobe-finned" fish, it was utilized on land and there eventually became the complex organ that is found in such animals as the birds and mammals of today (Fig. 13-19).

Thus two features, the bony appendage and the lung, made it possible for animals to attempt the greatest of all transitions—from the water onto land.

INVASION OF THE LAND: THE AMPHIBIANS

Of all the changes that have occurred in animals during their long evolution to present-day forms, one of the most intriguing is the fishes' forsaking of their aquatic life for life on land. According to Romer this was the "result of a happy accident." They would hardly have left the water in search of food, since during these times most animals were aquatic except a few insects, and fish would hardly leave a food-laden world for one almost devoid of food. They had already supplied themselves with a means of breathing air, so this could not have been the cause. Romer reasons that, if drought periods were too extensive, those fish which could breathe air and walk about on the land were able to move to other ponds, and survive. Thus the appendages and lungs aided them in finding water rather than

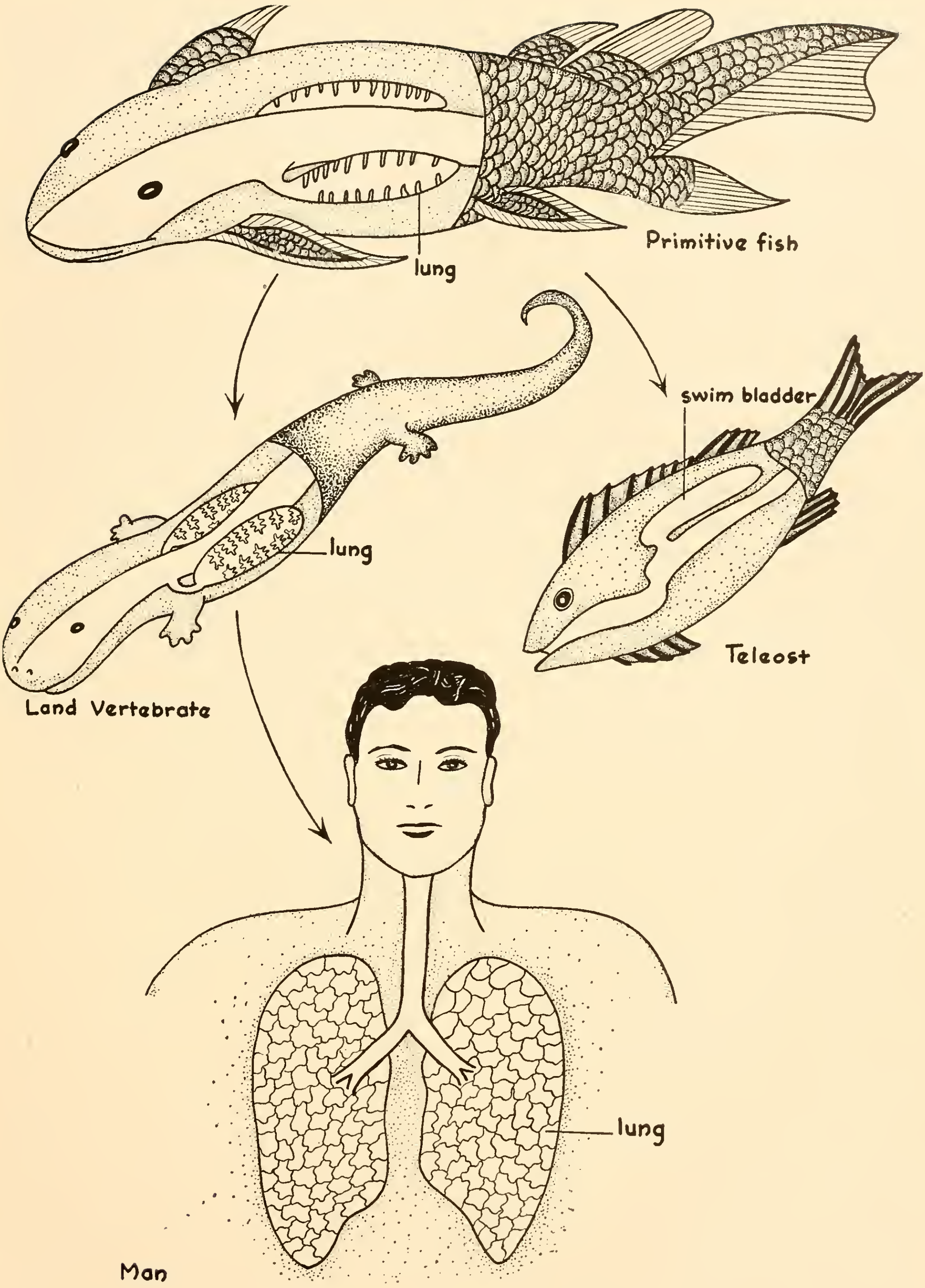


Fig. 13-19. History of lungs and swim bladder.

Fig. 13-20. The common tiger salamander (*Ambystoma tigrinum*) normally undergoes a typical amphibian metamorphosis resulting in the adult shown in Fig. 13-21. One variety of this species living in western North America, particularly in the southwest, becomes sexually mature while still a larva and never reaches the adult stage. The specimen on the extreme left is a young larva, while the one next to it is a sexually mature larva. This is as far as development proceeds in nature. Several specimens similar to this one were placed in water with a high level of iodine. During the next few weeks the "adult larvae" metamorphosed to typical adults as the next two pictures show.

leaving it. However, during these excursions some may have found abundant food near the water's edge, whereas others which could not stand drought may have found it more profitable to wander from pond to pond in search of food. Again, it does not take a great stretch of the imagination to see how some might have found other members of their own group to feed upon, while others might have changed to a herbivorous diet (as some we know did), since vegetation was abundant. From such beginnings the great variety of life among land vertebrates appears to have developed.

There were undoubtedly numerous unsuccessful attempts by many groups of the fishes to make the transition onto land. The ancestors of the "lobe-finned" fish apparently were successful, and gave rise to the amphibians which include our present-day frogs and salamanders. As the name *amphibian* implies, these animals live both in and out of the water. Their larval stages are always spent in an aquatic environment, but the adults of most species are able to live out of water, although they usually do not venture far from moist surroundings.

The life history of the frog is common

Fig. 13-21. This normally occurring adult tiger salamander is in no way different from the one "artificially" produced in Fig. 13-20.

knowledge to every school child (Fig. 13-22). He knows that frogs deposit their eggs in the water much the same as fish do, that the eggs hatch into tiny fish-like tadpoles which breathe by means of gills, that during the weeks and months that follow the tadpole eventually loses its tail and develops lungs and jumping legs, which enable it to move onto land. It took the fish many million years to accomplish what the tadpole now repeats in a few weeks.

The amphibians are tied to water in varying degrees. Some species have tried to divorce themselves completely from the water, as, for example, the South American toad, whose eggs brood in fluid-filled sacs upon its back. Other species, such as the mud-puppy, spend their entire life in the water and cannot be forced to leave it. A curious intermediate is a variety of tiger salamander (*Ambystoma tigrinum*) which normally spends its entire life in the larval body form, but which, if fed thyroid extract or high levels of iodine, can be made to lose its gills, develop lungs, and come out on land just as its relatives do (Fig. 13-20). This tiger salamander larva was thought to be a different species from the usual adult (Fig. 13-21) and was called the **axolotl.** It would seem that while the axolotl has descended from forms that attained the adult state, it "preferred" to retain its larval body form, perhaps because of more abundant food or for some other reason. Among the amphibians, then, there are those which attempt to leave the water altogether and those which tend never to leave it. This is exactly what would be expected if evolu-

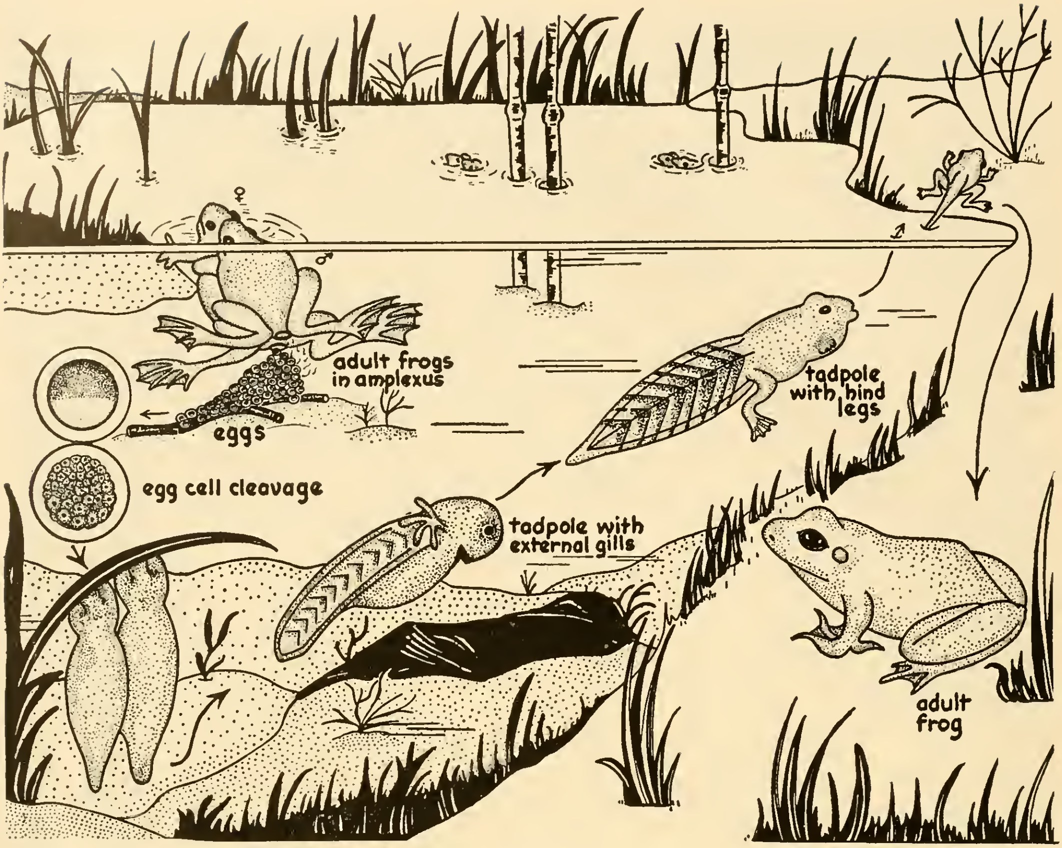


Fig. 13-22. Life history of the frog.

tion has occurred as has been described on these pages.

The frog: the halfway vertebrate

If numbers be taken as a criterion for success, the amphibians were much more successful at an earlier time than now. At that time they did give rise to very successful groups of animals, the reptiles, birds, and mammals. The amphibians seem to have reached the halfway mark between the aquatic and the land forms and for that reason they show some very interesting intermediate structures. To study a bird or a mammal without reference to the frog would be like studying the present-day government of the United States without recourse to the struggle for independence. Understanding of a mammal can only come from a historical approach to the whole problem, which means that it is essential to examine an intermediate type. There is no better form to use for such a study than a representative amphibian, and the frog lends itself especially well for several reasons. First, aside from its well-developed, atypical, jumping legs, it possesses most of the typical ancestral amphibian characteristics. Secondly, it occurs universally, which makes it an inexpensive form for study. Lastly, it is of such a size that it is easily handled in the laboratory by students; a larger or smaller animal offers some difficult problems in this respect. A thorough knowledge of the "halfway" animal at this point provides the background for a better understanding of the mammal.

Life history (Fig. 13-22). One of the first harbingers of spring is the familiar croaking of the frogs. The one heard most frequently

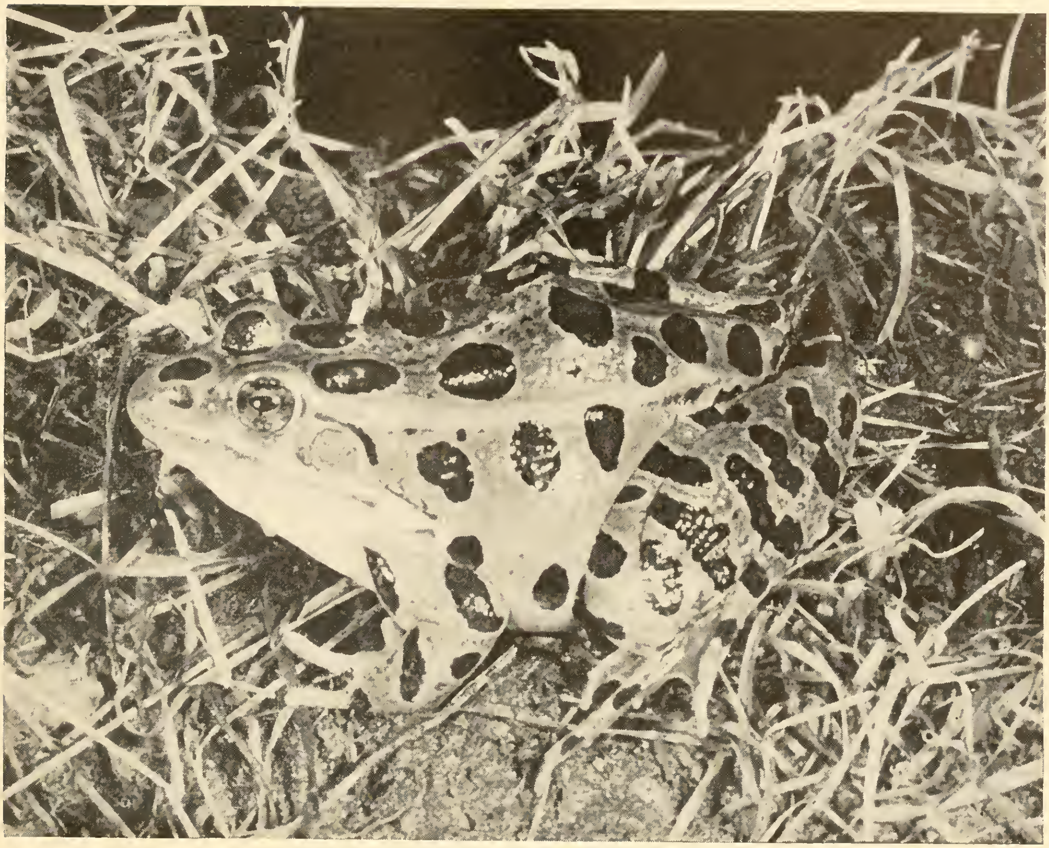


Fig. 13-23. The common leopard frog (*Rana pipiens*).

is the leopard frog, *Rana pipiens* (Fig. 13-23), found in shallow ponds and streams. The small, green tree toad, *Hyla versicolor* (Fig. 13-24), emits its musical sounds from wooded areas near ponds, while the bullfrog, *Rana catesbiana* (Fig. 13-25), gives forth its resounding bellows from larger bodies of water. While these "delightful" sounds are very much welcomed by everyone, they have more important meaning to the frogs. The male frogs usually emerge from hibernation first and begin the croaking in order to attract the females who follow some days later. At this time of the year, the eggs in the body of the female are fully mature; as a matter of fact, they have been fully ripe for many months, waiting the coming of the breeding season. The male mounts and clasps the female with his front legs, grasping her just back of her front legs and pressing the small swollen parts of each thumb (**nuptial pads**) against her breast. This process is called **amplexus** (Fig. 13-26), and is a kind of copulation. As the female lays her eggs the male discharges a milky fluid containing sperms, thus fertilizing them. Very shortly thereafter, the gelatinous matrix surrounding the eggs swells, causing them to adhere to twigs or any other underwater debris (Fig. 13-27). The egg mass resembles cooked tapioca, and the eggs themselves are at first black above and white below, a characteristic which may possibly offer some degree of protection during the early stages of development.

If an egg is viewed under the microscope, one can see it divide, once, twice, three

Fig. 13-24. A tree toad (*Hyla versicolor*) croaking. Note the greatly extended vocal sacs which aid in producing its shrill sound.

Fig. 13-25. The great bullfrog (*Rana catesbiana*), which may reach a length of a foot over-all. The large ear-drum identifies this as a male.

Fig. 13-26. A pair of toads in amplexus.

Fig. 13-27. A woodland pond with egg masses of the woodfrog (*Rana sylvatica*).

times, and so on, producing furrows along one side, then elongating, and finally developing a small tail. Sometime later a tiny tadpole emerges from the jelly mass. By means of a pair of suckers under the mouth, the tadpole remains attached to the mass for a few hours while it is undergoing further development. Presently, however, it begins to swim about and can be seen to feed by a scraping movement of its mouth as it moves along a leaf of a water plant. In this stage it breathes by means of gills just as fish do and as its ancestors did. It is a vegetarian, feeding exclusively on algae and other plant life.

After some months or years, depending on the species of frog, the tadpole rather suddenly begins to develop miniature hind legs while its tail becomes shorter. At the same time its mouth grows larger and wider, and its digestive tract shortens. It gradually seeks shallower water and occasionally comes to the surface for air as its lungs develop. These trips for air become more frequent until finally the frog hops away from the water, sans tail and strictly carnivorous, a common sight to everyone. Thus, in a brief period it has reënacted the entire race history of this long and arduous migration out of the water onto land, a most remarkable feat!

The summer months are spent in search of food which consists of insects, spiders, earthworms and even tadpoles and other smaller frogs. These are sought in damp places, usually near the water, although some species such as the leopard frog venture considerable distances from the water in search of food. Eggs develop rapidly within the ovaries of the female, so that by midsummer they are fully mature. Ample amounts of fat are stored in special organs called fat bodies before the frogs go into hibernation at the approach of winter. Frogs are cold-blooded, as are turtles and snakes, and usually spend the winter buried in the mud at the bottom of ponds and streams. As the temperature drops, their body processes slow down simultaneously until the heart is beating very slowly and all metabolism is reduced to the lowest possible rate necessary to maintain life. In this state of inactivity the food demands are very slight, so that stored food carries the frog along quite adequately through the winter months. As the temperature rises in the spring, frogs soon become active and enter at once into the breeding period.

Each female frog lays from several hundred to several thousand eggs depending on her age. Of these eggs, only a very few, perhaps none, become mature frogs. Enough manage to come through to maturity, however, to maintain the race, although with the onslaught by birds, turtles, snakes, fish, and man it is amazing that this little animal does survive and one wonders if it will continue to do so. One of the greatest demands for its body is by beginning zoology classes to verify points discussed in this book.

The frog body plan. Frogs range in size from the tiny cricket frog (*Pseudacris*), about an inch long, to the bullfrog which may be a foot over-all. In general, their features are so similar that, aside from coloration and habits, a description for one fits them all. When a study is made of a living frog, the moist, slippery skin is at once conspicuous even if the frog is kept away from water for some time. This is due to tiny **mucus** glands in the skin which constantly pour out their fluids to keep it wet. Like the earthworm, the frog receives considerable amounts of oxygen through its skin and must therefore have a moist skin. The slippery skin also cuts down friction when the frog is swimming through the water.

Other distinctive features include the large eyes which when touched are pulled down into the head (though actually they bulge into the mouth cavity). The protruding eyes permit the frog to come to the surface of the water and see without exposing the rest of its body, a definite protection against possible enemies. Lying just back of the eyes are the large eardrums which are a part of the hearing mechanism. Above the tip of the nose are the **nostrils** which have valves that can be opened and closed at will. These function in breathing. The **mouth** is a very large one, and is kept shut all of the time except when the frog feeds. At the posterior end is the **anus**, which is the terminal opening of the **cloaca.**

The front legs are turned in, "pigeon-toed," and there is a swelling (nuptial pad) on the inside digit of each front foot of the male, already referred to in the process of mating. These legs function in breaking the fall after a jump, as well as in supporting the anterior portion of the body. The long muscular hind legs are beautifully adapted for jumping. When the frog is at rest on land they are kept along side or partially under the body in the jumping position, but in the water they are customarily left dangling behind. When surprised on land, the frog suddenly straightens out its legs, throwing the body forward several feet. This process can be repeated in rapid succession, so that it requires an agile pursuer to overtake the little animal. These are the principal external features that are noted in a cursory examination.

Outer covering. Like all vertebrates, the skin of the frog consists of an outer thin **epidermis** and a thicker underlayer, the **dermis.** The outer layer, which is shed periodically, is made up of flat cells. The dermis contains many glands which provide the mucus for keeping the skin moist. Some species have, in addition, smaller glands in this region which secrete a substance that is offensive to animals that might feed upon it. The dermis is also heavily vascularized for its function in breathing.

The dermal scales of the fish are noticeably absent among the modern amphibians, although fossil remains indicate that their ancestors were well covered with scales. Scales offer excellent protection from attack and it seems strange that the amphibians have given up this apparently valuable aid in self-preservation. It must be remembered, however, that in present-day species the skin is an "accessory" lung and very important in respiration. Only because of this condition is it possible for the amphibian to spend its quiet periods in an environment where breathing with lungs is impossible.

The locomotor organs. When the loose skin of the frog is removed, a set of muscles is exposed that far surpasses anything possessed by fish. The most conspicuous difference noted between the frog and fish is the remarkable development of the muscles that operate the appendages, which are responsible for the agile jumping movement on land. Although many of the muscles approximate the position and seem to function much the same as similar muscles in man, most comparative anatomists agree that only a very few of them are identical. Apparently they are derived from similar muscle masses of ancestral forms but probably followed different lines of evolution. The muscles of the frog are named in Fig. 13-28 and should be studied in terms of their function in locomotion and not from a comparative point of view.

Muscles are contractile tissues which function much like rubber bands. They are always under slight tension in life, even when relaxed. They differ from the rubber band analogy in that they have the power to contract violently when stimulated. The contractile portion is the fleshy or "belly" part of the muscle which is attached to the bones by **tendons.** The latter are fibrous, tough, and non-contractile. A muscle is identified by noting its **origin,** which is the end that moves less when contraction occurs, and its **insertion,** the end which moves more. Muscles are attached to the bones in many positions, and they vary in size from the tiny muscles that close the eyelids to the large muscle that extends the leg. It is the great variety both in the muscles themselves and their points of attachment to the bones that make possible all of the many movements made by the frog. When such a system is carried to higher animals, man, for example, it is evident that there must be a great many muscles to carry out the many and complicated movements of which such a form is capable.

The supporting structure. Although the internal skeleton of the frog is made of bone and in many respects resembles that of man, in other respects it must be considered as the skeleton of a "specialized" vertebrate rather than a "generalized" form because it differs so markedly from primitive vertebrates (Fig. 13-29). Perhaps its most conspicuous loss it that of ribs and a tail which the majority of primitive vertebrates possess, but which the frog, for some reason, has lost. Furthermore, its body is much foreshortened with the loss of many vertebrae. Most vertebrates have from 20 to 30 vertebrae, whereas the frog has only nine.

The appendages are attached to the vertebral column by means of girdles, the **pectoral** in front, the **pelvic** behind. These are quite generalized and hence much like those in most other vertebrates. The pectoral girdle consists of three principal pairs of bones attached to a series of midventral bones called the **sternum.** The **scapulae** are located on the dorsal side of the trunk (the flat extension is called the suprascapula) and this structure is similar to the human shoulder blade. It joins ventrally with the **clavicle** and **coracoid** which in turn fuse to the sternum. The clavicle (collar bone) is well developed in man but the coracoid is only a small "bump," fused to the scapula. The pelvic girdle is composed of three pairs of bones, which in the adult are fused into a single structure. The long, flat, anteriorly

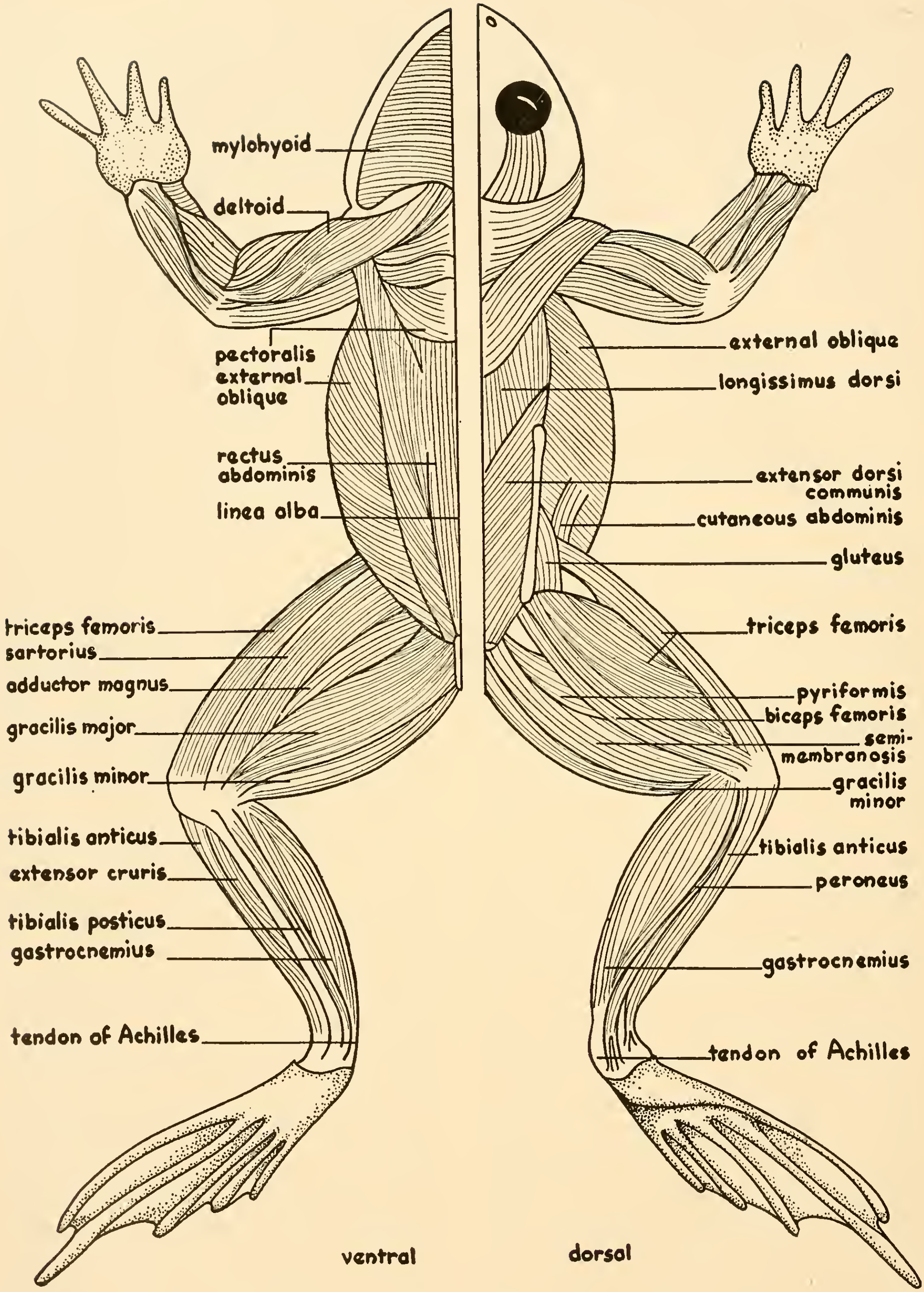


Fig. 13-28. Frog muscles, dorsal and ventral views.

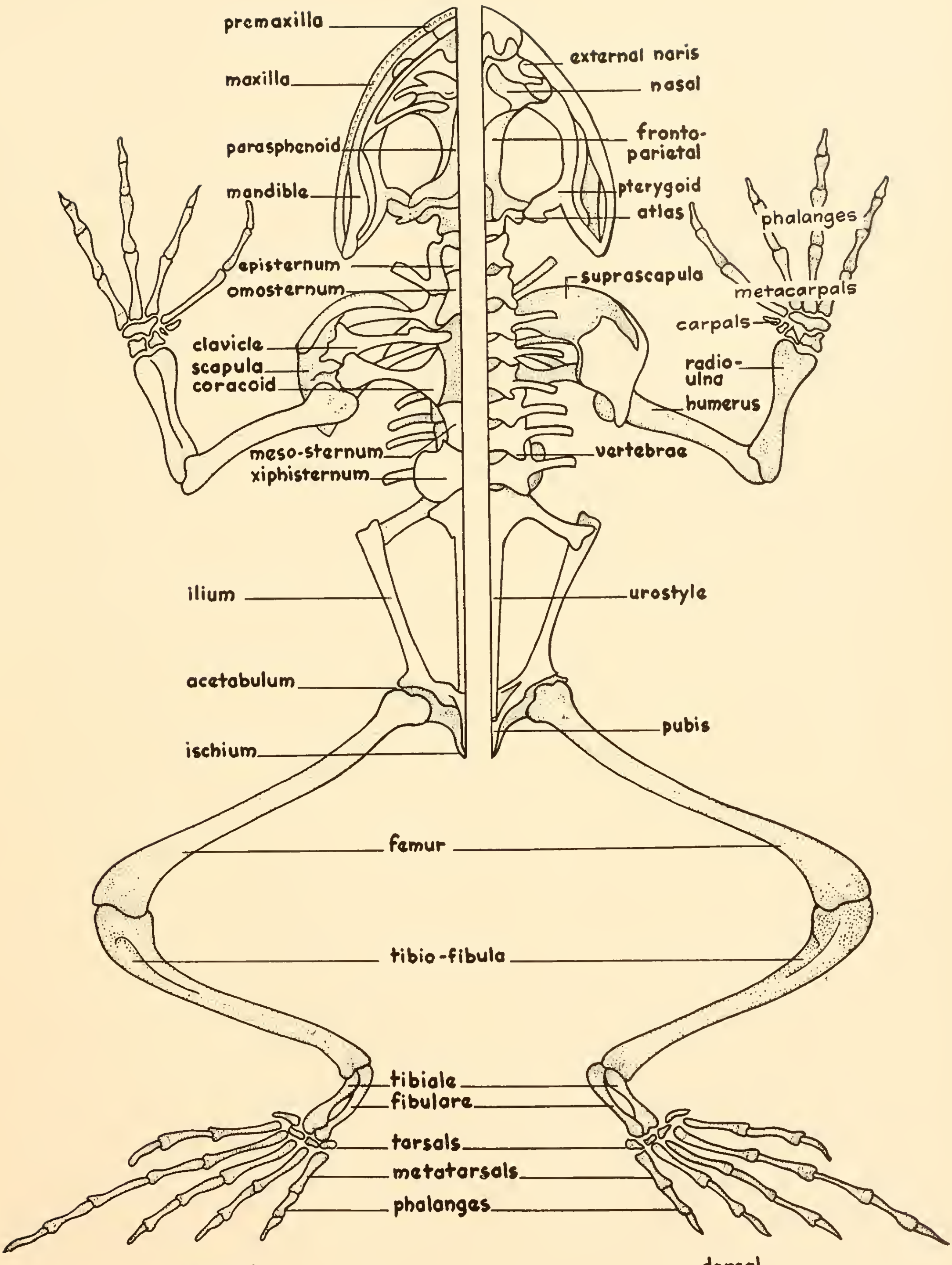


Fig. 13-29. Frag skeleton, dorsal and ventral views.

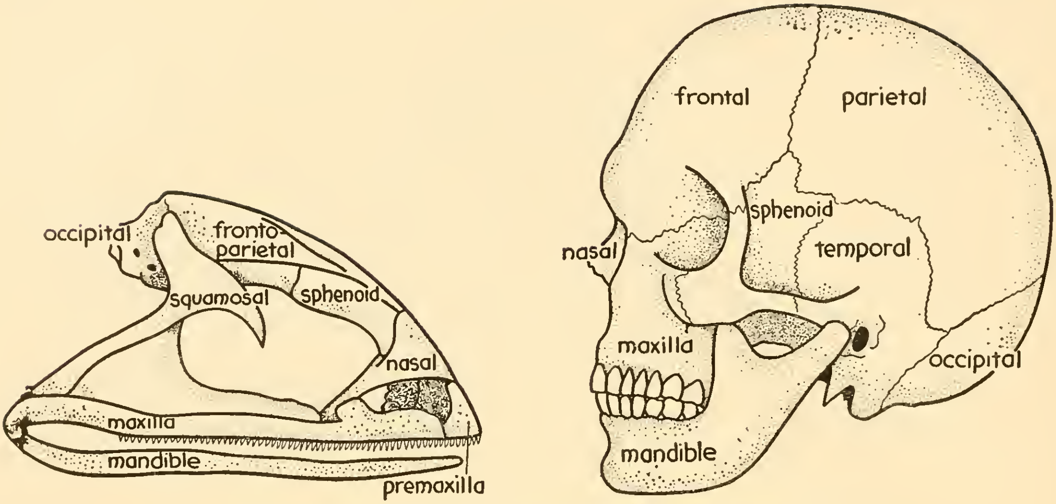


Fig. 13-30. Comparative study of the skulls of frog and man.

directed **ilium** joins posteriorly with the **ischium** and ventrally with the **pubis** (the latter remains as cartilage) to form each half of this girdle.

The front and hind legs of the frog are homologous, that is, they are very similar, possessing approximately the same bones although of somewhat different proportions. A single bone, the **humerus**, which fits into a cavity (**glenoid fossa**) of the pectoral girdle, forms the top of the front leg; this is followed by a pair of bones, the **radius** and **ulna**, which are fused together in the frog but separate in most other vertebrates. The wrist is composed of several bones called **carpals**; these are followed by the **metacarpals** and **phalanges** of the **digits**. The posterior appendage likewise has a single bone, in this case called the **femur**, which fits into a socket (**acetabulum**) in the pelvic girdle; this bone is followed by a pair of bones, the **tibia** and **fibula**, which again are fused in the frog. The **tarsals** are next, and two of these are enlarged to add a joint in the hind legs, thus facilitating jumping. Following the tarsals are the **metatarsals** and finally the **phalanges**. The bones of these appendages have remarkably similar counterparts in the human skeleton.

The anterior end of the spinal column articulates with the base of the skull. This skull is no longer a primitive and generalized type. Fusion of the many bones found in fishes has taken place to such an extent that some of them have been entirely lost in the long evolution to the amphibian type of skull. Above the level of sharks there are two types of bones present in all skulls: **replacement bone**, which is that bone replacing cartilage as the individual develops, and **dermal bone**, produced from the dermis. The frog skull is made up almost entirely of dermal bones, and the only replacement bones present are those immediately surrounding the brain.

The skull has been used to trace the origin of the amphibians as well as other types of animals. It has generally been thought that amphibians have given rise directly to the mammals; this idea is based on the fact that both mammalian and amphibian skulls possess two **condyles** (bony projections) on either side of the large opening, the **foramen magnum**, through which the cord passes at the base of skull. Recently, however, it has been discovered that primitive amphibians, like fish, have but one condyle. This simply means that both mammals and amphibians have followed similar paths in their evolution.

In addition to that portion of the skull which protects the brain, there are the parts

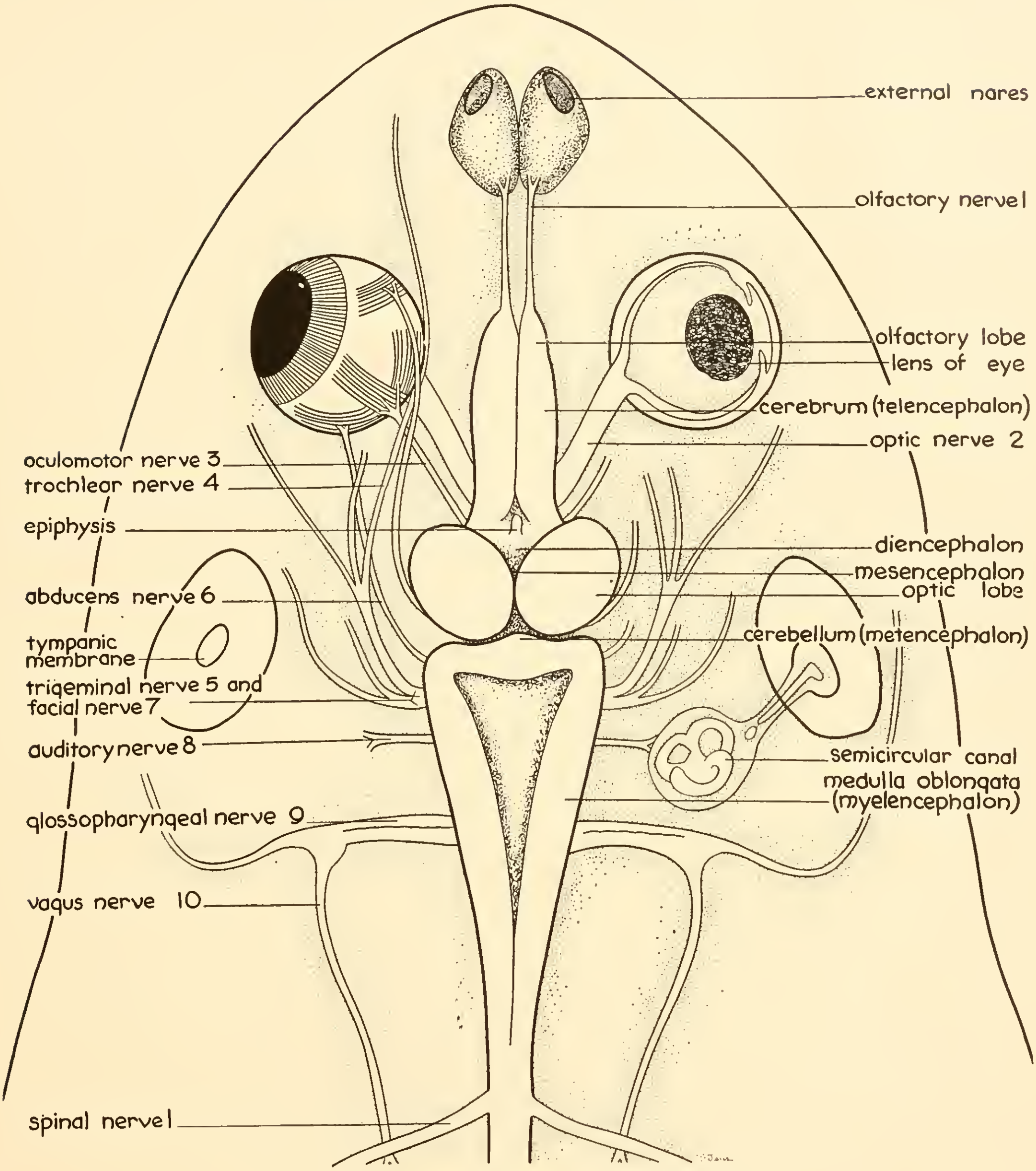


Fig. 13-31. Frog brain and cranial nerves, dorsal view.

which make up the food-getting and breathing mechanism. The jaws of the frog are made up of three bones and resemble the gill arches of the shark from which they were derived. In man these bones have fused into a single bone, the **mandible** (Fig. 13-30). Behind the jaws and lying between them is the **tongue,** which possesses a rather good support, the **hyoid apparatus.** The hyoid apparatus, like the jaw, has been derived from the gill arches. Other gill arches have been modified into supporting structures for the **larynx,** the sound-making apparatus. Here is seen the method constantly used in evolution, that is, the formation of new structures from old ones which no longer function in their original manner.

Nervous system. The nervous system of any animal begins with the end organs which receive stimulations from the outside world. These sense organs are well developed in the frog and are very similar to those in man. To begin with, the nose bears a pair of nostrils with valves on them so that air may be taken in intermittently. The nostrils open into small but well-developed nasal passages which are lined with sensory cells that join the olfactory nerve (Fig. 13-31). Tests indicate that the frog does rather well in identifying its odoriferous world and makes use of this sense in orienting itself in its environment.

To the frog, as well as other animals, the eye is one of the most important organs of sense. It differs from the human eye in minor details only. For example, the lids will not cover the eye completely; to close it all the way, the frog must pull the eye down into its socket. The typical six muscles for moving the eye in all directions are present, just as is the case in all higher vertebrates, and these will be studied later. The lens is fixed in place so that the focus cannot be changed as in man by altering its own shape, or as in the fish by moving back and forth. Therefore, the frog sees clearly only at one distance, and it is near-sighted in air and far-sighted under water. The **rods** and **cones** of the **retina**, which are the parts of the eye sensitive to light, are scattered, rather than concentrated in one spot as in man. Consequently, the frog probably does not see as distinctly as higher forms do. Due to the position of its eyes the frog does not possess **stereoscopic vision** and therefore cannot see depth. Although the frog eye is considerably inferior to that of mammals, it appears adequate to the needs of the animal.

The conspicuous **eardrum** of the frog is exposed to the outside world, whereas in higher forms it is buried deep inside the head. Lying beneath the drum is a cavity in which a single bone, the **columella** (one end of which is homologous with the stapes of higher animals), extends from the thin eardrum to a tiny bit of sensory tissue which is stimulated by the vibrations as they are passed to it, through first the drum and then the bone. Because of the rather primitive nature of the auditory organ, the frog probably hears most notes at the same pitch, that is, while it might hear a thud or a chirp, they would both sound the same. The organs of equilibrium (**semicircular canals**) are similar to those of both lower (shark) and higher (man) forms.

The frog possesses a **lateral line system** only during the tadpole stage. All fish have such a row of sacs extending along each side of the body which are sensitive to vibrations and movement of the water. It is interesting to note that in the evolution onto land these structures were lost, and certainly they were not sufficiently sensitive to detect similar movements in air. No higher animals possess any organs that resemble the lateral line system of fish and the tadpole.

With the exception of a few major modifications there is remarkable similarity between the brain of the frog and man. The brain is proportionately much larger in man and the spinal cord sends out three times as many nerves. The foreshortened body of the frog accounts for the fact that there are so few spinal nerves. When the brain and cord are dissected out and viewed as a unit, the brain seems to be no more than a slightly expanded anterior end of the cord (Fig. 13-32). Starting at the base of the brain and progressing forward, the five parts of the brain can be seen.

The first enlarged portion is the **medulla oblongata** (myelencephalon—5) which gives rise to most of the cranial nerves (Fig. 13-31). These have to do with most of the automatic functions of the body, just as they do in man. A slight projection which runs transversely across the medulla is the **cerebellum** (metencephalon—4) which is much smaller in the frog than in most other vertebrates. This may be owing to its function in muscular coördination, which is

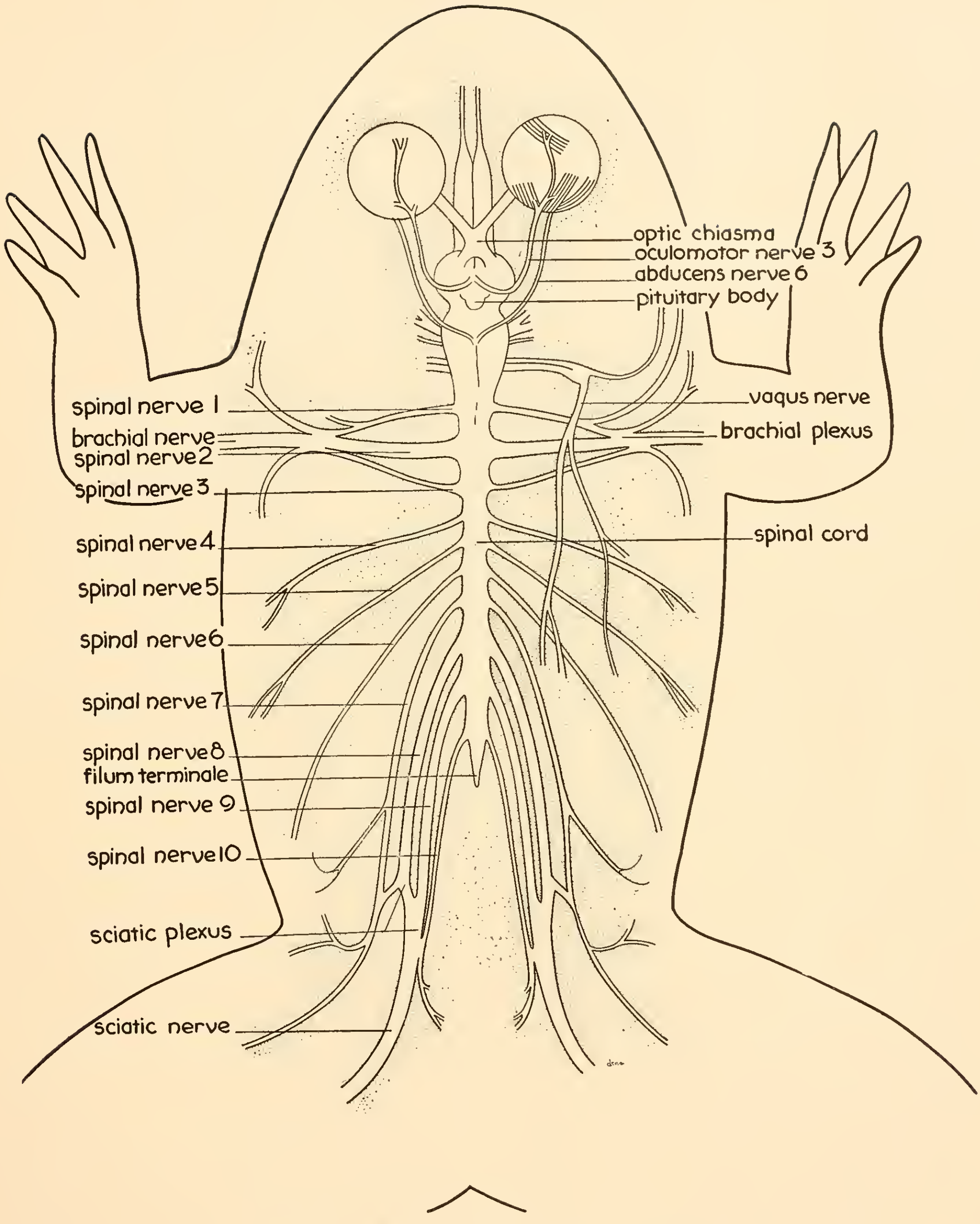


Fig. 13-32. Ventral view of the frog nervous system.

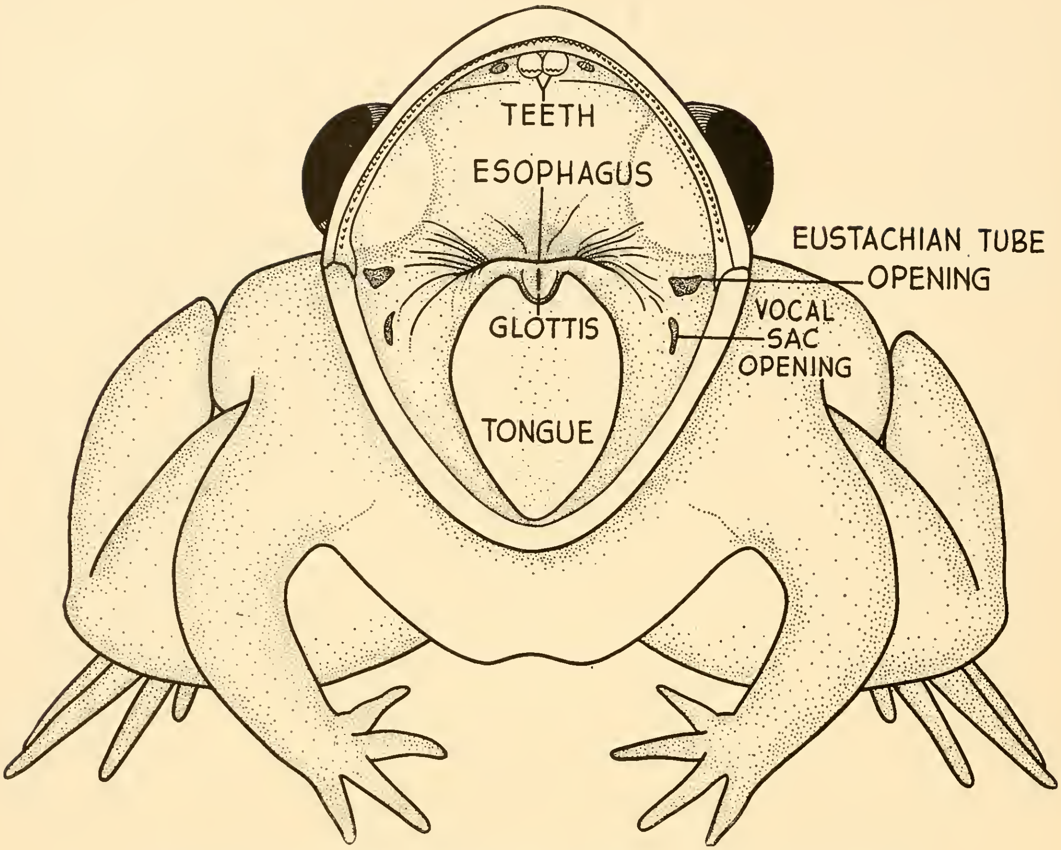


Fig. 13-33. Oral cavity of the frog, showing the openings of various tubes that enter it.

poorly developed in amphibians. Animals that move in three dimensions, such as fish and birds, have proportionately larger cerebellums.

The most conspicuous objects of the entire brain are the **optic lobes** (outgrowths of the mesencephalon—3) in which nerves from the eyes terminate. These lobes seem to function in inhibition of spinal cord reflexes, rather than as the centers for sight. The small projection just anterior to the optic lobes (diencephalon—2) is the **epiphysis**, an organ of doubtful function. On the ventral side of this same region is a tube-like stalk which terminates in an enlargement, the **pituitary** (hypophysis) (Fig. 13-32), a very important gland of internal secretion about which more will be learned later.

The anterior part of the brain (telencephalon—1) is only poorly developed in the frog. It is composed of a pair of lobes which are partly divided transversely. The two anterior parts are the **olfactory lobes** to which the **olfactory nerves** are attached. The posterior parts of these lobes make up the **cerebral hemispheres**, the functions of which are not clear. In fact, when this portion is removed the animal responds, in a near-normal fashion when various stimuli are applied (Fig. 16-15). This is one of the greatest differences between the frog and man, for in man many important sensations occur in the conspicuous cerebral hemispheres.

The frog has only ten cranial nerves, but reptiles, birds, and mammals possess well-developed eleventh and twelfth cranial nerves. There is some evidence that primitive amphibians, too, had these additional

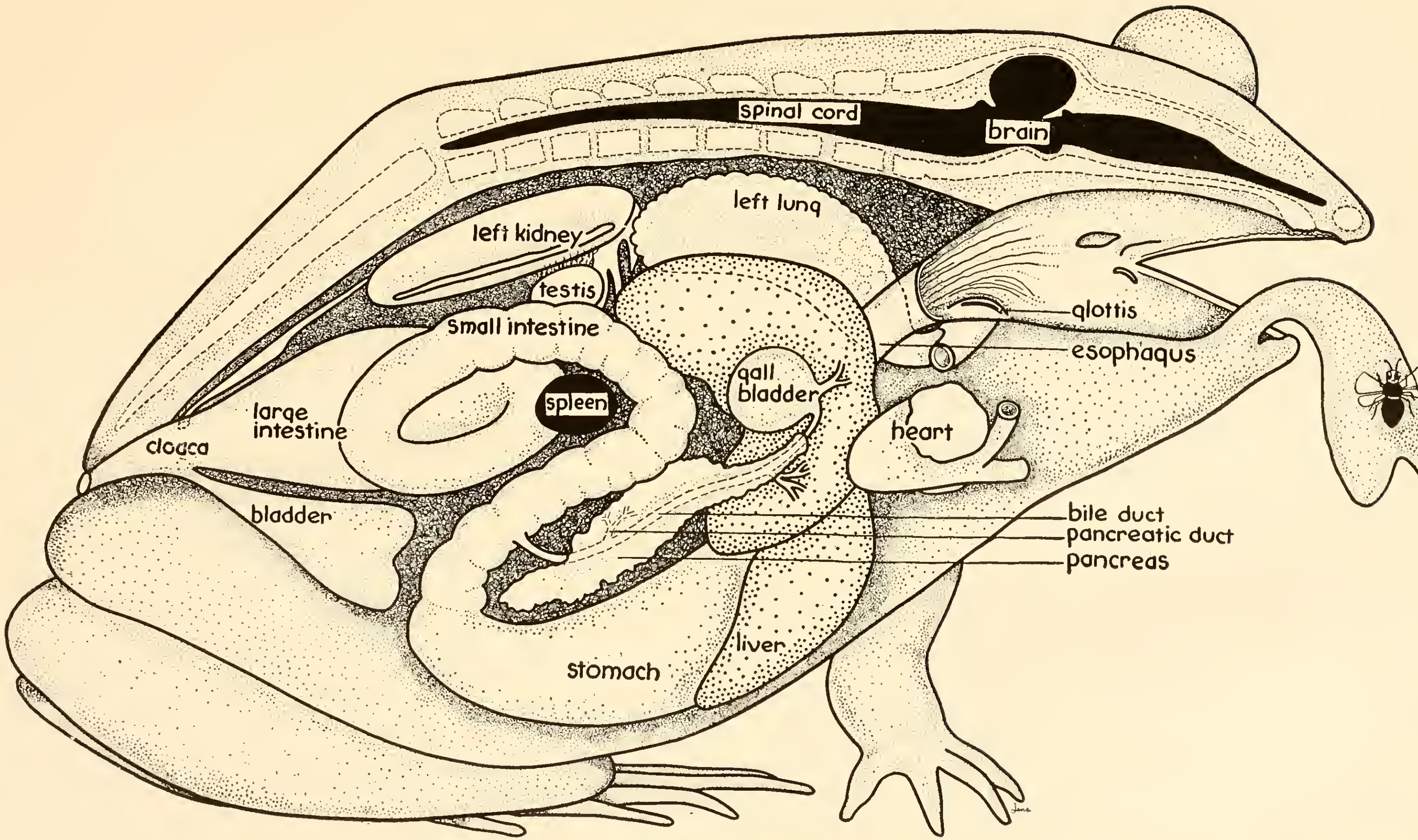


Fig. 13-34. Longitudinal section of the frog, showing internal organs.

nerves, but strangely enough, the frog seems to have lost them somewhere along the way.

The spinal nerves that pass to the legs are grouped together in two plexi, the anterior **brachial plexus** and the posterior **sciatic plexus** (Fig. 13-32). From these regions the nerves spread out again and pass to all parts of the appendages. The larger nerves are in the regions of the legs, as one might expect, since it is there that more of the messages must travel.

Digestive system. This system starts with a disproportionately large mouth which when fully open can enclose a body one-fourth the size of the frog itself (Fig. 13-33). The jaws are feebly armed with a top row of teeth and a few on the front edge of the palate. The teeth function only in holding prey and are incapable of crushing or chewing. The large protrusible tongue lies on the floor of the mouth with the two pointed tips directed down the throat. It is attached in a peculiar manner, the anterior end being fastened just inside the lower jaw (Fig. 13-34). When in use, the mouth is opened wide and the tongue is flipped out with lightning-like speed, so fast, in fact, that it has no difficulty in capturing agile insects, since the sticky mucus secreted by mouth glands makes a good adhesive agent. There are no digestive enzymes in the saliva and hence no digestion occurs in the mouth.

Openings into the mouth cavity are those of the **eustachian tubes** which connect with the cavity under the ear drums, the **internal nares**, which connect with the nostrils, and the **esophagus** which leads abruptly into the large U-shaped **stomach.** The back part of the mouth, the **pharynx,** is lined with cilia which beat continuously and help carry food down to the stomach. The stomach is merely a portion of the digestive tract which is enlarged for storage of food, and the frog has occasion, indeed, to use a sac of such ample proportions. Some digestion takes place in the stomach, much as in the stomach of man. The lower extremity is marked by a constriction, the **pyloric sphincter** (a band of circular muscles which, when contracted, closes the opening). The stomach is followed in turn by the **small intestine** which receives the pancreatic juice and bile from a single duct (Fig. 13-34). The **pancreas** is a long, light-colored, ribbon-like organ that lies between the stomach and the first part of the intestine. The liver is composed of three lobes, two large lateral lobes and one smaller median lobe. The **gall bladder** usually lies dorsal to the smaller lobe, and the **bile duct** passes from it through the substance of the pancreas on its way to the intestine, picking up the **pancreatic duct** along the way. The gall bladder is green in color because of the **bile** which it contains.

The small intestine of the herbivorous tadpole is very much longer than that of the carnivorous adult frog, a distinction that generally separates animals that feed on vegetation from those that feed on meat. Digestion takes place much faster where meat is the principal diet and therefore a shorter gut is sufficient. On the other hand, the cellulose found in plant tissue requires a longer period to digest; hence a longer gut is necessary in animals that are vegetarians. The small intestine of the frog opens directly into the short expanded **large intestine** which soon constricts down to the **rectum** and then opens into the **cloaca** (sewer). Here the **genital** and **urinary** ducts also empty. Undigested food deposited in this region is soon voided to the outside through the **anus.** The cloaca is found among reptiles, birds, and low mammals, but among all higher mammals the urogenital and digestive tubes have separate openings to the outside of the body.

Circulatory system. Just as in the animals already studied, the circulatory system in the frog must transport food and oxygen to the cells of the body and waste products away from them. In fish, the heart is a simple pump in which all of the blood is carried through a single circuit; the blood

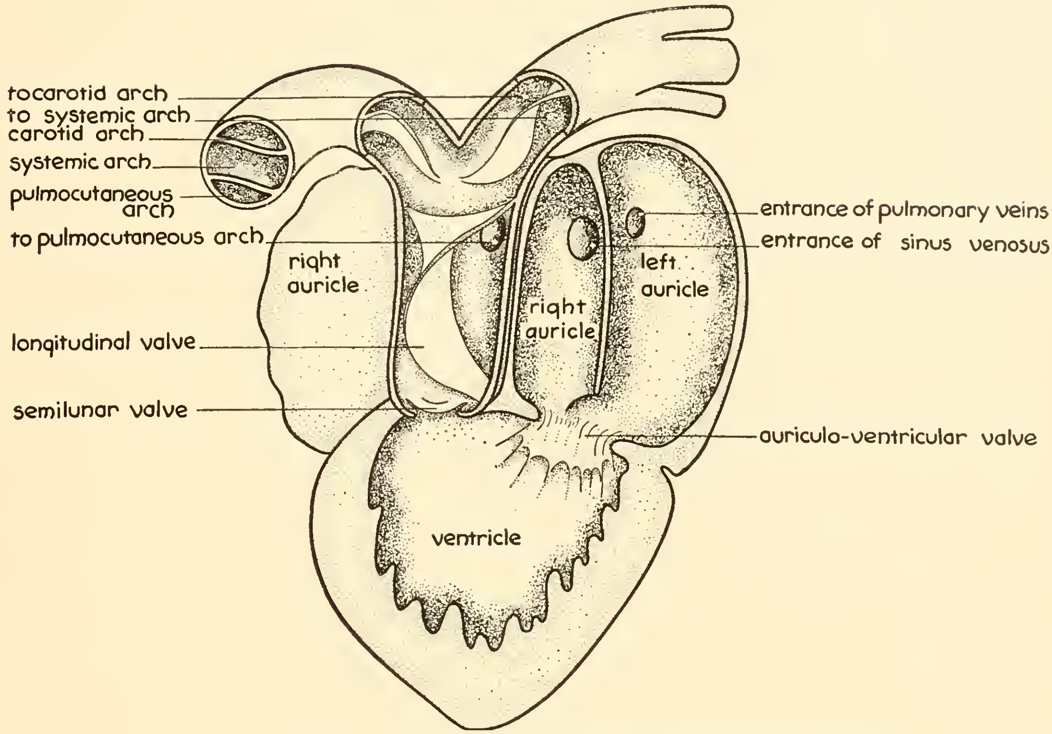


Fig. 13-35. Ventral view of the frog's heart, sectioned to show chambers and valves.

coming to the heart has lost its oxygen and must be sped on its way to the oxygen-replenishing station, the gills. The function of the heart of the fish is simply to keep this mass of blood in motion. In the air-breathing frog, however, a new complication arises: there are two circuits of the blood. One circuit carries blood rich in oxygen to the tissues, and then brings the "used" blood, poor in oxygen, back to the heart, while the other carries this depleted blood to the lungs and brings it back after oxygenation to the heart. These two circuits must be kept separate in order to do an efficient job. Since the amphibians were the animals to take the first step onto land, they were the first ones to begin the solution of this complex problem, and are interesting to study because they give some information as to how this development and evolution all came about. The higher reptiles (crocodiles), birds, and mammals have solved the problem very nicely by producing two complete hearts, but the amphibians seem to have been unable to make the complete transition, and have gotten along these millions of years with a rather crude system.

The blood coming from all parts of the body first enters the sac-like **sinus venosus** and then the right auricle; simultaneously blood rich in oxygen enters the left auricle from the lungs. It would seem that upon syncronous contraction of the two auricles the blood would be badly mixed and that all blood leaving the heart could be mixed blood. This is not the case, however, because of the anatomical arrangement of the ventricle. By studying Fig. 13-35, it is seen that the opening of the right auricle leads into the ventricle to the left of the opening from the left auricle and then delivers its blood nearer the exit, the **conus arteriosis.** When the blood from the right auricle flows into the ventricle it is just a little ahead of the blood from the lungs. When the ven-

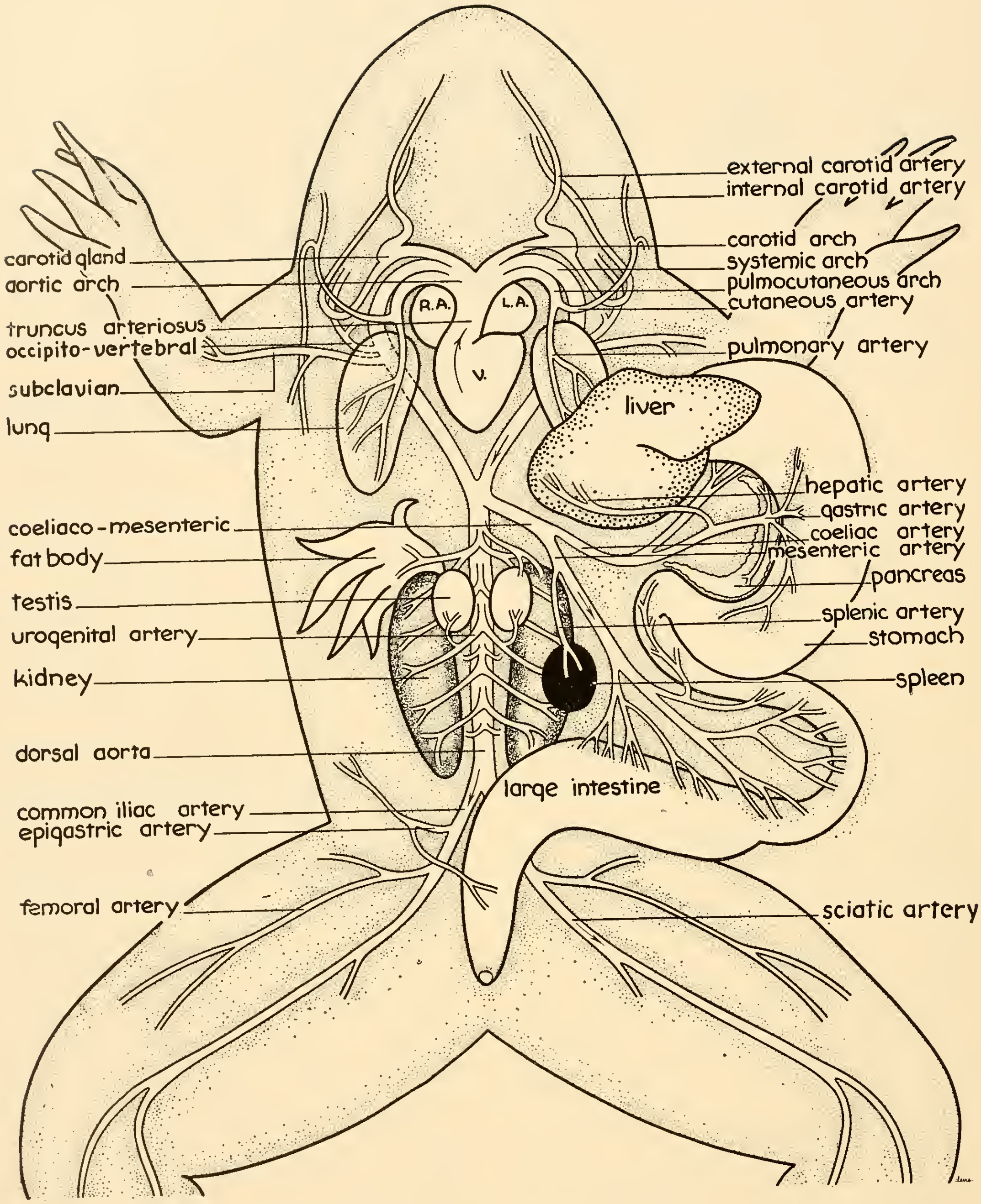


Fig. 13-36. Ventral view of the frog arterial system.

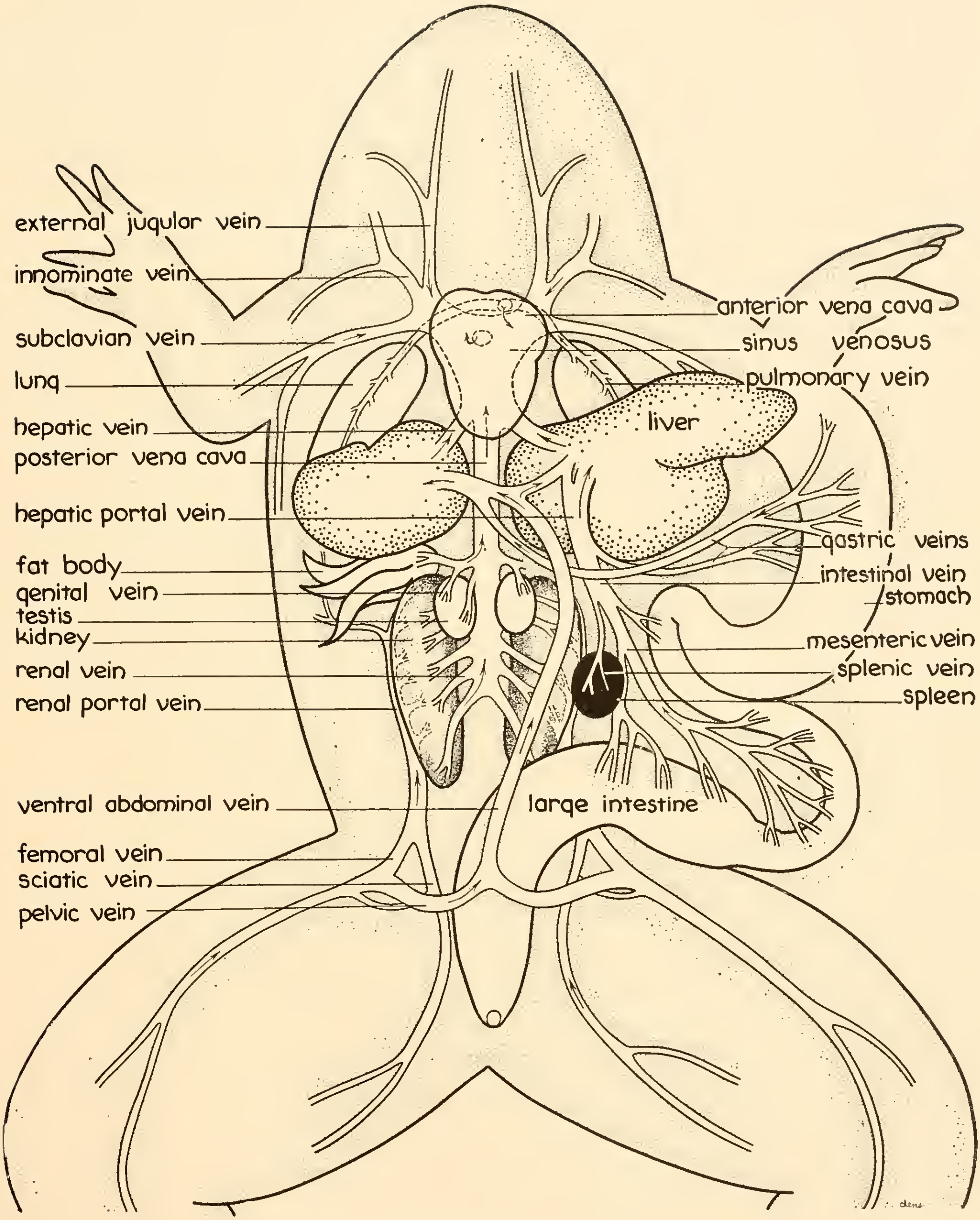


Fig. 13-37. Ventral view of the frog venous system.

tricle contracts, the "used" blood passes out first. To further aid the separation of the blood there is a **longitudinal valve** located in the conus arteriosus which tends to direct the first blood into the pulmonary arteries and the later blood into the systemic arches and head regions where it should go because it is richer in oxygen. There is some mixing of the blood poor in oxygen with that rich in oxygen in this system, and it is not as efficient as that found among the higher forms where separation is complete.

Arteries. There are three pairs of large arteries leaving the heart: the **pulmocutaneous** which goes to the lungs and skin, the **systemic arches** which join and become the **dorsal aorta,** and the **carotids** which go to the head and neck regions (Fig. 13-36). Each of these vessels divides many times until a network of capillaries is formed, and these networks supply all portions of the body with oxygen and food.

Capillaries. The arteries terminate when their walls become one cell layer in thickness. Through vessels of this diameter blood cells can only pass single file, and these tiny, thin-walled tubes are the **capillaries.** There are a great many capillaries in all of the tissues of the frog body just as there are in the tissues of man, and it is difficult to injure a portion of the skin anywhere without breaking one of these tiny vessels. These are the most important tubes of the entire vascular system because it is through the capillary walls that food and oxygen can get to the cells. The passing of the corpuscles through the capillaries can be easily observed under the microscope. The larger vessels in such a preparation are the **arterioles** and **venules,** which can be distinguished from each other by the fact that the blood flows in spurts in the arterioles and only gently in the venules.

Veins. After leaving the capillaries, the vessels become **veins** which carry the blood back to the heart. These grow larger and fewer as they approach the heart (Fig. 13-37). The blood from the hind legs has an alternate course in getting back to the heart. It may pass via the kidneys through the **renal portal system,** or via the liver through the **hepatic portal system.** A portal system is a system of veins which starts and ends in capillaries. The frog, like other lower vertebrates, has two such systems, whereas man and the higher vertebrates have retained only the hepatic portal system. It can be seen that this system is most important in carrying the blood heavily laden with food to the liver where it can be stored and otherwise processed. If it were not for this short circuit much of the general circulation would be bogged down with sugar and other food products. The two **precavas** and the single **post cava veins** enter the sac-like sinus venosus through three openings before proceeding on to the **right auricle.** Blood coming from the lungs in the **pulmonary veins** empties into the **left auricle,** thence into the ventricle where it joins the blood from the sinus venosus.

Blood. The plasma of the frog's blood is very similar to higher as well as lower forms, but the cells that float in it are somewhat different. The **red cells** are large, oval, nucleated cells, but at some seasons of the year many of the cells are without nuclei as are the red blood cells of mammals. There are several types of **white cells** which vary somewhat from those found in human blood. The blood also contains small **spindle cells** which are concerned with blood clotting.

Breathing system. The tadpole breathes by means of gills much the same as fish do. As it metamorphoses into the adult frog it gradually loses its gills and develops a pair of lungs. The **larynx,** formed from the cartilages that were used earlier to support the gill arches, is located at the point of junction with the mouth cavity, and contains the vocal cords which, when vibrated, produce the characteristic sounds of the frog, sounds which vary with the different species and are used as means of identification.

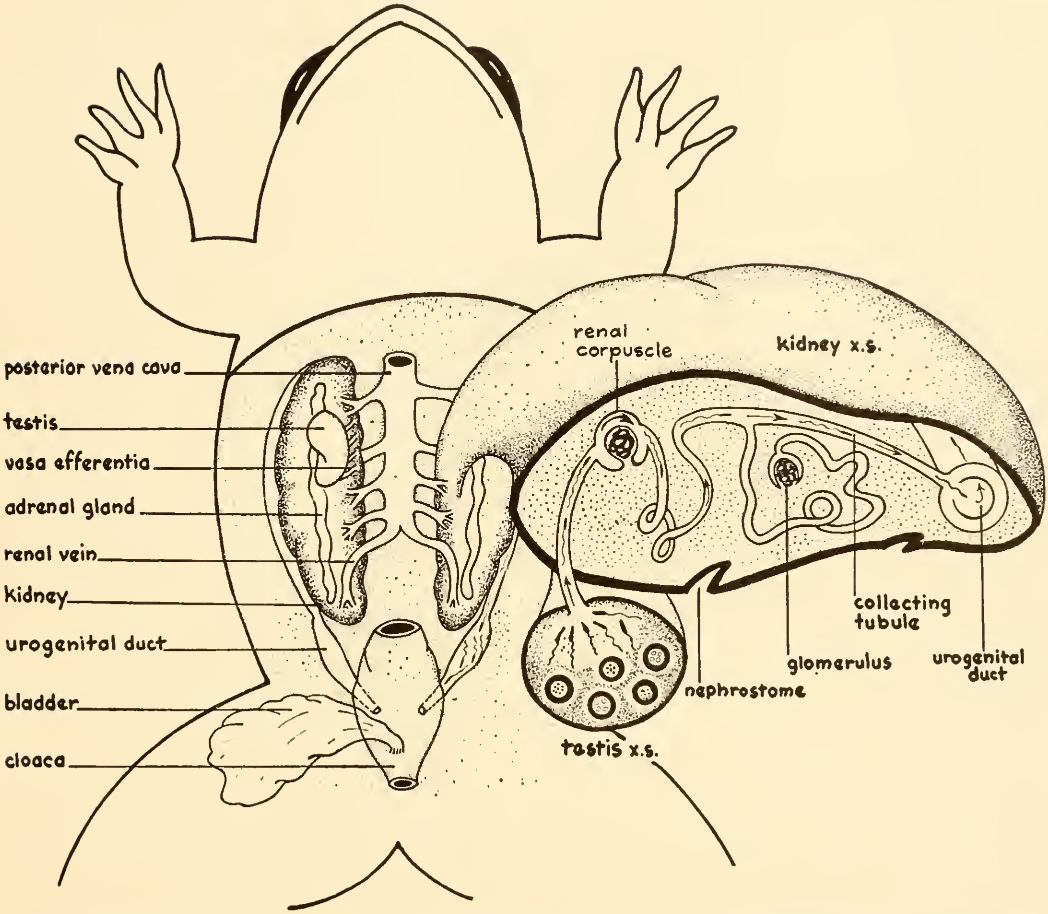


Fig. 13-38. Male frog urinogenital system, showing the kidney and testis enlarged and in cross-section.

The air passes into the mouth cavity through the nostrils where it is actually swallowed into the trachea and lungs through the **glottis**, a slit-like opening in the rigid circular larynx (Fig. 13-34). The trachea, into which the glottis opens, is very short and immediately branches into the two thin-walled, sac-like **lungs**. These are very inefficient organs of respiration when compared to those found in mammals. In fact, they are so inefficient that the animal must rely to some extent upon the skin to supplement the lungs in obtaining sufficient oxygen.

The process of breathing in the frog differs considerably from that in man because of the lack of both ribs and a diaphragm. The air is brought into the mouth through the nostrils by the sudden lowering of the floor of the mouth. The valves in the nostrils are then closed and the floor of the mouth raised which causes the air to be swallowed into the lungs. However, much of the respiration takes place in the mouth alone, for only now and then is the air taken into the lungs. Apparently, respiration can take place through the lining of the mouth, as well as the lungs and skin. When the animal is quiet and the water is cold it can remain submerged for long periods of time, as through the winter months, receiving all of its oxygen and giving off all of its carbon dioxide through the skin. Exact measurements show that actually more carbon dioxide is given off through the skin than through the lungs. The frog has thus made the transition to land, but, as indicated by its respiratory machinery, the adaptation to its new mode of life is far from perfect.

Excretory system. The excretory system of the frog is essentially the same as in invertebrates, such as the earthworm or lobster, as far as the individual units are concerned. It is made up of a great many nephridia massed together into a pair of organs, the **kidneys.** Urinary wastes, urea, salts, and so forth, are withdrawn from the blood as they pass through the kidney. The blood coming forward from the posterior parts of the body passes to the kidney and as it does the vessels break up into tiny masses (**glomeruli**) in the **renal corpuscles** (Fig. 13-38). As the blood passes through the glomeruli the urinary products are removed in a manner similar to that in man (p. 525). They pass down a long coiled tubule and finally reach a larger duct, the **urogenital duct,** in the male (**Wolffian duct**). The corresponding duct in the female carries urine only. The urine is deposited in the **urinary bladder** which in turn opens into the **cloaca.** Urinary wastes and feces, as well as the genital products all pass to the outside through a single opening, the **anus.**

Reproductive system. The male: The sex organs of the male are the yellowish **testes** located ventral and anterior to the kidneys (Fig. 13-38). They hang in a sheet-like bit of tissue, the mesorchium, through which tiny tubules, the vasa **efferentia,** pass on their way from the testes to the kidneys. Upon entering the kidney, the vasa efferentia connect with the uriniferous tubules which are connected to the renal corpuscles. Therefore, the tubules carry both sperms from the testis and urine from the renal corpuscles. The two products flow to the lateral edge of the kidney where they are poured into a larger tube, the **urogenital duct,** which eventually deposits its sperm load into the **sperm sac** and its urine into the bladder. In reviewing this peculiar situation it might be said that the testis has more or less "taken over" a portion of the original urinary system in order that the sperm cells might be carried conveniently to the outside of the body. This may be true, because lower forms such as the cyclostomes have no ducts to convey their products to the outside of the body, whereas higher forms such as man have separate ducts for removing urine and sex cells from the body.

The female: Between breeding seasons, the ovaries are tiny, wrinkled organs lying in the same position on the kidneys as the testes do in the male. Sometime in the summer months when the food is abundant the residual eggs lying in the walls of the ovaries begin to grow; and continue at a rapid pace until the ovaries are tremendous in size, almost filling the body cavity. The eggs develop in tiny pockets in the wall of the hollow ovary (Fig. 13-39) and when the breeding season approaches the mature eggs burst out in the body cavity. Here they are swept along by the united effort of cilia which line nearly all the walls. Their goal is the **ostium,** the tiny anterior opening of the long coiled **oviduct.** All of the cilia beat in such a manner as to direct the eggs to the ostium alone. Once inside the opening, the eggs make their way single file through the long oviduct which is also lined with cilia. During their passage they accumulate a jelly-like substance on their exteriors which swells rapidly the moment the eggs become immersed in water.

The oviducts are much longer and more convoluted during the breeding season than between seasons. Near their posterior end just before they join the cloaca they enlarge into thin-walled sacs, the **uteri.** Here the eggs are stored until amplexus occurs, at which time they are laid. Male frogs of some species possess rudimentary oviducts, just as male mammals possess rudimentary mammary glands. There is a time in the

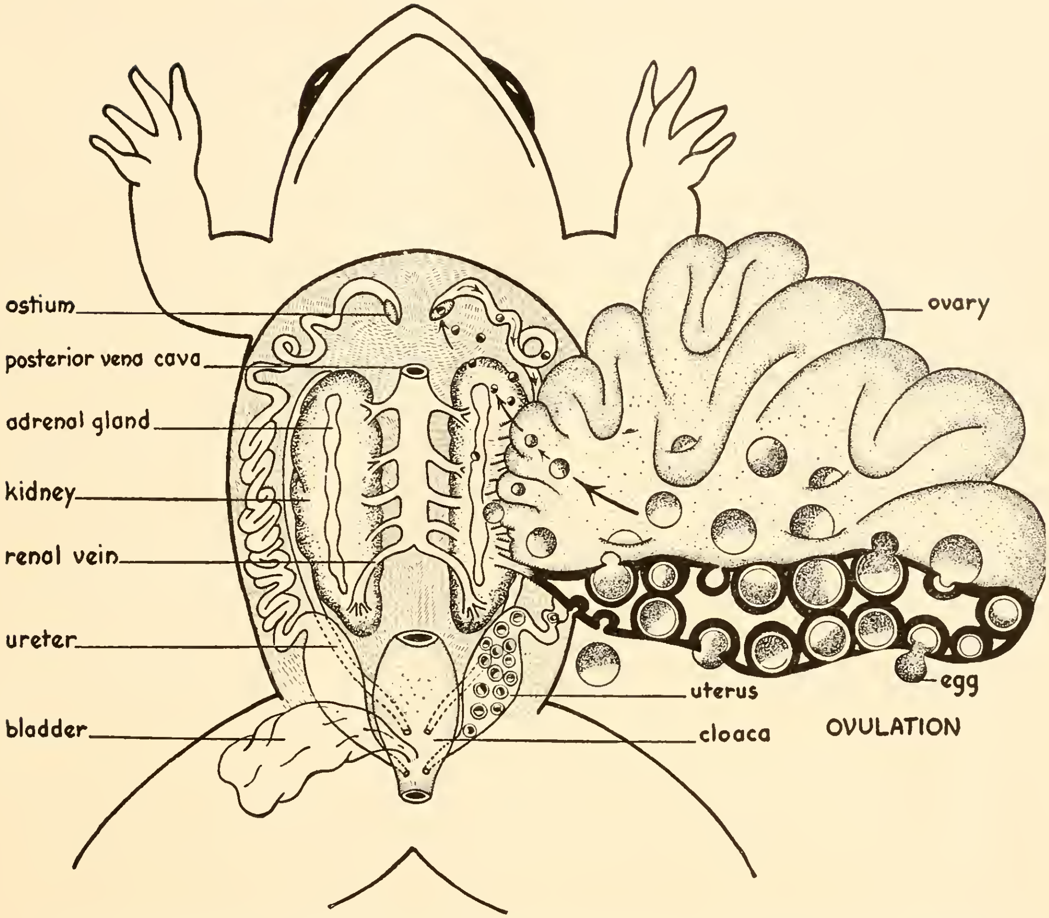


Fig. 13-39. Female frog urinogenital system, showing the kidney and ovary enlarged and in cross-section.

early development of the animal when the sex is not determined, so "to be certain," both organs are produced; later only one becomes functional.

LAND CONQUERORS: THE REPTILES

The amphibians were forced to spend their embryonic life in the water and were able to leave water only as adults. The reptiles moved one step farther in the long trek to complete terrestrial existence. They spend no part of their life in the water unless they choose to do so. In order to accomplish this feat, radical changes were required in the physical provisions for their early development. Means were provided whereby the early embryos could exist in a fluid environment, and this medium was supplied with sufficient nourishment to carry the embryo through the stages equivalent to the tadpole stage among amphibians. Enough food was stored in the egg so that the oncoming young one might be well along in its development when it emerged on its own, and, as a result, be able to care for itself, eat the adult diet, and move about under its own power on land. For this reason, reptilian eggs are large, with great quantities of stored food in the form of yolk and albumin (Fig. 13-40). The young reptile starts its life on the top of a large yolk mass in the egg, and eventually it incorporates the entire yolk mass into its intestine and uses the stored food for growth.

During this time it is floating in a fluid environment, reminiscent of its amphibian ancestors. A large, fluid-filled sac, called the

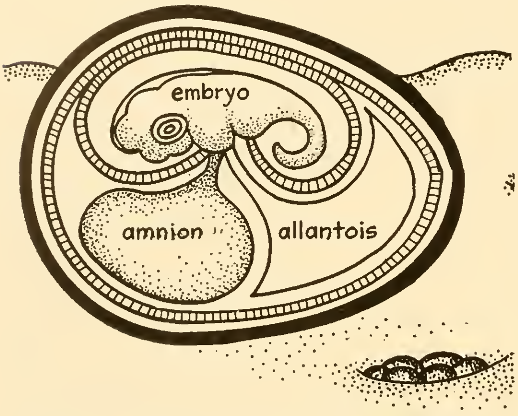


Fig. 13-40. In order for vertebrates to completely divorce themselves from water they needed some means of caring for their young during their early development. This was accomplished with the evolution of the land egg.

amnion, develops around the embryo which not only provides a fluid environment, but also protects the developing embryo from injury and desiccation. Shortly after the formation of the amnion, the **allantois** develops from the posterior end of the embryo. This enveloping membrane receives discarded material, including carbon dioxide, from the embryo. It lies very close to the porous, rigid **outer shell** so that a gaseous exchange can readily take place. Therefore, in addition to being an organ of excretion, the allantois acts as a temporary respiratory organ during embryonic life. The young reptile need not be immersed in water at any time during its life, and thus the first true land animal has been evolved. This animal can seek out any environment it wishes without regard to water beyond its metabolic needs. This was probably the greatest step forward in conquering the land.

These changes in the developing embryo were undoubtedly the greatest ones that took place in the reptile, although other changes also occurred that made it better suited for a terrestrial existence. Since an aquatic environment was no longer essential, internal fertilization became a necessity to protect the delicate reproductive cells. Therefore, efficient copulatory organs developed from the floor of the cloaca of the male, insuring a direct transfer of the sperm into the genital tract of the female. In addition, reptilian legs became longer and were usually more ventrally located, making it possible for them to support the body completely off the ground, a feat which the amphibian had not accomplished (Fig. 13-13). The heart also began to form a complete partition in the ventricle, producing the beginnings of a four-chambered heart and thereby separating the pulmonary and systemic blood to make a much more effective circulatory system. The greater endurance and strength of reptiles reflects the effectiveness of this change.

Early reptiles

This group of animals has had a long and luxuriant history. Living forms, such as the turtles, crocodiles, lizards, and snakes, are relatively insignificant animals on the earth today. However, there was a time during the Mesozoic Era, the so-called Age of Reptiles, when this group dominated all animal life on the earth and reached such peaks that perhaps no other animal, not even mammals, will ever attain. Reptiles may be said to be the most successful animals that have thus far existed, man not excepted.

Sometime in the distant past there must have been forms stemming from the amphibians that gradually took on reptilian characteristics. Such animals have been found in fossil remains and are called the Stem Reptiles. Among these is *Seymouria*, which was probably the first animal that began to show what is now known as reptilian characteristics. *Seymouria* was found near the small Texas town of Seymour. This

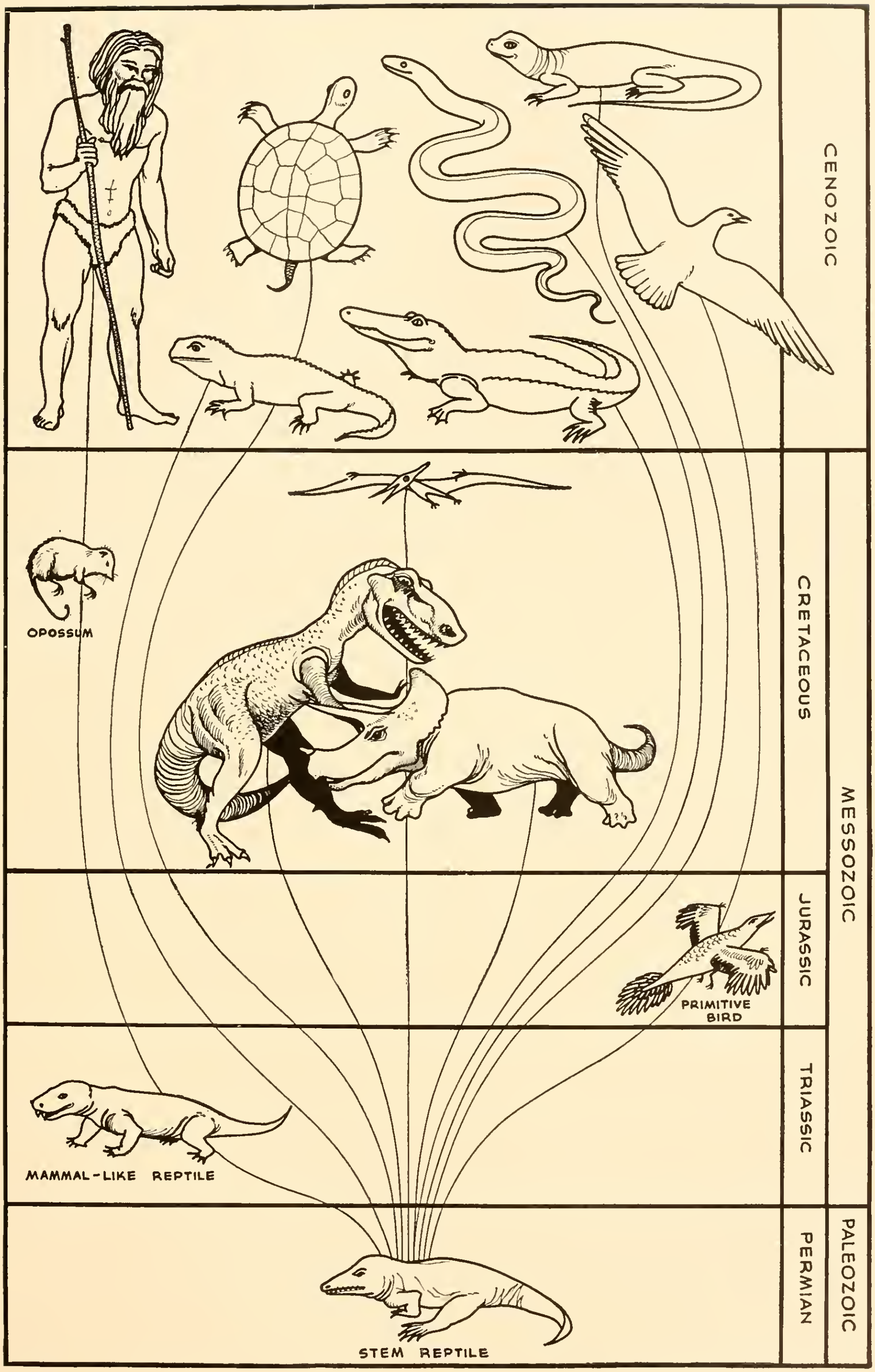


Fig. 13-41. Primitive reptiles gave rise to all higher groups of animals. The reptiles as a group have been the most successful of all vertebrates, as indicated by their great numbers and variety of form in Mesozoic time and by the fact that they gave rise to the birds and mammals.

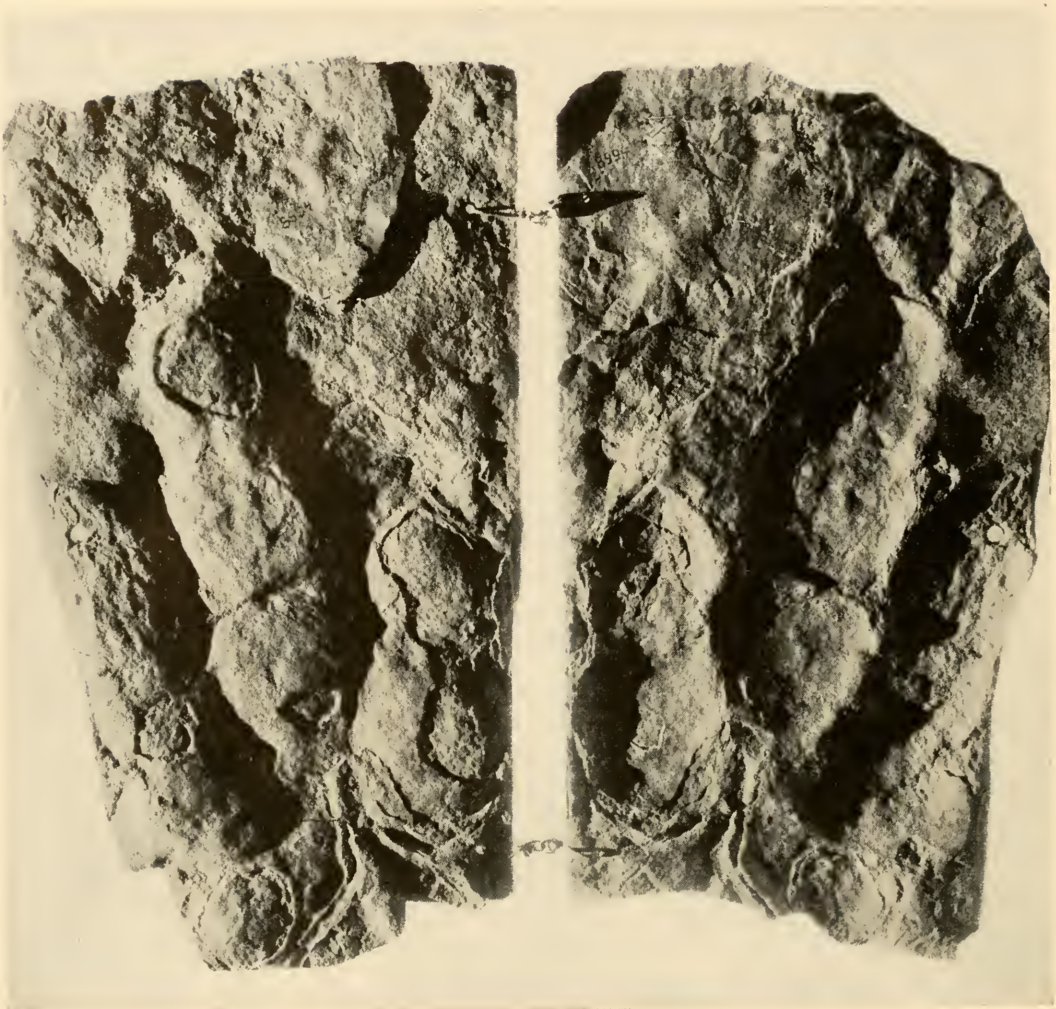


Fig. 13-42. Dinosaurs often left footprints in soft mud that later became buried with fine sand, leaving almost perfect impressions of the feet of these ancient animals. The sedimentary rock in which this one was found separated, so that both the mold (right) and the cast can be seen.

discovery is a missing link, bearing resemblances to both amphibians and reptiles. It, or forms like it, probably gave rise to the great variety of reptiles known to have lived during the Mesozoic Era and indeed, to birds and mammals as well (Fig. 13-41). The Age of Reptiles lasted over 100 million years. By comparison it is estimated that man is no older than a million years at most.

The dinosaurs

The saga of the dinosaurs presents one of the most amazing stories ever told, a story which has unfolded through a careful study of fossil remains over a long period of time. Dinosaurs had their meager beginnings in the Triassic Period when they were small unimportant animals. Evolving in both size and numbers during the Jurassic and Cretaceous periods they reached the pinnacle of walking land vertebrates near the close of the Mesozoic Era, finally disappearing from the earth never to appear again. They ranged in size from the barnyard fowl to the largest of all land animals.

Many of the dinosaurs developed the bipedal method of locomotion, that is, they rose on their hind legs when in haste and propelled themselves entirely by these two appendages. This idea proved successful in some of the largest flesh-eaters, which had powerful hind legs but only short anterior appendages (Fig. 13-41). Bipedal locomotion in four-footed animals is, then, very ancient.

Footprints left in various parts of the world by these ancient animals have given paleontologists some interesting evidence as to the nature of the reptiles that made them (Fig. 13-42). For example, in the old mud flats of the Connecticut Valley there are those that resemble bird footprints of today, and hence were first thought to be those of giant birds. One interesting small dinosaur was the "ostrich dinosaur," which was toothless and possessed a hornlike bill resembling that of a bird. It had long hind legs, indicating its great ability to run. Scientists have debated its possible habits; one suggestion made is that the animal probably fed upon the eggs of other dinosaurs. With such a diet, it would be understandable why the animal had no teeth. Long legs would be its means of escape once it was detected by the owner of the eggs. One report, according to Romer, states that a crushed skull of the ostrich dinosaur was found near the nesting grounds of the horned dinosaurs; if the complete story were known, it might be a case where the owners caught the thief practicing his trade.

The flesh-eaters grew to enormous size and the largest one unearthed, *Tyrannosaurus* (tyrant reptile), reached a height of 19 feet (Fig. 13-41). It must have been an awesome creature in those prehistoric times, perhaps feared by all living creatures. Its skull was over 4 feet in length and the jaws were armed with a formidable set of teeth, which must have functioned well in rending and tearing other animals to bits. It possessed massive hind legs and small front ones. It is thought that its chief source of food was the giant amphibian forms which existed at the same time.

The great amphibious dinosaurs were vegetarians and grew to great lengths and heights but did not become as massive as the flesh-eaters. *Brontosaurus* and *Diplodocus* grew to the largest size and are the ones most commonly displayed in museums. They reached a length of 85 feet and a weight of 40 tons or more. They walked on all four feet and could look over a three-story building. Their powerful legs were placed in such a position as to carry their body evenly balanced. The neck and tail were very long, in fact, they seem to balance one another on opposite ends of the trunk. The head was much too small for the size of the animal, and it is difficult to see how it could house a brain sufficiently large to govern such a massive hulk. Furthermore, the jaws were so small and weak that the animal must have been forced to eat continuously to maintain itself. The dorsally-placed nostrils have led scientists to conclude that the animal was amphibious and probably remained submerged most of the time with only the nostrils protruding above the surface of the water for breathing air. The tremendous burden would thus be partially buoyed up, relieving the legs from bearing the entire weight.

In the hip region, the spinal column supported an enlargement several times the size of the brain. Apparently impulses received by the brain from the sense organs were sent down to the large posterior ganglion which operated the posterior legs and perhaps the rear portion of the body. The strange anatomy of this great beast inspired the late Bert L. Taylor of the *Chicago Tribune* to write the following poem:

Behold the mighty dinosaur,
Famous in prehistoric lore,
Not only for his power 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 was he, so wise and solemn,
Each thought filled just a 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 judgment to revoke.
Thus he could think without congestion
Upon both sides of every question.
Oh, gaze upon this model beast,
Defunct ten million years at least.

Horned dinosaurs such as *Triceratops* were the last of the large dinosaurs (Fig. 13-41). The body was relatively bare but the head was heavily armed with bony organs of defense. Two great horns protruded anteriorly over the eyes and another over the ridge of the nose. An enormous flare of bone extended out from the back of the neck which probably functioned admirably in preventing an injurious blow to this vulnerable region.

It has been a question why these great animals became extinct by the end of the Cretaceous Period. There are many answers, but possibly a combination of many factors was responsible for their extinction. Since the flesh-eaters depended on the plant feeders for food, a gradual extinction of the latter meant annihilation of the former as well. Geological changes going on at that time indicate that the land was gradually rising, culminating in the formation of the Rocky Mountains in this country. This meant not only less water and consequently fewer swamps where these animals lived, but also cooler climates and perhaps much less vegetation. With the declining food supply the great herbivores starved to death, taking the carnivores with them. Thus ended the reign of the greatest group of animals that have ever lived on the earth thus far. The future may brings others but it seems highly unlikely that they will reach such size as these mighty beasts.

Modern reptiles

From the time of *Seymouria* certain reptiles have continued down to the present time. In some regions they are rather numerous, but in comparison to their glorious past they are mere remnants. At least sixteen orders of reptiles have lived on the earth; today only four remain (Fig. 13-41). Of these, one is nearly extinct but it does include a species, *Sphenodon,* more commonly known as Tuatara (Fig. 13-43), which is of considerable interest because it carries in its body many anatomical features definitely identifying it with the earliest of reptiles. Tuatara has appropriately been called a "living fossil." Many of its characteristics show a definite relationship to the stem reptiles as well as to modern reptiles. It is always interesting to speculate why such isolated members of a once flourishing group were able to survive down to the present day when all its relatives are long since extinct. In the case of Tuatara, its location is probably responsible; the reptile lives in New Zealand where it has had few, if any, natural enemies. Tuatara living in other parts of the world were set upon and apparently destroyed by the aggressive, more agile mammals. Thus it can be said that isolation has saved one species of animal. Since its environment has remained unchanged, Tuatara, itself, has changed but little through the past 200 million years.

The surviving members of the great ruling reptiles, the dinosaurs, are the crocodiles, the caimans of the Amazon, the gavials of the Ganges and the alligators of today (Fig. 13-44). Although feeble in size and small in numbers compared to the dinosaurs, some do reach a length of 30 feet. They inhabit the large rivers of the

Fig. 13-43. Tuatara (*Sphenodon*) from New Zealand. A "living fossil."

world and are often hunted for their valuable hides. These animals show some anatomical features which place them among the highest reptiles. For example, they have a nearly completely divided ventricle in the heart, resulting in a four-chambered heart like that of birds and mammals. They also possess the mammalian characteristic of a nearly complete **diaphragm,** which is a muscular separation between the chest and abdominal cavities. Another interesting characteristic of these large reptiles is that their scales do not overlap, but instead consist of plates placed upon dermal bones. The resulting very heavy protective armor is resistant to almost any attack of modern animals.

The turtles

These are the most odd looking of all reptiles (Fig. 13-45). If they were extinct man would regard them with wonder, but

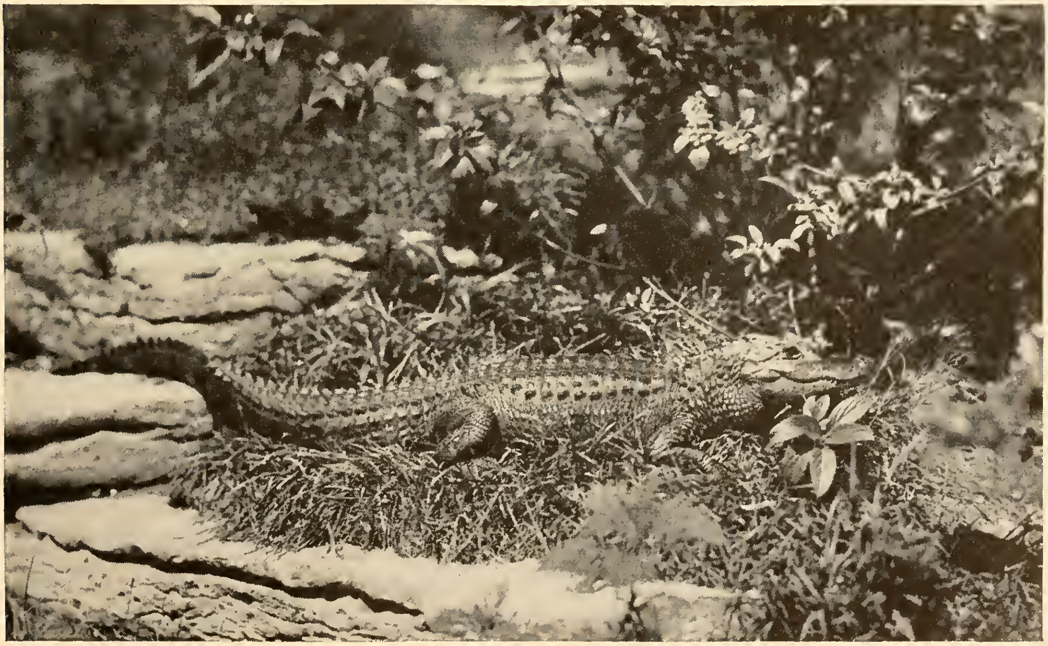


Fig. 13-44. American alligator (*Alligator mississippiensis*). These grow to 16 feet in length.

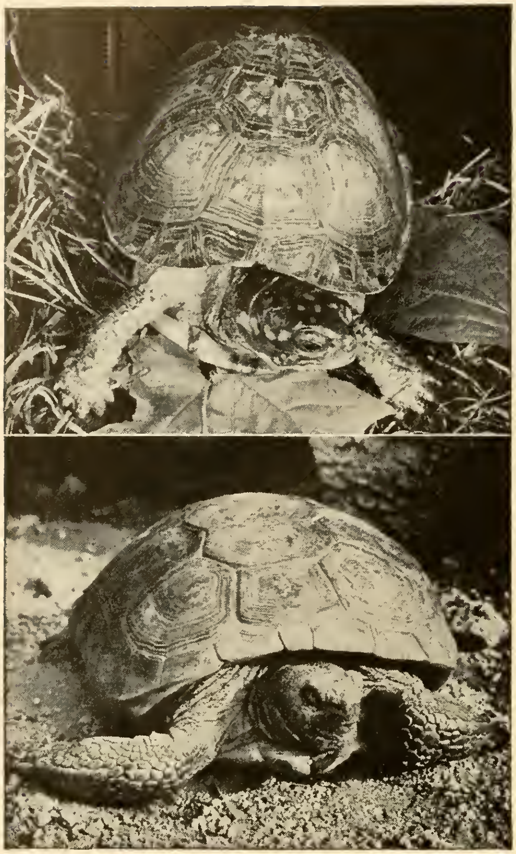


Fig. 13-45. The turtle is one of the strange animals of the world, yet it is so commonplace that it goes unnoticed. It is completely protected by the shell which has the disadvantage of limiting the movements of the appendages.

The above picture is that of the box turtle (*Terrapene ornata*) and the lower picture is that of the huge green turtle (*Chelonia mydas*). While the former gets around well on land, the latter is particularly adapted for life in the water. Note how its anterior appendages are adapted for swimming.

because they are so commonplace we think little about them. Turtles have existed a long time on the earth, since the earliest ones were contemporaries of the most primitive dinosaurs. The great reptiles came, and passed on again to extinction, but the turtles have persisted. Even with the advent of mammals the conservative turtle, concealed in its protective armor, has maintained itself and, who knows, may survive long after the mammals, including man, have passed out of existence.

The turtle shell is a combination of structures identifiable in other reptiles. It is composed of horny scutes similar to the ordinary reptilian scales, with bony plates lying underneath which are fused firmly dorsally to the internal skeleton, including the clavicles, ribs and vertebral processes. A similar plate, the plastron, completes the shell on the ventral side. The combined "box" affords a first-rate exoskeleton into which the animal can withdraw almost completely to shield itself from the outside world. Such a rigid outcovering has limited its movements to a large extent. By a paddle-like motion of the four appendages it slides along on its ventral side. It moves very slowly and awkwardly so that when it is in danger it merely stops and "pulls into its shell" and outwaits its would-be predator. Body muscles have pretty much degenerated but the leg muscles are well developed. Breathing is accomplished by a pumping action of the neck and leg muscles.

Turtles live both on land (tortoises) and in the water. Like many other groups of land animals they have returned to the water and have so modified their bodies that they are well adapted to an aquatic existence. The great sea turtles, such as the hawksbill and the green (Fig. 13-45), have their appendages modified into flippers. They are never seen on land except during the egg-laying season. Others, such as the common snapping and painted turtles, are usually found in water but are also frequently seen on land near bodies of water. Still others, like the high-shelled tortoises, live in certain parts of the world where they have no enemies and grow to enormous sizes, often weighing 600 pounds. These desert forms feed on vegetation alone and rarely if ever take any water. Members of this group have penetrated all habitats from the sea to the desert and have prospered through millions of years.

The snakes and lizards

Perhaps the most despised of all animals alive today are the snakes and lizards, not because they are particularly harmful to

Fig. 13-46. One of the largest lizards alive today, *Iguana iguana*, reaches a length of 6 feet. It inhabits tropical America.

man or because he inherits a fear of them, but because he is taught to be afraid of them, particularly snakes. The group as a whole does little harm to man or his domestic animals, and what harm is done is offset by its creditable deeds.

Both lizards and snakes are covered with scales which they shed periodically.

The lizards are four-legged animals and exemplify the typical modern reptile, that is, they show the least amount of modification in body form of any of the reptiles. A good example of the group is the Iguana (Fig. 13-46). The group contains rather bizarre types, among them the horned toad (Fig. 13-47) and the tree-dwelling chameleon. The latter possesses a prehensile tail and feet that have three fused toes opposing the other two, an ideal adaptation for arboreal life. It also has the ability to change its color rapidly, a characteristic not confined to reptiles alone by any means. However, this lizard does show a greater extreme in color change than most other animals. It also has a protrusible tongue almost equal to its body in length, a convenient tool for catching insects. The only poisonous lizard is the Gila monster (Fig. 13-47), a highly colored, sluggish, plump creature found in various desert regions of the world. It uses its venom in killing small animals which make up its diet. Its bite is rarely, if ever, fatal to man. The venom flows into the wound from the base of the teeth as a result of chewing action; this is a far less efficient mechanism than that of the snakes.

The lowly snake is forever pursued and killed by mankind the world around. It is feared and hunted because some members

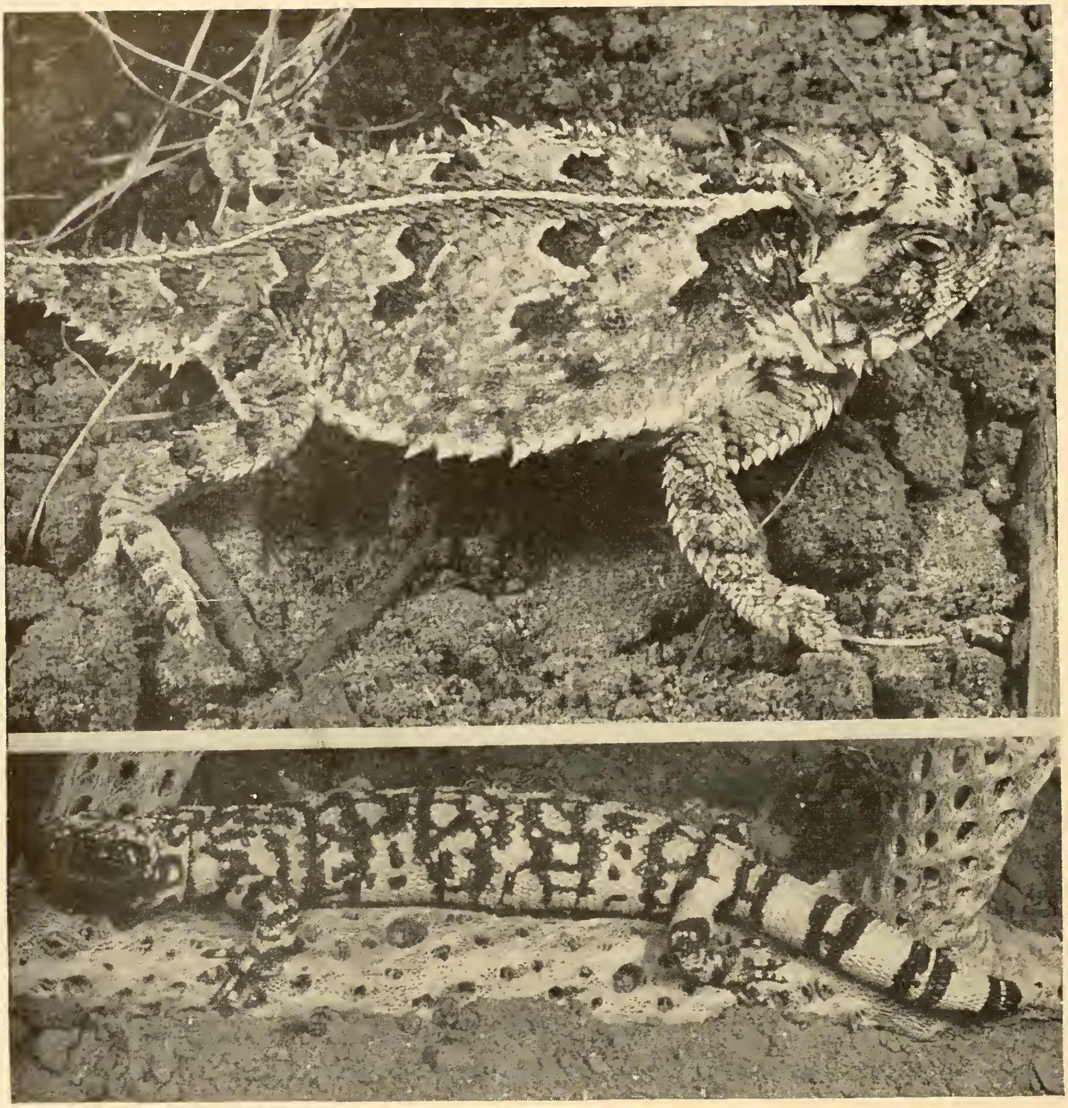


Fig. 13-47. These two reptiles inhabit the Southwestern United States. The horned toad (*Phrynosoma*) is not a toad at all (top). The gila monster (*Heloderma suspectum*) is the only poisonous lizard in the United States (bottom).

such as the cobra are deadly. There is little reason for man to wreak his vengeance on every helpless snake that crosses his path and yet he does so with unrelenting fury. Once he has made the kill, he often proudly displays the mutilated body of a creature that could never do him any harm but, if allowed to live, could do him considerable good by its constant pursuit of insects and small rodents which are its diet. In the United States, all snakes except four are helpful rather than harmful.

With the exception of pythons and boas, snakes are without limbs. They move in an undulating fashion much the same as fish swim. The posterior edge of the ventral scales is loose, thus allowing these scales to make a firm contact with the ground, which, in turn, permits the animal to move forward but not backward. Their eyes are large and without lids. Their sound-recording organs are superior to those of amphibians. The snake possesses a long forked tongue which passes in and out through a notch in the upper lip, a conspicuous habit when it is investigating new territory. The tongue has sensory functions in tracking down prey (Fig. 13-48).

The snake's mouth is equipped with sharp teeth that curve inward and are well adapted for holding its victim (Fig. 13-49); any struggling movement of the prey tends to force the creature further down the throat of the snake. Since all of the snake's diet consists of whole animals, another convenient adaptation associated with food taking is the enormous potential size of the mouth, which can be stretched to accommodate an animal several times its own diameter (Fig. 13-50). A python has been known to swallow a full-grown hog. The reason for this great distention lies in the

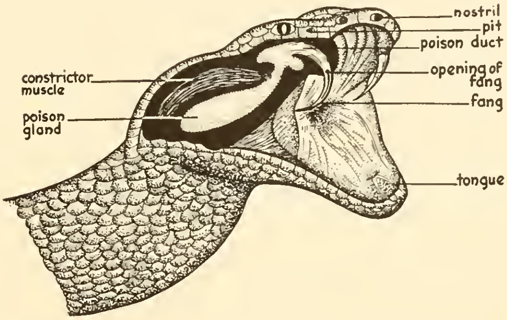


Fig. 13-48. Head of rattlesnake with the right cheek dissected away in order to show the poison sac and other parts.

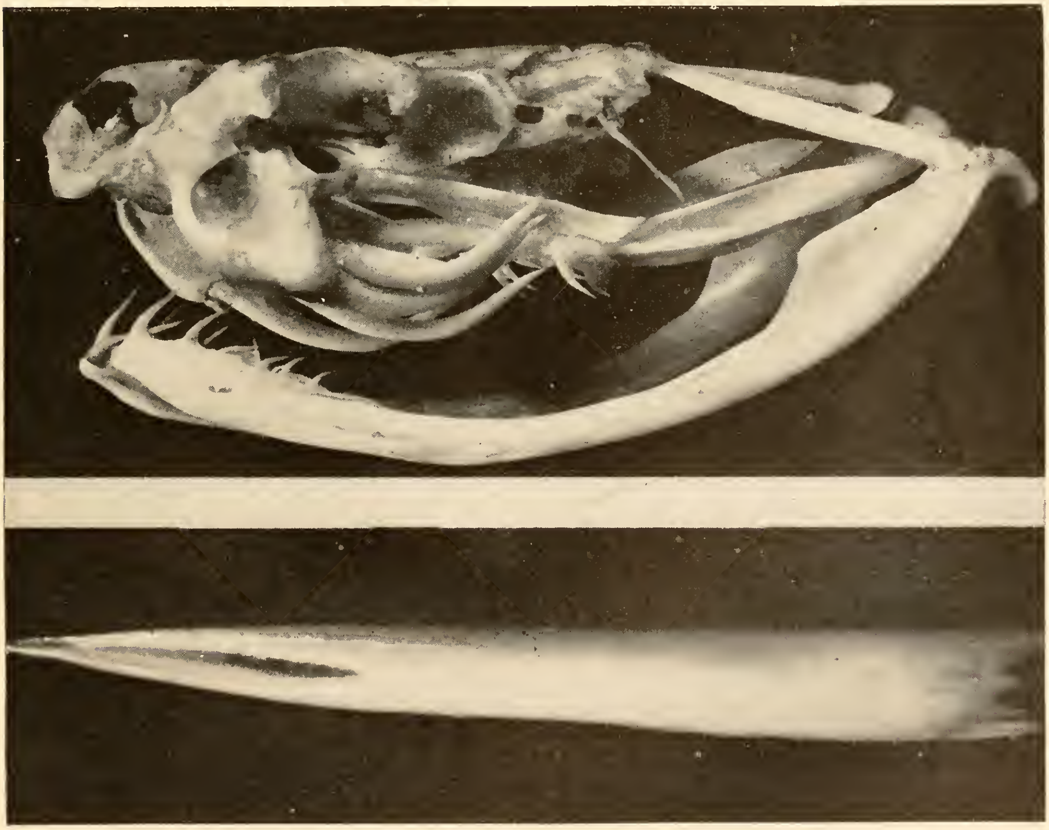


Fig. 13-49. The skull of a rattlesnake. Note how loosely the jaw bones are attached to the skull. This, together with the lack of fusion of the jaw bones in front, makes it possible for the snake to swallow an animal several times its own diameter. One of the fangs has been enlarged in the lower picture to show its hollow construction. It resembles an inoculating needle.

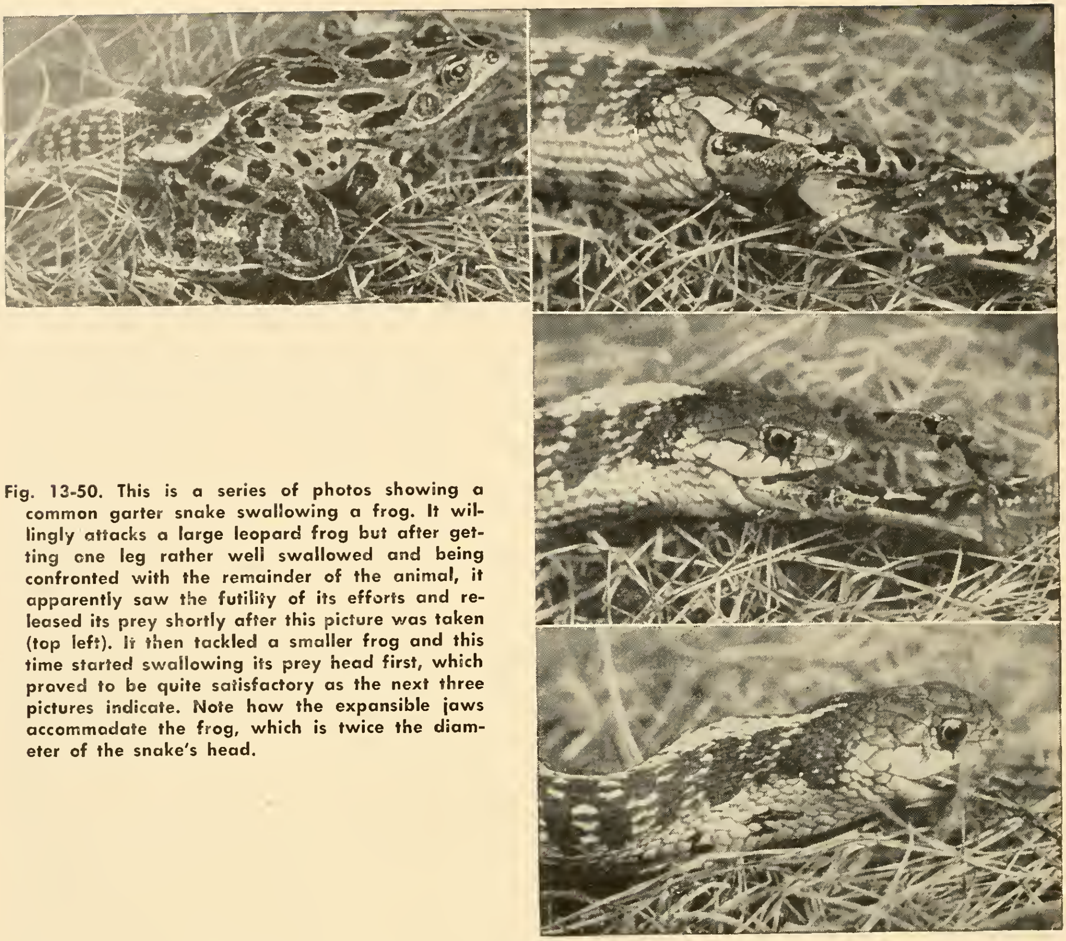


Fig. 13-50. This is a series of photos showing a common garter snake swallowing a frog. It willingly attacks a large leopard frog but after getting one leg rather well swallowed and being confronted with the remainder of the animal, it apparently saw the futility of its efforts and released its prey shortly after this picture was taken (top left). It then tackled a smaller frog and this time started swallowing its prey head first, which proved to be quite satisfactory as the next three pictures indicate. Note how the expansible jaws accommodate the frog, which is twice the diameter of the snake's head.

fact that the lower jaw articulates with the skull very loosely by means of two slender bones; furthermore, the lower jaw can spread at the anterior midpoint, allowing a lateral expansion (Fig. 13-49). With such a loose jaw arrangement, it is possible for the snake to spread its mouth to an extraordinary degree (Fig. 13-50).

The snakes have received their bad reputation from the poisonous members of the group. Just how these creatures evolved this deadly offensive and defensive mechanism is hard to say. Many different kinds of tooth formations have been produced for inoculating the poison into the wound made by the sharp teeth. In some forms, such as the rattlesnake, the fangs possess a hollow tube through which the venom is injected, as with a hypodermic needle (Fig. 13-49). Others, such as the cobra, have deep-grooved fangs which allow the poison to enter at the base of the tooth and exit near the tip so that, upon striking, it would be deep within the wound. The poison glands are located above the angle of the jaw and empty their venom into a flap of skin at the base of the fangs (Fig. 13-48). Normally the fangs lie against the roof of the mouth pointing down the throat, but when the head is thrown back they are forced forward until they protrude at right angles to the roof of the mouth. The head is then thrown forward with a sudden lunge, about two-thirds the length of the animal, striking the prey and penetrating the skin. The compression of the victim's skin against the loose skin at the base of the fangs causes the poison to be inoculated into the wounds. Once the venom has entered the blood stream, its effect is very rapid, causing a small rodent to become paralyzed in a matter of a few seconds. The venom acts by destroying the red blood cells. Antivenoms have been prepared for all of the common poisonous snakes and have proved valuable in alleviating the effects of their bite. A normal person rarely dies from the bite of a poisonous snake, although he may be very sick. Of the four types of poisonous snakes in the United States, the most common are the rattlesnakes; the others are the water moccasin (cotton mouth), the copperhead (Fig. 13-51) and the beautifully banded coral snake. The last, although poisonous, is quite different from the other three in that it has no fangs but resembles the Gila monster in its method of imparting venom.

Fig. 13-51. The copperhead (*Agkistrodon mokasen*) is one of our venomous snakes. Note the vertically slit pupil and the "pit" just in front of the eye. These two features characterize most poisonous snakes.

AIR CONQUERORS: THE BIRDS

It is a far cry from the lowly turtle and slithering snake to the most decorated of all animals, the birds, yet with few exceptions the birds are little different from the reptiles (Fig. 13-52). An early biologist has called them "glorified reptiles," which describes them very well. They have mastered the air, as is obvious to the hunter who matches his marksman's skill against the abilities of the wary mallard to avoid being hit. In conquering the air several body modifications have been necessary. The drastic need for a lighter body framework was met by lighter, hollow bones, and a lessening of the weight of the outer covering (Fig. 13-53).

The scales of the reptiles have probably given rise to the feathers of birds, and actually there is little difference between them except in weight and texture. Their general arrangement is very similar. The bird still carries scales on its legs and sometimes around the base of the beak. Because of their loose arrangement, feathers act as excellent insulating material, an extremely important need for birds who often fly in regions of very low temperatures. The wings are the modified anterior legs of the reptiles in which the three fingers have fused at the tip and the space between has been spanned by a sheet of skin covered with feathers. The wing spread is due principally to the large quill feathers at the outer edges of the wings. The breast bone is greatly over-developed. It is known as a **keel** and functions as an anchor for the powerful breast muscles which are used to give the power stroke in flight.

Other structural modifications have been essential for the flying animal. In order to keep active during all times of the year in temperate and arctic regions, it was necessary to maintain the body at a constant temperature which, in birds, is slightly higher than in man. This, of course, meant greater expenditure of energy, thus requiring a better circulatory system. Many of the higher reptiles possess four-chambered hearts (alligators and crocodiles), whereas among birds it is the universal rule. The hearts of birds are large and very well developed, an essential factor in maintaining a rapid circulation when so much energy is consumed in flight.

Fig. 13-52. All birds resemble one another anatomically, differing only in minor details. Their body parts are adapted to fulfill certain functions that are associated with their particular mode of life. For example, the beak in these four birds is modified for food-getting. Both the eagle (top right) and the owl (top left) are predators, usually feeding on small mammals. The beak is well suited for tearing prey. The woodpecker (bottom left) has a sturdy beak used for drilling holes in tree trunks in search of insect larvae, which it feeds upon. The young duck (bottom right) has a beak adapted for straining the water and retaining the small plant and animal life that forms its food.

In order to secure its food and avoid its enemies the bird is compelled to rely on its keen eyesight. Its large eyes are protected by bony capsules which apparently prevent the pressure of passing air from forcing the eyes back into the head. The brain also is considerably larger than in reptiles. However, the difference in size is owing primarily to those parts having to do with sharp vision, as well as balance and muscular coördination, functions essential to flight.

The birds in general exhibit some rather fascinating habits which are not always well understood, as, for example, the return of a pair of purple martins each year to a particular bird house on precisely the same day, the building of a specific type of nest by the young bird without ever having done it before, or, and still more perplexing, the migrations of many species covering vast distances, often over great bodies of water. Many observations have been made, demonstrating that birds do these feats with remarkable regularity, and all efforts up to the present to discover the sense involved have been unsuccessful.

It has been thought that birds return to their nesting grounds, and in many species to the same nesting site, year after year at particular times because they are able to measure the exact angle of the sun. This is logical when one recollects what the bees, using similar devices, are able to do. Crows taken several hundred miles from their nesting grounds and released will return (almost to a bird) within the period of time predicted, which has been based on the "cruising" speed of the bird. One might suspect that the bird would recognize landmarks along the route and use them to guide it back again. The birds have been kept in covered cages or actually placed on turntables and swung continuously throughout the trip, but even then they will return in the expected time. Some have guessed it to be simply a matter of chance—the birds merely fly at random and finally stumble upon their way home. That this is not true

Fig. 13-53. Skeleton of the domestic fowl. The skeletal design is adapted to accommodate flight and bipedal locomotion. The large keel provides a secure point of attachment for the powerful wing muscles.

has been shown by many experiments. For instance, if some birds are taken twice as far from home as others and released simultaneously, the birds farthest away should require four times as long to get back by the wandering technique. This is not the case, however, because they arrive in about one half the time that it would take them if they flew on in a random manner. This homing instinct, present to some extent in other animals, is remarkably developed among the birds, but its explanation is still a mystery.

Why or how birds are able to follow such varying paths in their migrations is as mysterious as their homing instincts. Everyone is conscious of the fall migration of great flocks of birds all heading south. Of course, a possible explanation is immediately obvious: once the breeding season is over and the young are able to care for themselves, the approaching winter with its accompanying food shortages and severe cold might be reason enough for heading southward to regions where food is abundant and the climate more comfortable. Most humans would certainly enjoy such an arrangement. All efforts to show that the migration south is started by a sudden drop in temperature have been to no avail. The duck hunter will attest to the fact that his quarry will often leave the swamps during a spell of warm weather, whereas at other times, even in the face of an unseasonal snow flurry, they will not budge from the swamps in which they were reared.

Experiments have shown rather definitely that migrations start at remarkably regular periods which can be determined only by the amount of light received by the birds. It has been found, for example, that birds will start to lay eggs even in the winter time if the length of daylight is increased artificially. The farmer has profited from this information by turning on lights in the chicken houses, thus stimulating the hens to lay more eggs. Light shining on the retina of the chicken apparently stimulates the pituitary gland (a ductless gland which secretes a number of hormones), which then activates the ovary to produce eggs out of season. It hardly seems fair, does it?

The paths taken by some birds in their migrations are truly amazing and that of the American golden plover is especially so. It nests in June on the northwestern shores of Canada above the Arctic Circle; shortly after the young birds leave the nest, the adults desert them and start across Canada, flying eastward to Labrador where they arrive in early autumn. From there they take a direct course south, flying out over the Atlantic Ocean until they reach Venezuela; they then fly more leisurely on to the region of Paraguay where they overwinter. Another remarkable point is that the young birds follow a month later over approximately the same path, a total distance of over 6,000 miles, with no experienced birds to guide them. The answer to this mystery will be exciting, if and when it is found.

The first birds

It would be amiss not to mention some of the ancient birds that have been unearthed with the other animal fossils. As has already been mentioned, the birds apparently stem from reptilian ancestors (Fig. 13-41), a fact that should reveal fruitful intermediate types, animals that are neither reptile nor bird but a combination of both. *Archaeopteryx,* an ancient bird about the size of a crow, was found in limestone about 75 years ago in Germany. Strangely enough, in all of the subsequent diggings no other remains have been discovered. These remains, however, were sufficiently intact to describe the bird rather well, even the feathers being preserved. Aside from them, however, the other parts of the animal appear very similar to a small dinosaur. The wings were weak and the finger tips bore claws. The beak was lined with teeth and the skeleton was made up of heavy bones, in contrast to the light, hollow bones of modern birds. The fact that the bones were heavy and that the keel was poorly developed indicates the bird was a poor flyer. In fact, if it could have been observed at that time it undoubtedly would have been seen to glide from branch to branch of trees much the same as the flying squirrel does today.

Some of the marine rocks of Kansas reveal later birds. One, the "fishbird" (*Ichthyornis*), shows considerable advances over *Archaeopteryx* in that it possessed a large keel bone, indicating excellent powers of flight. It did retain a toothed beak, however. Aside from this feature it probably was not greatly different from the modern tern.

Some giant wingless birds

There are several species of wingless birds on earth today as there apparently were over a long period of geologic time also (Fig. 13-54). These birds are all much alike; they are usually very large, some

Fig. 13-54. The ostrich is one of the largest flightless birds. Its powerful legs carry it swiftly over the ground, and they can be used as organs of defense.

reaching as much as 12 feet in height, with powerful legs, small heads and rudimentary wings which are useless for flight. They depend on their fleetness for security. An interesting fact is that all modern flightless birds live in regions where there are no carnivores, that is, no members of the cat or wolf tribes. Examples are the ostrich of Africa, the cassowary and emu of Australia, the rhea of South America, and the kiwi of New Zealand. Romer has suggested that these birds once were able to fly but because there were no terrestrial predators that might harm them they simply ceased flying and remained on the ground all of the time, thus conserving their energies for the important job of obtaining food. One reason that birds probably took to the air in the first place was to be better able to flee from their enemies. If the enemies are removed, then the need for flight is no longer present; hence, why fly?

THE CLIMAX ANIMALS: THE MAMMALS

The dominant and most complex animals on the earth today are the mammals. What was their origin and what characteristics have they been able to accumulate that have caused them to outstrip all others, at least temporarily? They are certainly as varied in size, shape, and habitats as any animals that have ever lived (Fig. 13-55). They seem to have invaded every possible portion of the earth, water, and air, and are reasonably successful in all environments. Just how long they can retain the zenith where they now find themselves is a problem for speculation. If they follow the pattern of former dominant types they will eventually decline, to be succeeded by some other form which is today, perhaps, an insignificant animal.

According to the best estimates, the

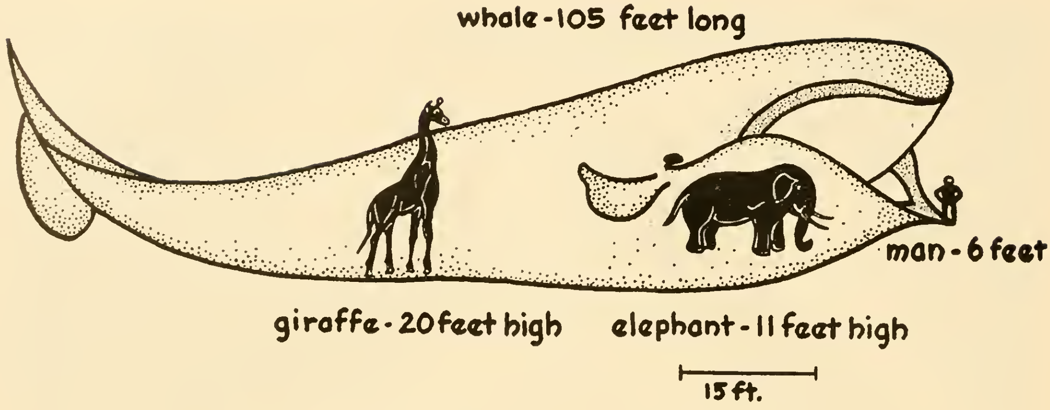


Fig. 13-55. Relative sizes of a few mammals.

origin of mammals took place approximately 150 million years ago (Fig. 13-41). These early forms were neither reptiles nor mammals as we know them, but probably intermediate in character, with resemblances to both. It is generally agreed that mammals had their beginnings in some reptilian type and the first ones were probably more lizard-like than mammal-like (Fig. 13-41). One of the earliest animals that showed mammalian features was *Cynognathus* ("dog-jawed"), in which several skeletal improvements over the typical reptile are observed. The legs had assumed a more ventral position so that they not only lifted the body farther off the ground but in addition were capable of forward and backward motion, resulting in more forward speed. Thus, instead of crawling as its reptilian ancestors did, it was able to carry itself a considerable distance above the ground and undoubtedly travel much faster. This characteristic has culminated in such modern animals as the horse and giraffe.

The skull also had certain modifications, such as the more posterior position of the entrance of the internal nostrils into the mouth, for example. Being warm-blooded now, it was necessary for the animal to breathe continuously and rapidly so that sufficient oxygen could be supplied to the tissues to maintain the high temperature. In order that breathing might not be interrupted during feeding, the internal nostrils opened into the mouth farther back and were walled off by a plate, the **palate.** These characters are present in this primitive mammal. Furthermore, the teeth show the beginnings of a typical mammalian pattern, consisting of the front nippers (incisors) and the large fang-like canines, followed by the shearing molars. Reptiles have no such dental pattern.

These primitive mammals were present on the earth long before the coming of the great dinosaurs but they were small and inconspicuous, and probably kept in hiding throughout the reign of these great beasts. During this long period of perhaps 15 million years they were a source of food and, consequently, were forced to live "by their wits," which gave them an opportunity to try out many devious plans for a better body as an aid to survival. They remained small and insignificant until the dinosaurs met their end. The world was then left free for any animal that was ready to take over. The mammals apparently "saw their chance and took it." Even then, while the mammalian characteristics in general persisted, many "ideas" were evolved that produced animals not able to survive very long—the mammoth, saber-tooth tiger and the giant sloth, for example. The more intelligent and versatile did survive, however, and gave rise to the present mammalian population of the world.

The presence of hair in place of scales was an accessory structure necessary in a warm-blooded animal. Sweat glands aided in regulating body temperature, which is nearly constant as distinguished from other animals, except birds, which have temperatures varying with the external environment. In addition, the heart was a double one: one for circulation through the body, the other for circulation through the lungs.

One of the more important characteristics that has contributed to the success of mammals is their method of caring for their genital products and subsequent offspring. All reptiles lay large, yolk-packed eggs, whereas mammals typically have very small eggs which are fertilized internally in the female and go through a great part of their early life inside the body of the mother. Although internal hatching of eggs is not uncommon in lower forms (reptiles and fish), receiving nourishment from the mother during the process of development is only rarely found (for example, placental shark) in the animal kingdom. These early mammals apparently found that it was better to have fewer offspring and retain them longer within the body in order to give them greater protection while allowing them, at the same time, to develop to a more advanced state, than to lay the eggs as the reptiles did and rely on chance for subsequent maturity. Furthermore, since mammals are so much more highly organized, longer time was needed to develop the young to a stage where it could care for itself. The transition took place very slowly and over a long period of time. Even though fossil remains offer little real proof about such things, it is reasonably certain that this process of caring for the young within the mother started very early in the evolution of mammals.

If the embryos were to remain within the mother, it was necessary first of all that some means be devised for them to receive nourishment from the fluids of the mother. This was done by a temporary fusion of the allantois and other membranes to the uterine wall of the mother, forming a **placenta** (p. 533). At first the placenta must have been a very primitive affair and only partially satisfactory in performing this important function of nourishing the young. Consequently, the young were born in a very immature state and needed extra-uterine care. This was furnished by the use of a belly pouch, called a **marsupium,** in which the young could not only be protected from the cold but also could receive nourishment from the mammary glands through nipples located inside the marsupium (Fig. 13-56). Later in their evolution, more and more time was spent in the uterus and less in the marsupium until the latter was finally discarded as unnecessary. This is a possible explanation of how the present mammalian reproductive system came into being; it is recapitulated in the mammals of today from the duckbill to man.

In certain parts of the world such as Australia, which were isolated during the time the mammals were evolving (Eocene), there survives to this day two different types of primitive mammals which might help to bear out the narrative of the preceding paragraph. They belong to the group known as Monotremes, which means "one opening," so named because both the urogenital and intestinal tracts open into a common cavity, the **cloaca** (a reptilian character), with only one external opening. The spiny anteater (*Echidna*) and the well-known platypus or duckbill (*Ornithorhynchis,* Fig. 13-57) are the two examples that remind us of what must have happened many millions of years ago when the earliest mammals were struggling with this problem of caring for their offspring. These animals lay large yolked eggs like the reptiles and birds and they possess bills like the latter. They are partially warm-blooded and the duckbill incubates its two eggs (Fig. 13-56). When the eggs hatch the

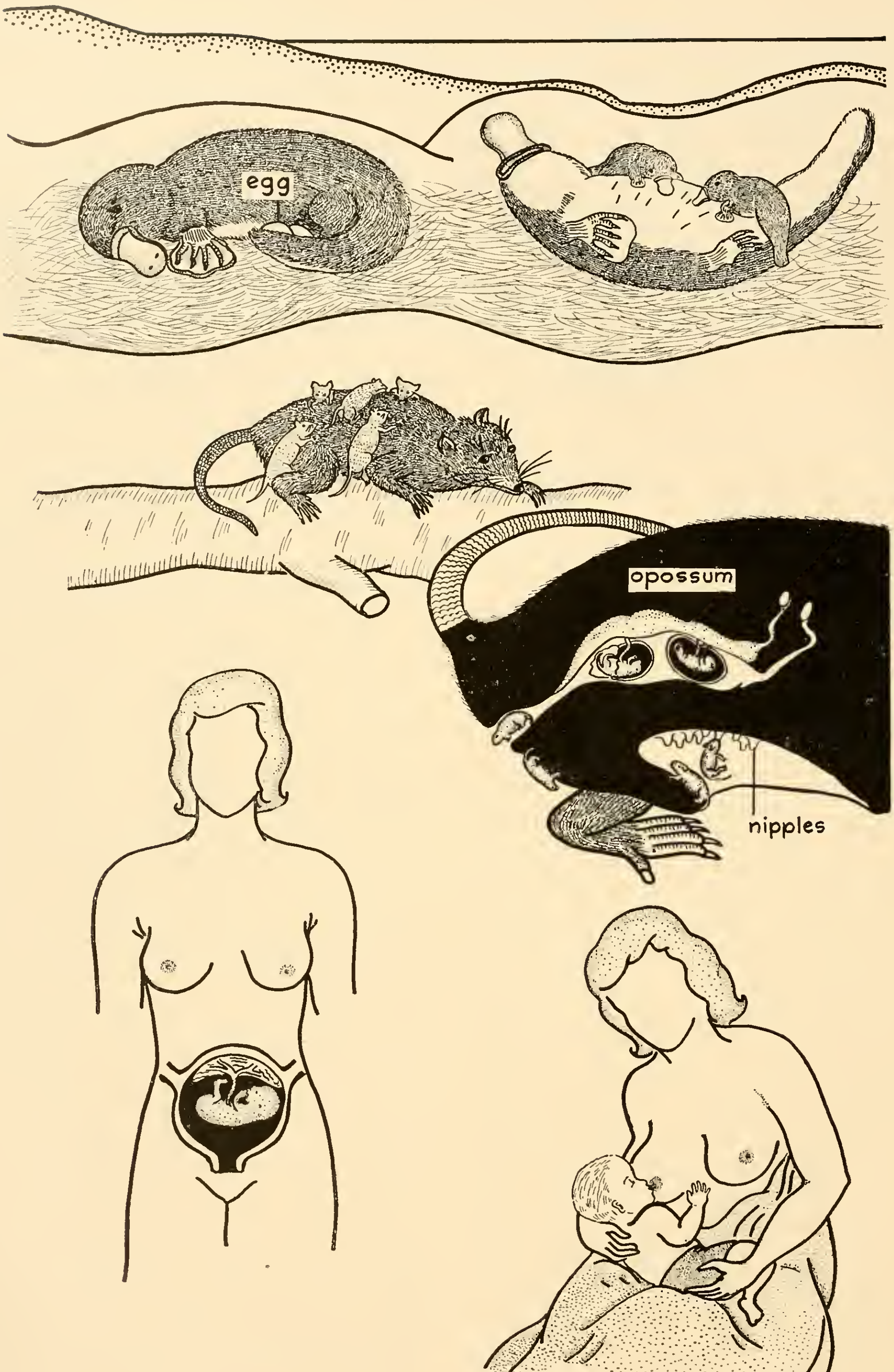


Fig. 13-56. Evolution of the care of the young in mammals, from the duckbill to man.

Fig. 13-57. Platypus (*Ornithorhynchus anatinus*), an egg-laying mammal. It possesses both reptilian and mammalian characteristics.

young are nourished for a time from milk secreted by two rows of glands along the belly side of the mother. There are no teats and the young merely lap up the secreted milk. It is noteworthy to mention again that these archaic animals have survived up to the present time due to their isolation. Had they been forced to compete with modern mammals they would long since have vanished from the earth. Isolation may be either by actual land or water barriers or by environments in which there is little competition. It is indeed fortunate that such animals have been preserved for us to study, making possible more logical conjectures as to just how present animals came about.

The next step on the road toward "true" placental mammals would be the intermediate types, namely, the **marsupials.** There are many of these interesting animals, including the kangaroo of Australia and the opossum of North America (Fig. 13-58). These do not lay eggs like the monotremes but retain them in the uterus where a rudimentary placenta forms. Since this organ is inadequate to maintain the embryos for any great period of time the young are born in a very immature state (Fig. 13-56). A 200 pound kangaroo for example may give birth to offspring no longer than 2 inches. Following birth, the embryos make their way, or are placed, in the marsupium where they grasp and practically swallow the nipples of the mammary glands to which they cling during what is equivalent to later embryonic life of a more advanced mammal (Fig. 13-59). After a time they are able to face the world and they come out of the pouch to feed for themselves, retreating to it only in case of danger. Although the marsupials give us a clue to the past history of mammals, their direct line probably diverged from the reptilian mammal stock very early in geologic times.

The placental mammals

The next step in the evolution of the mammals must have been the formation of a well-developed placenta, one that was adequate to care for the developing offspring within its mother for the period of time necessary to develop the complex structures essential for success once it was born. This organ increased in size and efficiency until it was capable of receiving sufficient food and oxygen from the blood stream of the mother to allow for advanced development of the offspring (Fig. 13-59). Since, in these animals, so much of the nourishment is obtained from the mother, eggs with large amounts of yolk were unnecessary. Reduction of the yolk is reflected in present-day mammals where the egg is very small (0.5 mm. across), whether it be that of an elephant or a mouse.

Along with the development of a successful reproductive system, the placental mammals showed further refinement in ancestral systems. For example, the brain became an even more conspicuous part of the central nervous system and its functions were much more precise. The coördination and precision of operation of all the parts of the body were brought to an all-time high in these animals. This combination of improvement on systems inherited from their reptilian ancestors has been responsible for the success of mammals.

Fig. 13-58. Marsupials. A female kangaroo (top), showing the young in the pouch or marsupium. Below, a mother opossum with two half-grown offspring.

The important mammalian groups

The most primitive modern mammals, that is, the ones that resemble ancestral forms most closely, are the insect feeders (Insectivora). While there are some fairly large, highly specialized forms such as the moles in this group, the most typical are the tiny shrews. These mouse-like creatures are probably similar to the stock that gave rise to higher mammals including man, himself. Their mouths are armed with needle-like teeth which aid in securing their specialized diet of insects. They are extremely active animals, in fact, so active that it requires a volume of food equal to their body weight each day to satisfy their needs. Most of them live in burrows and are such secretive animals that they are seldom seen by the casual observer; only the biologist armed with cleverly devised traps is able to capture and study them. It is this secretive habit, reminiscent of their ancestral cousins, that made it possible for them to survive up to the present. They are as isolated in their burrows as if they were separated by impassable water or mountain barriers. Some, however, live in trees much the same as the ancient forms that gave rise to the tree-loving primates (Fig. 13-67).

Fig. 13-60. One of the smaller carnivores, the raccoon (*Procyon lotor*). Its diet consists of many things, among them crayfish, which is the goal of the present search.

Fig. 13-59. The young of the opossum (top picture) are born in a very immature stage and must continue their development in the marsupium. Here they are shown clinging to the teats in the pouch. The young of higher mammals are well developed at birth. This calf (bottom picture) is able to stand and even run alongside its mother, though only a few minutes old.

The next group significant in the evolution of mammals are the flesh-eaters, the carnivores (Carnivora) (Figs. 13-60, 13-61, 13-62). These are very successful today, as shown by the numbers and kinds of such animals as cats, dogs, weasels, bears, civets, and the marine forms such as the walruses and seals. All our present dogs and wolves are supposed to have arisen from one form, *Cynodictis*, which resembled a weasel as much as a dog. The carnivores have teeth well adapted to the rending and tearing of flesh. The large canines readily tear through tough skin and the shearing molars cut the flesh into pieces sufficiently small to be swallowed. Furthermore, since meat is easily digested, the alimentary canals are

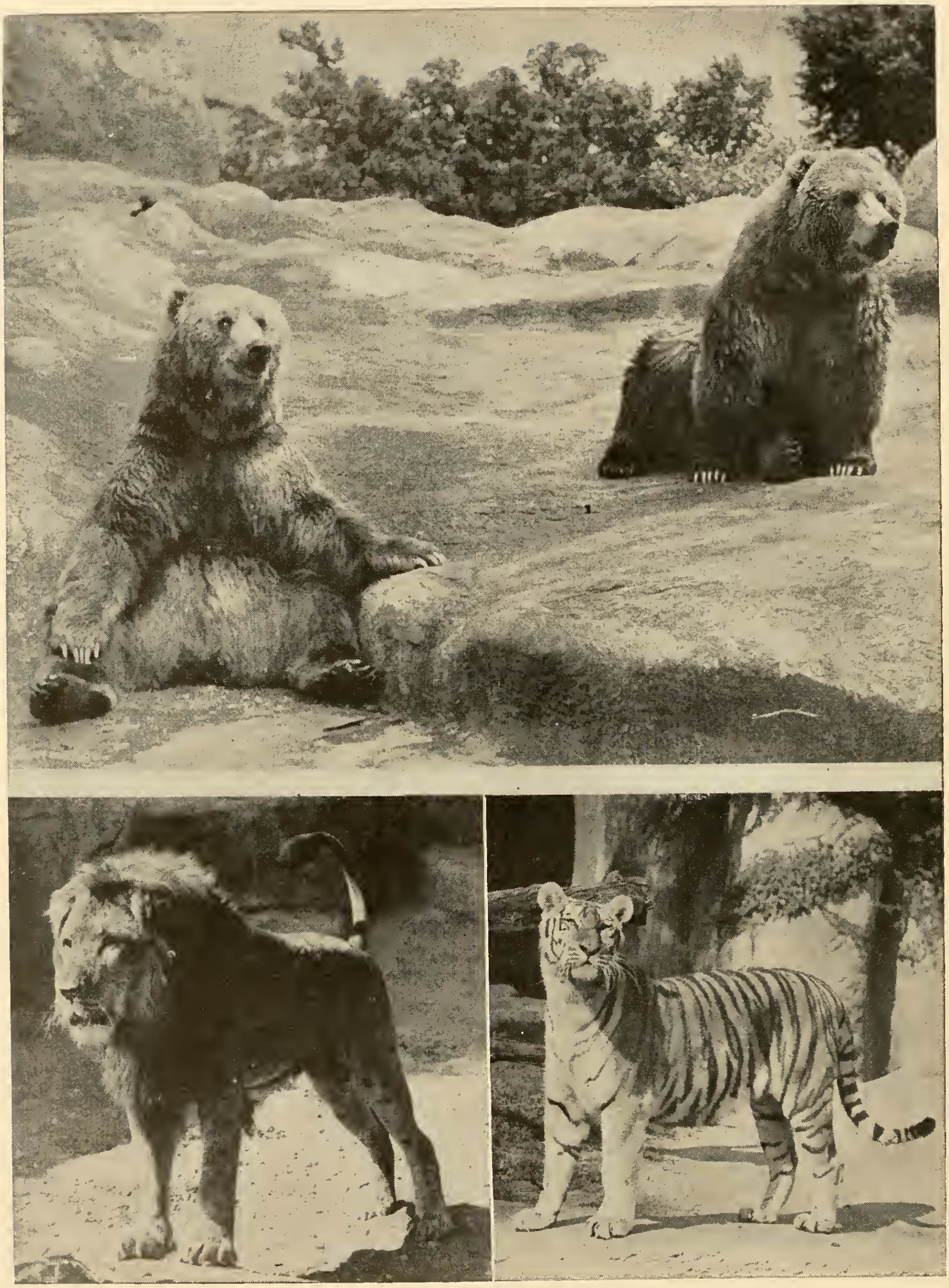


Fig. 13-61. A few of the larger carnivores.

Fig. 13-62. Marine carnivores. Seals (*Phoca vitulina*) off the coast of Maine (top). Elephant seals (*Macrorhinus*) off the coast of Southern California (bottom).

Fig. 13-63. The African rhinoceros (*Rhinoceros*). The thick armor-like hide and the two snout "horns" (not true horns) provide this great beast with ample protection against its enemies.

short when compared to the plant feeders (Fig. 17-7). In general, the carnivores are active and sometimes vicious animals, some hunting in packs like the wolves and others leading more or less solitary lives like the big cats (Fig. 13-61). Man has made friends with at least two members of the group many centuries ago—the domestic cat and the dog. Although he has taken a hand in changing the body form of cats by selective breeding, his greatest efforts and success have been with dogs. How successful he has been with his handiwork is well illustrated by the many kinds of "man's best friend."

Some very interesting and bizarre carnivores are those that have taken to the water in a serious way, with the result that they have all but lost their ability to locomote on land. These are represented by the seals, sea lions, walruses, and others (Fig. 13-62). They are relatively helpless on land but in the water they compare favorably with the best of the true aquatic forms, including the fish. Having gone out on land long enough to acquire the intelligence and cunning of the mammals before returning to their original environment, they should perhaps offer considerable competition for the stupid fishes. These animals are dog-like in many respects. Their appendages have become flippers which are effectively used in locomotion. They swim in a fish-like manner by undulating motions of the body. Curiously enough, the tail has dwindled to a useless structure and the two posterior legs have taken over its function.

Seals come out on land, usually specific isolated islands, during the breeding season (Fig. 13-62). The males arrive first, and when the females appear they gather as many as they can about them and jealously protect them within the family circle. Should a female stray some distance from the circle she is rudely retrieved. Males battle ferociously for the females throughout the breeding season and at its end they go back into the sea, rather badly battered.

In contrast to the carnivores are the herbivores, represented today by the domestic horse and cow. The horse possesses an odd number of toes (Perissodactyla) and the cow an even number of toes (Artiodactyla) or "cloven" hoof. In their evolution, the former came first and reached large sizes, as illustrated by the giant rhinoceroses that attained a shoulder height of 18 feet. Those alive today are doomed to extinction in spite of the fact that man has been able to save the horse by domestication. Members of this group have their weight borne on three toes in the case of the rhinoceros (Fig. 13-63) or on one toe in the case of the horse. The even-toed herbivores have four toes, of which two bear the main weight of the animal; this is illustrated by cattle, sheep, goats, pigs, deer, elk and many others. These have dominated the previous group both in the past and present. The present-day forms are the ruminants or "cud-chewers." Their stomachs have several compartments, a condition which permits large amounts of hastily acquired food to be temporarily stored and then brought back into the mouth at a later period to be properly chewed at the animal's leisure. This is a most comfortable and effective adaptation as well, since the the animals might feed voraciously during certain periods of the day when grazing would be less dangerous and then retire to secluded spots to finish the job of chewing. The teeth of both the odd- and even-toed animals are well adapted for cropping grass and grinding it to the proper consistency for digestion.

The boy who attends the circus is forever in awe of the slow moving, thick-skinned elephant (Proboscidea) with its nose, in the form of a proboscis or trunk, touching the ground (Fig. 13-64). This handy organ is responsible for the unusually short neck of the elephant because it performs the function of securing its grassy diet from the ground or any other place it may be found. It is also useful in obtaining water. Actually, it is a prolongation of the upper lip including the nostrils, a structure which has become highly muscular and very powerful. The teeth have undergone several changes, the most striking of which is the formation of the great tusks, which are over-developed incisor teeth and, incidentally, excellent weapons for offense. These tusks are sought by the hunter because there is a good market for ivory.

There have been many elephants in the past which were known as mammoths and mastodons and which apparently have only recently died out (15,000 years ago) (Fig. 25-2). In Siberia, within the past few years, mammoths have been taken from glacier ice in which they were completely preserved, skin, flesh, and all. Such bodies have been found partially eaten by wolves, and in some cases man has fed upon these ancient remains.

Fig. 13-64. The Indian elephant (*Elephas indica*) with its upper lip and nose drawn out into a trunk, a remarkable prehensile organ.

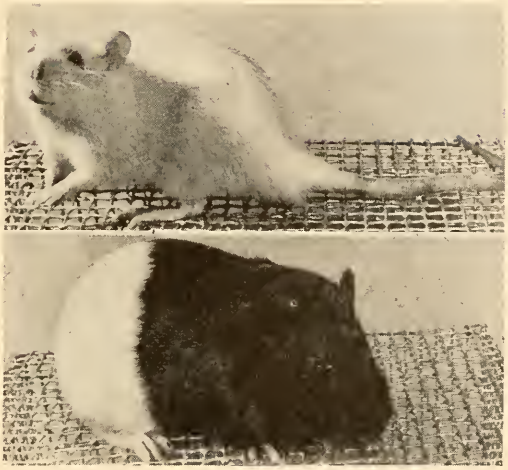


Fig. 13-65. Two rodents that have become popular laboratory animals. The white rat (top), a domesticated variety of the Norway rat (*Rattus norvegicus*) and the guinea pig, a domesticated variety of the South American cavia (*Cavia porcellus*).

Some relatives of the elephants went into the sea and became adapted for an aquatic existence. These are the Sirenia, which include such mammals as the dugong of the Indian Ocean, the sea cows formerly from Bering Straits but now practically extinct, and the manatee from the Atlantic Ocean in the tropics. These ugly, stupid beasts feed on the abundant marine vegetation along the shores but are unable to come ashore themselves because they lack posterior appendages and the front ones are adapted for swimming only. The Sirenia are not related to the whales; fossil records indicate that their closest relatives seem to be the Proboscidea, in spite of the vast difference in their external appearance and way of life.

The most successful of all the mammals are the rodents (Rodentia), the "gnawers." These include many small mammals commonly known to everyone: squirrels, chipmunks, beavers, porcupines, guinea pigs (Fig. 13-65) and even the pestiferous rats (Fig. 13-65) and mice. They must have been highly successful as a group because all the families alive today have been in existence a very long time, and none has become extinct as is the case with most other groups. They are characterized by their large chisel-like incisor teeth which are self-sharpening and which are kept almost incessantly active. The incisor teeth grow continuously and if not worn down would soon become so long that the animal could not close its mouth. If, as often happens, a member of this group loses one of the incisors, the tooth opposing it will then have nothing against which to grind, and continues to grow, passing through the anterior portion of the skull. Since the tooth is curved, as it grows longer it tends to form a circle. As the movement of the jaws becomes restricted such an animal is in danger of starving to death. In some cases squirrels with one or more teeth grown into complete circles have been reduced to feeding on the soft food found in garbage.

Most rodents are small today, although at one time there were giant beavers which grew to the size of a small bear (Fig. 25-2). Rodents have a high degree of intelligence and are usually secretive animals, many living in burrows. One, the beaver, is almost human in its ability to build dams. It selects a place in a small stream, which is just what any engineer would do if he were building a dam. Beavers cut trees in such a way that they fall in the exact spot that will do the most good; they entwine the branches so that the debris coming down the river will catch there and make the dam water-tight. When they have finished the job, a first-rate dirt dam is the result. In some regions where conservation laws have made it possible for them to come back, they have become almost pests because of their habit of damming every small stream in large areas, thus flooding all the fields and roads in the surrounding country.

The bats (*Chiroptera*) have conquered the air. To be sure, other mammals such as the flying squirrel are able to soar from tree to tree but they have not approached the bat in any sense as a flying creature. The bat competes very well with the birds; in fact, it can perform some feats that birds cannot. The wing is merely a modified hand with the fingers greatly extended and covered with skin. Many species of bats live in deep caves, such as the Carlsbad Caverns in this country, where they are forced to fly in complete darkness. Just how these animals could avoid objects as small as tiny wires strung across a room that is totally dark has puzzled biologists for a long time. Recently, however, with the aid of delicate electronic equipment, it has been discovered that the bat, instead of being a silent animal as all had thought, does emit bursts of high frequency sound waves during flight. These have a frequency of about 50,000 vibrations per second and are therefore beyond the range of the human ear, the upper limit of which rarely exceeds 16,000 vibrations per second. When these high frequency sounds made by the bat strike an object, no matter how small, they bounce back to its ears; this happens at such speed that the animal can respond soon enough to avoid obstacles without the use of its eyes. Man now uses this same principle in detecting distant objects but instead of sound waves he uses radio waves. Thus the bat has had in operation for ages the first radar system.

Bats usually feed on insects, although there are the so-called "flying foxes" which are herbivorous. A small number are blood suckers, though not as gruesome as current stories and moving pictures would imply.

The whales (Fig. 13-66) and porpoises (*Cetacea*) are probably the most specialized of all mammals. They are descendants of land carnivores which have returned to the sea, and become so successful in this environment that they are found in all of the oceans of the world. The story of how they happened to return to an aquatic environment is lost because fossil records are very scanty. They probably were flesh-eating mammals much like the present-day otters, fishers, and minks, which, returning to the water in search of prey, gradually became better and better adapted to marine life.

Whales have few anatomical features remaining that are reminiscent of their land life. They have lost their posterior limbs, although they still have useless remnants left buried deep in their bodies, and their anterior appendages have modified into efficient flippers. They are lacking hair completely in the adult except around the mouth region in some species. Their nostrils have moved back to the tops of their heads, which facilitates breathing at the water surface without exposing the head. A tremendous tail is the principal organ of locomotion; it undulates horizontally rather than vertically as in the case of fish.

Even though the first whales were probably all carnivorous, many subsequent species became herbivorous. All whales today are divided into two groups: the **whalebone whales** and the **toothed whales**. The latter have retained their teeth, which are used in crushing fish and squids, their chief source of food. The more interesting whalebone whales have evolved a sieve-like structure called whalebone which hangs from the roof of the mouth and is used to strain small marine organisms. Whalebone is actually modified skin, including the hair which makes up the strainer. The sperm whale, also a whalebone whale, has prospered on this diet of minute marine life, and some specimens reach a weight of 150 tons, which exceeds that of any other animal that has ever lived, dinosaurs not excepted. Oddly enough, they reach this great size by feeding on some of the smallest plants and animals. It has been said that the reason why these animals can grow so fast and so large is that all of the energy received from the food is saved and goes to form tissue rather than being lost in keeping the animal warm. There is practically no heat loss at all from these great bodies because they are enveloped in a thick layer of blubber just beneath the skin which acts as an insulator against the cold water in which they live. Another problem that is difficult to understand is how this animal can dive to great depths and remain under water for 30-45 minutes without being crushed and getting the "bends" (see p. 488), a disease that humans get under similar circumstances. It apparently has oxygen reserves and other devices for satisfying its needs under these rigorous conditions. The whale is truly a remarkable animal and many aspects of its life will probably remain a secret for a long time, since it cannot be brought into the laboratory and studied like other animals.

Fig. 13-66. A small beached whale called the beaked whale (*Mesoplodon*). Note the scratches in the hide as a result of being pounded on the rocks.

The primates

This, the last group of mammals, is the most important of all because we belong to it. Other members of the group are the great apes, the circus monkey, the fierce-looking baboon, the lemurs, and the wide-eyed tarsiers, all coming from an arboreal insectivore ancestor (Fig. 13-67). It is difficult to name any especially striking characteristics that set the primates off from all others, though there are several minor

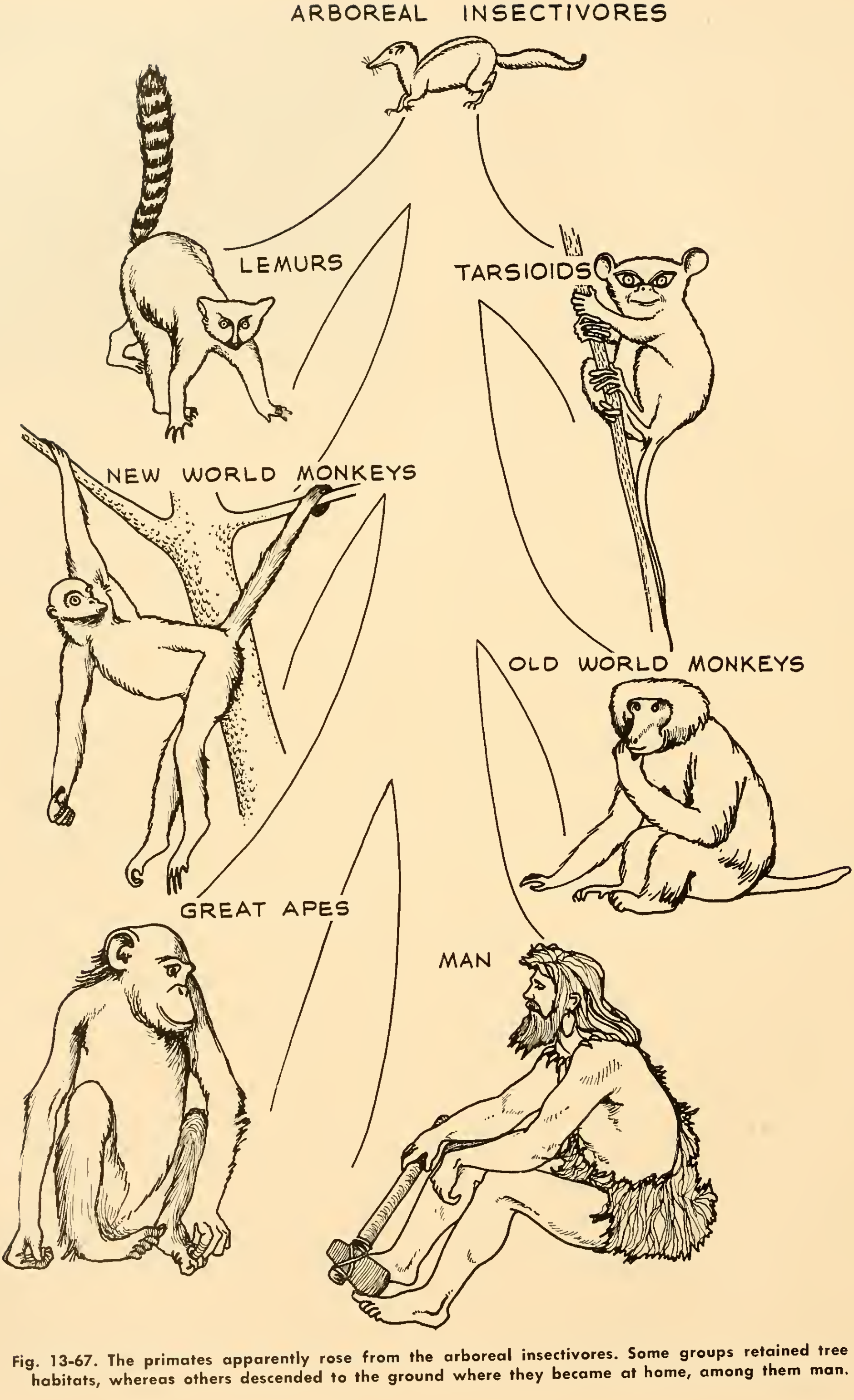


Fig. 13-67. The primates apparently rose from the arboreal insectivores. Some groups retained tree habitats, whereas others descended to the ground where they became at home, among them man.

variations which distinguish them as a group. First of all, most of them possess a brain and central nervous system that is developed far and above that of all others. It must be said, however, that some of the lowest primates are probably not as intelligent as some of the brightest carnivores. But the group as a whole can be characterized as having very large brains, the corrollary being, of course, that they possess the most integrated and most coördinated bodies of any animals living or extinct. This implies excellent sense organs, particularly those of sight, because in order for the brain to perform its function it must receive accurate impressions.

The lower mammals have depended to a large extent on their sense of smell to orient themselves, for their vision at best is not very good. But the primates, having taken to the trees, needed good vision to detect their enemies on the ground and this was more important to them than a keen sense of smell. Arboreal life thus appears to have been one of the reasons for the development of the excellent visual organ of primates. Since the animal could see better, it probably had a greater desire to examine things more closely which, in turn, would be correlated with further brain development. One other very important aspect of this course of events is that arboreal life had a profound effect on the skeleton.

As the appendages became well adapted for life in the trees, both the anterior and posterior digits became modified for grasping limbs. The great toes and thumbs opposed the other four digits and the claw of the carnivores flattened out into nails. The legs became relatively short, so that the arms seemed to be unusually long. The appendages became well developed for supporting the body weight and for carrying it with considerable speed from limb to limb through the tree tops. When at rest, the hands were free to handle objects and to bring them close to the keen eyes for closer observation. Freeing the front appendages from the burden of supporting the body weight and development of the prehensile hand have probably both been responsible to a large extent for the advance in the primate brain. This superior brain is undoubtedly the one reason why these animals dominate all others today.

Other minor characteristics of the primates are the tooth pattern and skull structure. The early primates were apparently omnivorous just as most primates are today, and a generalized mammalian tooth pattern is characteristic of all of them. They possess two incisors, two premolars and four molars in each half jaw, making 32 in all, considerably less than that possessed by the primitive mammals. The jaw is short, so that a relatively short face results; this is obvious when the faces of a monkey and a dog are compared (Fig. 15-3). Furthermore, the large nasal chambers essential to lower animals which depend upon smell are much reduced in primates with a corresponding reduction in this sense. Since the brain has grown a great deal in size, it has risen over the face, bringing the latter into a more vertical position. Along with this change has come a gradual shifting in the position of the eyes from the lateral position occupied in lower forms to a frontal position. This has resulted in over-lapping images, producing stereoscopic vision, essential to tree-dwellers for judging distances accurately, and to men for driving a car. The great advantage of superimposed images is easily demonstrated by viewing an object at a distance first with both eyes and then with only one. The sense of depth is lost with monocular vision.

Primates are rather shy, avoiding other animals that might be dangerous and preferring the seclusion of dense foliaged forests to open areas. The more primitive ones remain in the safety of the tree tops most of the time. The more advanced forms, such as the chimpanzee and gorilla, have descended to live on the ground, but even these retreat to the trees on occasion.

Fig. 13-68. Lemurs are primitive primates that are found only in isolated parts of the world. They are stupid, sluggish animals. This is the ring-tailed lemur, *Lemur catta.*

The mother primate gives birth to single offspring as a rule, and multiple births are rare. This is to be expected in an arboreal animal, since a single young one is about all she could manage in the tree tops. She lavishes meticulous care and protection on her offspring, keeping it close to her chest at all times during the first few months of its life, close to the food supply. Primates possess only two mammae or breasts although occasionally even in humans several pairs may appear, located in the same position as on the lower mammals which produce multiple offspring (Fig. 25-16). The ungulates, such as horses and cattle, for example, also produce a single offspring at a time but in this case the mammae are in the pelvic region. Dogs, on the other hand, produce numerous young at one time and consequently multiple mammary glands are necessary for all to get their share of the milk. The development and location of the mammae seem to be correlated with the number of offspring and the method of caring for them.

The various primates

The lemurs. The lethargic lemurs are not greatly removed from the insectivores (Fig. 13-67). They are slow moving, sluggish, stupid animals quite unlike the other primates. Their primitive nature is indicated by the fact that their eyes still lie in such a lateral position that their images do not overlap (Fig. 13-68). They live in the tree tops where they move about so conservatively and cautiously that they are rarely seen by enemies and consequently have been able to survive in Madagascar up to the present time. They would not have lasted long if they had been forced to compete with their aggressive cousins.

Tarsier. The East Indies are the home of the only hopping primate, which is not much bigger than a rat (Fig. 13-69). Its mark of distinction lies in the fact that zoologists consider it intermediate between the lemurs and the monkeys. Its rat-like tail and long legs are well adapted for leaping, which it performs with great agility. The swollen tips of its digits are useful in catching limbs of trees as it forages for insects during its nocturnal sorties. The extremely

Fig. 13-69. Tarsier (*Tarsius tarsier*) is a rat-sized hopping primate. Note its tremendous eyes and the padded finger tips which aid in grasping twigs.

large eyes are directed forward and probably permit stereoscopic vision.

The characteristics of this peculiar little animal place it directly between the monkeys and lemurs, and this fact has caused zoologists to wonder if it might be the branch from which man sprung. Fossil remains indicate that in the Eocene period there were a great many tarsioids, contemporaries of the lemurs, and it may well be that man descended from this group.

Anthropoids. The highest group of all primates are the anthropoids, the man-like primates. These include the **monkeys,** the **great apes,** and **man.** While visiting the zoo many will resent the thought that these animals are our closest relatives, but after viewing them for any length of time only the most doubting are unconvinced. It is important to point out, however, that man did not descend from monkeys, nor is the monkey a degenerate man. Both had separate beginnings a long time ago and have been and are traveling along separate paths in their evolution (Fig. 13-67). The monkey may become more man-like and the opposite may happen, though it is unlikely. But the monkey will never become man as we know him today, any more than the tiger will become a lion or vice versa.

The monkeys. These creatures, endowed with unlimited curiosity, are man-like both in physical characteristics and in attitudes. They are primarily arboreal, although they are able to get along on the ground. They walk on all fours, but when at rest usually sit down on their haunches, thus freeing their hands for the job of manipulating

Fig. 13-70. This spider monkey (*Ateles paniscus*), a representative of the New World Monkeys, possesses a handy adaptation, namely, its prehensile tail which functions as a fifth appendage.

food or any other object that strikes their fancy. Their large and forward-placed eyes are probably as keen as those of humans and in appearance they certainly resemble them, even to the expression of emotions.

The monkeys are divided into two groups, New World forms of Central and South America and the Old World forms of Asia, Africa, and Europe (Fig. 13-67). Two members of the New World monkeys are of interest because of their specialization: the spider monkey, with its prehensile tail (Fig. 13-70) which functions as a fifth hand, and the howler monkey, which has a remarkable voice made possible by modifications of the throat into large, bony resonating chambers. Each has specialized in its own peculiar way and these variations set them off from all other members of the group.

The Old World monkeys exhibit a wide variety of form and habits, from the sacred langur of India to the highly colorful ground-dwelling mandrill (Fig. 13-71). Most of them are tree-dwelling, although the baboon lives on the ground entirely. The baboon is of interest because some have highly colored callosities (buttocks) and dog-like snouts. When on the ground they walk on all fours. The baboon is as firmly committed to life on the ground as the spider monkey is to life in the trees. It would be interesting to know how these closely related animals came to adopt such distinct habitats. When in the course of events did man's precursor leave the trees and come down to the ground? Had he come with the baboons he would need shoes on both hands and feet today; had he stayed in the trees much longer he would never have been able to come down because his body would have been so modified that it would be unwieldy on the ground. He must have made the shift before his legs got too short or his arms too long.

The man-like great apes. These predominantly large primates, the gibbon, orangutan, chimpanzee, and gorilla, separated very early from the common stem that also produced the monkeys, probably about the same time a branch separated off on its long course toward man. This appears to

Fig. 13-71. The mandrill (*Mandrillus sphinx*) is a colorful member of the Old World Monkeys. It is noted for its dog-like face and its highly colored cheeks.

have taken place at least 20 million years ago. Some think that among the great apes the gibbons do not appear to be very close relatives of man, whereas others believe they are more closely related than any of the rest. Certainly the skull and general trunk proportions are man-like. However, the gibbon has become so completely adapted to arboreal life that its arms are disproportionately long and the fingers are modified into hook-like structures for grasping limbs, the thumb being reduced to a tiny protuberance (Fig. 13-72). Its long arms allow it to brachiate through the trees with great speed, that is, to move hand over hand along branches in a swift, graceful manner. Even in a cage, excited gibbons are a spectacle to observe.

Brachiation in the gibbon may have some bearing on the achievement of upright posture in man. The gibbon hangs in a perpendicular position, with the legs suspended and the back vertical, in other words, in a man-like position. It is possible that ancestral arboreal forms began to assume this position at an early date but before specialization had gone as far as it has in the case with the gibbons, and that at this point they descended to the ground and started their terrestrial existence. The gibbon stayed in the trees and became further adapted to arboreal life. Just why man's precursor, and the baboons too, for that matter, came out of the trees is a matter of speculation. It may have been due to a wasting away of the forested areas, in which case adaptation to life on the surface of the earth had to be made in order to survive.

The orangutan, another tree-dweller, lives exclusively in Borneo and Sumatra and is more restricted in its range than any of the group. Its name means "man of the forest," which certainly describes this cumbersome beast. In direct contrast to the swift-moving gibbons, the orangutan moves cautiously and very deliberately among the tree branches. It is well adapted to life in the trees, with its long arms, powerful

Fig. 13-72. The long-armed gibbon (*Hylobates lar*) is strictly an arboreal primate, being able to travel more rapidly through the tree tops than many animals can travel on the ground. This specimen has her nursing baby held securely between her legs.

enough to handle its great weight easily and the hooked hands with very small thumbs like the gibbon. On the ground its small legs serve poorly as locomotor organs. Its brain case has a capacity of about 500 cc., which is considerably more than that of the gibbons but less than that of the gorilla. In the latter, the brain case has been known to reach a capacity of well over 600 cc. The orangutan's eyes are close together and its general facial appearance resembles that of many people.

The closest relatives of man are probably the great African apes, the gorilla, and chimpanzees. There seems to have been a tendency among the primates during Miocene times to try their luck at terrestrial existence. These apes have gone part of the way. Although they are at home among the trees, particularly the chimpanzee which brachiates very well even today, they still spend a good deal of their time on the ground. The gorilla even seems to prefer

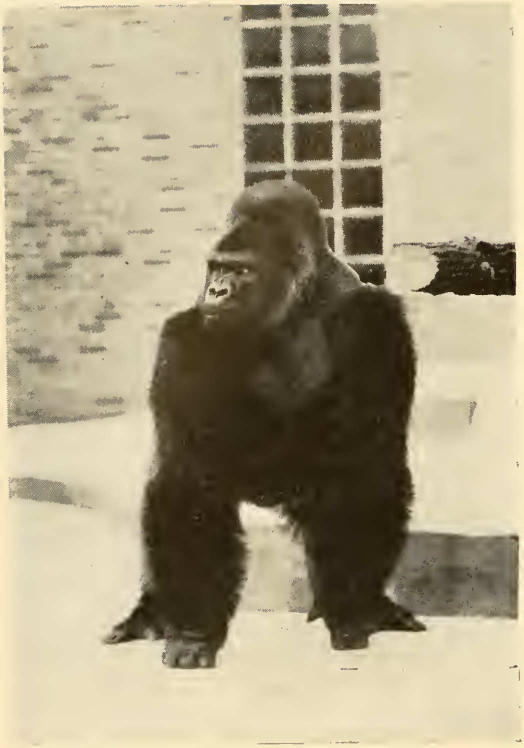


Fig. 13-73. The gorilla (*Gorilla gorilla*) is the largest and probably the most intelligent of all the great apes. This is a young male that has just been enticed into new quarters which it is thoroughly investigating.

the ground, retreating to the trees only to sleep. Man, of course, is the only one that has succeeded in making the complete transition from arboreal to ground life.

The chimpanzee possesses a disposition more favorable to captivity and for that reason a great deal more is known about its behavior than that of any of the other great apes. In size it matches man very well, being about 5 feet in height and weighing about 150 pounds when full grown. When young it is easily handled, and is a very affectionate, playful, and extremely curious animal. It seems to approach the human type of intelligence as illustrated by its ability to solve problems. Experiments, notably those by Yerkes, have shown that the "chimp" will solve simple problems much like a small child. For example, if food is placed just out of its reach and several boxes are placed near by, the chimp will pile the boxes in order to obtain the food. It has also been found that, if given two bamboo poles which fit together, it will so place the two parts in order to reach a desired object. This requires a kind of intelligence far greater than that possessed by the smartest carnivores.

The gorilla is perhaps more intelligent than the chimpanzee, but because of its sullen and individualistic disposition it will not tolerate training or testing of any sort (Fig. 13-73). A two-year-old gorilla responds very similarly to a child of about the same age or a little older. Soon, however, it develops a morose disposition and cannot be trusted for close association with man. In size the gorilla exceeds all other primates, and an old male may reach a height of 6 feet and a weight of 500-600 pounds. Its massive torso and long, very powerful arms make it a formidable beast in a battle with almost any other animal. Because of its herbivorous diet the gorilla is not a predator, and for that reason does not get into much trouble. Since it is shy, it retreats into the dense forest and will not fight unless provoked. The gorilla walks rather well on the ground but frequently reverts to all fours, especially when in a hurry. Its short sturdy legs and man-like feet support its weight well, although it is not a swift runner.

The next step—man

The great apes apparently had a greater day during the Miocene and Pliocene than they have had since. They lived over vast areas of Africa, China, and even large parts of Europe. One of these, *Dryopithecus*, ranged over all of these regions and, it is thought, may have been the stem from which the present-day great apes and man were derived. It seems that this animal was well adapted to tree life, being able to brachiate expertly, although its arms did not reach the length of those of the gibbon. It may be that these forms descended to the ground in the upright position they had achieved from their habit of brachiating, and became the terrestrial forms, including man, of today. However, there is a great deal of doubt by most paleontologists on this matter at the present time.

Fossil remains of early man have been few and only fragmentary to date, a fact which makes the reconstruction of man's evolution a very difficult one. However, certain important discoveries have been made which give some clue as to his origin. The most primitive skull of a man-ape is that found in South Africa, called **Australopithecus,** the "southern ape." The several skeletons or parts of skeletons that have been found were in Pleistocene deposits, the period in which man made his long slow evolution to present-day types. This fossil ape skull shows characteristics of both the great apes of today and of man, which is what would be expected in a "missing link." Its brain case has a capacity of over 700 cc., which exceeds that of the largest gorillas today, but is still a long way from that of the next higher fossil man, *Pithecanthropus,* with a capacity of about 900 cc. Its teeth and brain development certainly could have belonged to a form that was heading toward modern man.

Pithecanthropus has stirred up more controversy since its discovery than any other fossil man. This is understandable since its discoverer, Eugene Dubois, a Dutch Army officer, set out to find the missing link between man and the apes, probably because of the intense controversy that had been stirred up by Darwin's *Descent of Man,* which was at the time in the minds of everyone. It is most remarkable that a man should set out to accomplish such a difficult task and actually carry out his promise. Others searched furiously for the next few years, but it was not until 1936 that other similar skeletons were discovered. The original material, which consisted of a skull cap, three teeth, and a femur bone, was discovered in the banks of the Solo River in Java in 1892. Dubois called these finds *Pithecanthropus erectus,* the "erect man" (Fig. 13-74). His claim was that this was an intermediate form, half ape, half man, which may well have been the case, because other skeletons tend to bear out these assumptions. The man had a very low brow and the size of his brain case was about 900 cc., a much greater capacity than that of the great apes though smaller than any modern man (average about 1500 cc.). The tooth pattern is definitely human, and it is interesting to note that the wisdom teeth show no signs of disappearing as is common in modern man. He probably lived in the neighborhood of 500,000 years ago.

A close relative of *Pithecanthropus* is **Sinanthropus,** commonly known as the Peking man because the remains were found in a cave some 30 miles from Peking, China. These middle Pleistocene deposits stimulated Dr. Davidson Black in the 1920's to investigate them for the possibility of human remains. He found first only a tooth here, but during the next decade over 30 individuals were unearthed, so that the evidence is very complete concerning this primitive man. In most respects, *Sinanthropus* is very similar to *Pithecanthropus,* except for the fact that the brain case is somewhat larger on the average (915-1200 cc.). The lower jaw still maintains a gap for the fitting of the upper canines, a definite simian character. The leg bones indicate an upright posture. He apparently had a culture which was far above anything the apes would be likely to have. He used fire and made stone tools. There is evidence, according to Romer, that he was cannibalistic, based on the fact that so many skulls are present in the deposits, each one crushed at the base. This might mean that the bodies were eaten and the brain removed for the same purpose, a horrible but probably not uncommon custom for early man.

The **Neanderthal** man was the first fossil man discovered (1856) and many of his remains since have been uncovered, indicating that he roamed over parts of Asia,

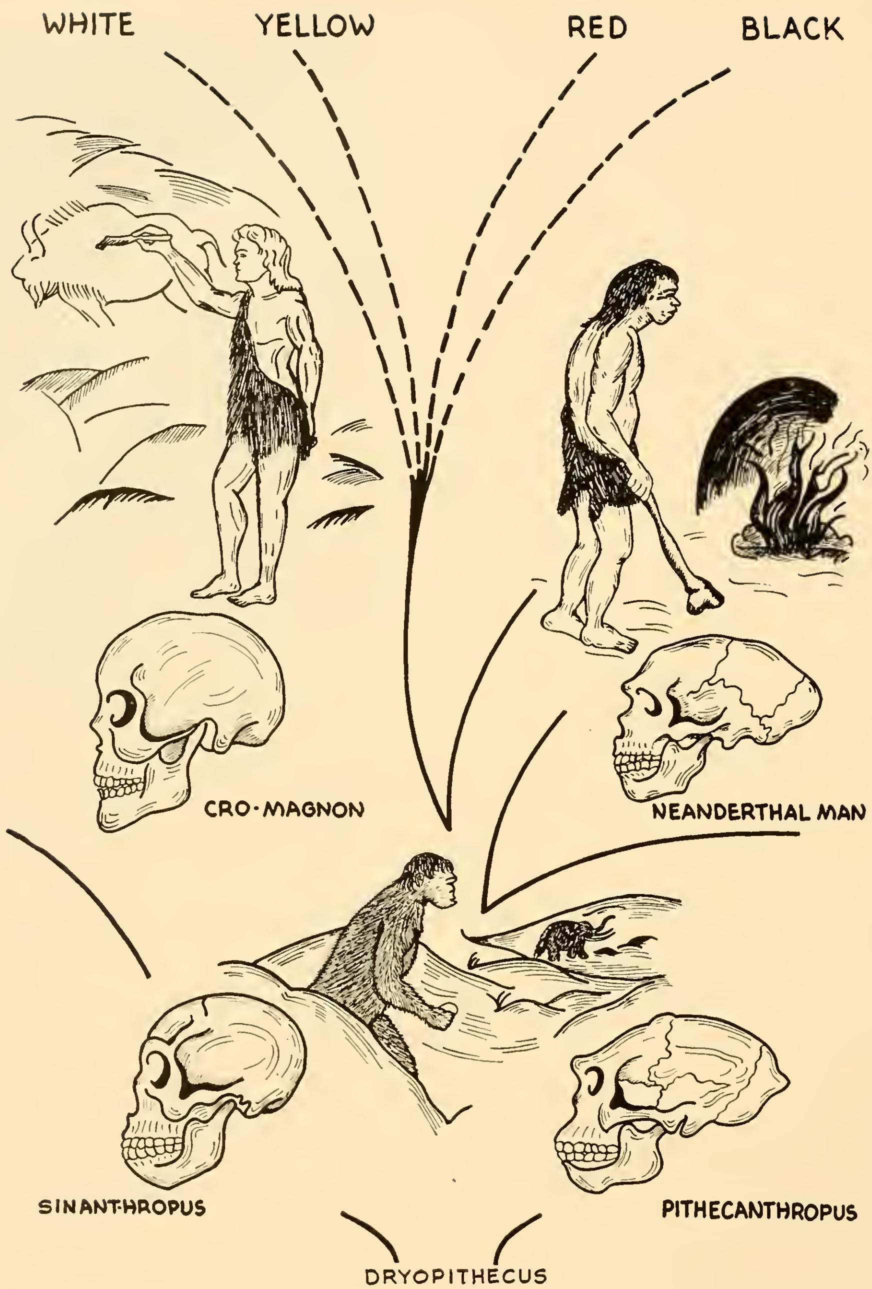


Fig. 13-74. Evolution of man.

Africa, and Europe about 100,000 years ago. Physically he was a rather short man, not exceeding 5 feet 4 inches (the females were several inches shorter), but very powerfully built (Fig. 13-74). His upper arms and femurs were short and the latter were curved forward so that in posture he probably walked with his knees bent slightly forward. Furthermore, his massive head was set somewhat forward over his thick neck and barrel chest, so that he was probably quite gorilla-like in appearance. His brain case capacity was 1550 cc., larger than the average for modern man, although it had different proportions. The forepart of the brain case, the seat of higher intelligence, was rather small, the larger portion being in the back of the head. His skull was heavy, with large protruding brows, and the massive jaws bore teeth much more substantially built than those of modern man. The mandible was chinless just as among the apes; a chin is a more recent development.

He had some type of culture which included religious rites, because he buried his dead—probably the important reason why so many remains have been found. He had learned to shape and use stone implements in the daily business of securing food, and these, together with bones of the animals he hunted, are found in Neanderthal deposits.

There is always great interest not only among anthropologists but also among laymen concerning the story of the origin of modern man. Which of these early men gave rise to *Homo sapiens*? Was the Neanderthal man the immediate forerunner of *Homo sapiens*? There has been a great deal of discussion over this point and, like all problems under controversial fire, there are probably several possibilities, the real answer perhaps lying in a compromise. It must be admitted certainly that Neanderthal showed considerable advance over *Sinanthropus* and *Pithecanthropus*. Whether or not he gave rise to *Homo sapiens* is questionable. There is evidence to indicate that he was wiped out rather suddenly by another race, probably *Homo sapiens*. If this was the case, then the latter must have been derived from another stock as yet not unearthed. The discovery in 1912 of a very old skull in Sussex, England, may throw some light on the question, although it is still a subject of much argumentation. This man is known as the **Piltdown** or "dawn" man, named after the Manor where it was found. From the position of the deposits, it would appear that this man lived as a contemporary of *Pithecanthropus* or even before, certainly early Pleistocene or late Pliocene. The skull shows certain ape-like characteristics in the lower jaw, but the shape of the brain case as well as other features definitely place it on the direct line toward *Homo sapiens*. It is possible, as Romer postulates, that two lines of men were in existence at this early period: one, *Pithecanthropus*, evolving to the Neanderthal man, and the other, the *Piltdown* man, evolving to *Homo sapiens*.

Whenever *Homo sapiens* made his appearance he split off into many races which spread over the entire world. One of the outstanding of these is the **Cro-Magnon**, who lived in Europe 15,000 to 40,000 years ago (Fig. 13-74). Most of the remains, about one hundred skeletons, have been found in France, and the records afford a rather complete story of the culture as well as the anatomy of this man. He was tall, many males reaching 6 feet in height, although the females were considerably shorter. His skull was long and massively built with the tremendous capacity of 1700 cc., which is greater than that of any race today. Furthermore, the shape was definitely modern in that the forehead was high and the back part rounded as in modern man. None of the ape-like characteristics observed in *Pithecanthropus* are evident in this man. The mandible terminated anteriorly in a pronounced chin and the face was short and broad with the eyes set far apart. Undoubtedly, he was a handsome fellow.

In culture these men far surpassed their predecessors. They made their hunting weapons skillfully, producing the spear and axe, and they may have even devised the bow and arrow. They apparently were superior hunters, as judged by the contents of their caves, which are strewn with the bones of large animals they had killed and feasted upon. They probably clothed themselves with skins of animals to protect their hairless bodies from the elements. They evidently possessed great skill in making and mixing paints, and in depicting the life as it existed in their time, for they have left behind on the walls of many caves in Spain and southern France, magnificent paintings showing many of the animals which they hunted. These are portrayed in a most realistic manner, even to the natural colors which have resisted the ravages of time. From these paintings a great deal has been learned about the fauna of these areas, much of which has since become extinct. The remains of these men would indicate that they were superior both mentally and physically to any races alive today. What, then, has happened to them? Some think their descendants still live in Europe today. If so, are they degenerate types? Is *Homo sapiens* actually on the decline?

Knowledge of early *Homo sapiens* in other parts of the world is not as complete as in Europe, although remains have been unearthed elsewhere that give an inkling as to the origin of some present-day races. One might expect to find some early Negroid types in Africa, the home of the Negro. An early skull from the Sahara does show Negroid characteristics. As this part of the world becomes more modernized the diggings of various sorts which always accompany the process will perhaps throw more light on this problem. Undoubtedly, rich deposits exist in parts of Asia which when unearthed will reveal an interesting story concerning the origin of the Mongoloids about whom little or nothing is known today.

Apparently, *Homo sapiens* invaded America comparatively recently, because no remains of very early man have been found. The primates that were here in the early Tertiary times became extinct and no others appeared until modern man made his way from Asia across Bering Straits. It is highly probable that this is the path he took in populating the Americas, because geologists have shown that a drop in the sea level of 100 feet would leave a land connection between Asia and North America. Such rising and falling of the sea took place near the end of the great glacial period. For many thousands of years it was possible for these people, filtering gradually over this narrow neck of land, to migrate southward to the semi-tropical and tropical regions of the Americas.

Races of Homo sapiens

It hardly seems possible that all men from the African pigmy to the towering Swede are of the same species, yet by our definition of species this is true. The fact that all members of the human race alive today will interbreed is one of the most important criteria for a species. When an attempt is made to differentiate between races (varieties of mankind) the matter of criteria to be used for distinction is a monumental problem. It has never been possible to use national boundaries or even languages to differentiate races. For centuries man has been on the move constantly, roving from place to place; today his wanderings are even greater than they have ever been, due to improved transportation. However, some limitation has been placed upon him by boundaries laid down by both emigration and immigration laws; if it were not for these the intermingling would be such that in a few centuries it would be more difficult to distinguish races than it is today.

The criteria that have been used to distinguish the various races are such points as stature, hair, face proportions, skull shape, complexion, eye and skin color, and blood groups. Although there is no clear-cut line of demarcation between many individuals due to interbreeding, there are certain racial characteristics present that make it possible to set up a tentative classification. Using the simple basis of color for comparison, there are three major groups: the Negroids (black), the Caucasoids (white) and the Mongoloids (yellow).

The Negroids. These are the darkest of all people, and include the Negroes, pygmies, Bushmen, and Hottentots. Aside from the heavy pigmentation in their hairless skin which gives them the dark color, their hair is black and has a kinky texture much like wool, their heads are long, their noses are flat, and their lips are thick and curved outwards from the mouth. This group includes the African Negroes as well as those of the many Pacific islands from New Guinea to the Fiji Islands and elsewhere. They range in stature from the tall, powerful Zulus to the tiny African pygmies (Negritos). The group as a whole has done well both in their natural environments and when transplanted to other parts of the world.

Special mention should be made of the natives of Australia because they possess certain bizarre characteristics reminiscent of the animals on this isolated island. They are a very primitive people both in anatomical features and in culture. There are only about 60,000 of them left today and these are located along the northern coasts of Australia. Physically they are of a "low" type, exhibiting many features, such as heavy brow ridges, which remind one of the Neanderthal man. Although they have the broad nose, skull, and jaws of the Negro, they do possess characters that approach those found among white races, namely, greater hairiness, lighter skin color, wavy rather than kinky hair, and only moderately swollen lips. It has been suggested that since this race of colored people seems to be neither Negroid nor white, perhaps they made their way to Australia from Asia where the main human stock evolved at a time when the human race had reached the stage in evolution which they represent today. Due to isolation, they remained pretty much the same up to the present time, along with other animals living under similar conditions on this great island. If this idea is correct, we can observe today a "living fossil" of man.

The Caucasoids. This group includes a wide range of people, in fact, about all of those that are neither Negroid nor Mongoloid. In general, they possess characteristics that are consistent within wide limits. For example, they have skin color ranging from white to dark brown, eye color from blue to dark brown, and hair color from light blond to dark brown, the hair itself being straight or wavy but never kinky nor wooly. This group includes the most aggressive people of the world, representatives of which have inhabited Europe, the Americas, and parts of Asia. Some of the major types belonging to this race are listed below:

1. *Mediterranean.* These are dark-eyed, dark-skinned, long-headed, straight-haired people of slender build, inhabiting the regions along the Mediterranean from Spain to India. They are the native Indians of India; those who pushed farther eastward to the East Indies are known today as the Polynesians. They have expanded still more to practically all of the Pacific Islands from New Zealand to Hawaii. They are a sturdy, hardy stock that has been able to travel great distances to inhabit these widely separated islands.

2. *Ainus.* In northeast Asia and particularly in a small section of Japan these long-headed, hairy, and dark complexioned people have established themselves. They are geographically isolated and represent as near a "pure" race as can be found.

3. *Nordics.* These are tall and slender

people with typically long heads. They have ruddy complexions with blond straight or wavy hair and blue eyes. They are found in the Scandinavian Peninsula and the East Baltic shores, as well as in Great Britain and the Low Countries. It is interesting to note that during and previous to World War I Hitler's régime was encouraging the propagation of more Nordics who actually make up only a small part of the population of Germany. The name later was appropriately changed to Aryan, which refers to culture rather than to race. The Celts, who reside today in Ireland, Scotland, and Wales, are not true Nordics.

4. *Alpines.* These are short, stocky, round-headed people with brown hair and eyes and a skin that ranges from white to olive in color. These are the first "broad heads" which, according to anthropologists, are a more recent race of people. They are supposed to have appeared in relatively recent times and have dominated the long heads. They are most common in central Europe today.

Mongoloids. Much of Eastern Asia and the Americas were originally populated with members of this race which includes the Chinese, Japanese, Eskimos, and American Indians. They are characterized by coarse, black straight hair, and skin that has varying shades of yellow and brown. Hair is confined to the head where it is abundant, whereas the face and the rest of the body are relatively naked. The head is round and the face broad with high cheek bones and a small nose. Many possess slanting eye apertures in which a peculiar fold of skin covers the upper eyelid; this is a specialized feature, the function of which is not clear. They are usually rather short and stockily built.

These people have thrived both in Asia and the Americas, although the North American Indian has not fared as well as his oriental cousins. Indians that made their way south into Central and South America have maintained themselves but those that stayed north have not done so well since the infiltration of Europeans. Most of them were little concerned about culture although some, such as the Aztecs and Incas, did reach a rather high degree of civilization until it was interrupted by the white man. The nomadic Indian could hardly develop a culture when he was always on the move.

The Eskimos, while definitely Mongoloid, are quite different from the Indian. They have narrow heads which might indicate some earlier admixture from one of the long-headed races. Their northern habitats caused them to build up a particular culture and they were a successful group until the coming of the white man who introduced, along with his good will and his religion, his own infectious diseases, all of which the Eskimo would have been better off without.

Man's present status. One might think that with all laws of evolution operative through these past 500,000 or more years present-day man might be a "super" human being, an animal physically perfect in all respects and geared beautifully to his environment. This, in fact, is far from the truth. The number of people with defective vision is a glaring example. The occasional inadequacies of the various organ systems is confirming evidence that they do not always function as they were intended, at least under present treatment which itself may be at fault. One is no farther from the state of health of the American people than he is from his radio; to listen would convince the less astute that these past one-half million years have delivered upon the world a species of animal that cannot possibly cope with his own surroundings. His environment has become so outrageous that he must constantly concoct and devise supplementary ingredients to his normal diet in order to keep his body functioning. This problem is far more economic than biological, and aside from differential birth rates and the possibility of self-annihilation the human race today might go on for a long time.

In spite of all of his apparent caducity, man has done rather well, biologically speaking. He has spread himself over a very large portion of the globe and has reached well over two billion in numbers, not a large figure, to be sure, when one considers that there are more bacteria in a quart of sour milk! He has managed himself rather well in most respects; he plans for his own food and shelter as well as other comforts of life. He has, by concerted effort, been able to allow himself some leisure time from the endless task of providing the bare necessities of life. He has used this time creatively, thus improving not only his immediate environment but also his relation to it. What is more important, he has written down the information he has acquired so that his knowledge can be passed on to others. Man can learn in his own lifetime more than experience could bring him in 100 or perhaps 1,000 lifetimes. This has been the real secret of man's skyrocket ascent to his present position in the world, at least the civilized world.

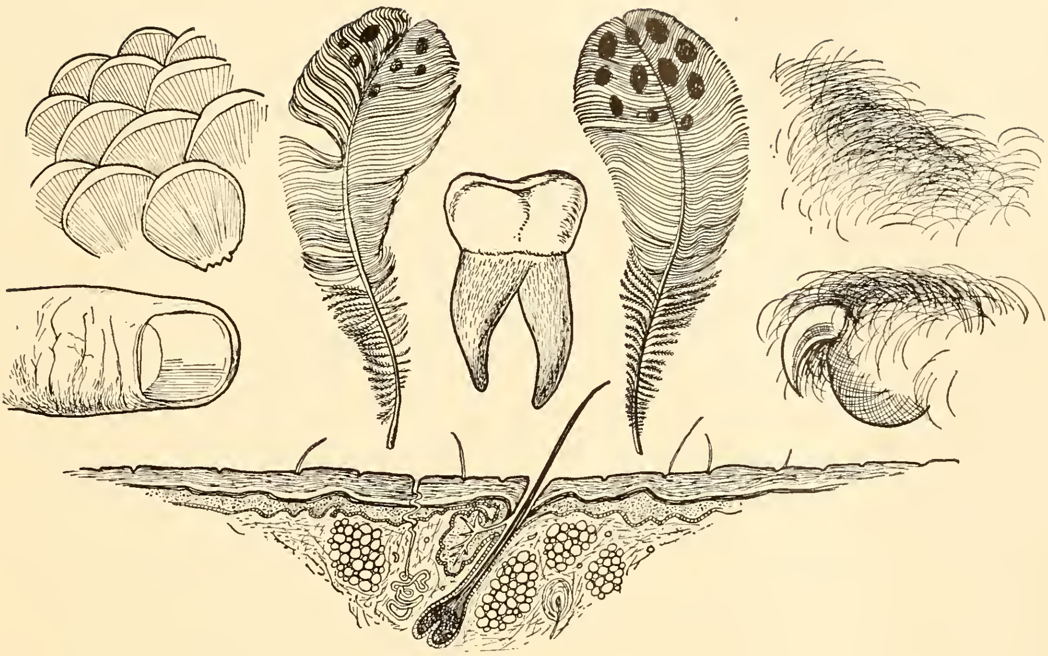
There has been little, if any, improvement in our brain since the Cro-Magnon man, and during the intervening 50,000 years progress toward civilization as we know it has been extremely slow. Only during the last 5,000 years, and particularly the past 300 years, has outstanding progress taken place. Why was man so slow in rising as a social animal, and why, when he started, did he rise so rapidly? It was undoubtedly due to the fact that he acquired the ability to put down in writing what he had learned so that those who followed could profit by his experience. Once this idea took root it flourished and with it the progress of mankind. Information is accumulating today at a staggering rate. Most scientists have great difficulty reading the literature that has been and is accumulating even in their own restricted field, to say nothing of that in the cognate sciences. It is doubtful if a person working 24 hours a day could read the titles alone of scientific papers that appear continuously. One of the big problems today is to condense this information so that any one person can have some understanding of it all. If the present rate continues, all the university buildings on all campuses will be filled with literature in another 100 years!

It is well worth while, then, to study rather carefully this animal that has made such stellar progress in the past few hundred years, and whose primary mark of distinction is a huge brain.

PART V

Organ Systems of Man

CHAPTER 14



HOUSING—SKIN AND ITS DERIVATIVES

MAN: A TYPICAL MAMMAL

The gradual evolution of animals has been discussed in the preceding chapters and considerable time has been spent on each group so that a working knowledge of their anatomy and physiology was covered. In studying the last group of animals, we have selected man as a typical mammal. A study of the rat, cat, guinea pig, or dog would afford no more information than that of the human body and for the readers of this book certainly no more interest.

Man is quite a typical mammal, unusual only in the size of his brain. He is not the largest or the smallest mammal, nor is he highly specialized when compared to the whale, for example. In fact, he is a rather mediocre mammal, being poorly endowed with organs of offense and defense. His puny, flat finger nails and short canine teeth are no match for the claw and tooth of the tiger or lion. His hide is not thick, like that of the elephant or whale, and it is completely unprotected by hair, the normal coat for most mammals. He has no horny outgrowths for defense, like the ungulates, and even his locomotor appendages are only fairly effective in getting him out of danger.

Man is no longer at home in the trees but has taken up life on the ground and with it the bipedal method of locomotion, a method far from new since the great carnivorous dinosaurs also employed it. Other present-day bipeds such as the ostrich can easily outstrip him in cursorial travel. He is poorly fitted for life in the water where his appendages are not well adapted for locomotion. He can submerge for only very short periods without coming up for air, and in cold water his survival time is very short.

He has, however, one crucial organ that accounts for most of his success, his well-developed brain. This organ, by its intricate disposition of nerve impulses, has made it possible for man to compensate for all of his physical deficiencies. With it he has been able, through the power of speech, to communicate with his fellows and later to put words down in writing. Over a long period of time this type of specialization has finally "paid off" because man today is the dominant species on the earth.

In order to understand man it has been necessary to study other forms of animal life. Man does not lend himself well to experimentation for obvious reasons and, furthermore, he grows too slowly to permit studying succeeding generations. He cannot be kept under the controlled conditions that are possible with rats in a cage. However, most of our information about his functioning has come through the careful study of lower animals. If it were not for these experiments our knowledge would be very meager. This brings up an interesting and important point concerning attitudes of the species, *Homo sapiens*.

There are small isolated groups of people who oppose any animal experimentation (primarily experiments on dogs, cats, and other pet species), sincerely, perhaps, or stirred by some ulterior motive such as publicity, for example. In any case, they are a small but usually active group who are constantly stumping for legislation which would curtail present-day experimentation. It requires only a slight knowledge of the subject to realize that most of the information about the functioning of the human body can come only through such experiments. How would anyone suffering from appendicitis, for example, particularly an antivivisectionist (the self-styled name applied to these people), appreciate having a doctor who has had no experience whatever on lower animals attempt to remove the offending organ? If the antivivisectionist lived up to his code, he should rightly refuse any medication which stemmed from a study of lower animals. However, it is highly probable that if he is taken ill he will proceed with all haste to obtain the best available skill, no matter how it was acquired. Such groups today are only a general nuisance, although they frequently cause the loss of valuable research time of prominent biologists who must stoop to the task of defending themselves. Much more could be said on the topic but perhaps at this point it would be well for the student to draw from his own experiences and form his own conclusions about this matter.

We shall now turn to a discussion of the organ systems of man, as illustrative of vertebrate organ systems in general. Each system will be discussed at some length, together with a brief account of similar structures in other animals from the lowest to the highest. Although some attention has been paid to these topics in the discussion of each animal group, it is well to review the information briefly before each system of man is studied. With this approach, perhaps the structures and their functions as found in the human body may be better understood.

OUTER COVERING—THE SKIN

As we have seen in the preceding chapter, all animals are provided with an exterior covering that functions as a barrier against the outside world. This is extremely simple in the lower invertebrates, but becomes

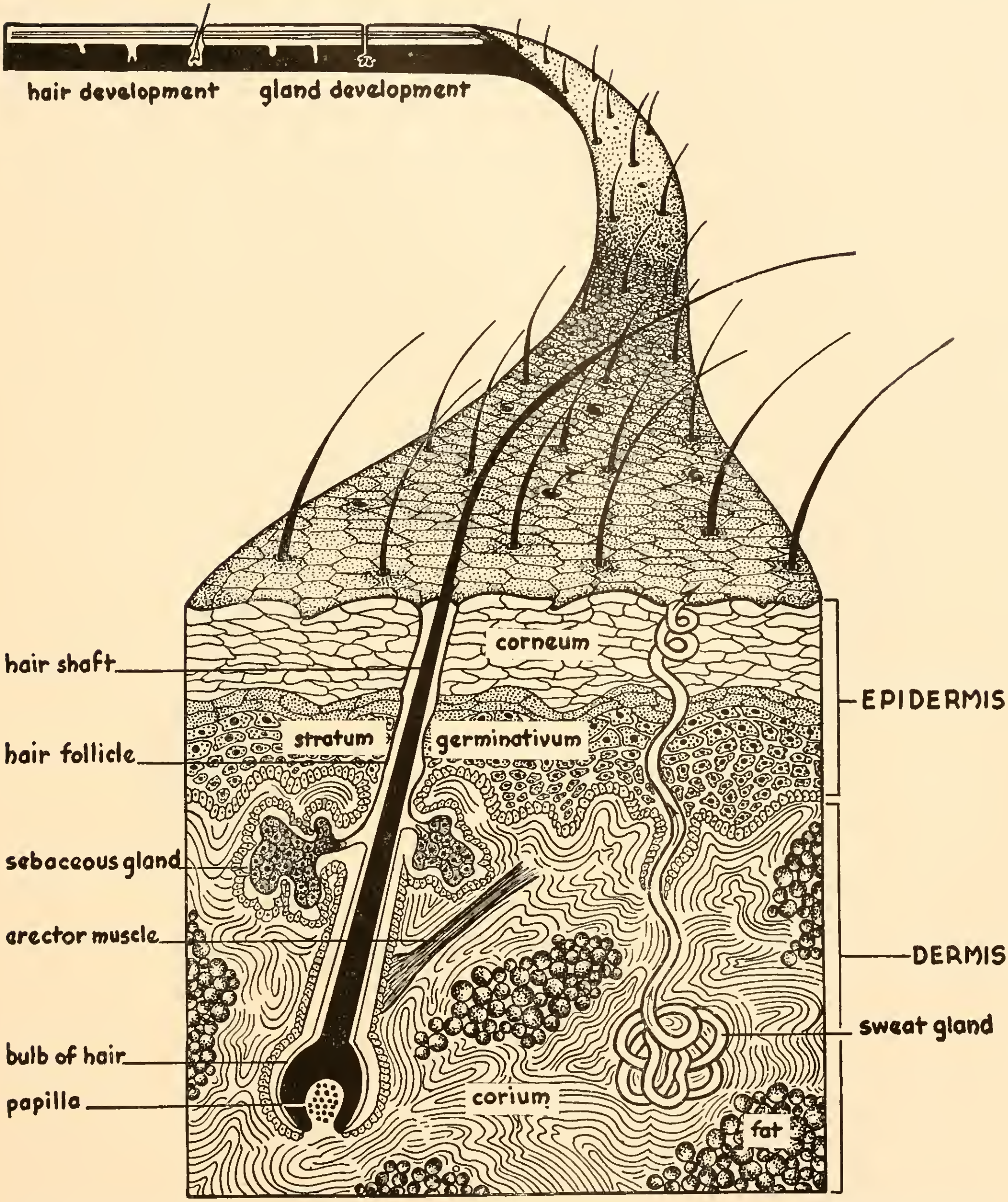


Fig. 14-1. Human skin in cross-section. Gland and hair development are shown in several stages (top left).

much more complicated in higher forms; as, for example, in the vertebrate skin with all of its derivatives.

In these animals the skin forms a continuous unbroken sheath which protects the internal structures from the environment. In addition to being tough itself, it is often fortified with scales, feathers, or hair for added protection against physical injury by predaceous enemies. Moreover, it is refractive to bacteria and other microörganisms that could be injurious if allowed to enter the internal environment. It is impervious to most harmful chemicals and is important in regulating the water content of the body, functioning differently in aquatic and terrestrial forms. Heat regulation is also controlled by the skin indirectly through water loss, as well as by various insulators such as hair and feathers. The penetrating effect of light is regulated by pigmentation of the skin. Among some vertebrates the skin takes part in respiration (for example, the frog). These many functions of the skin signify its importance.

It is necessary to examine the skin microscopically if one is to understand how it performs its many and sundry jobs, and we will take human skin as our example. It is usually divided into two parts, the outer, thinner **epidermis** and the inner, thicker **dermis** (Fig. 14-1). The epidermis is composed of an outermost non-living covering, the **corneum**, which is the part in immediate contact with the outside world; lying beneath it is a layer of epithelial tissue which is composed of actively growing cells. As the cells grow they move towards the outside, die, and eventually become the corneum. These dead cells are constantly being sloughed off in mammals and many of the lower vertebrates. Everyone is familiar with the loss of these cells in unexposed parts of the body such as back of the ears and between the toes. They are particularly noticeable in the hair, where they resemble flaky "scales" and do not have an opportunity to escape readily. These dead cells are spoken of as dandruff and often erroneously assigned a pathological condition, particularly by certain business establishments whose chief concern is to sell a product that will clear up this "malady." The corneum is perforated by many tiny holes through which **sweat** passes from **glands** that lie deep below. The corneum becomes very thick on the soles of the feet and the palms of the hands (calloused), especially in people who perform heavy labor requiring the use of these appendages. Another interesting characteristic of the corneum of these areas is the formation of **friction ridges.** It is the presence of these in the hand and foot which causes fingerprints and footprints. These friction ridges apparently have come through a long evolutionary history, being

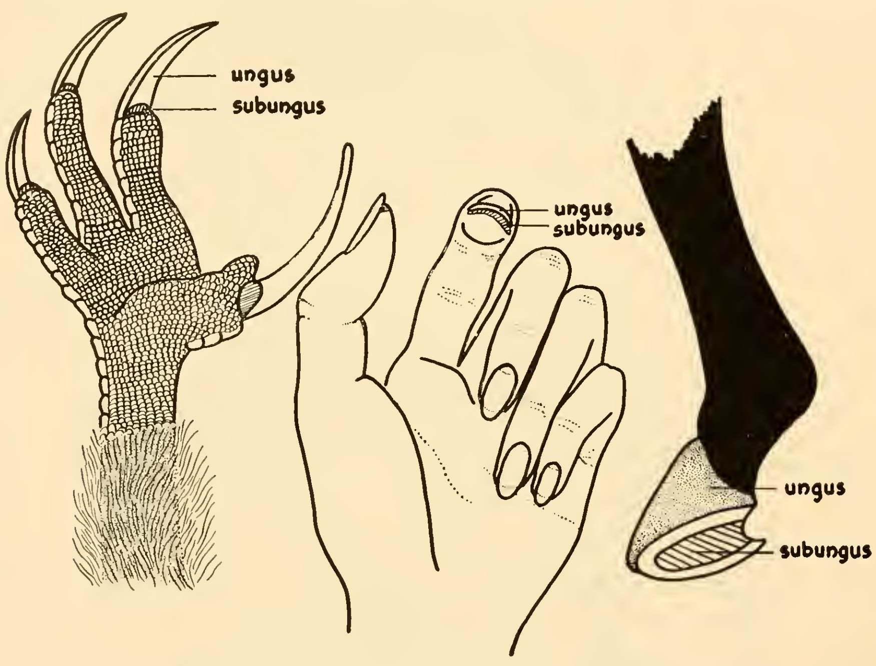


Fig. 14-2. Homologous digital tips, claws, nails, and hoof.

originally digital pads of four-footed animals. When mammals took to the trees, the pads developed into transverse ridges which functioned in increasing the friction between the hand and the branch, thus preventing slipping. In man the ridges are generally arranged in whorls, although they are transverse to the long axis of the fingers for the most part. The designs appear to be infinite in numbers and never seem to be repeated on the tip of any digit, either on the hand of one individual or on any other individual. This has provided a convenient means of identification because it positively distinguishes one person from another, and its primary use today is in criminal investigations.

The actively growing layer of the epidermis (**stratum germinativum**) produces many structures which on the one side are sunk deep into the dermis and on the other side are an important part of the external covering. The scales of fish and reptiles, the feathers of birds, and the hairs of mammals have such relationships (Fig. 14-1). Although these all have similar origins, in the final adult stage they are quite different both in structure and function. Digital tips in various vertebrates, such as the carnivore claw, the ungulate hoof, and the primate nail, are likwise produced from this region of the epidermis (Fig. 14-2). They are all homologous, since each has the same origin but performs a different function.

Derivatives of the epidermis

Scales and feathers. Both of these outer coverings have a common origin (Fig. 14-3) and they are much alike both anatomically and functionally. Scales are found principally among the fishes and reptiles, although birds have them on their legs and some evidence of scales appears among the mammals (for example, tail of rat and beaver). Structurally, they resemble overlapping or abutting plates that offer considerable resistance to outside mechanical injury. When overlapping like shingles, they are so arranged as to offer the least resistance to forward motion.

Feathers resemble scales in their overlapping arrangement, although otherwise the likeness is not so obvious. They are much lighter in construction, possessing numerous tiny filaments that offer resistance to the passage of air through them. The wing feathers of birds will allow air to pass one way but not the other—a beautiful example of adaptation to flight.

Teeth. Teeth are also epidermal outgrowths, having a common origin with scales (Fig. 14-4), particularly those of the shark (placoid). Since the mouth is lined with ectoderm (the germ layer that gives rise to the epidermis), we might expect that it (the mouth) could be equipped with any structure that could come from ectoderm. The scales in sharks enlarge and grow over the edge of the jaw, producing teeth. Human teeth come likewise from ectoderm and fit into cups or sockets provided for them in the jaw.

Hair. These tiny projections from the skin of mammals perform a protective function against both physical injury and heat loss. The numerous hairs tend to provide a dead air space just above the skin which prevents heat loss much like insulation materials in a house. Feathers also act as heat insulators, a fact readily observed on cold days when birds ruffle up their feathers to improve the insulating properties of their integument. On a hot day, a bird keeps its feathers close to its body to allow as much heat to escape as possible.

Mammals, with the exception of the whale and man, are covered with a thick coat of hair. Man has lost most of his hair, probably because he evolved in a warm climate. Today it is present only in the pubic regions, under the arms, and on the face and head. The facial adornment is a male secondary sexual characteristic because it is not found in the female. The rest of the body is usually covered with very tiny hairs which are vestigial, for they perform no function in

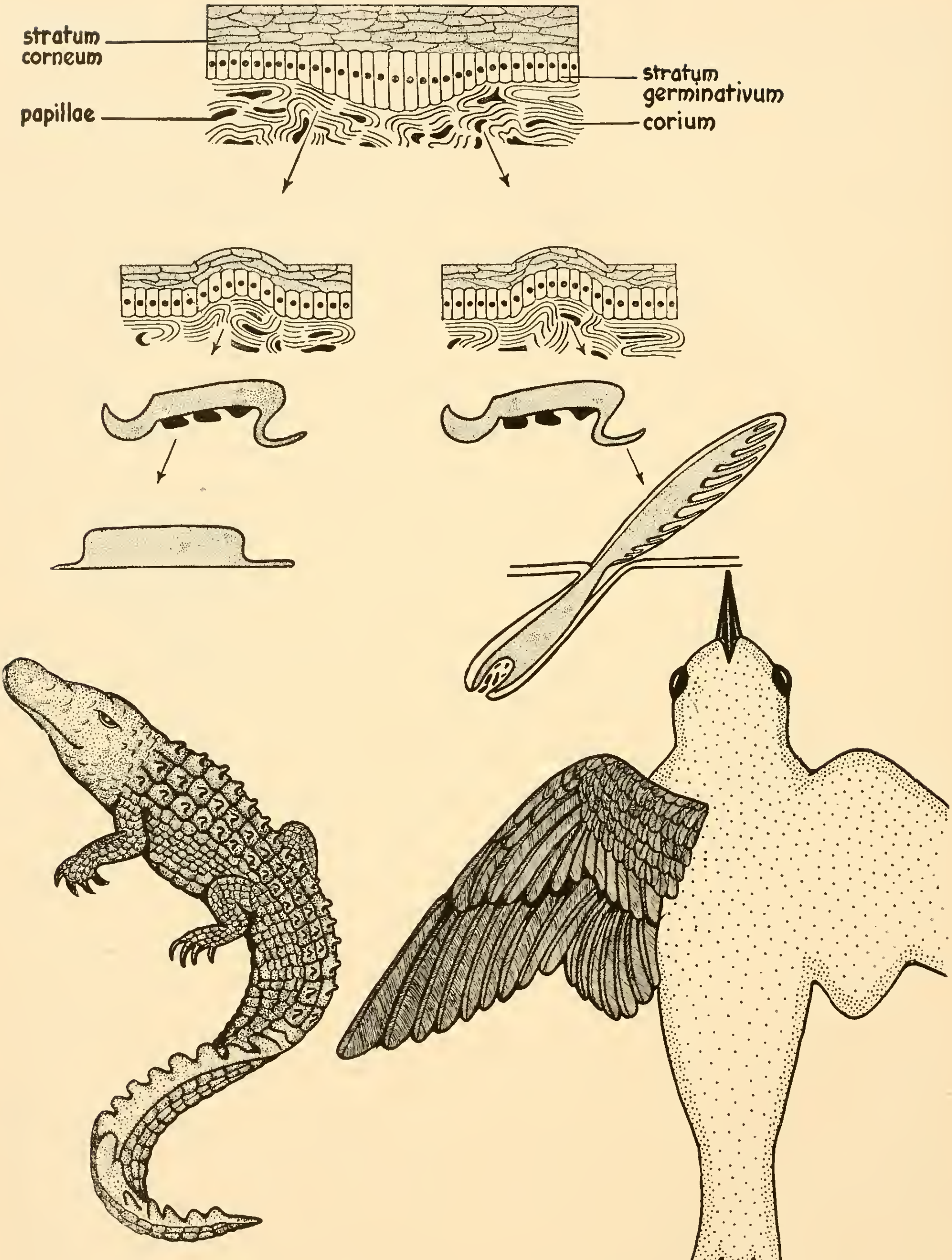


Fig. 14-3. Stages in the development of reptilian scales and feathers, showing their common origin.

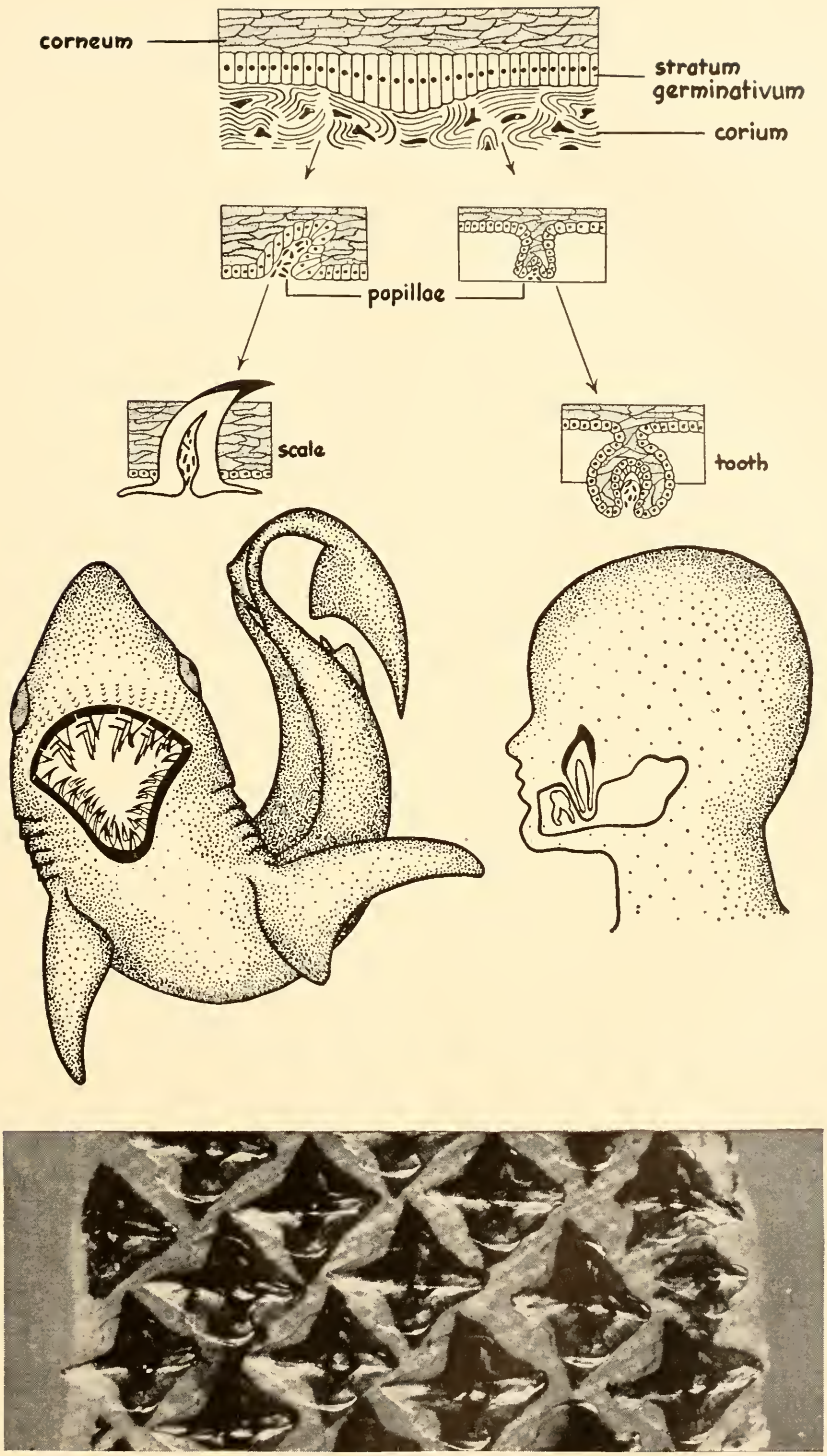


Fig. 14-4. Stages in the development of scales and teeth, showing their common origin (top). A photograph of shark's skin showing the tiny scales. Note their tooth-like nature (bottom).

modern man. This loss of body covering carries with it the obvious disadvantage of rapid heat loss in a cold climate and man has thus been forced to clothe himself with an artificial covering. The adornment feature of clothing cannot be overlooked, for even in hot climates aboriginals frequently cover themselves, particularly if the cloth is highly colored.

Hairs are arranged in definite patterns in the various regions of the body of man as well as other mammals. They are not perpendicular to the skin surface but slant, usually in a specific direction. For example, in a dog the hair slants away from the mid-dorsal line, usually in the direction of the pull of gravity, and this probably helps in shedding water. In man the direction of the hair slant in the back region is the same as in dogs. On the arms and legs it also follows a common pattern but on the top of the head it sometimes forms whorls or "cowlicks," which, strangely enough, are specifically inherited from generation to generation.

Attached to the base of each hair are tiny muscle fibers which, when contracted, cause the hair to stand on end, producing "goose flesh" (Fig. 14-1). These muscles are under the influence of the autonomic nervous system and are therefore beyond voluntary control. When one is frightened or sometimes under other emotional stress, the hair can be seen to stand on end, particularly along the spine. The common statement, "Chills run up my back," has a physiological foundation. A similar reaction can be observed in a dog and cat when in the presence of potential enemies.

Pigment granules lying in the lower epidermal layers of the human skin give it color ranging from no color at all, as in the abnormal albinos, to the dense pigmentation in black people. Sunlight has a decided effect, not only on increasing the amount of pigment (tanning), but also on increasing the thickness of the epidermis itself. The purpose of such a response is protection because ultraviolet light damages unprotected skin, as most people know. Continual exposure to bright sunlight produces a dark, tough skin, even in white people—a far cry from the complexion recommended by beauty experts. Yet would-be beauties will often expose their bodies too long and too often so that the damaging rays of the sun produce the type of skin that is considered undesirable.

Glands. Near the base of each hair is a tiny sebaceous gland which secretes an oily substance designed to keep both the hair and the skin in a soft, pliable condition. These glands, like other skin glands, come from the epidermis, although they are buried deep in the dermis (Fig. 14-1). The tiny, much coiled, sweat glands are likewise found deep in the dermis where they function in extracting water from the blood and tissues and spreading it over the surface of the skin for the purpose of cooling the body (Fig. 14-1). The resulting evaporation reduces the temperature of the skin and thereby aids in the regulation of the temperature of the entire body. This is very important to a mammal, although in many species these glands are localized in small areas, which are quite different in different mammals. The cow, for instance, has them confined to its nose, whereas others such as the horse and man have them distributed rather generally over the body. In man they are concentrated in the palms of the hands, soles of the feet, and under the arms.

Another very interesting skin gland found only among mammals and fully developed only in females is the *milk* or *mammary* gland, a name that is linked with the group. These are modified sebaceous glands and are confined to areas most convenient for suckling the young mammal, which they supply with a complete food during its early post-embryonic life, a sort of continuation of umbilical feeding.

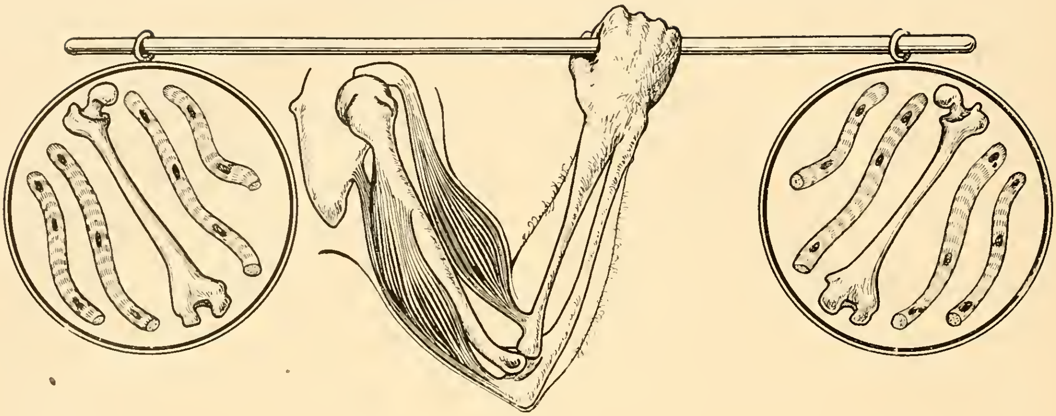
The dermis

This layer of the skin is much thicker than the epidermis and is composed of tough connective tissue (Fig. 14-1). The nature of this layer becomes apparent if one recalls the various kinds of leather that are employed by man for thousands of purposes. It is interesting to note that man uses the skins of other animals to supplement his own. Fat has a tendency to store itself in the deeper parts of the dermis and becomes localized in characteristic regions of the body familiar to everyone. In unusual cases, the stored fat can weigh as much as the remainder of the body, a character which is admired by some races of people and abhorred by others. The distribution of this layer of fat is characteristic of the sex. For example, in the female the layer is thicker, giving the skin a more velvety touch and, the body contours are smoother curves with the underlying muscles less pronounced than is the case in males. Women are therefore better insulated than men, although they seem to suffer more from the cold, perhaps due to their scanty artificial covering, a mere fraction of that with which the male burdens himself.

Many tiny bundles of blood vessels project up from below into the dermis where they function in bringing the blood close to the surface for cooling the body when it is too warm. They contract when the body is cold (**vasoconstriction**), preventing the blood from coming to the surface. They are under the influence of the autonomic nervous system and may be influenced in some people by emotions such as in blushing (**vasodilation**). Also, the dermis contains many nerve endings which are receptors for heat, cold, pressure, touch, and pain. With the exception of the pain nerve endings, they are specially designed end organs for special stimuli. Since the skin is in contact with the outer world all of the time, a great deal of information comes to the brain from it. Pain, for example, is a very uncomfortable sensation, ideally designed to make the animal do something about the situation, if possible. This sensation is responsible for preservation of the individual, for without it great areas of the body might be destroyed without the organism being aware of it. A few people have no nerve endings in their skin and hence feel no pain; as a consequence, they can be seriously burned or injured in other ways before becoming conscious of the danger.

Thus we see that most animals possess some sort of protective covering. They also need some internal support, particularly the larger forms and those animals that live on land. Let us study the way vertebrates, and man in particular, have solved this problem.

CHAPTER 15



SUPPORT AND MOVEMENT

Animals have devised many forms of support for their bodies. The various structures not only hold the body together but also, in many cases, have an important protective function. To be sure, such single-celled animals as amoeba exist completely naked, with no protective covering whatever. Their close relatives, however, such as *Difflugia* (Fig. 15-1), secrete a substance which collects tiny siliceous particles (sand) and cements them together to provide an enclosure into which they may draw themselves when hard pressed. Paramecium possesses a semi-rigid **pellicle** which gives it some external support so that its body maintains a relatively constant shape. Sponges produce minute angular **spicules** which afford a rather rigid skeleton, and many coral animals secrete substantial external skeletons. Larger invertebrates, such as arthropods and mollusks, provide themselves with hard outer coverings which not only lend the body substantial support but are highly protective as well. Vertebrates, on the other hand, have adopted an internal skeleton designed primarily for support. It affords very little protection to the soft external parts of the animal, although it provides excellent protection for such vital organs as the brain, heart, and lungs.

Let us consider the human skeleton as an example of a vertebrate skeleton.

THE SKELETON SYSTEM IN MAN

The skeleton of man is similar to that of other mammals, almost bone for bone, but certain parts are emphasized more or less than similar parts in other mammals. This is because of the upright position his body has taken. All animals that have taken to bipedal locomotion, the dinosaurs, the birds, and the kangaroo, for example, have shifted their body weight so that some parts of the

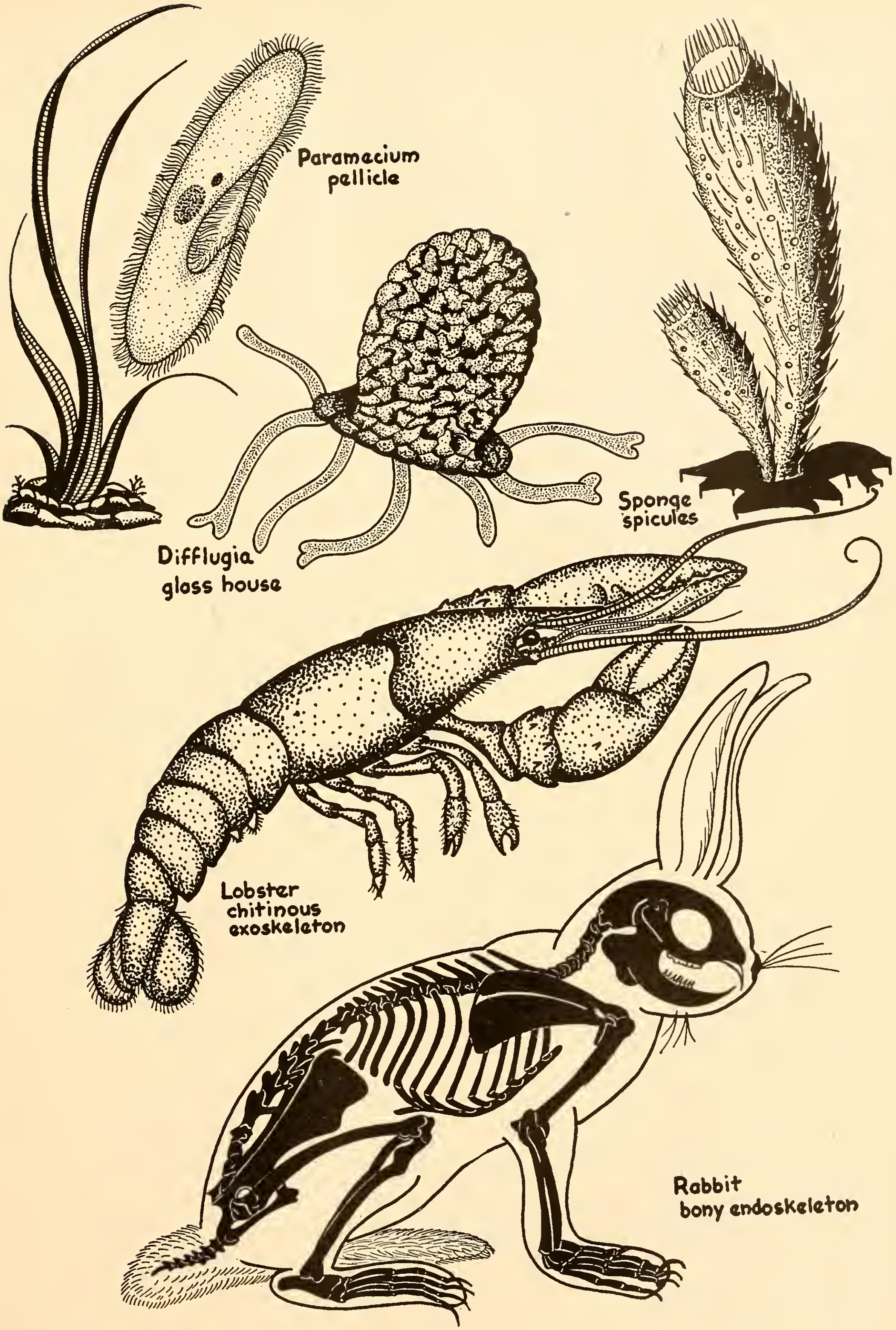


Fig. 15-1. Representatives of some animal groups showing the way they have solved the problem of support.

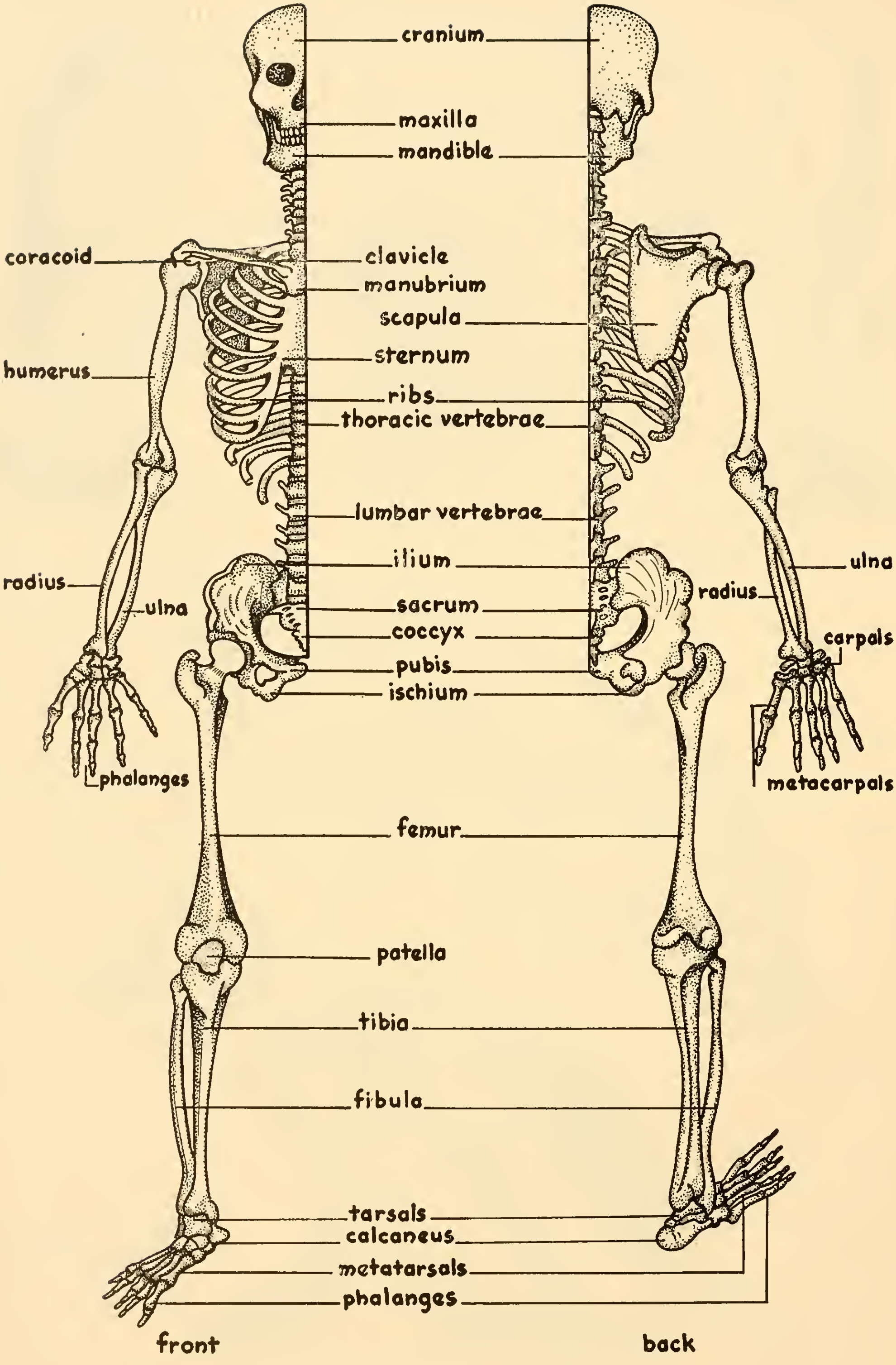


Fig. 15-2. The human skeleton, front and back views.

skeleton must bear a greater portion of the burden than other parts. In quadrupeds the spinal column and legs resemble a suspension bridge where the column functions as the bridge itself and the legs as the supporting piers at either end. In man and other bipeds the body is elevated at one end until it is in a vertical position which requires more secure footings at the base. This is essentially how a tall building such as the Empire State Building in New York is constructed—merely a bridge stood on end with elaborate footings. In the human skeleton, this shift in weight has also necessitated more rigid connection between the supporting vertebral column, and the pelvic girdle to which posterior supporting appendages are attached. This appears to function in a fairly satisfactory manner, although if one may judge by the number of middle-aged people suffering from a "sacroiliac" (the development of a faulty union between the column and pelvic girdle), it is clear that the arrangement is not as good as it might be.

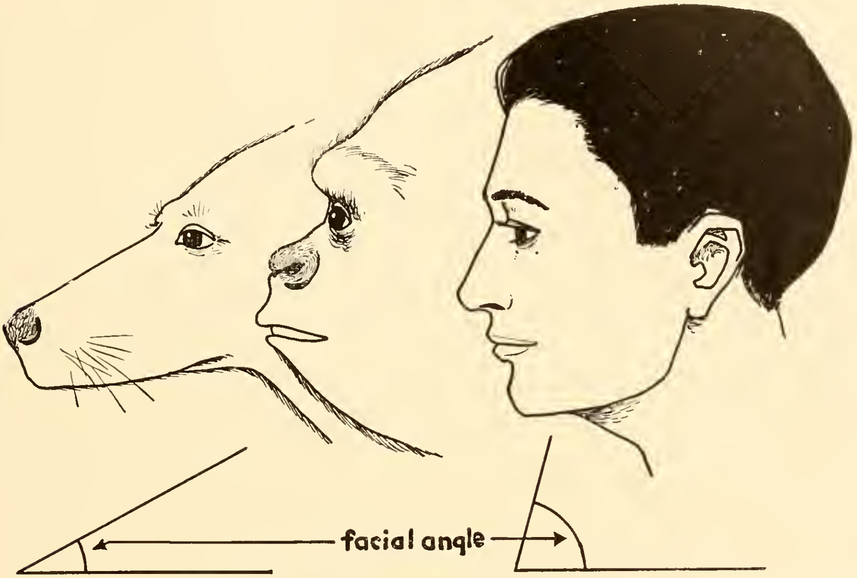


Fig. 15-3. Comparative profiles of the dog, monkey, and man to show the relative shift in the facial angle (see text). Because of the increasing size of man's brain, which has grown over his shortened jaws, his facial angle has increased over that of lower forms.

The axial skeleton

The skeleton is usually divided into two general parts: the axial region comprising the **skull**, the **column**, and the **ribs**, and the **appendicular** region which includes the appendages and their **girdles** (Fig. 15-2). All of the bones are so securely tied together with ligaments that they are torn apart only under great strain. In spite of this seemingly well-built frame, it is often badly mutilated in accidents as a result of our modern means of transportation.

The skull. The skull shows considerable modification when compared to that of lower vertebrates. The greater emphasis on the cranial case compared to the mandible is obvious when the heads of the dog, monkey, and man, for example, are placed side by side (Fig. 15-3). As the brain has grown forward over the shortened jaws, it is easy to see how the facial angle (angle between a line drawn along the forehead and one from the base of the nose to the foramen magnum) has increased and how the human face has been formed (Fig. 15-3).

The human skull is made up of 28 bones, 22 of which are joined by jagged-edged **sutures** (Fig. 13-30). The other 6 are the tiny ossicles of the ears. The bone which supports the tongue and larynx, the **hyoid,** is loosely connected with the skull. Although most of the skull is heavy, solid bone, certain portions contain cavities. These are remnants of chambers that formerly had specific functions but which apparently have lost these and perform no known function today. For example, the three sinuses in the anterior and middle portion of the skull once served the sense of smell but do not do so now. There is a pair of maxillary sinuses in the cheek region, a pair of frontal sinuses over the eyes, and a single sphenoid sinus in the posterior part of the nasal chamber. They all have small ducts which drain into the nasal chambers but the arrangement is such that drainage is not good, especially when the membranes are swollen with a cold. Under such conditions the large surface area of the sinus membranes becomes infected, causing the so-called **sinus trouble** which is often difficult to treat satisfactorily. Another spongy bone, the **mastoid,** lying behind the external ear may also become infected via the eustachian tube and the middle ear. Such an infection can reach the brain because the mastoid is separated from it only by very thin bone. Surgery, in which a portion of the bone is removed, is one of the methods of clearing up such infections.

The brain is exposed to the outside wall in only one place, and that is in the nasal chamber. The floor of the brain case, where the olfactory nerves leave the brain and pass down into the nasal chamber, is called the **cribiform plate.** It is a piece of bone perforated with many small openings through which the nerves pass and through which, unfortunately, nasal infections can reach the brain.

The cord enters the human brain case ventrally instead of posteriorly as is the case with most mammals. The large opening through which it passes is called the **foramen magnum.** Since the skull is precariously perched on the tip of the spinal column it might be expected that the cord could be broken at this point rather easily, and such is indeed the case. A severe blow at the base of the neck will snap the cord at the point where it enters the skull. This vulnerable spot is taken advantage of by man in getting rid of his incorrigible fellows, by hanging. Other openings into the brain case are the foramina for numerous small blood vessels and for the cranial nerves, including the optic nerves at the base of the orbits.

At birth, several bones from the brain case have not come together (sutured), so that five spaces are left without bony covering. These are called **fontanelles** (little fountains—so named because they rise and fall with each heart beat). This lack of suturing before birth plays a very important function in the birth process, for the head of the child undergoes severe squeezing while passing through the birth canal and needs to change its shape to fit the narrow passage. Were the skull hard, the difficult process of being born might be even more difficult or impossible. The head of the newborn child is very plastic and can be molded into almost any shape. Flathead Indians took advantage of this fact by placing a board on the head of the newborn, thus causing the forehead to have a peculiar flat appearance in the adult. As the child grows, the fontanelles gradually close, leaving five jagged lines at the junctures. The age of a skull can be told by the clearness of these lines. They are faint or absent in old skulls.

Injuries to the skull have been common throughout man's history. Early skulls often show evidences not only of natural injuries but also of apparent deliberate removal of small portions. Such drillings (called trephining) seemingly had some religious significance, but the remarkable thing about them is that the patients often recovered, as revealed by the smooth edges of the opening, indicating that the bone healed. Similar operations are performed today for entirely different reasons and with much more satisfactory results.

The spinal column. When a comparison is made between the spinal column of man and almost any of the other mammals, certain striking differences are noted (Fig. 15-4). These result from the upright posture man has assumed. In the dog, for example, the column forms a smooth arch between the two pairs of legs; in man, on the other hand, it forms a sigmoid or S-shaped curve. This serves an important purpose in an upright animal. With the head resting on the top end of the column, a rigid, straight rod would afford very little resilience whereas a curved column would spring gently, thus cushioning the jolts that are conducted through the legs from the feet as they come in contact with the ground. The curved spine of man is admirably designed to give the head a smooth ride. If the pliable spine of a growing child is subject to undue stress, it may ultimately affect the development of the adult skeleton. Much of our posture is dependent on the spine and there is much emphasis today on the desirability of good posture. While this is highly desirable, it is not a guarantee of good health. Good health is due to a great many things and cannot be guaranteed by any such simple formula.

The spinal column is composed of 33 articulating **vertebrae** of rather irregular sizes from the neck to the pelvis and they fit snugly together. They are securely laced together by many ligaments, so that the column as a whole is a beautiful piece of engineering. This is essential because the column houses the very delicate spinal cord which, if injured even only slightly, may cause dire effects in the operation of the appendages as well as other parts of the body. The column is more flexible in some regions than in others. For example, the

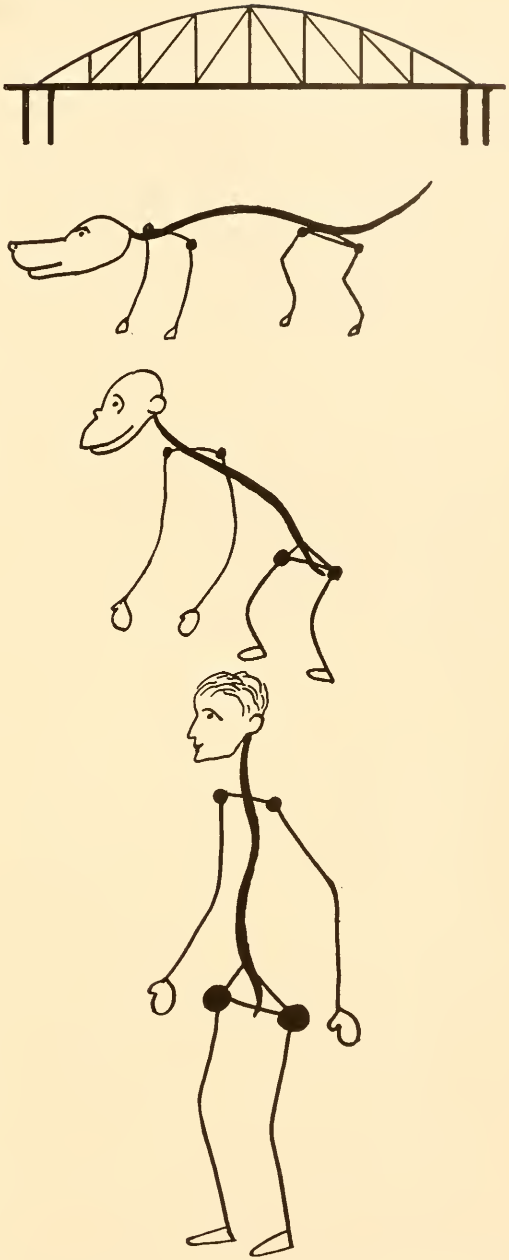


Fig. 15-4. The spinal column is the axial support of vertebrates and is subject to considerable variation among the different groups, depending on the stress and strain put upon it. In the quadraped, such as the dog, the column functions like a bridge with the two supports at either end. When the support is shifted to the two posterior appendages, such as in the ape, a more secure attachment must be affected between the column and the pelvic girdle. This is carried further in man, where we see a huge pelvic girdle, since the posterior appendages must provide the only means of support and locomotion.

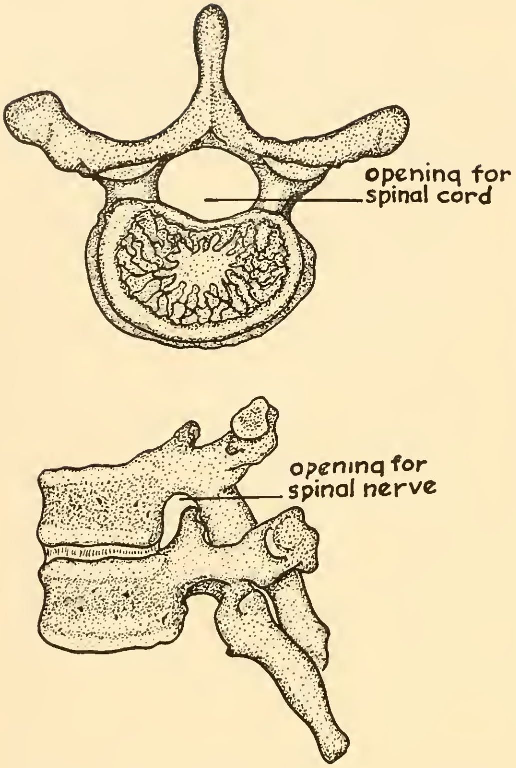


Fig. 15-5. The spinal column is composed of interlocking vertebrae that, taken together, form a sturdy, flexible support for the entire body. The large openings in the vertebrae form a bony canal in which the delicate spinal cord is housed. Between the vertebrae are paired openings through which the spinal nerves pass.

vertebrae of the thoracic region are relatively immovable whereas those in the lower back and neck region have considerable amplitude of movement. This arrangement allows for a large variety of movements of the trunk, as evidenced by the ballet dancer in action.

Pairs of small openings between the vertebrae provide exits for the spinal nerves (Fig. 15-5). Each vertebra has a large cylindrical passageway, and these taken together form the **neural canal** which houses the nerve cord (Fig. 15-5). Five of the lower **sacral** vertebrae are fused into a solid bone, the **sacrum**, which joins the **ilia** (singular—*ilium*) on the dorsal side, thus securely attaching the pelvic girdle to the spine. It needs to be a broad, secure attachment because the whole upper body pivots at this point and the stress is considerable. Unfortunately, the joint is not bone-to-bone but via ligaments, and when it partially gives way under unusual strain much distress is caused.

The spinal column terminates in several (5 to 12) tiny, useless vertebrae, collectively known as the **coccyx**. In many vertebrates they give support to a functional **tail**, but in man they are mere vestiges of the past. Undoubtedly, far back in man's early history, long before he was man, he had a tail. It must be remembered that the presence or absence of a tail means nothing from an evolutionary point of view. The bear and guinea pig are without tails, yet they are no more related to each other than either is to man.

The ribs. The 12 ribs are attached to the **transverse processes** and the **centra** on the column side and 10 of them to the sternum directly or indirectly on the ventral side. These together form the **thoracic basket**, a convenient enclosure for the vital organs located in the chest region. It is interesting to note that the number of ribs is not always 12. The millions of chest x-rays taken of soldiers in the last war brought to light the fact that there is considerable variation, ranging from 11 to 13, the latter number being the most common variation. Incidentally, the gorilla also possesses 13 ribs.

The appendicular skeleton

The remainder of the skeleton, consisting of the appendages and their supports or girdles, is called the appendicular skeleton. The **pectoral girdle** to which the arms are attached is located in the anterior region. It consists of two **clavicles** (collar bones) and two **scapulas** (shoulder blades); taken together they form a triangular brace with the arm hanging at the apex. Clavicles are rudimentary or absent in most mammals, but in the primates they are large, functional bones. This difference is owing to life in the trees, where brachiation was responsible for the development not only of the clavicle but also the nerves and muscles of the arms which make them such useful appendages today. While the clavicle is firmly attached to the sternum on the front, the scapula has no secure attachment and is loosely slung over the thoracic basket by means of muscles and ligaments. This arrangement permits a great deal of movement in which the shoulders can be freely rolled over the ribs. The anterior appendages have much more freedom of movement than the posterior appendages, whose primary function is locomotion.

The upper arm, the **humerus**, fits into a crude socket made by the union of the scapula and clavicle called the **glenoid fossa.** The humerus is held in place by ligaments at its upper end, but since the attachment is none too secure, under certain stresses it may be forced out of the socket, resulting in a dislocation. Such stretched ligaments allow dislocation more readily under similar subsequent stresses. The advantage of this junction lies in its loose arrangement which allows more freedom of movement for the arm. For example, the arm may be turned in a complete circle as well as rotated in the socket. A dog, on the other hand, could not possibly perform such a feat, for the arrangement of the bones in its pectoral girdle is much more rigid.

The two forearm bones, the **radius** and **ulna,** form a combination whereby hinge action as well as partial rotation can take place. This means that the forearm can be flexed (bent on itself) in a straight pull or it can twist through 180 degrees. The number of times one performs these movements each day is almost unlimited. At the wrist another hinge is produced by the end of the radius and the **carpals,** the small wrist bones. Actually this is as much a universal joint as it is a hinge, with the result that the hand can move in all directions with equal facility. The hand with its large, opposable thumb is a primitive but most useful instrument and it is hard to imagine life as it is lived today without it.

The **pelvic** girdle is the most specialized part of the entire skeleton. A quadruped, running on all fours, does not require as secure an attachment to the column as does a biped, whose pelvis has become correspondingly modified. However, in the case of man the pelvis has become not only an excellent support for the entire body but it has also broadened and flared out so that it functions as a support for the organs of the abdominal cavity. This again is a satisfactory method of handling the pendent viscera of the upright animal.

The pelvis is composed of three pairs of fused bones: the large, flat and cupped **ilia** (singular—*ilium*), the **ischia** (singular—*ischium*, the bones used in sitting), and the **pubic bones** which complete the girdle in front. The fused vertebrae of the sacrum form a complete circle at the back, leaving a large opening through which all mammal offspring must pass in the process of birth. The urinary and digestive tracts pass through here also. The dimensions of this opening are one of the clues used in determining the sex of a skeleton. Not only is the opening larger in females but, in addition, the attachment of the pubic bones is not so broad. Both features are essential to allow such a large object as a fetus to pass through. The ilia also flare outward more abruptly in the female than in the male; this changes the position of the legs somewhat so that the method of walking and running differs in the two sexes. The familiar female "waddle" is a result of skeletal arrangement, not any intention on her part. For the same reason it is highly unlikely that a woman will ever run the 100-yard dash in 10 seconds.

The **femur** is the longest bone in the skeleton. Its proximal end (end nearer the body) is a pronounced ball which lies at an angle to the rest of the bone and which fits into a deep socket in the pelvis called the **acetabulum.** This is a much more secure arrangement than the one in the shoulder region, although it does not have equivalent freedom of movement. For this reason the hip joint is not nearly so apt to dislocate as the shoulder joint. The leg can circumscribe a narrow cone but not a wide one like the arm. The leg is primarily concerned with the business of carrying the body forward in progression and consequently is constructed to function essentially in a forward and backward motion.

At the distal end (end farther from the body) the femur flattens out, forming a hinge with one of the two lower leg bones, the **tibia** or shin bone. The other lower leg bone is the **fibula**, which is smaller and lies on the outside of the leg. Together with the tibia it affords a point of contact, in turn, with one of the two large ankle bones. The other forms the heel. These two, together with the **metatarsals** and **phalanges**, form the foot. This part of the skeleton is man's contact with the ground and is a very important part of his anatomy. When something goes wrong here he is practically helpless.

There are two arches in the foot, **longitudinal** and **transverse**, which are primarily supported by stretched tendons that come from muscles in the lower leg. Being always under tension, they possess a resilience that puts a "spring in one's step" and they also take away the shock from sudden contact with the substratum. Flat feet may be caused by undue stress such as comes from overweight or they may be inherited. Such dislocation of the bones of the feet may cause considerable pain and make normal walking difficult.

We have considered in some detail the arrangement of the structural units of the vertebrate skeleton. Let us now examine the composition of these units.

The composition of bone

If a long bone like a femur is cut in cross-section, it will be found to be hollow with a soft spongy material, the **marrow**, occupying the cavity (Fig. 4-4). The outer portion is very hard and resists breaking. The tubular nature of the bone makes it even stronger than a solid piece of equal weight; to understand this, one has only to compare solid and tubular rods of steel with respect to strength where bending and twisting is concerned. The hard part of bone is composed of calcium carbonate, or lime, and potassium phosphate, as well as an organic matrix which resembles cartilage. This can easily be demonstrated by placing the bone in an acid solution which dissolves out the minerals, leaving the matrix. Although the bone still retains its original shape it is very soft and pliable and as such could certainly be of no use to an animal. On the other hand, the organic matrix can be removed by heating the bone for some time so that only the minerals are left. Such a bone also retains its original shape but if disturbed crumbles into ashes. Again a bone of this composition would be of no use to an animal. Minerals and matrix taken together, then, are necessary to produce satisfactory material of which to construct skeletal units.

Bone growth

It is obvious that the bones of a child, while fully formed and quite solid, must increase both in length and diameter as growth occurs. This is accomplished by a rather elaborate bone-destroying and bone-building process going on within the bone itself. The bone is covered on the outside by a thin cellular membrane, the **periosteum**, which has to do with the increase in the diameter of the bone. At the ends, called the **epiphyses** (singular—*epiphysis*), there is also active cellular growth which causes the increase in length. As bone is produced by both periosteum and epiphyseal cells, a simultaneous bone destruction is going on within the marrow cavity. In other words, as the bone cells produce bone on the outside and at the ends of the bone, similar cells are destroying bone on the

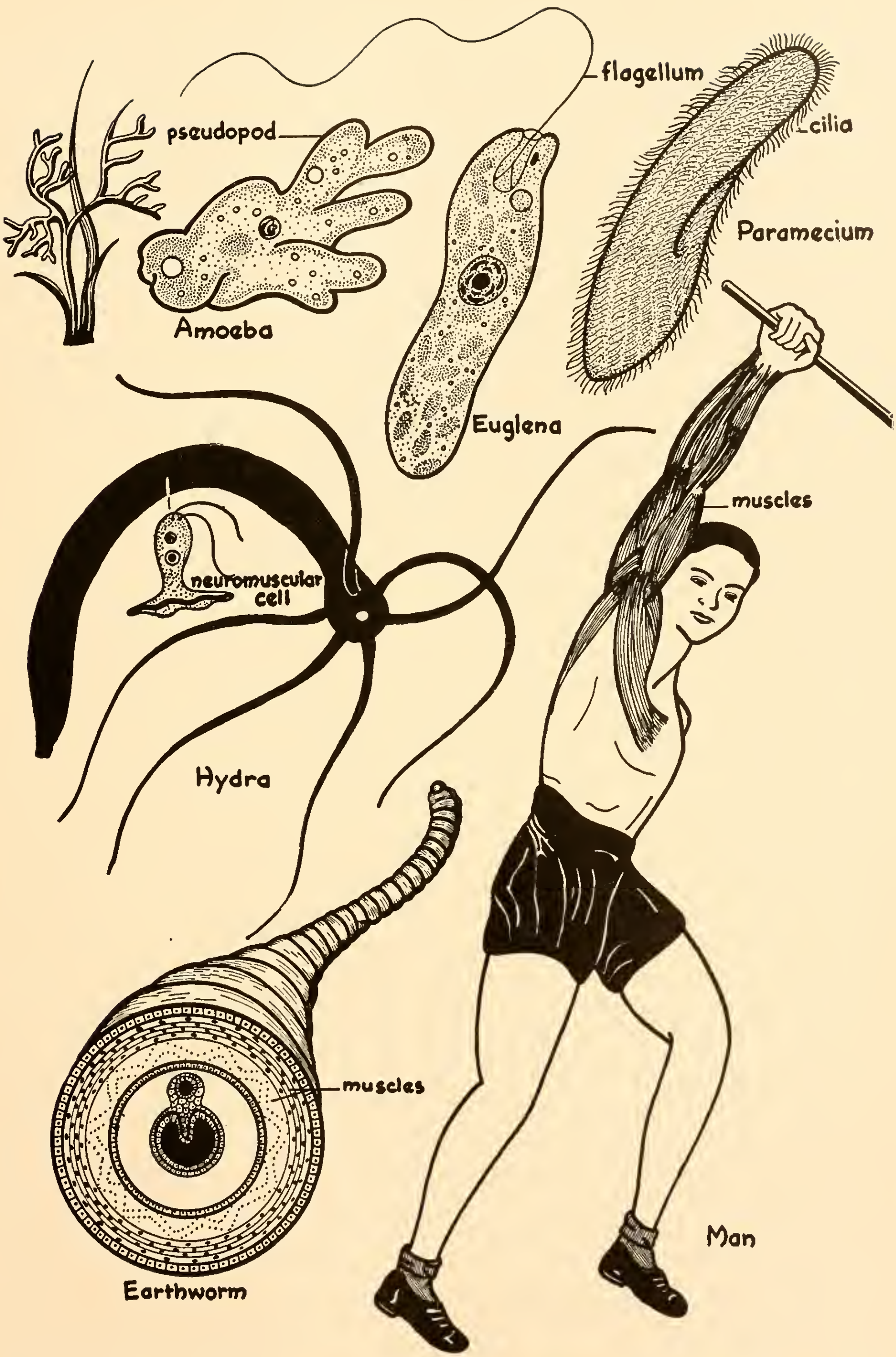


Fig. 15-6. Various ways in which animals from representative groups have solved the problem of movement.

inside. Thus the bone gradually becomes longer and increases in diameter.

Although bone may seem dead, it is far from it, as was pointed out earlier (p. 72). The **Haversian system** (Fig. 4-4) consists of a canal in the center containing blood vessels and a nerve, surrounded by concentric rings of bony matrix, and between them scattered tiny spaces, **lacunae,** filled with the bone cells. Very tiny tubes (canaliculi) connect the bone cells with one another and the central canal, and it is through these canals that the cells are nourished and kept alive. These bone cells secrete the bony matrix in which they are entombed. It is as if a mason were to surround himself with a concrete wall of his own building and thus be enclosed in a chamber which he could never leave, but in which he would be kept alive by small portals through which nourishment could be supplied.

Ability to move

Nearly all animals from amoeba to man have the ability to locomote, and the few which lack this are still able to move some parts of their body (Fig. 15-6). Amoeba moves by a complex sol-gel reversal mechanism which causes the pseudopodia to extend and retract. In addition to being able to move its body in a worm-like manner, Euglena has a contractile flagellum which propels it through the water. Paramecium is provided with numerous cilia that beat in unison to bring about its erratic movements. Hydra is the first animal with cells that contain muscle fibers which contract along an axis. It is the combined action of the many **neuromuscular** cells that makes it possible for this animal to contract and to extend itself in its movements. Once this type of movement, that is, muscular contraction, had appeared in animals, it persisted through all subsequent forms. We shall, therefore, spend some time in studying muscles and their operation, and again man will serve our purpose as well as any other animal.

THE MUSCULAR SYSTEM

One of the most striking characteristics of animals is movement. Since they are voracious feeders they must be on the move most of the time in search of food, and, movement is thus imperative to their continued existence. Among all but the Protozoa and perhaps a few others, contracting muscles are responsible for movement, not only of the body as a whole and its external appendages, but the internal organs as well, such as the organs of digestion and circulation. It is not surprising, therefore, that a man's body has more than 600 separate muscles.

The way muscles work

The muscle responds like a rubber band; it can do only one positive thing and that is **contract.** When it is not contracted it is said to be **relaxed.** The function of a muscle, then, is to pull two objects closer together. This means that there must be muscles which pull bones in one direction and those which pull the same bones back again (Fig. 15-7). Muscles working against one another are said to be **antagonists.** For example, by contraction of the large muscle in the front of the upper leg the bent leg straightens, as in kicking a ball. Once the leg is straight it must be bent again before another step or kick can be executed, and several large muscles on the back side of the leg carry out this movement. To be sure, there is no complete relaxation of one set of muscles during the contraction of their antagonists. Both contract some, the resultant action depending on how much each contracts. When bones are bent on one another the action is spoken of as **flexion;** when they are straightened out the action is described as **extension.** The example of kicking is a case of extension and flexion of the leg bones. Likewise, the closing of the hand is flexion; the reverse or opening of the hand is extension. Although there are many other types of muscle action, antagonistic ac-

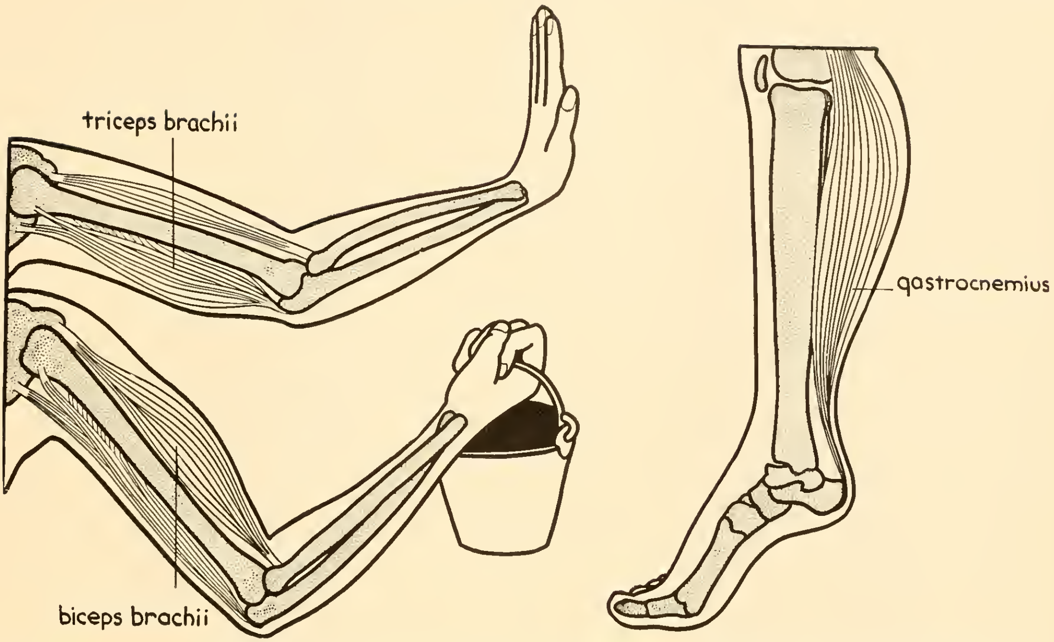


Fig. 15-7. Muscle action in the human arm and leg. In the upper left figure, the triceps brachii muscle contracts in extending or straightening the arm while the biceps brachii relaxes. In the lower left figure, the opposite action occurs, that is, the triceps brachii relaxes and the biceps brachii contracts. This flexes or bends the arm as in lifting. To rise on the toes as in walking the large gastrocnemius contracts (right).

tion is the most common in the animal body. Antagonist muscles are not equally matched as to strength. For example, the muscle which raises the jaw is stronger than the one that lowers it. Hence, when both contract violently as they do in convulsions the jaw is closed tightly (lockjaw).

Muscles vary considerably in size and shape, some being long and fusiform, whereas others are thin and flat (Fig. 15-8). Most of them have a fleshy middle or **belly** part and two tapering ends which terminate in round or flat cords called **tendons.** Tendons consist of tough, fibrous tissue that attaches the muscle to the bone. The two ends of the muscle are identified by the amount of movement that takes place in the bones to which the tendons are attached. The end which moves the bone the greater distance is called the **insertion;** the end which moves the bone the shorter distance is the **origin.** Thus the biceps brachii muscle (Fig. 15-7) has its origin on the point of the scapula and its insertion on the radius because the latter bone moves the greater distance when contraction occurs.

Tendons act like cables, attaching a muscle to a bone sometimes at a considerable distance from the muscle. This is a very convenient arrangement because it makes possible the location of muscles some distance from the point where action must occur. For example, the muscles that support and operate the foot are located in the lower leg. If one feels the calf of his leg while standing, the tenseness of the muscles in supporting the body weight is clearly apparent. The large tendon at the heel, the tendon of Achilles (Fig. 15-7), is like a steel cable when one is standing, particularly if he is on his toes. If the large calf muscles that are necessary in operating the foot were located in the foot itself the latter appendage would reach astounding proportions. Furthermore, the foot would function poorly as compared to the slim-ankled instrument that is man's, or better, woman's

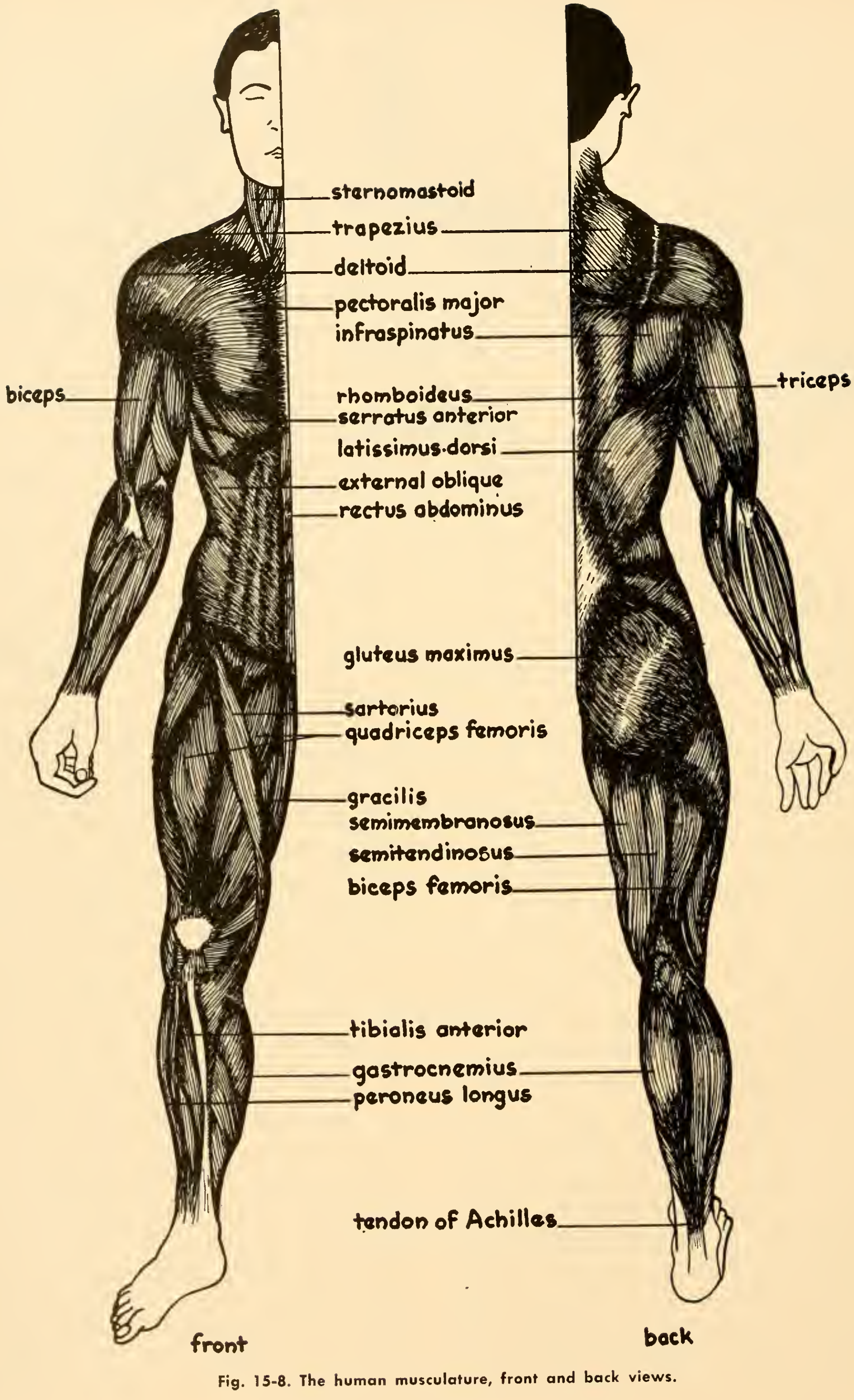


Fig. 15-8. The human musculature, front and back views.

proud possession. This trend to longer tendons and concentration of the muscle's action farther from the muscle is most beautifully illustrated by the leg of the deer. Its lower leg is little more than skin, bones and tendons, yet all the power of the strong leg muscles is transmitted efficiently to the tiny digits that contact the ground.

Muscle structure

Muscle is the principal part of the meat that is bought at the market and it usually makes up about 40-50 per cent of the body weight of large animals. Viewed with the naked eye, muscle is seen encased in a sheath of connective tissue which often glistens. The more expensive cuts of meat have bits of fat rippling through the muscle tissue; this simply means that the animal was fat and its obesity extended to its muscles. The color of the muscle may vary with the nature of the fibers, and with age; young mammals such as calves have lighter muscle tissue than older beef. Finally, muscles of the viscera possess a different texture than those of the skeleton.

By sectioning the various muscles of the body the real nature of the muscle can be studied. Cuts anywhere through the digestive tract will show **smooth** or **involuntary** muscle, the structure of which was described earlier (p. 72, Fig. 4-5). In man, smooth muscles are located in organs of digestion and in the skin, as well as in other places. They have to do with those movements which are not directly under voluntary control, such as peristaltic movements of the digestive tract. These muscles are slow to respond to stimuli and the response that eventually occurs is of long duration. For example, certain pains arising in the abdominal region may be caused by the formation of gas in various parts of the intestines. When the peristaltic wave produces undue stretching of the gut the pain begins slowly, gradually increasing its intensity and finally passing away. This coincides with the contraction of the smooth muscle. If one pricks the intestine of a frog with a sharp needle it may take from 1 to 10 seconds before any reaction is noted, but once contraction starts it lasts for a minute or two, clearly demonstrating the characteristic of smooth muscle action.

The microscopic anatomy of **skeletal muscle** was described earlier (p. 74, Fig. 4-5), so here we need to mention only some of its characteristics. Within each muscle fiber lie numerous fibrils (tiny fibers) suspended in the more fluid protoplasm, the **sarcoplasm.** Differences in the relative amounts of sarcoplasm and fibrils make a difference in the appearance of voluntary muscle tissue. Muscle fibers that contain a great many fibrils and relatively little sarcoplasm are light in color and when the proportion is reversed the muscles are dark. In birds such as ducks, where sustained flight for long periods of time is essential, the breast muscle fibers contain more sarcoplasm and are therefore red, whereas the breast muscles of the domestic chicken which flies only short distances, if at all, are white. This is also true of such birds as grouse which fly in short bursts but never for extended periods. It seems that bird muscles designed for sustained activity are red, whereas those that contract for only short periods are white.

Cardiac muscle, described in an earlier section (p. 74, Fig. 4-5), functions as a unit because of the nature of its cells. As a result of its sustained action, it is dark in color, as one might expect.

Muscle action

Even though one is not aware of it, the muscles of the body, both voluntary and involuntary, are under constant mild contraction. This is essential, for one thing, to keep the blood vessels sufficiently small to maintain adequate blood pressure. This contraction can be observed when a bullet pierces a muscle. The bullet makes a round hole on its way through, but the resulting aperture is a slit, because of the slight

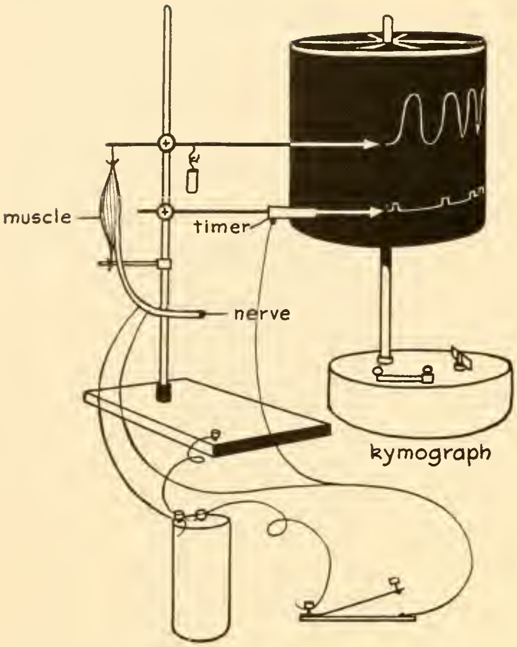


Fig. 15-9. Muscle action can be studied by attaching an isolated muscle, such as the gastrocnemius muscle of the frog, to a lever which can scratch a line of its path on a smoked moving drum (kymograph). When the muscle is electrically stimulated, the nature of the contraction can be recorded on the smoked drum.

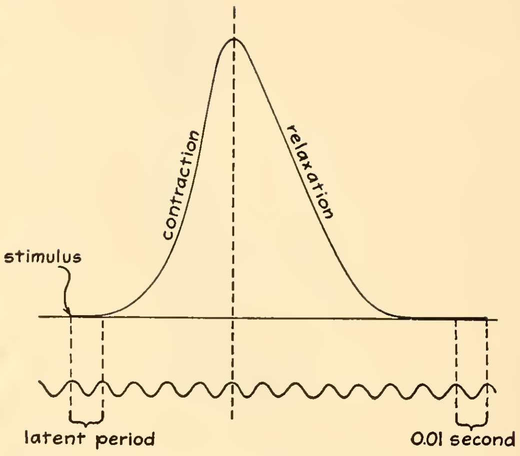


Fig. 15-10. This record was made when the frog gastrocnemius muscle contracted and relaxed, using a recording device as shown in Fig. 15-9. Note the time required for each event to occur.

pull of the muscles. Considerable energy is utilized in maintaining this continuous contraction and, as in all muscle contractions, a large portion of it is released in the form of heat. This heat helps to keep a constant body temperature.

Muscles normally contract as a result of impulses coming to them through nerves. However, an isolated muscle can be made to contract if stimulated directly by an electrical current, even though all the nerves have been destroyed. The nature of the contraction can be studied by attaching the muscle to a recording device (Fig. 15-9) and noting its action following stimulation. When the muscle first receives a very brief stimulus there is no visible evidence of anything happening. This period is known as the **latent period** (Fig. 15-10), and lasts about 0.01 second in the frog muscle. Contraction then begins and continues for 0.04 second. This is immediately followed by a relaxation period that lasts 0.05 second during which time there is a chemical readjustment taking place in the muscle (discussed below). If successive stimuli are increased in their frequency there will come a time when the contractions will be superimposed upon one another until there is a sustained contraction which is greater than any derived from single stimuli (Fig. 15-11). This is called **tetanus**, and is what usually happens in most muscular contractions, however short.

If a stimulus is given to an isolated frog heart muscle, contraction occurs, provided

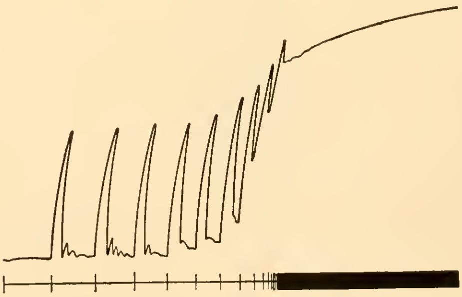


Fig. 15-11. This record shows that by applying stimuli to a skeletal muscle with gradually increasing frequency, contractions merge until there is a sustained contraction called tetanus. The contraction is stronger in tetanus than in the single contractions.

the stimulus is sufficient to initiate a response. No matter how much the stimulus is increased, the resulting contraction remains the same. This fact has led to the establishment of the so-called "all or none" principle, which means simply that if the heart muscle contracts at all, it will do so to its greatest extent. The question arises as to whether or not this applies to striated muscle. Obviously such muscles contract in graded amounts because one can contract any of his muscles as much or as little as he likes. Here the principle does not apply to whole muscle, but to individual fibers or to **motor units** (about 100 fibers). Although there still seems to be some question about it, the available evidence points to the fact that motor units do obey the "all or none" principle. Hence, the force with which a muscle contracts depends on how many motor units are stimulated. A mild contraction would result when only a very few were stimulated; a maximal contraction, when all of the units received a stimulus.

Just how muscles contract is still an unsolved mystery, although a great deal is known about the chemical and physical changes that take place. The movement of a human body does not differ from the movement of a car along a street with respect to the basic requirements. Both require energy to accomplish the feat and that energy comes from oxidation, a process with which we are already familiar. Muscles require oxygen indirectly in burning a series of energy-rich organic compounds. It was once thought to be a rather simple process, because when the leg muscle of a frog was stimulated continuously **lactic acid** accumulated, which subsequently burned to **carbon dioxide** and **water.** Since **glycogen** simultaneously disappeared from the muscle, it was considered to be the source of energy. Someone, not satisfied with this simple answer, discovered that after stopping the formation of lactic acid from glycogen (using the specific poison, iodoacetic acid), the muscle continued to contract. It was also found that the muscle, if denied oxygen, would contract with just as much force as in the presence of an abundance of the gas.

From where, then, did the energy come? Since there was no glycogen breakdown, there could be no lactic acid to burn to CO_2 and H_2O. This meant, of course, that hidden in the muscle were some other substances that released energy in a manner resembling that of oxidation. A diligent search revealed the presence of an organic phosphate, **adenosine triphosphate** (ATP for short), which is formed through oxidation and which changes suddenly to phosphoric acid and another compound with the release of large quantities of energy. This is done **anaerobically,** that is, without oxygen. Located in the muscle fibrils is another substance called **myosin,** which is known to consist of long protein molecules, and it is thought that the actual shortening of the fiber is due to a folding or contraction of these myosin molecules. The energy for such an action is obtained from the adenosine triphosphate breakdown. There seems, then, to be a series of reactions, a chain reaction, that makes the contraction of a muscle possible. The substances involved have been enumerated but perhaps their rôles may be made clearer if we put their reactions in the form of equations, similar to those used in expressing chemical reactions:

Contraction Phase

Adenosine triphosphate → phosphoric acid + adenosine diphosphate + energy (A)

Relaxation or Recovery Phase

Glycogen → lactic acid (20%) → CO_2 + H_2O + energy (B)

(B) energy + phosphoric acid + adenosine diphosphate → adenosine triphosphate

(B) energy + lactic acid (80%) → glycogen

(B) energy → heat (body heat)

From this it is seen that during contraction the adenosine triphosphate breaks down to form phosphoric acid and adenosine diphosphate, releasing energy in a sudden but controlled manner. There is no oxygen involved in this reaction, which accounts for the fact that a man can run a hundred yards without taking a breath. When the adenosine triphosphate has been expended, no further contraction can occur without its recovery. Such an exhausted person must remain quiet undergoing rapid respiration to supply sufficient oxygen to allow the next reactions to proceed. This involves glycogen breakdown to lactic acid (a rearrangement of the molecules) and the subsequent oxidation of the latter substance to CO_2 and H_2O. This last step requires large quantities of oxygen, hence the deep breathing after severe exercise (or during, if prolonged). The energy released from this reaction is utilized in three ways: part of it is utilized in restoring adenosine triphosphate, part of it to convert 80 per cent of the lactic acid back into glycogen, and the remaining part is converted into heat that keeps the body warm. It will be observed that the entire chain reaction results in the most economical method of obtaining the greatest possible energy from the stored food products. It means that the animal body is unusually efficient, about 40 per cent of the available energy being released in the form of work, 60 per cent as heat. This is a very satisfactory figure when one considers that the best internal combustion engines rarely exceed 25 per cent.

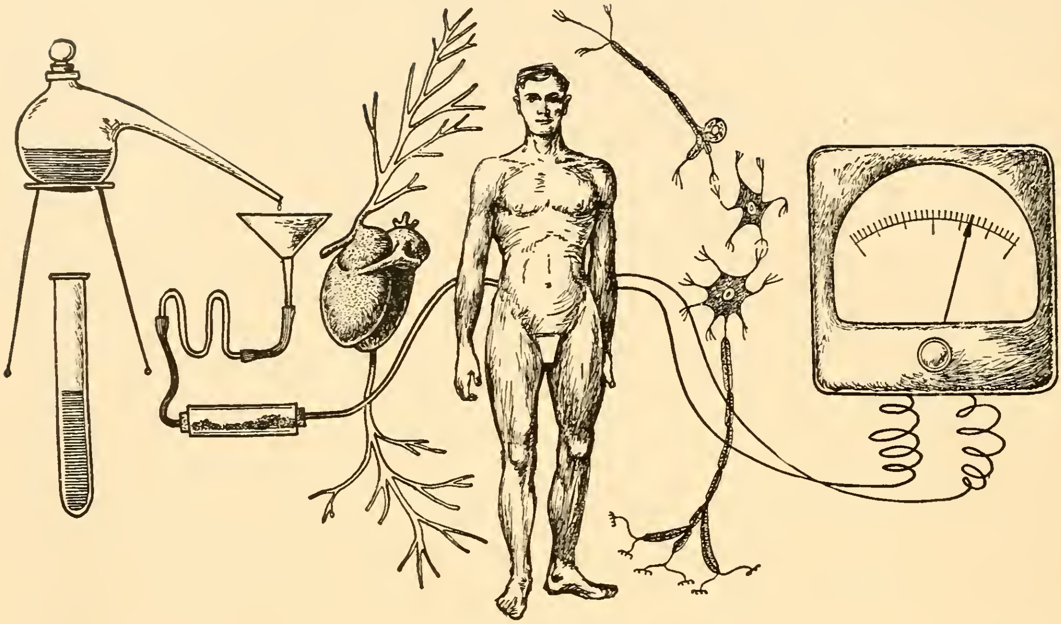
Returning to the runner, the reason why he could run the entire hundred yards without taking a breath was that his ATP was being used up, but when he terminated the run he was forced to remain quiet and breathe deeply for some time. During the run he was building up an **oxygen debt**, which he "paid back" during the heavy breathing period at the termination of the race. The obvious advantage of such a mechanism is that a muscle is ready to contract with all of its force on a moment's notice. It can contract until its reservoir of high-energy phosphate is exhausted; then it must stop and wait until the blood brings sufficient oxygen to restore its glycogen and ATP to the original unspent condition. This can be compared to a toy gun which operates with a spring; once it is shot the spring must be tightened before it will shoot again.

One of the great complaints of human beings is **fatigue**; mankind would never forget the scientist who could discover a way of preventing its regular and persistent occurrence. From the foregoing discussion it is quite obvious that fatigue involves the accumulation of lactic acid and the exhaustion of glycogen and ATP in the muscles, although this is not the entire story because in an intact animal fatigue is pronounced before there is an appreciable amount of lactic acid present in the muscles. Experiments have demonstrated that the site most susceptible to fatigue is the junction between the muscle and nerve, and not these organs themselves.

The limitations for work are set by the ability of the body to restore exhausted organic compounds in the muscles; this depends indirectly on the functioning of the respiratory, circulatory, and excretory systems which, in turn, the muscles must depend on to receive their quota of burning material (sugar and oxygen) and to carry away their accumulated wastes (urea and CO_2). There are great individual differences among human beings for this capacity. Some get along well with very little sleep —Edison was such an example—whereas others require eight hours or more per day.

Muscles can be developed to considerable size and strength if they are constantly put to difficult tasks. By lifting heavy weights each day the muscles of the entire body will grow disproportionately large and will function very well in lifting heavy objects. If this is to be the life work of the individual it is wise to have such a set of muscles, just as it is wise for the man who handles a shovel all day long to have thick calluses on his palms. It seems a bit ridiculous, however, for an office worker to develop a set of muscles that would make it possible for him to lift tremendous burdens when his most muscle-provoking task each day is gliding a pen over a piece of paper. Although a strong body is highly desirable, it hardly seems necessary in our modern living to make what is equivalent to a draft horse out of a person who is going to have no occasion to use his great strength. It is like using a ten-ton truck to carry a loaf of bread home from the store.

CHAPTER 16



COÖRDINATION

The business of coördination is obviously a fundamental problem from the very beginning, because even the tiniest single-celled animals have some method of coordinating their separate parts. Amoeba must decide which way it will throw out its pseudopods in order to move in a certain direction. Euplotes (Fig. 16-1) shows an advanced degree of specialization because it is able to control the rhythmic beating of its cilia so that the direction of progression can be changed suddenly. However, Metazoa such as hydra have a coördinating mechanism in the form of a simple arrangement of nerve cells, the **nerve net.** The first steps toward a centralization of these net-like nerve cells are seen in planaria, where there is a well-defined anterior brain with two large lateral nerve cords running posteriorly. Being a larger animal composed of more cells, and a much more complicated animal, a more elaborate coördinating mechanism is essential. The idea of centralization in the coördinating mechanism is continued and elaborated through the invertebrate and vertebrate groups as animals become larger and more complicated. The growth and organization of the individual may be likened to the expansion of a telephone system as the small monohippic village grows to a great city. As the latter increases in size, the system becomes more

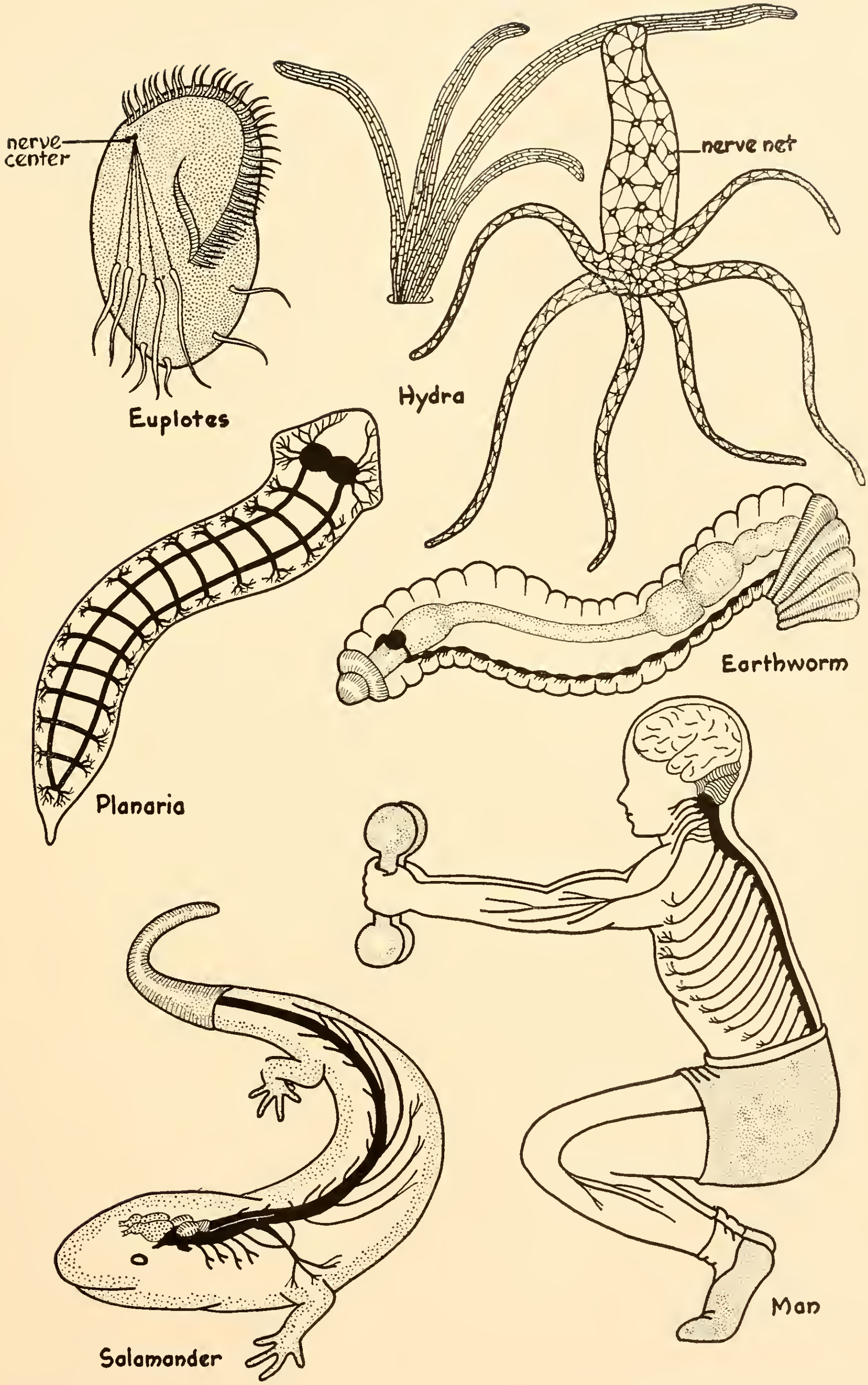


Fig. 16-1. Animals from Protozoa to man have solved the problem of coördination in many ways.

and more intricate until a telephone system like that of New York City is about as difficult to understand as the nervous system of a grasshopper or a man.

Among some of the higher invertebrates and all the vertebrates the network of tiny fibers connecting all parts of the animal has apparently proven inadequate, because a supplementary system has evolved, namely, an **endocrine system.** In this system an entirely different principle is employed; instead of impulses passing over tiny fibers, specific chemicals produced by special glands are released into the blood and circulate to other parts of the body where they produce a specific effect. This method has proven very satisfactory for certain types of responses, as will be pointed out a little later in this chapter.

In handling this very complex problem of coördination we shall use man as our example. We shall begin with a discussion of stimuli from the external world and the internal environment as received by the **sense organs** and other **receptors,** then proceed to the nervous system which is the intermediary for the transmission and interpretation of the stimuli, and conclude with the **effectors**—muscles and glands—which give the response.

RECEPTORS

The receptors in the human body consist of specialized end organs located in strategic regions and are highly sensitive to certain kinds of stimuli. Conspicuous sense organs such as the eye and ear are familiar to everyone; others, such as the tiny receptors located in the muscles and other parts of the internal body, are not so well known but are just as important in the proper coordination of the organism.

Skin receptors

It might be expected that the outer covering of the body would be highly sensitive to the environment around it, and this is true, from the lowly planarian to man himself. A pin prick in the skin almost anywhere over the surface of the body results in a pain sensation; this fact indicates that these nerve endings are very numerous and widespread. The same is true of the nerve endings for touch, pressure, heat, and cold. A thin section of the human skin will reveal tiny, oval-shaped **tactile corpuscles** from which nerves lead inward. Any pressure brought to bear on them causes impulses to be discharged from the specialized cells within the corpuscle which travel along nerve fibers to the central nervous system. Other kinds of sensory end organs which respond to pressure stimuli over larger areas are located in the deeper skin and in many internal organs. Free nerve endings which register pain terminate in the epithelium within the internal organs as well as in the skin. The endings ramify and come into contact with nearly every cell, which explains why pain sensations are felt even if only a small area is stimulated, such as in pricking with a pin.

By marking off specified areas on the skin and using a stiff bristle as a stimulus the appropriate receptors can be located, and they will be found to be quite unevenly distributed over the body. It is difficult, for example, to distinguish two points one-half inch apart in the middle of the back, whereas on the tip of the finger or tongue a distance of one-sixteenth of an inch is perceptible. Likewise, if metal pointed instruments (styluses) are used, the hot and cold end organs can be detected. There are more cold spots than hot spots and that is why, for instance, one shivers at first if suddenly exposed to a hot shower. When all of the end organs are stimulated simultaneously, as would be the case in the above situation, the total response is that of coldness at first because there are more of the cold than hot spots. Later, the proper interpretation of the stimulation is recognized. Pressure end organs can be found by applying a blunt metal stylus having the same temperature as the skin to various regions. Other sensory nerve endings are located in the tendons and muscles which respond to tension placed on these tendons and muscles. These are important in balance and will be discussed under that topic later.

Chemo-receptors

All of the receptors of the skin have to do with identifying energy changes that occur at or very near the body. In addition, there are chemo-receptors that identify substances dissolved in the saliva of the mouth, giving one the sense of **taste**, and chemicals dissolved in the mucus of the nasal chambers, imparting the sense of **smell**. In the latter case, the organism is made aware of changes in its environment some distance away. The sense of smell is, in this respect, like the senses of hearing and seeing which extend perception to great distances.

Taste. The so-called sense of taste is actually a combination of stimuli coming from the mouth cavity. Stimuli from the end organs of touch, heat, and cold located in various parts of the mouth cavity give a composite sensation which is called taste. The difference in the "taste" of hot and cold foods is due to stimuli other than those which are caused by dissolved chemicals. The sense of smell is also important to taste, as anyone with a bad cold is well aware. The end organs of taste are called **taste buds** and are distributed over the surface of the tongue, laryngeal region, and parts of the roof of the mouth (Fig. 16-2). They are oval-shaped bodies made up of several cells which terminate in a slender sensory process on the end toward the mouth cavity.

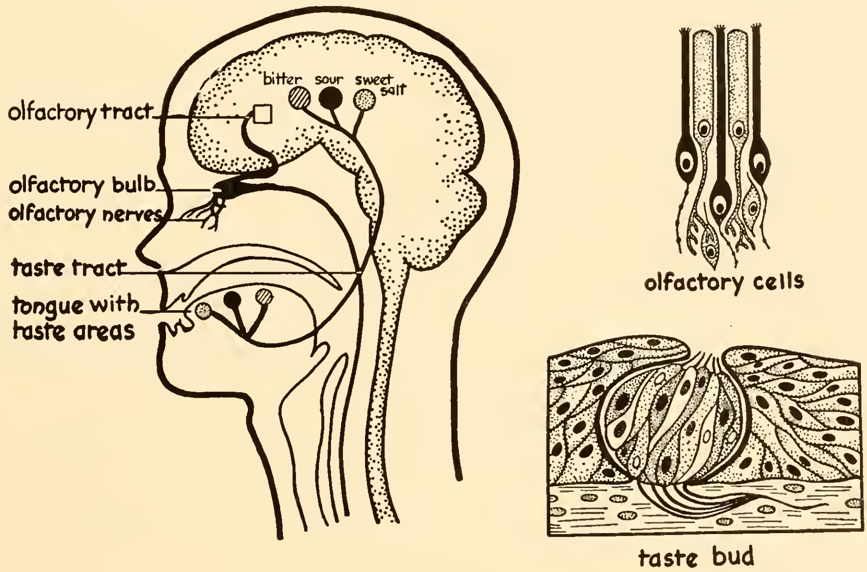


Fig. 16-2. The end organs for chemo-reception are located in the nasal chambers (smell) and on the tongue (taste). They are shown here in detail together with the nerve pathways that conduct the impulses to the brain.

There are four kinds of taste sensations and consequently there are four different kinds of taste buds, each with a rather specific distribution on the tongue and other mouth parts (Fig. 16-2). The taste buds registering **bitter** are located at the base of the tongue, **salt** and **sweet** on the tip and **sour** along the edges. These can all be identified both microscopically and experimentally. No matter how these buds are stimulated the resultant sensation is always sweet, sour, salt, or bitter. Some chemicals stimulate two kinds of taste buds, but in each case the taste bud responds as it should according to its predetermined function. There are some classes of substances which have a consistent taste, for example, acidic substances usually taste sour, basic substances bitter. The threshold (a stimulus that is just sufficiently strong to elicit a response) is very low for the sense of both taste and smell. For example, it is possible to taste quinine in concentrations of one part in two million, and much greater dilutions of odorous substances can be smelled.

Smell. The olfactory end organs which are responsible for the sense of smell are located in the nasal membranes, and it is through these organs that gaseous chemical stimuli (odors) are received. While in man the receptive area in the two nasal chambers is only about 10 square centimeters, in most mammals it is much more extensive. It will be recalled that the sense of smell is far more important to ground dwellers than to those that live in trees, where keen vision is of more value. It is not surprising, therefore, that when the primates took to the trees the sense of smell diminished and in the present primate is very poorly developed. The dog, on the other hand, receives a great deal of information about the world through his nose. This sense is so keen that the dog can pick up the odor of an animal that has passed over a trail some hours before. Most game dogs rely more on their sense of smell than on sight except at close range, and, in fact, many bird dogs are very near-sighted.

The olfactory cells give rise to fibers (Fig. 16-2) which coalesce, after passing through the cribiform plate (p. 378), to form the **olfactory bulb**, which becomes a large nerve leading to the brain. The location of the olfactory end organs is such as to protect them from the desiccating effects of incoming currents of air during respiration, and the nasal passages are kept continuously moist in order that the incoming odors may dissolve in the fluid bathing them. A dry olfactory end organ cannot be stimulated any more than can a dry tastebud.

It may be necessary for large quantities of air to pass over the receptors before stimulation is possible. As more air passes over them more of the chemical in gaseous form becomes dissolved in the fluid of the nose, thus increasing the concentration to a point where the threshold is exceeded. This accounts for the constant sniffing of the dog, or man, too, on occasion, to bring more air into contact with the nasal epithelium.

Our knowledge of the sense of smell is very limited, as indicated by the fact that no satisfactory system of classification of odors has yet been set up. Odors are still referred to by the name of the aromatic substance in question, and there are nearly as many names for odors as there are aromatic chemicals. It seems highly improbable that there is an infinite number of kinds of olfactory nerve endings, although when they become fatigued to one odor they seem to respond with normal vigor to another. Different chemicals apparently do not stimulate the same nerve endings. In general, the nerve endings fatigue readily, and it is a familiar experience that an odor which is very strong when one first enters a room soon fades away until it is unnoticed, not because the chemical in the air has diminished in quantity but because the olfactory end organs fail to be stimulated beyond a certain brief period. Just why this is so is not clearly understood at present.

Vision

This is the most perfect of the distance receptors. It provides us the means of keeping aware of our environment at small or great distances, whether reading this page or looking at the stars. Not only is this sense the most important for man but for all primates, as well, and most of their information concerning their environment comes through this sense.

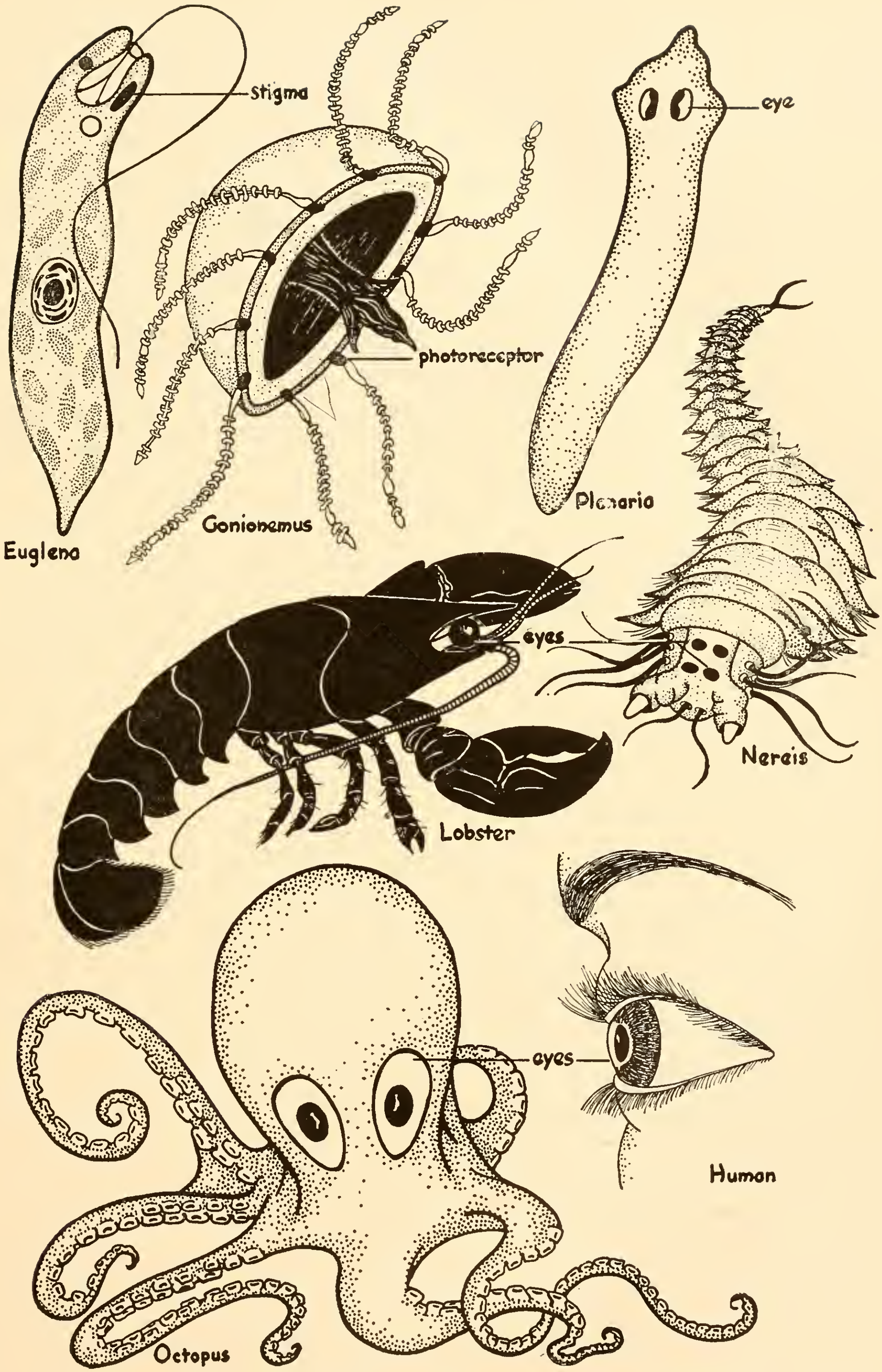


Fig. 16-3. A few of the various kinds of photoreceptors that are found in representative animals.

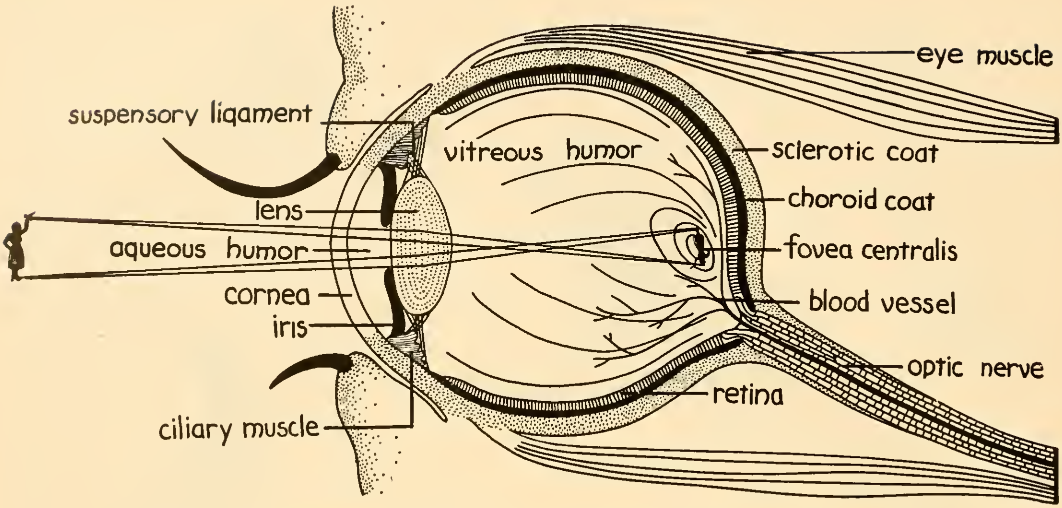


Fig. 16-4. A longitudinal section of the human eye to show its internal structure.

Nearly all animals from the simplest to the most complex are sensitive to light. Not that they all are sensitive to the same wave lengths that are recorded by the human eye, but nearly all have evolved some sort of receptor which is sensitive to light. It has been proved, for example, that the bee sees shorter light waves than we can see. Dogs, on the other hand, appear to be color-blind. It is thus abundantly clear that different animals see, hear, smell, and so forth, quite differently from man. Indeed one must carefully avoid an anthropomorphic attitude with respect to all behavior.

Euglena orients itself with respect to light by means of the stigma, and without this photo-sensitive organelle it would be unable to seek proper illumination for photosynthesis (Fig. 16-3). The delicate jellyfish (*Gonionemus*) possesses photoreceptors that help orient it to light in the ocean. Planaria has rudimentary eyes which produce no images but detect direction. Neanthes has a set of four eyes which may be superior to those of planaria. The lobster has excellent compound eyes, the details of which were discussed earlier. The octopus, as well as some of its relatives, possesses a remarkably perfect eye. Strangely enough, although it has evolved along an entirely different path, it resembles the vertebrate eye very closely in most respects. This is one of the very interesting cases of **convergent evolution,** where very similar organs have evolved along two entirely different routes (p. 660).

The vertebrate eye. Although there are some minor differences in the eyes of various vertebrates, the human eye will serve as representative of the group in our discussion (Fig. 16-4). It is first necessary to consider briefly the way light behaves before an understanding can be had of the function of the various parts of the eye, particularly the lens.

Light travels in straight lines at a speed of 186,000 miles per second in air, but it travels at different rates in other media such as water, glass, and transparent tissues such as the lens. Therefore, when light passes from one medium to another it bends (refracts). It is a familiar fact to those who have observed it that when a stick lies at an angle partially in water, it appears bent. Actually, of course, the light is coming to the eye through two different media, water and air, and at different speeds, hence the bending at the juncture of the two media. Light coming through glass is bent in a similar fashion, and when the glass is

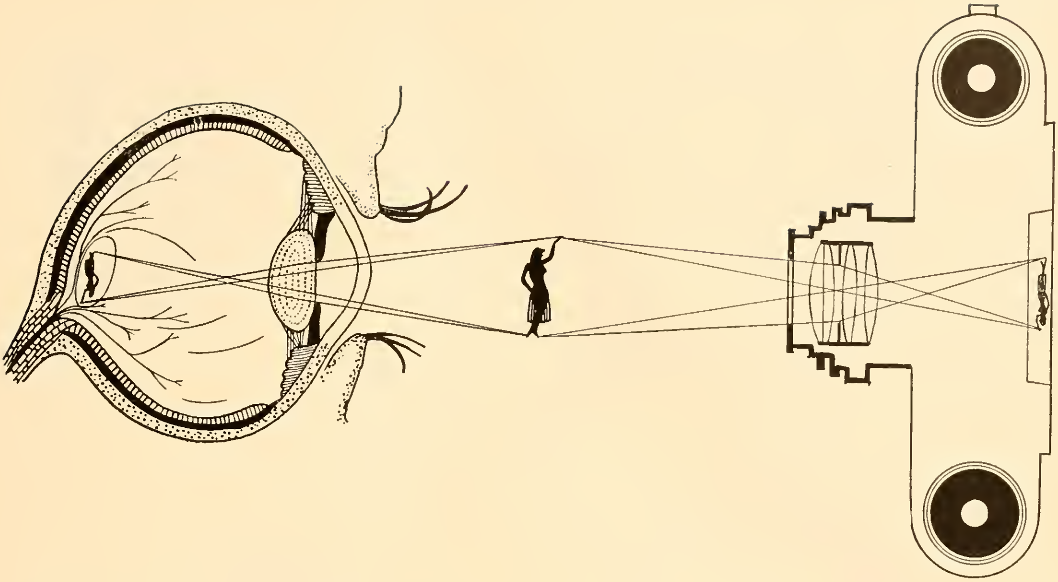


Fig. 16-5. A comparison of the camera and the human eye. Note the likenesses and differences. (For names of parts of the eye see Fig. 16-4.)

shaped so that it is uniformly curved on both sides (a convex lens) the rays of light are bent toward one another so that they come to a point, or **focus**, as it is called. Just how light passes through the lens depends on the angle at which it strikes the surface. The amount of bending increases with the increase in angle between the light ray and the surface of the glass. Therefore, a highly curved surface will bring the rays to focus at a very short distance (**focal length**), whereas a more flattened surface will bring them together at a greater distance. Depending on conditions, therefore, a lens is said to have a long or short focal length. For example, in the objectives of the compound microscope the low power lens has a focal length of 16 mm., whereas the high power lens has one of only 4 mm. The lens with the shorter focal length has the greater curvature and consequently magnifies the greater, also.

Light coming from an object on one side of a convex lens passes through and comes to focus on the other side at the focal length of the lens. The light comes from an infinite number of points on the object, and passes through the lens with the result that the image is completely reversed. With this knowledge of the working of the convex lens we can better understand how the eye functions.

The remarkable similarity of a simple camera to the eye will help us to understand how we see (Fig. 16-5). Both have convex lenses which bring the rays of light to focus upon a sensitive plate, the film in the camera and the **retina** in the eye. The amount of light entering the chamber is controlled by the **iris diaphragm** in both cases. The housing is a lightproof case which allows the rays of light to pass through unobstructed; in the camera it is made of an adjustable tube or collapsible bellows and in the eye it is composed of a tough outer covering, the **sclerotic coat** and a highly pigmented inner lining, the **choroid coat** (Fig. 16-4). In the eye the space behind the lens is filled with a semi-liquid substance, the **vitreous humor,** and the cavity in front of the lens is occupied by the **aqueous** (watery) **humor.** These maintain pressure within the eye and keep it from collapsing.

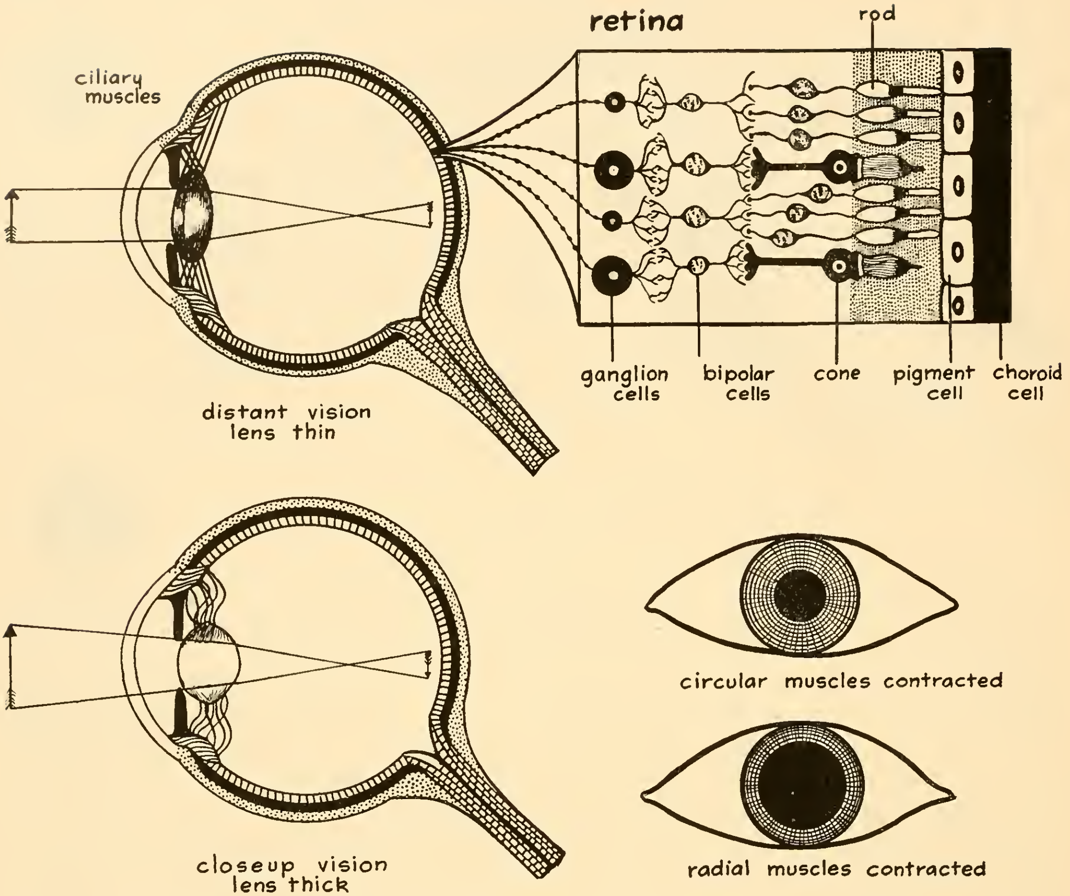


Fig. 16-6. Accommodation is accomplished by changing the thickness and curvature of the lens. The amount of light entering the eye is controlled by the iris diaphragm. The image recording mechanism is the retina.

There are some very important differences between the camera and the eye. First of all, the film and the retina function differently. Once a picture is taken the film is used up, that is, it must be replaced by another, whereas in the retina a continuous series of pictures can be recorded without exhaustion of the sensitive cells. The retina might be compared to the film in a movie camera which is constantly being replaced. Secondly, the method of bringing objects at different distances into focus on the sensitive plate operates differently, although the end result is the same. In the camera the lens maintains one shape and must be moved forward and backward until the image is in focus on the film. In the human eye, however, the lens itself changes its shape, becoming more curved for close objects and less curved for distant objects. This change in shape of the lens is called **accommodation.** Aside from the lack of a shutter in the eye, unless the eyelids could be so considered, there are no other differences. It is unfortunate in many ways that the human eye cannot be focused like a camera, for if it could many people would be relieved of placing glass lenses in front of their eyes, some all their lives, others during most of the "down hill" years.

In the eye, the job of bringing the light rays to a focus upon the retina is done by the **cornea**; only the slight differences that are needed to produce a sharp picture are accomplished by the lens itself. This slight variation, however, makes the difference between clear, sharp vision and poor, fuzzy sight. Accommodation is effected by the action of the **ciliary muscle**, located near the point of attachment of the **suspensory ligament** which supports the lens (Fig. 16-6). When this muscle contracts the tension of the ligament is relaxed and the lens becomes more curved, that is, thicker, which brings near objects into focus. There is also a change of internal pressures in the eyeball that influence the change in lens curvature. When the muscle relaxes the ligament tightens and the pressures are shifted so that the lens flattens out, causing distant objects to come to focus on the retina. Therefore, the ciliary muscle is active only when one is looking at close objects (under 30 feet) which is the reason why the eyes can be rested by looking out the window at a distant object.

The amount of light entering the eye is controlled by a sheet of circular muscular tissue, the **iris**, which contains the pigment granules responsible for eye color. Both radial and circular muscles are present in the iris and it is the antagonistic action of these muscles that do the job of enlarging or constricting the opening, the pupil. They are under the control of the autonomic nervous system and therefore beyond voluntary control. When the eye is exposed to bright light the circular muscles contract, constricting the pupil, whereas in dim light the radial muscles contract, causing dilation of the pupil. Thus a delicate arrangement is provided to project just the right amount of light on the retina to obtain the best possible picture reception of the external world.

Exactly how light rays are transformed into the nerve impulses that pass over the optic nerve to the brain is only poorly understood at the present time. The conversion from light energy to nerve energy takes place in the retina, a very delicate and complex structure. It is composed of numerous cells, some of which are sensitive to light. These are the **rods** (sensitive to white light) and **cones** (sensitive to colors) (Fig. 16-6). The cones are crowded around a central region, the **fovea centralis**, where visual acuity is most pronounced. Elsewhere in the retina the cones are mixed with the rods and vision is not so clear. In order to see clearly, it is necessary to look directly at the object so that the image falls on the fovea—all other vision is peripheral and is less clear. This is readily demonstrated by attempting to determine detail while looking to one side of an object.

The rods are more sensitive to light than the cones and detection of weak light sources is best made when looking to one side of the source. Fliers search for beams at night with their peripheral rather than foveal vision. Careful observation by scientists has shown that the immediate stimulus is probably chemical, much the same as with the senses of smell and taste. The rod cells of the retina contain a purplish red pigment, **visual purple** (**rhodopsin**), which breaks down into a protein and a substance called **retinene** when exposed to light. A further degradation occurs, producing **vitamin A**, a familiar accessory food. The chain of chemical events, thus initiated, leads to that physico-chemical condition which is the nervous impulse and which is propagated along an optic nerve fiber to the brain.

Since vitamin A is produced upon visual purple breakdown, it must also be essential in its formation. People who have a deficiency of this vitamin suffer from "night blindness," that is, they cannot see in dim light. A person who upon entering a moving picture theater in the afternoon cannot see the individual sitting next to him within fifteen minutes had best increase the amount of vitamin A in his diet.

Visual purple is derived from the rods only. It has recently been discovered that the cones in some reptiles and birds each contain one of four different pigments: red, orange, yellow, and white. The pigment is in the form of a globule resting on the tip

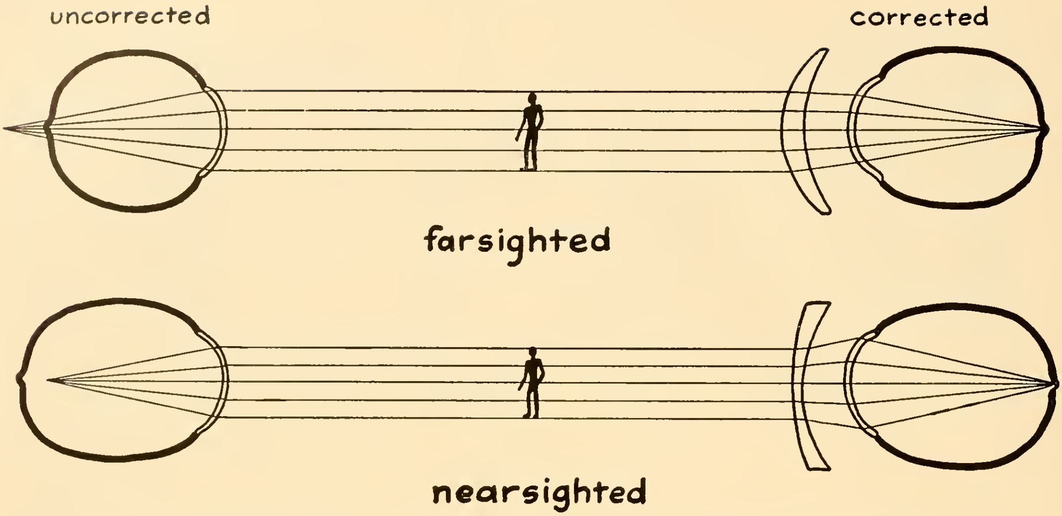


Fig. 16-7. Common human eye defects and how they are corrected with lenses (spectacles).

of each cone. All light passing through the globule is filtered out except that of the particular globule. The various colored cones are scattered through the retina so that color images are possible. It is probably the reduction or the lack of certain cones that is responsible for color-blindness. It is interesting to note that chickens have mostly cones with very few rods in their retinas and therefore do not see well in dim light, accounting for the fact that they go to roost with the setting sun.

Eye defects. The inability of many human eyes to produce clear images under usual conditions is evidenced by the large number of people wearing glasses. Perhaps the number of defects is no larger today than formerly, but the demands for clear vision in modern society are far greater than ever before, so that greater effort to correct these defects has been made. It is highly important that in driving an automobile the driver should have good vision. Like other defects in present-day civilization, congenitally poor vision is fostered and passed on to succeeding generations. In primitive man such a defect would have often prevented its owner from growing to adulthood, thus eliminating the defect before it got a "foothold."

The most common defects of the eye are caused by the inability of the focusing mechanism (cornea and lens) to form an image on the retina in a clear form. If the rays come to focus in front of the retina, the person suffers from **myopia,** or **nearsightedness;** if they come to focus behind the retina, the defect is know as **hyperopia** or **farsightedness** (Fig. 16-7). In order to correct these conditions it is only necessary to place in front of the eye a lens ground so that it bends the rays of light just enough to compensate for the defective focusing mechanism. In the case of nearsightedness a biconcave lens is needed, while in farsightedness a biconvex lens will bring about the proper correction. When either the cornea or lens is irregular in its curvature the defect is called **astigmatism.** This can be corrected by using lens that are ground in such a manner as to compensate for these variations in curvature.

Sometimes, as a result of disease or for other reasons, either or both the lens and the cornea may become fogged over so that vision is dimmed or completely obliterated; this defect is referred to as **cataract.** If the lens becomes fogged, it can be removed and a substitute lens placed in front of the eye either in the form of conventional glasses or of contact lenses which fit tightly against the eyeball. If the cornea clouds over it can be replaced by one from a normal eye, restoring the vision to normal. This is an extremely delicate operation but one that is becoming more and more common. People often "will" their corneas to others at the time of death; this custom is prevalent enough now that cornea "banks" have been established.

Hearing

Hearing is another sense that records stimuli coming from a distance. This is a convenient supplement to vision in that sound travels around corners and in the dark, two very important adjuncts to the problem of orientation. Nearly all groups of animals have some means of receiving water or air vibrations (Fig. 16-8). Underwater forms such as fish receive vibrations in the water and can, therefore, hear, although they possess none of the apparatus found in higher vertebrates that is used to receive and amplify sound. They do possess the inner ear structures that are essential for hearing. Apparently they can receive only vibrations set up in their own bodies. Air breathers, both vertebrate and invertebrate, have not only solved the problem of receiving air vibrations but also of setting up such vibrations. The katydid, for example, produces its chirp by rubbing its wings together, and the sound waves are received by special "ears" located on the tibias of the front legs. This form of communication serves in bringing the sexes together in mating and may also be important in notifying other members of the species of fertile food sources.

When the vertebrates evolved onto land they, too, started to solve the problem of sound making and sound receiving in air, although fish not only received sounds in water but some even made sounds. The frog has a crude ear and emits a very simple sound. It is interesting to note that in providing for this change old structures, the gill arches, which now served no special function, were employed in making the new organs. For example, the tips of the jaws and the hyoid arch which evolved earlier from gill arches became the ear bones, and some of the remaining gill arches became the **larynx** (voice box) as well as other elements of the upper respiratory system (Fig. 25-11). In man, the production of sound has probably been carried to its greatest perfection, birds excepted, although the sound receiving apparatus of some other vertebrates, such as the dog, has a greater range than the human ear.

Intimately associated with and usually considered as a part of the ear in the vertebrates is another organ that is physiologically quite separate from the sense of hearing. This is the organ of equilibrium, which is a receptor for changes in conditions of balance and rotation. In the invertebrates these two organs are quite unrelated. Organs of equilibrium are found in many invertebrates, from the jellyfish to the crayfish.

Among the lower vertebrates such as the sharks and skates both the hearing organ and the organ of balance are connected to the brain through the eighth cranial or auditory nerve. It is generally believed that hearing came later in evolution and merely took over a part of the eighth cranial nerve which had initially functioned only in conveying impulses from the organ of equilibrium. A discussion of the organ of equilibrium will be found in a later section (p. 408).

The human ear is composed of three portions, the **outer**, or **pinna**, the **middle**, which connects with the throat by means of the **eustachian tube**, and the **inner**, where the **cochlea** (sound receptor) and **semicircular canals** are located (Fig. 16-9). The outer ear is merely a skin-covered, cartilaginous projection from the head, designed to catch and concentrate sound waves. In some animals, such as the mule and rabbit, this can be moved in several directions to help de-

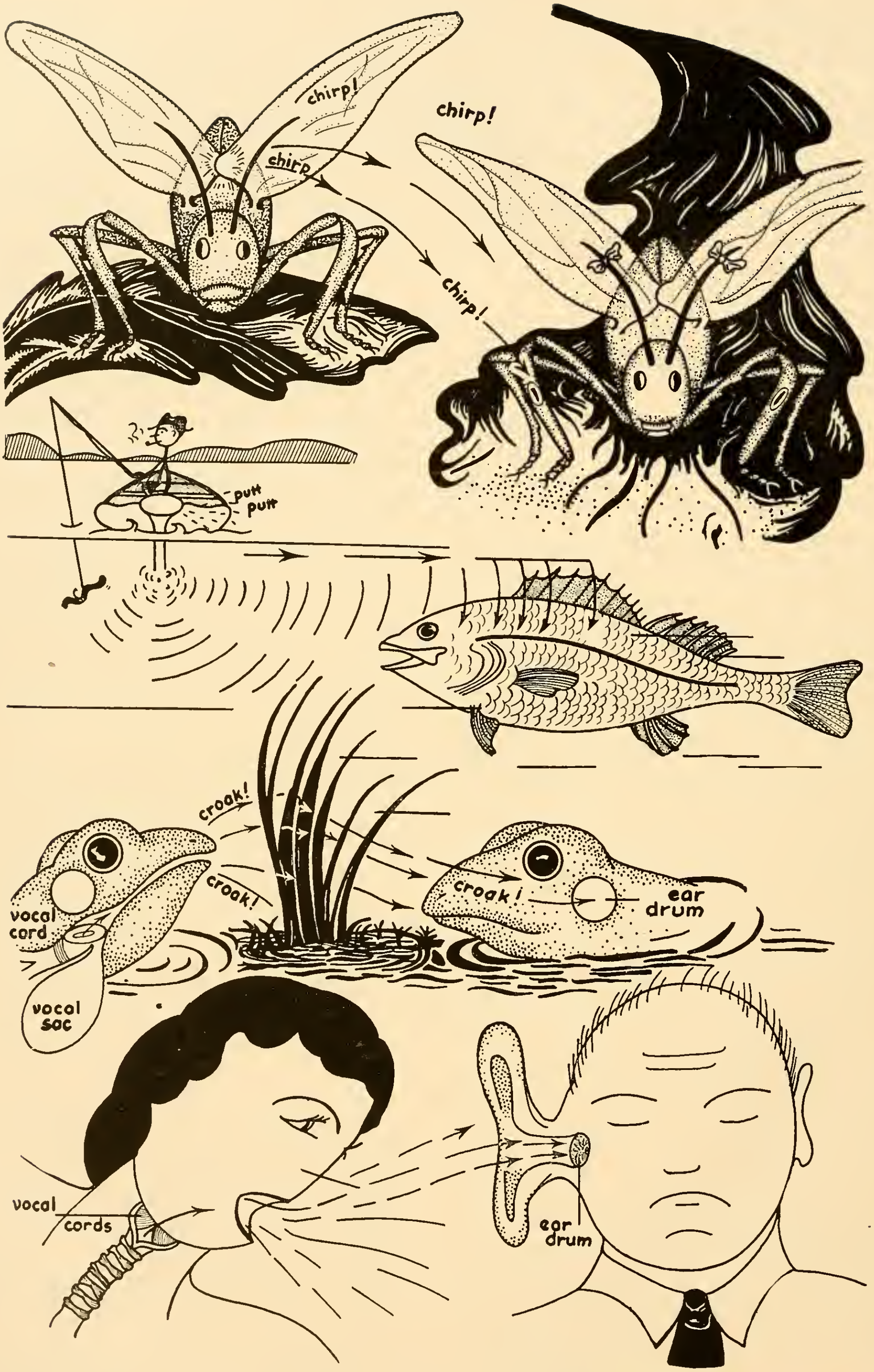


Fig. 16-8. Some animals and the manner in which they produce and receive vibrations in the air and water.

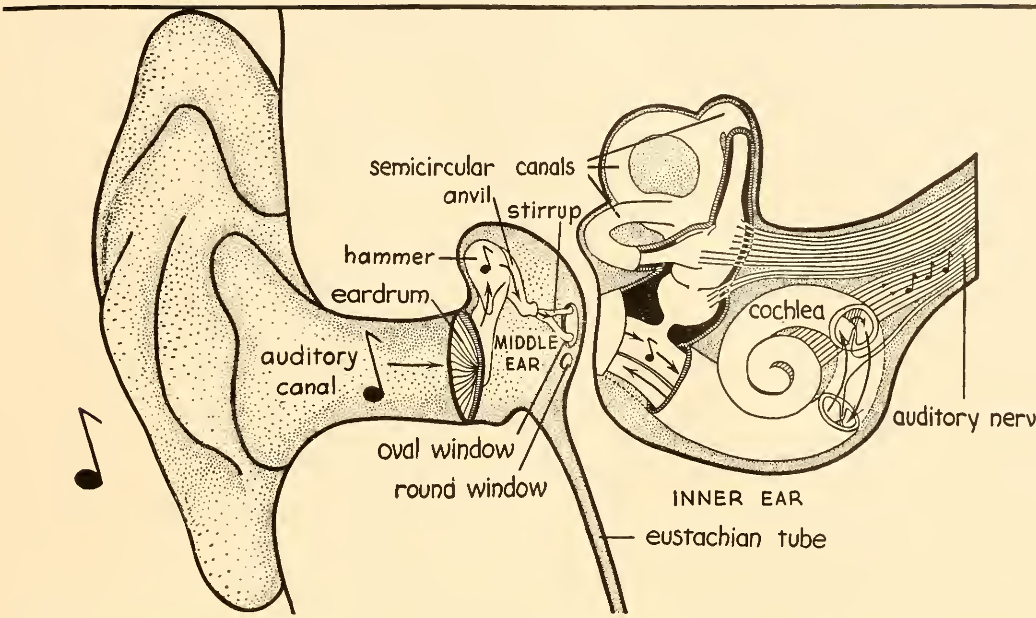


Fig. 16-9. The human ear dissected in order to show the various parts that have to do with receiving sound and the part that is concerned with balance.

termine the source of the sound. In such forms where the appendages are especially enlarged, they also function as temperature regulating mechanisms, for their great size and profuse vascularization provides an ideal apparatus for cooling the blood. In man, the function of the pinnae is dubious, since auditory acuity is no greater in those with generous pinnae than in those who have small external ears. Furthermore, movement of the ears is limited to a privileged few, even though everyone possesses a full set of muscles to accomplish the feat (Fig. 25-14). The external ear surrounds the opening which leads through the **auditory canal** and terminates at the **tympanum,** or **eardrum.** The walls of the canal are supplied with glands that produce wax which discourages small creatures such as insects from entering.

The middle ear consists of a chamber connected to the pharynx by the eustachian tube, an old gill pouch remnant. Bridging across this air chamber is a series of three bones (**ear ossicles**) which conduct vibrations of the tympanum to the cochlea. Although the eustachian tube is advantageous in equalizing the pressure on both sides of the eardrum, it does have a disadvantage in that microörganisms in the mouth can make their way through this tube and infect the middle ear region. Such infections can be dangerous, sometimes leading to deafness. The tiny bones are named the **hammer, anvil,** and **stirrup** (malleus, incus, and stapes, respectively) because of their shapes (Fig. 16-9). Together they produce a lever arm which diminishes the amplitude of the tympanic vibrations but at the same time intensifies them. The hammer is attached to the eardrum and the anvil, while the stirrup, attached to the anvil at its opposite end, fits into the **oval window** of the cochlea. Vibrations conducted through the chain of bones are conveyed to the liquid-filled cochlea. Another membrane-covered opening, the **round window,** allows the fluid to vibrate freely, without being lost from the closed chambers. Since liquids do not compress, the vibrations retain all of their vigor until they are delivered to the sensory cells which generate impulses that are

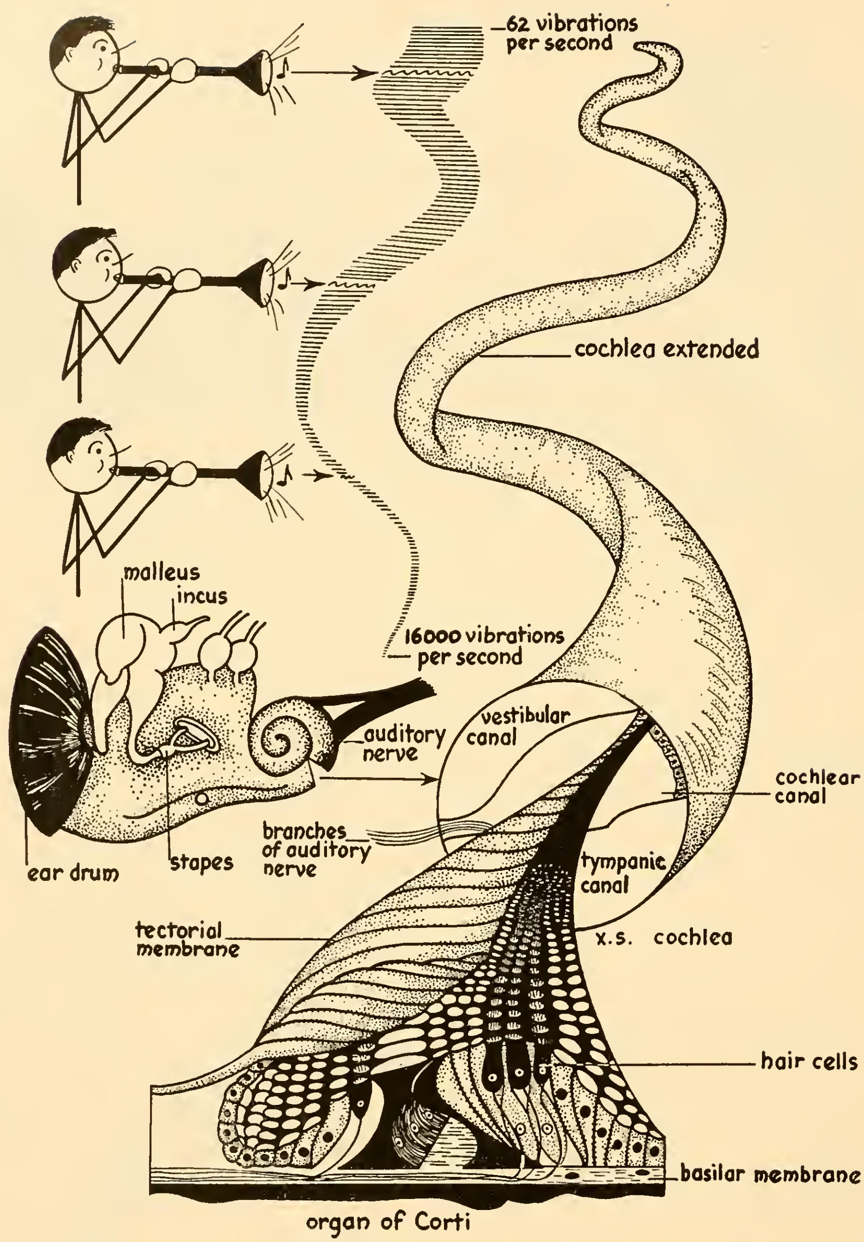


Fig. 16-10. The cochlea uncoiled and cut in cross-section to show the organ of Corti in detail. The parallel lines to the left indicate the wave lengths of the various notes and the approximate position in the cochlea where the organ of Corti picks them up.

transmitted to the brain over the auditory nerve.

The highly complex cochlea can best be studied by uncoiling and cutting across it in order to examine its internal structures (Fig. 16-10). It is a long tapering tube which is divided into three chambers, all filled with fluid. The middle chamber contains the **organ of Corti** (named after its discoverer) which is the most important part of the vibration-receiving mechanism. It consists of a **basilar membrane** composed of tightly stretched connective tissue fibers which are longer at the top of the spiral and shorter at the larger or lower end. Above this membrane are the so-called **hair cells** which send out nerve fibers that make up a part of the auditory nerve. Overlying the hair cells is the **tectorial membrane**, a thin sheet of tissue, which lies very close to the tiny hairs projecting from the hair cells. There are other structures too which, however, need not be considered in this discussion. How air vibrations are converted into impulses that give the sensation called hearing is the next problem.

Sound perception. The fluid in the canals of the cochlea is set into vibration by the stirrup entering the oval window. It seems probable, although no one has seen it, that these vibrations set the basilar membrane into sympathetic undulations which cause the hair cells to touch the tectorial membrane, and that such touch stimuli set up impulses in the nerve fibers of the hair cells. Since the basilar membrane is shorter and tighter at the bottom, or largest, portion of the cochlea (which seems quite contrary to reason), it probably responds to the higher notes whereas the hair cells at the top of the spiral are stimulated by the low notes. This can be borne out be experimentation. If an experimental animal is exposed to sound of high pitch and considerable amplitude (loudness) for a long period of time, the hair cells in the lower end of the cochlea are destroyed and the animal is deaf over this range. Other segments of the organ of Corti can be destroyed in a similar manner by appropriate frequencies. The same phenomenon has been observed in people suffering from the so-called "Boiler Makers" disease where the constant din of a trip hammer over many years finally destroys that portion of the organ which records the same pitch as that of the hammer. It seems, then, that vibrations coming in stimulate various parts of the organ of Corti according to the frequency of the vibration (pitch). When vibrations of various pitches come in simultaneously the corresponding segments must be stimulated. This is quite remarkable when it is recalled how many different tones can be distinguished when listening to a symphony, for example. Certainly the vertebrate ear is one of the most amazingly complex organs found in any living thing.

Hearing defects. The human ear can detect low and high tones ranging from about 20 to 16,000 vibrations per second. A young child can hear even greater ranges, and some animals such as the dog and bat can hear vibrations considerably beyond that detected by the human ear. In man, the range diminishes in the upper limits with advancing years.

Deafness is usually caused either by faulty transmission of sound through the middle ear or by some difficulty in the cochlea, rarely by any deficiency in the central nervous system. One of the common causes of deafness is middle ear infections. Infectious bacteria can make their way up the eustachian tube to the middle ear where they can cause damage to the ear bones or drum. Such infections can often be cleared up by puncturing the eardrum to allow the pus to drain out through the ear canal, thus preventing severe damage to the ear bones and drum. Repeated infections usually result in some impairment of hearing. With the advent of antibiotics such infections are not as common in children as they once were and the coming generations should suffer less from deafness.

With the refinement of electronic equipment, hearing aids have gradually been perfected to a point where they are very useful to those who have imperfections in the transmitting portion of their ears. Obviously defects in the cochlea cannot be compensated for by hearing aids. These instruments merely amplify the tones so that sluggish or imperfect ear bones will, by sheer force of the vibrations, pick up and transmit them to the inner ear. The wearing of hearing aids should cause one no more concern than the wearing of glasses and it is gratifying to see these devices gradually being accepted socially.

Sense of balance

The sense of body position, both static and dynamic, is very important to an animal. The significance of this statement can be observed by watching the movements of an animal in which the balancing organs have been destroyed or by observing a person who has defective organs of equilibrium. In either case, when the eyes are closed there is loss of control in maintaining normal body position. What, then, are the organs that control balance and body position and movement?

There are three vastly different organs which have to do with the sense of balance and movement. The eyes, when functioning as indicated in the preceding paragraph, operate continually in this capacity. A second very important organ of equilibrium is a portion of the inner ear, the **non-acoustic labyrinth,** while the third organ is the system of **proprioceptors,** which are tiny sensory endings located in the muscles and tendons. Let us consider the non-acoustic labyrinth and proprioceptors a little further.

The non-acoustic labyrinth is composed of three **semicircular canals** and two small chambers, the **utriculus** and the **sacculus** (Fig. 16-11). While experimental evidence now shows clearly that even fishes hear, the cochlea is developed only in the higher vertebrates. In all vertebrates, moreover, the inner ear includes the organ of equilibrium. The parts of the non-acoustic labyrinth operate differently. The semicircular canals function when change in rate or direction of movement of the head occurs, and the utriculus and sacculus have to do with the position of the head.

The three canals on each side are semicircular tubes arranged so that each is at right angles to the others (Fig. 16-11); the importance of this arrangement becomes apparent when it is considered that no matter how the head is moved two of the canals (one in each ear) function. They are fluid-filled and each has a small swelling called the **ampulla** which houses a tuft of hair cells that are sensitive to the movement of the fluid. Any acceleration or deceleration of head movement causes the fluid to flow in definite directions in the canals, thus stimulating the hair cells to send impulses to the brain which results in the sensation of movement. When this occurs in a horizontal plane—the one people are accustomed to—no particularly unpleasant sensation results. However, if the head is moved in a vertical plane, such as in the abnormal movements of flying or riding in an elevator, some very unpleasant sensations are experienced; in fact, they may become so distasteful that nausea occurs, as in seasickness. Just why such movements should affect the stomach and bring about disagreeable feelings is not very clear. Fortunately, one can usually become accustomed to such movements so that eventually there is no more response to them than to horizontal movement.

Head position, that is, static position, is determined by the utriculus and sacculus. These two chambers are also filled with a fluid, and, in addition, each contains a tiny lime pebble (the **otolith**) attached to the sensory hair cells. Since the otolith is free to move in the chamber, when the head changes its position the pull of gravity shifts the tiny weight so that the hairs are bent in synchrony with its movement (Fig. 16-11). This is very similar to the operation of the statocyst in the crayfish (p. 218). It is the perception of this movement that makes a person conscious of the position of the body with respect to gravity.

Not only is it important to register the position and movement of the body as a whole but, if coördination of all the complex movements is to be had, there must be some way of bringing about this interrelationship. This is done by the hundreds of **proprioceptors,** tiny sensory endings lo-

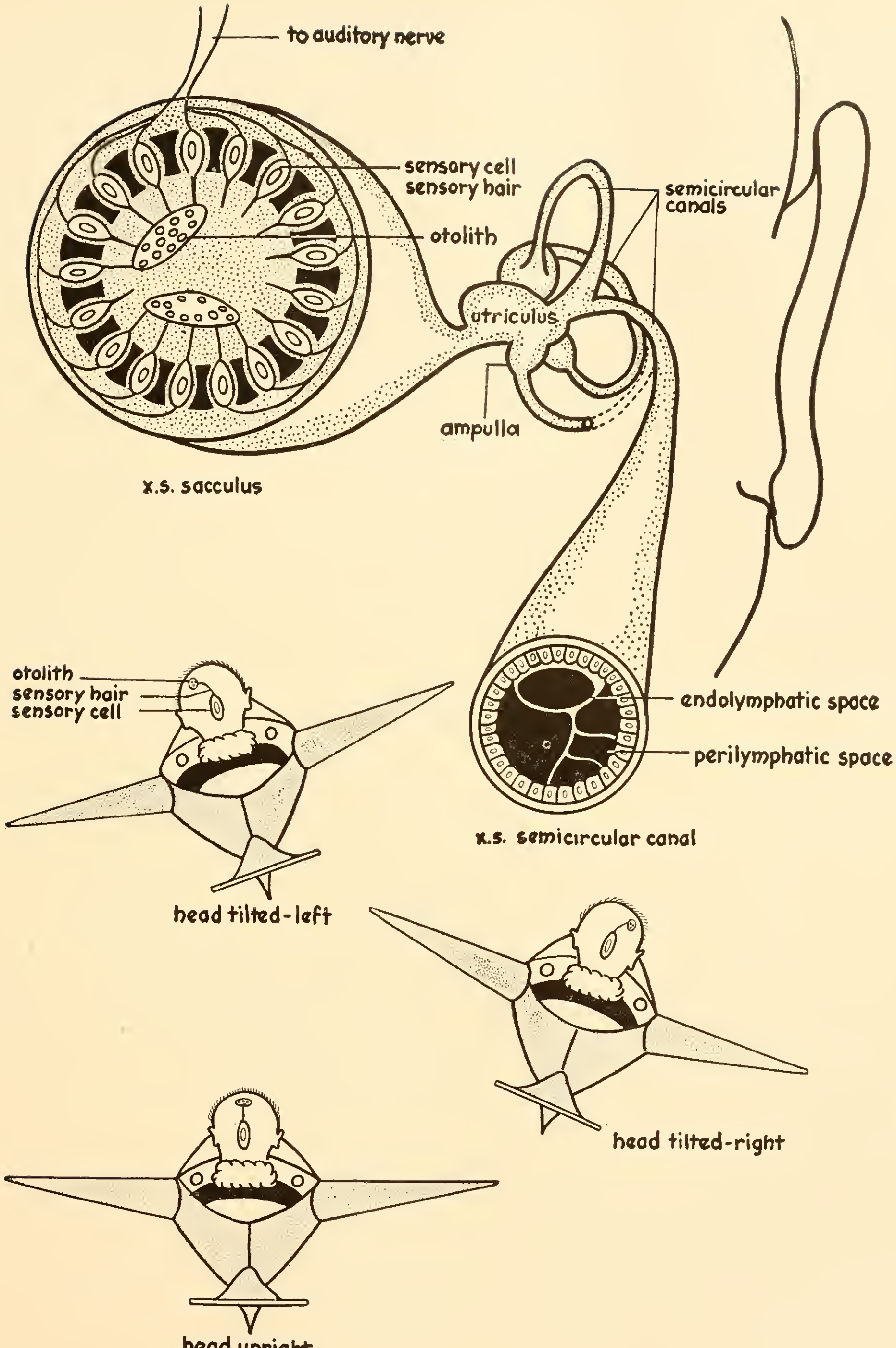


Fig. 16-11. The non-acoustic labyrinth with the sacculus and one of the semicircular canals cut in cross-section to show their internal structures. The lower figures indicate schematically how the otoliths aid in setting up stimuli coördinated with head movements.

cated in each muscle and tendon. These are sensitive to changes in tension. As the various muscles contract, proprioceptors send out impulses which eventually bring about an interplay of various or all muscles and tendons to perform a coördinated act. This goes on without conscious knowledge and functions without vision, since, for example, a person is able to play a piano in the dark. It is not only necessary to know that a muscle is contracting but also to know where the appendage is at all times. In such a simple action as grasping a fork and bringing some food to the mouth it is necessary to contract the proper muscles to extend the arm, flex the fingers on the fork, and further flex the arm in order that the fork be brought to the mouth. The contraction must be of just the right amount or the fork will over- or undershoot its target with resulting catastrophe. It is the proprioceptors that regulate the amount of contraction to bring this act to fruition. In a way, the muscles can be considered sense organs because sensory impulses are coming from them almost as rapidly as motor impulses are going to them, though the cells involved in the two cases are different. The tendons are also abundantly supplied with proprioceptor end organs but they receive no motor nerves and cannot contract.

It is because of the proprioceptors that one can judge weight. If a 24-pound weight is compared with a 25-pound weight, it is difficult to distinguish between them. There is no difficulty, however, in deciding that a 5-pound object weighs more than a 4-pound weight. In other words, one can determine the **relative differences** in weight and the heavier the objects the greater must be the difference to be discernible. For example, in the illustration above, there is a one-pound difference between the two lighter objects which is a 20 per cent difference; in the heavier weights, although there is also a difference of one pound, the relative difference is 4 per cent. People show considerable variation in their ability to detect this difference and this skill probably plays an important rôle in manual dexterity. Some people have great difficulty in using their hands effectively whereas others are very proficient in this regard. In selecting a life work such ability should be taken into consideration, and certain kinds of vocational aptitude tests are designed to determine this ability.

Now that we have learned something about how stimuli are received we must consider next the portion of the coördinating mechanism that adjusts these incoming impulses. This is the central nervous system with all of its ramifying nerves.

ADJUSTORS

The nervous system

When an animal is dissected, the brain together with its many ramifying nerves is most conspicuous even to the beginning anatomist. Early morphologists, however, thought the brain was an inert part of the body and could not assign a function to it. Today the anatomy of the nervous system is well known, although the last word is far from being written concerning its functions.

In its evolution it might be expected that the nervous system originated from the external part of the body because it is this part of the organism that contacts the outside world. Embryology and the history of the animal groups both bear this out. As animals became more complex, certain cells in the outside layer became specialized to receive and transmit stimuli. These cells later confined their entire attention to the job of receiving stimuli and thus became the receptors or sense organs such as those of the eye and the ear. Transmission of the impulses was left to other cells which combined to form the **sensory nerves**. These, in turn, carried the impulses to a central station, the brain and spinal cord, where adjustment and interpretation took place.

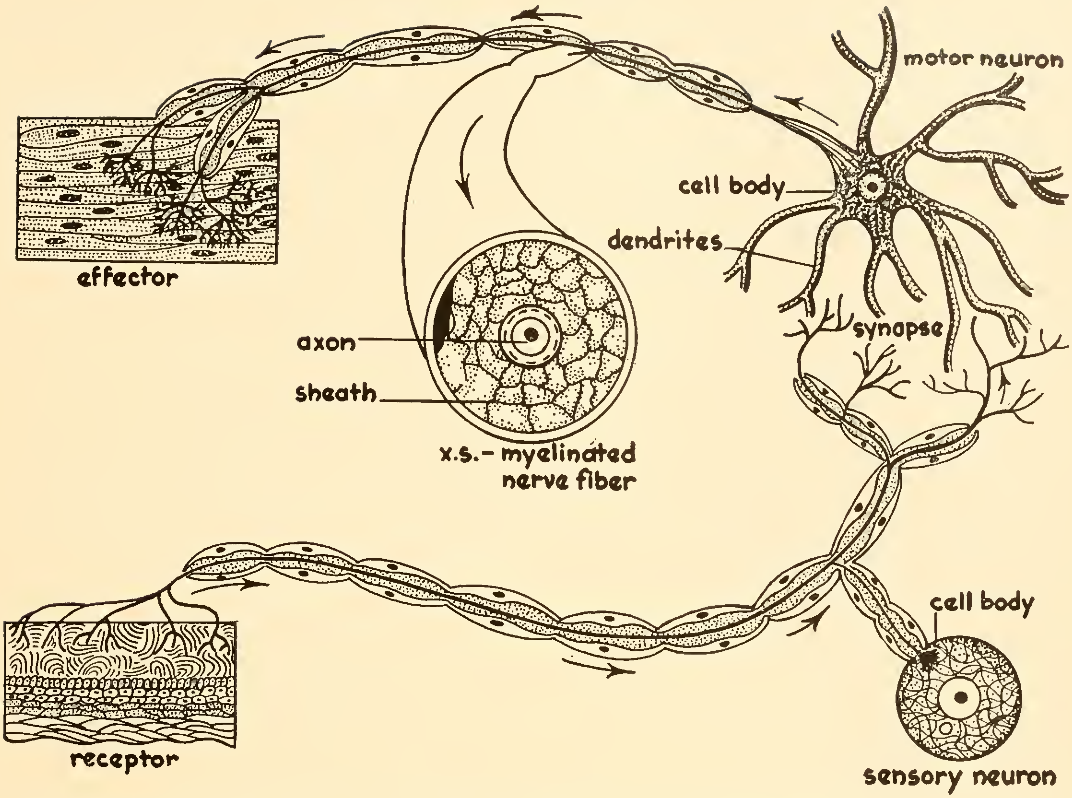


Fig. 16-12. Neurons, motor and sensory. A myelinated nerve fiber is also shown in cross-section. The two neurons constitute a reflex arc.

Another set, the **motor nerves**, carried the adjusted impulse to the glands and muscles where the final response was executed. With such a system it was possible for an animal to reach great size and complexity and still be intricately coördinated. The analogy of the centralized telephone system may be recalled to good advantage at this point.

It may seem surprising to learn that this very complex system is composed of only one general kind of cell, the **neuron.** Here the telephone analogy breaks down, because, while the organization may be similar, the nature of the wire itself is vastly different from the neurons which go to make up the entire nervous system of animals.

The neuron. Although all cells may conduct an impulse within themselves, the neuron has developed this characteristic to an advanced stage. Anatomically the neuron is divided into three parts: the **cell body,** or **cyton,** containing the nucleus, the **dendrites,** which consist of numerous protoplasmic outgrowths from the cell body, and the **axon,** a single, much longer extension terminating in a brush-like filament (Fig. 16-12). The cyton resembles many other cells in appearance and the dendrites merely extend its surface of contact. The axons are usually covered with a fat-containing **myelin sheath** which functions like an electrical insulator. The axons are usually long and an extreme example is illustrated by the giraffe, where they extend from the tip of the toe to the back, a distance of 6 feet or more. Many axons are bound together to form the nerve trunk, spoken of as the "nerve" by anatomists, which is covered by a tough sheet of tissue. This is remarkably similar to a telephone cable where each wire is insulated from all the others.

There are several major kinds of neurons located in specific parts of the nervous system. In the brain and cord they are highly specialized and occur only in certain locations. These neurons are called **association neurons,** and they function in connecting various parts of the brain and cord. Those that conduct impulses from the distal parts of the body **to** the brain or cord are called **sensory** or **afferent** neurons and those that conduct the impulses **away** from the brain and cord are called **motor** or **efferent** neurons. Some nerve trunks are composed entirely of one or the other, in which case they are called **sensory** or **motor nerves.** Most, however, carry both kinds of fibers and are called **mixed nerves.** In the vertebrates the cytons for the sensory neurons lie on each spinal nerve in a swelling, the **dorsal root ganglion,** just outside the cord, whereas those for the motor neurons lie within the cord itself in a region that is grayish in color (Fig. 16-16).

In order for a nerve impulse to complete its circuit, it must pass over more than one neuron; in fact, a great many are probably involved even in the most simple action. Neurons are not directly connected with each other but come in close association only. The region or area where the dendrite of one neuron is in close proximity with the axon of another is known as the **synapse** (Fig. 16-12). This is a very important part of the nervous system because it is here that a selection is made as to whether or not an impulse is permitted to pass on to the next neuron. The impulse can travel both ways within a neuron but where the neurons are in a series, as they always are, the impulse travels **toward** the cell body on the dendrites and **away** from it on the axon. The synapse, therefore, acts like a traffic signal on a one-way street.

Nature of the nerve impulse. Up to the present time, attempts to solve the nature of the nerve impulse have been made only with peripheral nerves, that is, those outside the cord and brain. Very little progress has been made toward an understanding of how they work within the brain itself, though there is no reason to doubt that in a general way the functioning is similar. However, our notions of how consciousness, reasoning, memory, thought, and so forth, are carried on is purely in the conjectural stage today. Perhaps an understanding will be reached some time; if and when that happens an understanding of life itself will undoubtedly be had. One can only conjecture to what extent the human brain may be able to comprehend its own mechanism.

The simplest way to study the nerve impulse is to observe the action of a muscle to which it is attached. The classic setup for such study is the sciatic nerve of the frog attached to the large gastrocnemius (calf) muscle and a mechanical device for recording the contraction of the muscle (Fig. 15-9). Various stimuli can be used to stimulate the nerve but an electrical one is the best and most convenient. Whenever the nerve is stimulated the muscle twitches, indicating that some change set up in the nerve has traveled along the nerve to the muscle, causing it to contract. This change is called the **nerve impulse.**

If a special instrument designed to detect minute electrical currents is placed on a nerve over which an impulse passes, there will be a definite response, indicating that the impulse has an electrical aspect (Fig. 16-13). If it were merely electricity, it would travel with the speed of electricity, namely, 186,000 miles per second. An early experiment, however, demonstrated that it traveled at a much slower speed, 30 meters, or about 100 feet, per second in the frog and only four times that rate in man. The nature of stimulation bears no relation to the speed of transmission and whether the nerve is stimulated with heat, pressure, or electricity the impulse travels at exactly the same speed. Furthermore, once the impulse is started it continues with equal vigor throughout its course, unlike electricity which as it travels along a wire gradually diminishes in intensity the farther it goes.

The fact that the nervous impulse continues throughout its course with equal vigor indicates that something is added to it as it travels. It might be compared to a path of inflammable material where each portion ignites the succeeding part so that the entire trail burns with equal intensity. A minimum amount of heat must be supplied to initiate ignition, but once ignited the flame burns with equal vigor from that point forward. Furthermore, any excess heat beyond the minimum necessary to ignite the material will not change the situation. It is likewise with a neuron, once stimulated, the impulse travels with equal intensity throughout the course of the cell. The neuron, like the muscle cell, obeys the "all or none" principle. In other words, if a given stimulus elicits an impulse, the impulse starts and continues throughout its course with full vigor. No matter how the minimum stimulus is altered, the impulse travels with its full force or it does not travel at all.

Once an impulse passes over a nerve fiber there is a short period when the nerve is incapable of transmitting a second impulse, that is, it refuses to accept any further stimulus. This is known as the **refractory period** and is very short in most nerve fibers, lasting 0.001 to 0.005 of a second. It means that some reorganization is essential before the nerve fiber can once again be stimulated. This, in turn, is due to the physical make-up of the nerve fiber itself. The outside membrane of the nerve fiber is positively charged while the inside is negatively charged (Fig. 16-14), and is therefore said to be **polarized.** This condition is maintained until an impulse passes along which brings about a chemical change, resulting in the mixing of the charged ions through the outer perme-

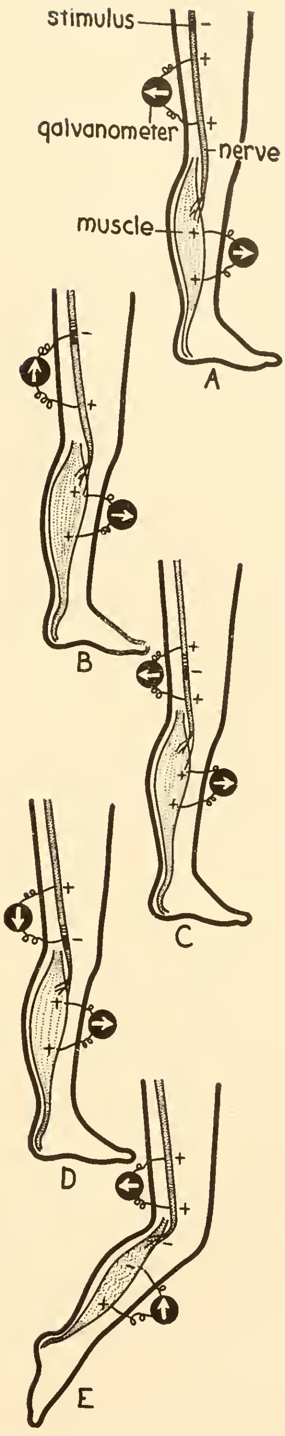


Fig. 16-13. Electrical changes occur in a nerve when an impulse passes over it (*A* to *E*) as indicated by the deflection of the galvanometer needle. Similar changes occur in a contracting muscle.

able membrane, and the membrane becoming neutral in the region of the impulse. It is known that the change is chemical as well as electrical because the nerve fiber consumes oxygen and gives off carbon dioxide, respiring just as all cells do. The neutral condition is coincident with the refractory period and therefore lasts a very short time. Impulses pass along a nerve in rapid succession and it is highly unlikely that a single impulse brings about a specific action. Impulses come in "bursts" like bullets from a machine gun

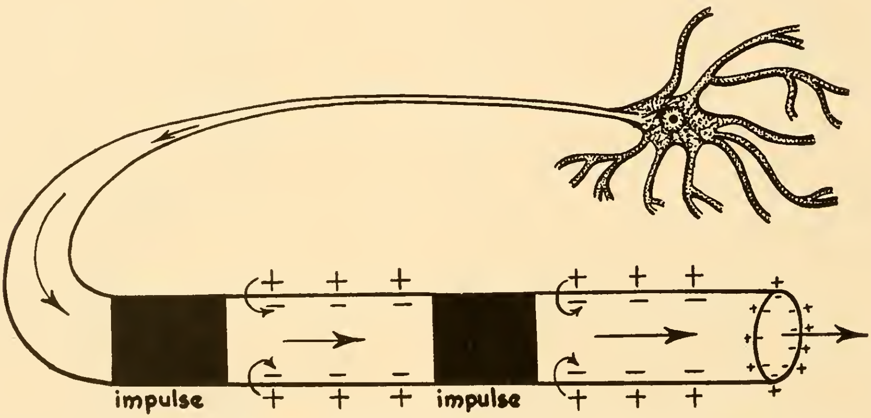


Fig. 16-14. The nerve is normally polarized, being positively charged on the outside and negatively charged on the inside. This polarity is lost coincident with the nerve impulse (indicated in black).

If a sensory nerve fiber is stimulated in its middle, a sensation results which we refer to the usual sense organ of origin. Such sensations in the case of pain are called **referred** pain. For example, if one sits for a considerable period of time with the legs crossed, he finds that upon rising the crossed leg fails to function properly and prickly sensations seem to come from the toes. The sciatic nerve (large leg nerve) was compressed in the middle during that time so the stimulation really came from this region, although the sensation seems to originate in the toes.

So far, consideration has been given only to the transmission of the impulses within the neuron itself. How does the impulse travel between nerve cells and from nerve cells to muscle cells? Careful and extensive microscopic examination has failed to show any protoplasmic connection either between nerve cells or between nerve cells and muscle cells. How, then, does an impulse pass from one unit to another? The best answer today is that the gap is traversed by chemical means. A specific chemical is formed at the termination of a neuron which stimulates the dendrites of the next neuron or a muscle fiber. This will be discussed a little more fully under the autonomic system.

Divisions of the nervous system. In an attempt to understand some of the more simple reactions effected through the nervous system, it is useful to divide it into parts, all of which, however, are very interdependent. The **central nervous** system is composed of the brain and cord while the **peripheral** system is made up of the nerves which connect the brain and cord to all parts of the body. Impulses enter the central nervous system through the afferent fibers of the peripheral nerves. Interpreting the incoming messages and subsequently dispatching them is the function of the brain, the cord acting primarily as a relay. The impulses leave the brain and cord for the muscles and glands on the efferent fibers. The simplest type of such action involving

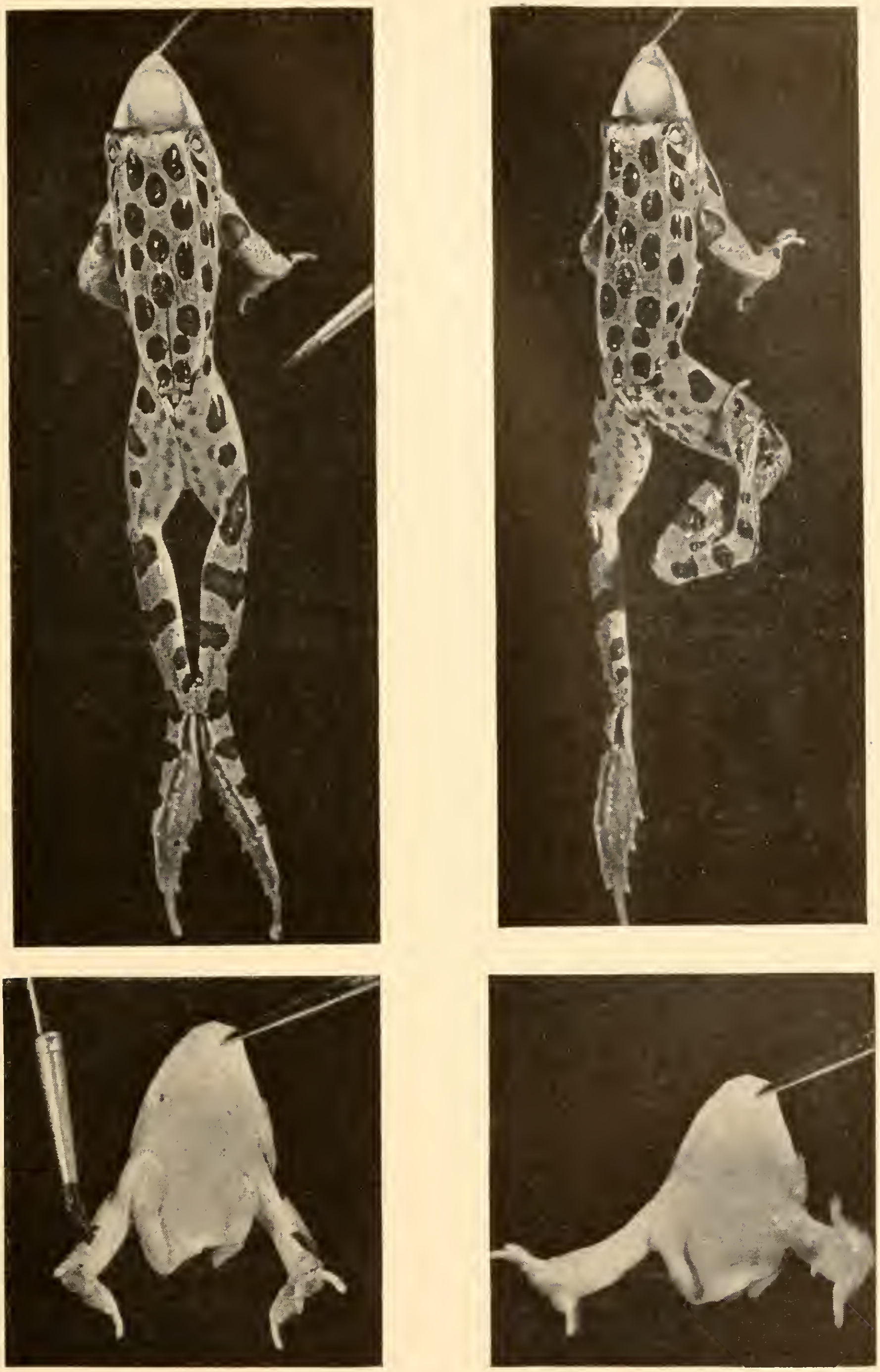


Fig. 16-15. The frog has had the cerebrum removed by a cut just back of the eyes. The cord is intact. Acetic acid has just been brushed on the thigh of the right leg (top left). The right leg flexes and the toes scratch the region which is irritated by the acid (top right). When the posterior part of the body is cut away from the same frog, reflex activity is intact in the remaining part. Here acetic acid is brushed on the right fore leg (bottom left). A moment later that leg flexes first then extends violently; the left leg does likewise, indicating the cross-reflexes operate also when only a small part of the animal is intact (bottom right).

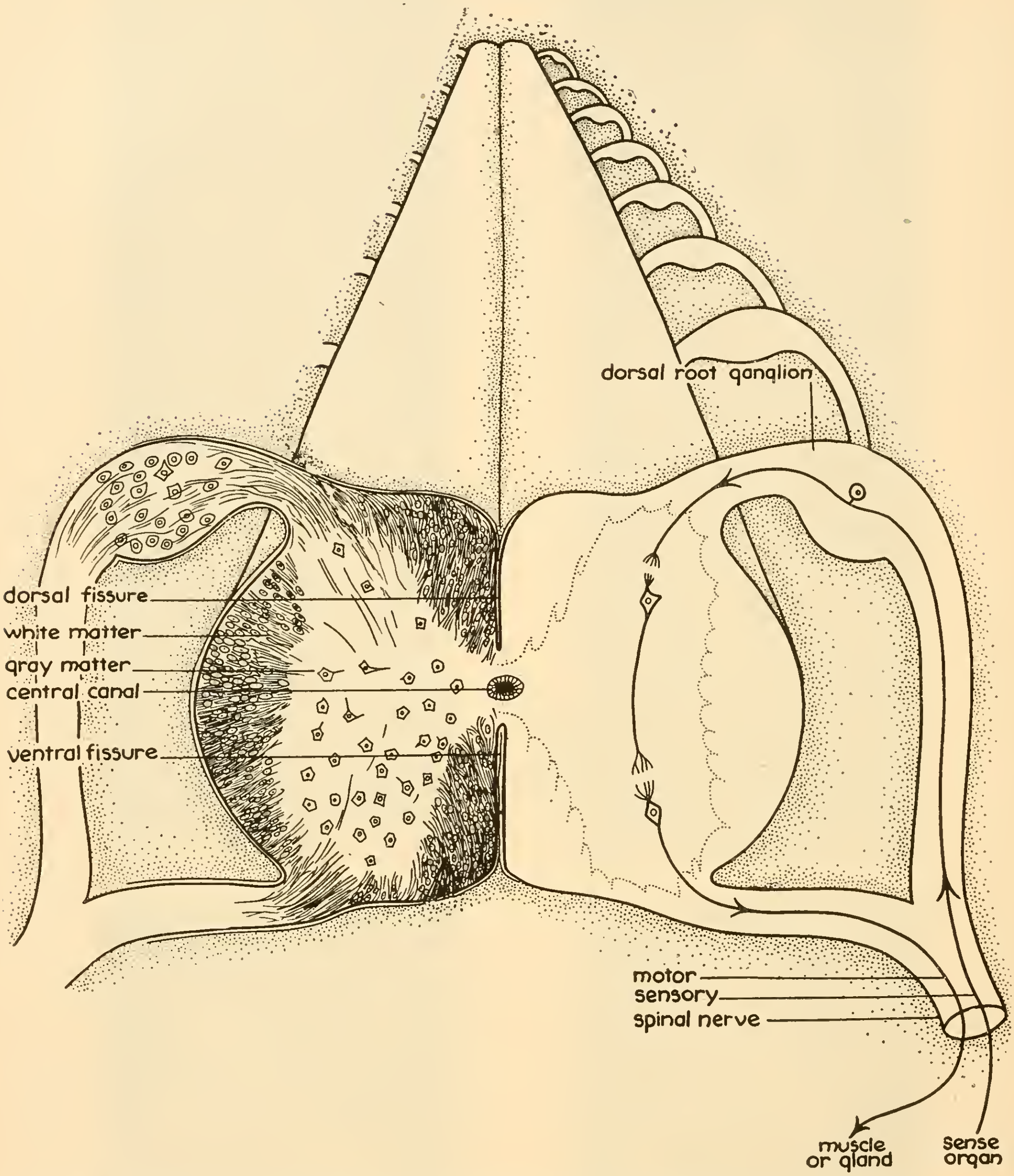


Fig. 16-16. A schematic view of the spinal cord in cross-section. The arrangement of the nerve cells is indicated on the left and the simple reflex pathway on the right.

the peripheral and central nervous system is called a reflex.

The cord and reflex action. Every person has experienced the operation of a simple reflex in his own body, as, for example, the quick withdrawal of his bare foot when it encounters a sharp object. It is difficult to determine whether the foot was removed after or just prior to the sensation of pain. A simple experiment with a frog can show that the reaction could have taken place without the sensation of pain. If the brain is removed and the skin irritated with acetic acid, the frog will withdraw its foot by appropriate leg movements (Fig. 16-15). The stimulus can be repeated again and again but the response will always be the same. Remember, there is no brain to interpret the message, yet the response is just as effective as if the brain had been intact. Similarly, people with certain regions of their cord injured feel no pain though they respond to the stimulus. It is apparent in these cases that the impulse from the stimulus must have traveled only to the cord, returning from it to the appropriate muscles for bringing about that response. Various portions of a frog's cord can be destroyed but the reflex will persist as long as the region where the sensory and motor nerves join the cord is intact. The complete action, then, must take place in a very localized region.

In order to understand how a reflex can take place, a little information about the anatomy of the cord is in order. A spinal nerve bifurcates as it approaches the cord to enter on the dorsal side as the **dorsal root** (sensory) and on the ventral side as the **ventral root** (motor) (Fig. 16-16). The dorsal root bears the **dorsal root ganglion,** in which the cell bodies of the sensory neurons are located. The cell bodies of the motor nerves are located in the ventral gray matter of the cord (called the **ventral horn**). The function of these roots can be definitely identified by cutting them and artificially stimulating the stumps. When the ventral root is cut, no impulses reach the muscle from the cord, but when the cut end on the muscle side is stimulated a response will be evoked. Likewise, by severing the dorsal root no impulses will reach the cord, but when the stump on the cord side is stimulated a response will take place. The dorsal root thus contains only sensory fibers and the ventral root only motor fibers. The spinal nerve, which is a union of the two, contains both, of course.

A simple reflex begins with an impulse coming from a sense organ and traveling over an afferent nerve fiber to the cord via the dorsal root (Fig. 16-16). Here it comes in close contact (synapse) with one or more association neurons. The impulse is then dispatched to the proper muscle or gland over an efferent nerve fiber via the ventral root. With few exceptions reflexes involve more than the three neurons just described. The incoming sensory neuron usually connects with more than one motor neuron through association neurons in the cord. Thus the impulse may not only elicit the simple response but may also pass along the cord to stimulate other efferent neurons and in turn cause a large group of muscles to contract. Indeed, this is the manner in which it usually happens. When applied to man the simple reflex accounts for many of our daily movements. These actions do not have to be learned, they are innate—one is born with them.

Not only are different levels of the cord involved but also neurons on the opposite side of the cord. There is a crossing over of the association neurons so that an impulse may travel to both sides of the body (Fig. 16-17). If, for example, acetic acid is placed on the ventral side of a frog whose brain is destroyed, the leg on that particular side will attempt to remove the irritating acid while the leg on the opposite side will extend (Fig. 16-15). Presently, the impulse will spread to the front legs so that eventually all of the legs are moving in such a manner as to rid the animal of the offending substance, and the body also begins to make mass movements as it would in attempting to crawl away from the irritation. To be sure, the first pathway is simple, but as the stimulus spreads many other pathways are involved until the whole animal is thrown into movement. Under these conditions the higher centers also are involved (Fig. 16-17).

In man, when the various parts of the brain are included, the impulse becomes a part of consciousness and one is aware of the reflex. When one steps on something sharp, for example, his foot may be with-

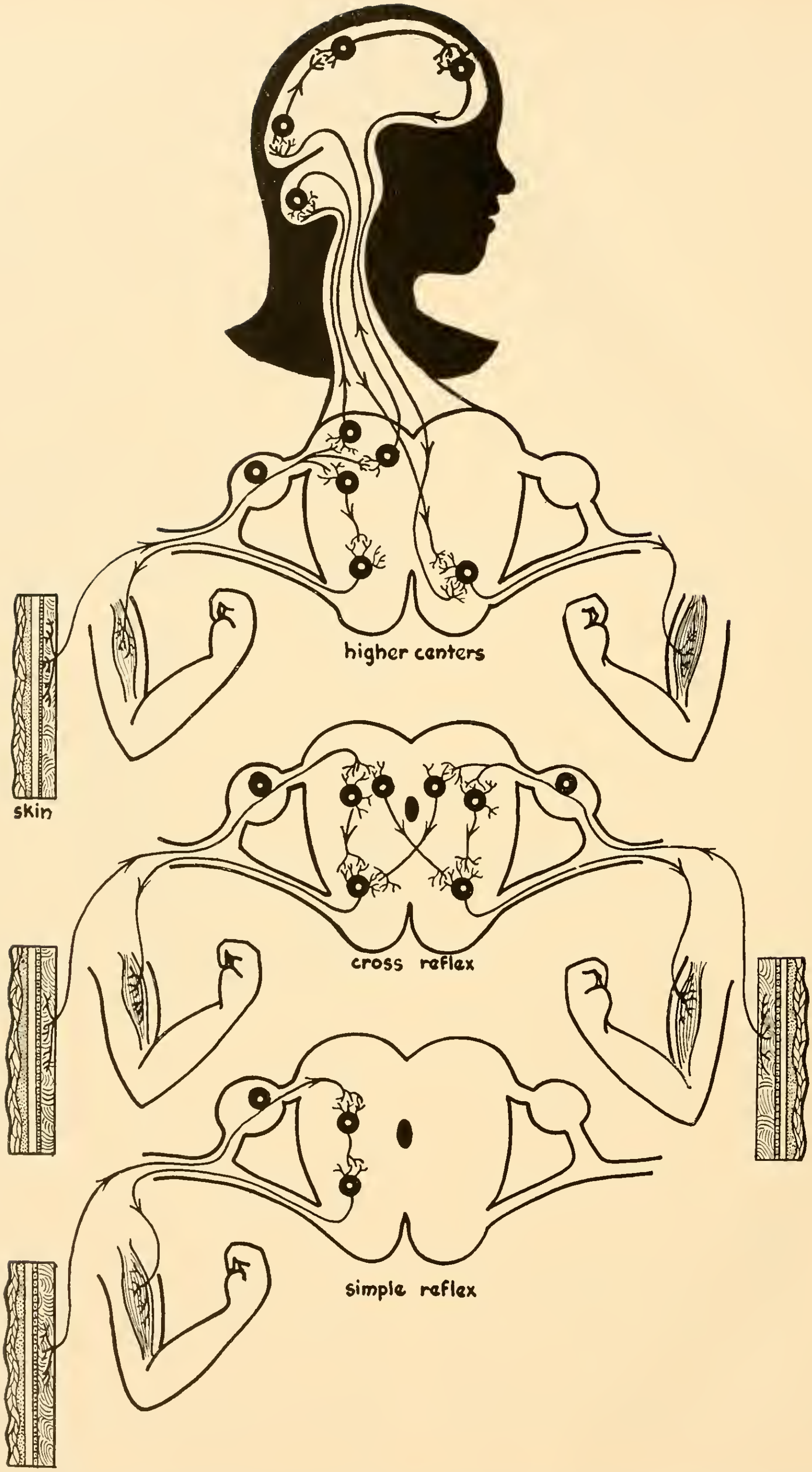


Fig. 16-17. A series of sketches showing the nerve pathways in the cord and brain. The lower and middle figures show those where only the cord is involved while the upper figure indicates the pathways to and from the brain.

drawn through simple reflex, but very shortly certain parts of the brain are involved, even to the cortex where reasoning and memory are possible. He may even consider the advisability of wearing shoes, or the injury may be sufficiently severe that he will remember the event for a long time.

It seems that the impulses usually travel over certain paths but these can be altered on a moment's notice and new paths are then followed. In other words, many conditions can determine the pathway over which an impulse may travel. There are many choices; which it chooses depends on a large variety of circumstances.

An illustration of how the reflex may be interrupted may be seen in the sneeze reflex. Sneezing is caused by a stimulus originating in the nasal chambers; its ultimate fruition is an explosive expulsion of air through these chambers to dislodge the irritation. If, when the sneeze sensation begins, a second stimulation is set up by producing pressure on the upper lip, the first pathway will be blocked. In other words, a new set of conditions blocked the original reflex pathway. Neurologists believed at one time that certain pathways were set up not only in the cord but in the brain as well, and that each pathway was traversed by the impulse in exactly the same manner, thus making it "deeper" until it was well established. There seems to be no evidence for this idea and it is now well known that the impulse may travel over different pathways and may never take the same course twice. Furthermore, pathways may be employed by different reflexes at different times. Which specific pathways are followed, and why, is one of the most important problems in neurology today.

Brain. This part of the nervous system is the most complex and, of course, the most difficult to understand. Only poorly understood today, the brain will, perhaps, never be adequately comprehended, but to accept such an attitude would be highly unscientific. A great German scientist once said that the speed of the nerve impulse would never be measured, and yet, just six years later, another scientist measured it very accurately; today any beginning student in physiology can duplicate the experiment with good precision. Such statements of finality are dangerous, especially for a scientist.

Nerve impulses come to the brain from all over the body on **afferent** nerve fibers like messages coming to the admiral of a fleet. Just as the admiral must make decisions that will be sent by messages to various parts of the fleet in order to accomplish a certain goal, likewise, decisions are made in the brain and impulses are sent out over **efferent** nerve fibers to various parts of the body in order that certain actions can be executed. Decisions are made for the most part in a routine manner, based on inherited principles or on experience gained through having made similar decisions before. Most of the decisions are made by the brain without breaking through to consciousness, so that one is not aware of most of its activity. This great center is indispensable to the harmonious working of the entire body. Aberrations in the brain, so slight that they cannot be detected as any physical change, produce such stark changes in personality and emotional stability that our society is forced to build special institutions such as prisons and asylums to house people so afflicted.

For a better understanding of the human brain it is best to start with a lower vertebrate type brain, which is relatively simple in structure, and follow through to higher forms. In the discussion of invertebrates it was shown that the obvious location for the brain is in the animal's anterior end, which is the part that arrives in any new environment first. Among vertebrates the brain likewise has its beginnings and its subsequent development in the anterior end of the organism, and as we progress from fishes to mammals (Fig. 16-18) it becomes increasingly prominent.

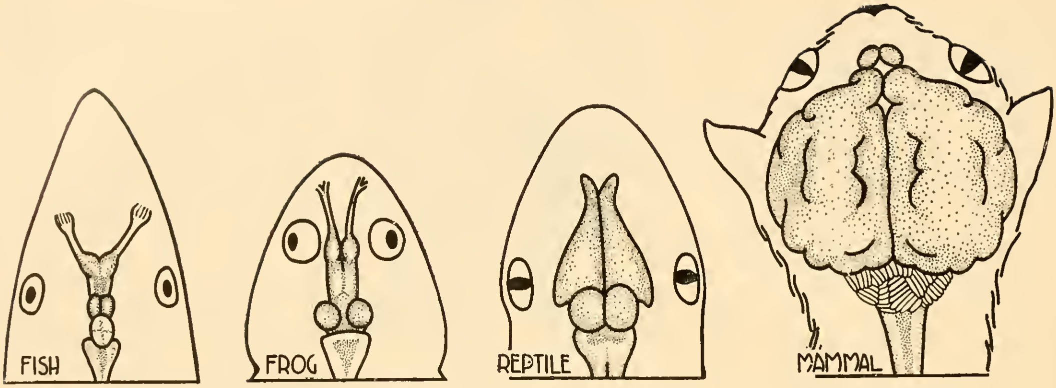


Fig. 16-18. The relative development of the various parts of the brain of representative vertebrates.

The three major regions of the brain, **fore-**, **mid-**, and **hindbrain**, are clearly marked off very early in the embryonic development of every vertebrate (Fig. 16-19). These three regions soon subdivide into five regions. The forebrain becomes the **telencephalon** and **diencephalon**, the midbrain remains undivided and is known as the **mesencephalon**, and the hindbrain divides to form the **metencephalon** and **myelencephalon**. Each of these becomes modified and develops other parts as the brain becomes more complex in higher animals. In the human brain the cerebrum comes from the telencephalon, the posterior lobe of the **pituitary** (an endocrine gland) and the **optic chiasma** from the diencephalon, the **corpora quadrigemina** from the mesencephalon, the **cerebellum** and **pons** from the metencephalon, and the **medulla** from

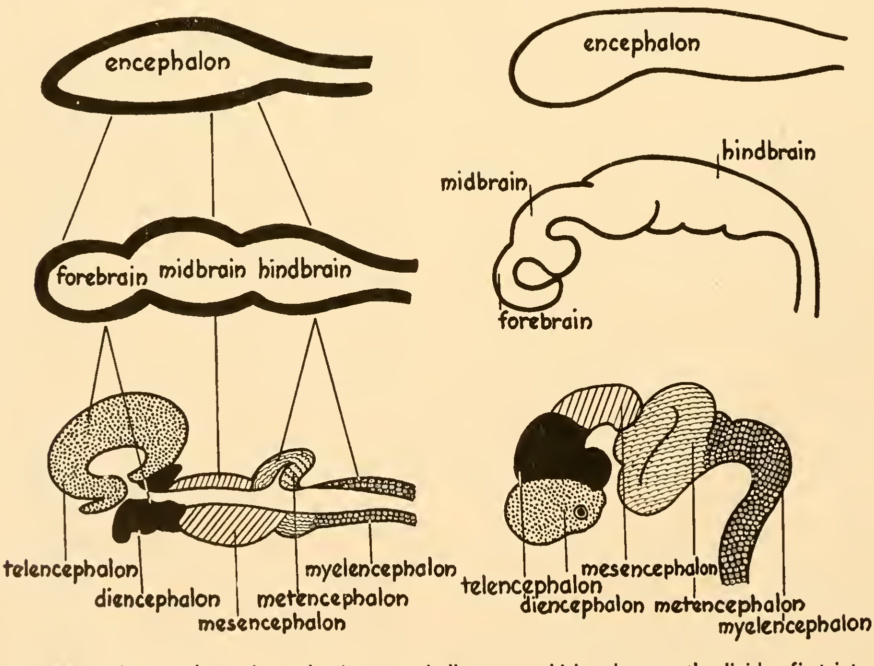


Fig. 16-19. The vertebrate brain begins as a hollow sac which subsequently divides first into three distinct regions and later into the many parts shown (left). The embryology of the human brain parallels that of other vertebrates as shown by the series of figures to the right.

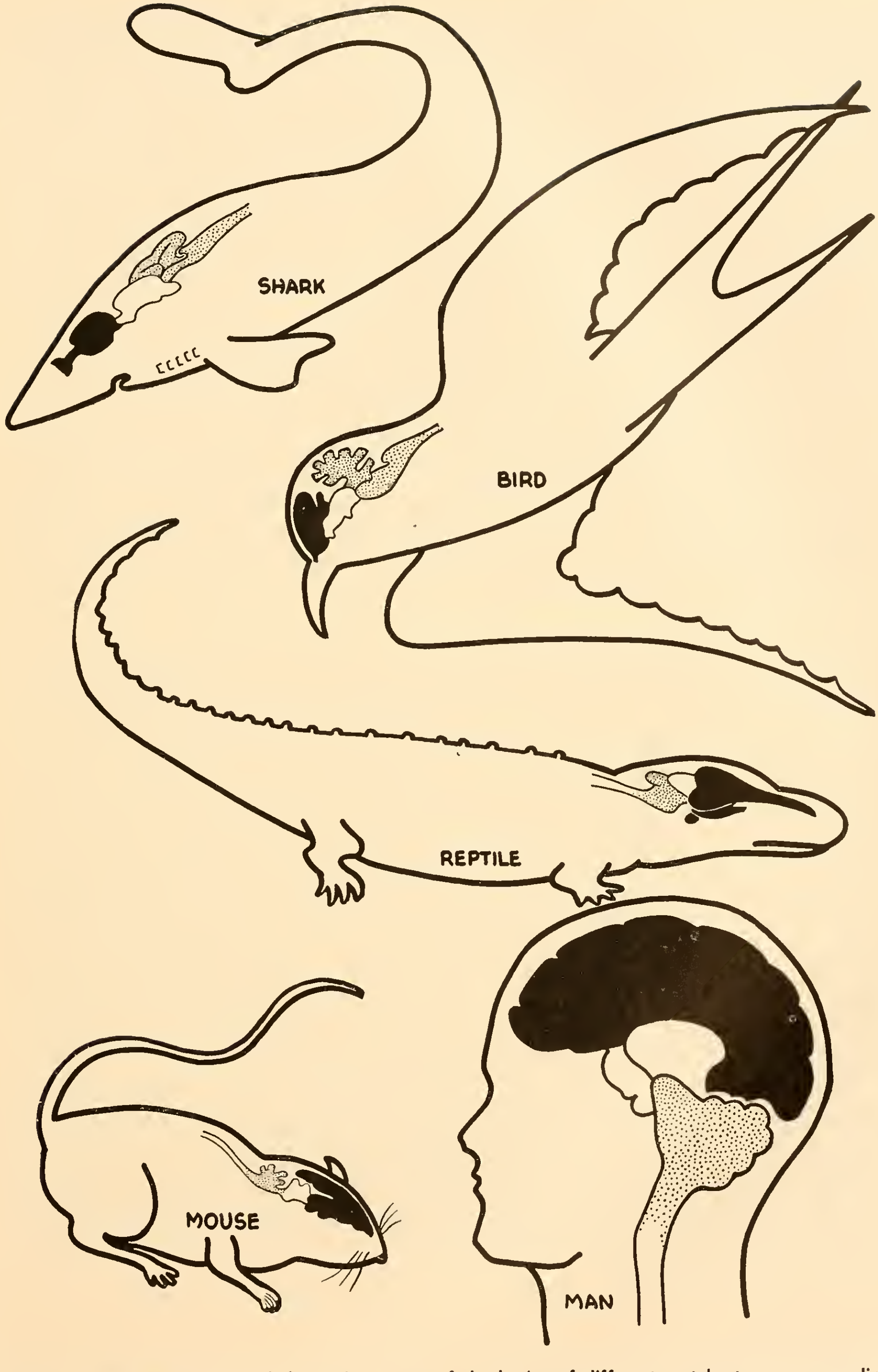


Fig. 16-20. The relative sizes of the various parts of the brains of different vertebrates vary according to the need. Animals that fly or swim need better muscular coördination than do those on land, hence their cerebellums are proportionately large. Likewise a well-developed cerebrum is essential to the success of mammals, hence this part of their brain is best developed.

the myelencephalon. There is a clear relationship between the size of a particular part of the brain of an animal and its importance in the life of the animal. In the lower vertebrates, such as fish and frogs, the olfactory lobes are large, because this is probably the most important sense these animals possess, whereas in birds where the sense of smell is only poorly developed this part of the brain is proportionately small (Fig. 16-20). In the lowest vertebrates the cerebrum is non-existent, or almost so, whereas in the birds it begins to dominate the anterior end of the brain and in mammals it overgrows all other parts to become the most prominent part. In man, this trend is carried to the most extreme point of development.

Emphasis of various parts of the brain seems to be associated with the kind of life its owner leads. For example, birds and fish, which move in three dimensions, require especially good muscular coördination to balance their bodies, and since this nervous center is located in the cerebellum, this portion of the brain is well developed (Fig. 16-20). Reptiles and land dwelling mammals (mouse and man), on the other hand, have a rather poor sense of balance because they move in two dimensions for the most part and do not require the coördination that fish and birds do for balancing their bodies in a fluid or gaseous environment.

The cord takes care of the simplest activities in the organism and its anterior end, the medulla, still retains that function to a high degree even in man. It is here that the reflexes for such basic activities as respiration and heart action center. The cerebellum functions in muscular coördination but the cerebrum, the last region to evolve, is the center of such highly complex activities as thought and reasoning.

As the vertebrate brain has evolved there was a gradual shift of function from the lower part, the brain stem, to the higher part, the cortex. This shift can be demonstrated experimentally. When the cerebrum of a frog is removed its normal activities are influenced only slightly. It jumps normally when stimulated and it can swim in a perfectly normal fashion (Fig. 16-21). Even a "decerebrated" reptile shows very little concern about its loss. Such an operation on a bird or mammal, however, brings about striking changes. The ability to locomote is destroyed and all actions which require considerable muscular coördination are lost. This simply means that the higher vertebrates have shifted their nerve centers from the lower brain stem to the cerebral cortex.

This shift has given these higher forms much greater plasticity in the control of their muscle coördination. For example, when certain muscles in man have lost their nervous connection with the brain in the disease known as facial paralysis, functional cranial nerves passing to relatively weak and less useful muscles can be transplanted to the larger more important muscles and eventually become functional through long retraining. In other words, impulses can be sent to a muscle via a wholly new nerve with the result that the muscle can eventually respond in its usual manner. In man, the cortex so completely dominates the body that it is physiologically possible by intense effort to learn to move muscles in almost any manner. This is well illustrated by the many human feats performed, activities that could never be executed by other animals because their nervous systems are constructed in such a way as to make it impossible. This shift of control to the cortex accounts for man's great versatility and is one of the major reasons for his success. It has also made possible the development of our type of society.

As the cerebrum increased in size in reptiles, birds, and mammals, it became necessary to increase the surface area while retaining a reasonable volume. This has been done by the formation of wrinkles or **convolutions**. Starting in the lower mammals with only very few convolutions, the

Fig. 16-21. The anterior portion of the head, which includes the cerebrum, has been cut away in this frog. When placed in water it swims in a normal fashion, indicating that this portion of the brain has little, if any, function in performing this act.

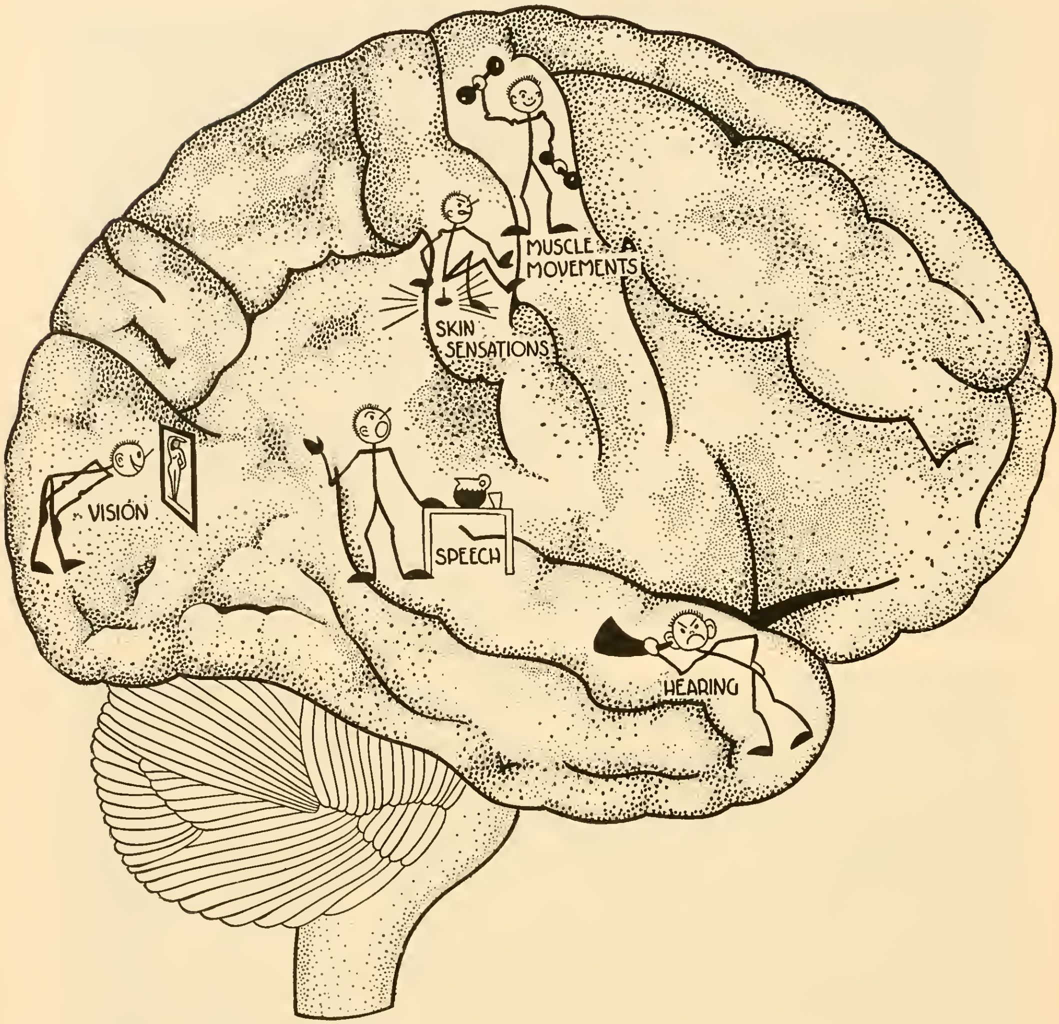


Fig. 16-22. Localized brain areas are concerned with special functions.

number and extent of these increases as the brain increases in size, reaching a maximum in man. Naturally, as the cortex has increased in size, the entire brain has increased with respect to the cord. The relative weights of these two structures for several common animals are shown in the following figures:

	Ratio of Weight of Cord	Weight of Brain
Frog	1.0	1.0
Cat	1.0	4.0
Monkey	1.0	15.0
Man	1.0	55.0

In general, the size of the brain is an indication of intelligence, although there are some notable exceptions, for instance, the brain of both the whale and elephant weighs more than that of man. Dogs, gorillas, and men of approximately the same body weights have brain weights of about 140, 450, and 1350 grams, respectively. Within limits of normal variation in a single species, brain size does not indicate intelligence. For example, woman generally possesses a brain which averages about 100 grams less than man, but what man would be so brave as to imply that she is less intelligent! Likewise, there is a wide variation in the size of brains of different individuals of the same sex, just as there is in stature and body weights. Famous brains have been preserved and weighed, out of morbid curiosity or for scientific purposes, and it has been shown that a variation of 800 grams exists between brains of apparent equal intelligence. So, within limits, brain size alone is not a criterion of intelligence. Intelligence is probably due to such things as the number of cell bodies or the number of association neurons in the cortex of the cerebrum which, in turn, is an indication of the number of pathways over which impulses may travel.

The two cerebral hemispheres are each divided into five lobes and the nerve cells associated with various functions are localized in these lobes (Fig. 16-22). The center for sight is located in the **occipital** or posterior lobe. Areas for smell, hearing, and taste are located in the lateral or **temporal** lobe, while centers for muscle movements are centered in the anterior or **frontal** lobe. Skin sensations lie in the **parietal** lobe. The fifth lobe (**insula**) lies beneath the frontal and parietal lobes and cannot be seen from the surface view. Large areas of the cortex are spoken of as "silent areas" because it appears that injuries to these regions result in no particular loss of sensory or motor function. These are the great unknown areas of the brain which have stimulated so much research in recent years.

The complex life human beings live in modern society has produced extremely intricate nerve pathways in the cerebral cortex, and in a so-called normal person these pathways are so arranged that he gets along well under normal conditions. During times of great stress, these pathways sometimes become so warped as to disqualify the individual for life in society. As a result, he must be confined to an institution. It has been found that by subjecting such a person to severe shock by means of insulin, electricity, and other agents, these aberrant pathways can sometimes be broken up and new, more compatible ones be established. A more drastic treatment is actually to cut across the pathways in the prefrontal lobe of the cerebrum. It is too early to predict how effective this type of treatment will be.

The medical profession is learning that more and more of the common ailments of mankind are due to an overactive cerebral cortex rather than actual organic disease; that is, people imagine they are sick, and this can be carried so far that actual symptoms from heart disease to stomach ulcers are present. This has resulted in a new field of medical research known as **psychosomatic medicine.** With proper treatment, certain neurotic tendencies can be overcome and the person miraculously "cured." This type of medical research is commanding increasing attention and holds hope for a different approach to the study of certain diseases.

The autonomic nervous system

A great many activities of the body such as peristaltic movement in the intestines, breathing, and heart action go on unnoticed and without voluntary control. These are all under the influence of the so-called **autonomic nervous system.** The name implies that the system is a completely automatic one, which is not the case, but it has become fixed by usage.

Anatomically, part of the autonomic nervous system can be seen as two rows of ganglia (lateral sympathetic ganglia) lying on each side of the spinal column in the thoracic and abdominal cavities. The ganglia are secured to the spinal nerves by means of two short connectives, a **white** and a **gray ramus** (Fig. 16-23). Distally they extend as small nerve fibers to the various organs of the chest and abdominal regions. The incoming (afferent) fibers pass through the dorsal root just the same as the voluntary nerve fibers, and the cell bodies are located in the dorsal root ganglion. The notable difference between the two systems is that the efferent fibers of the autonomic

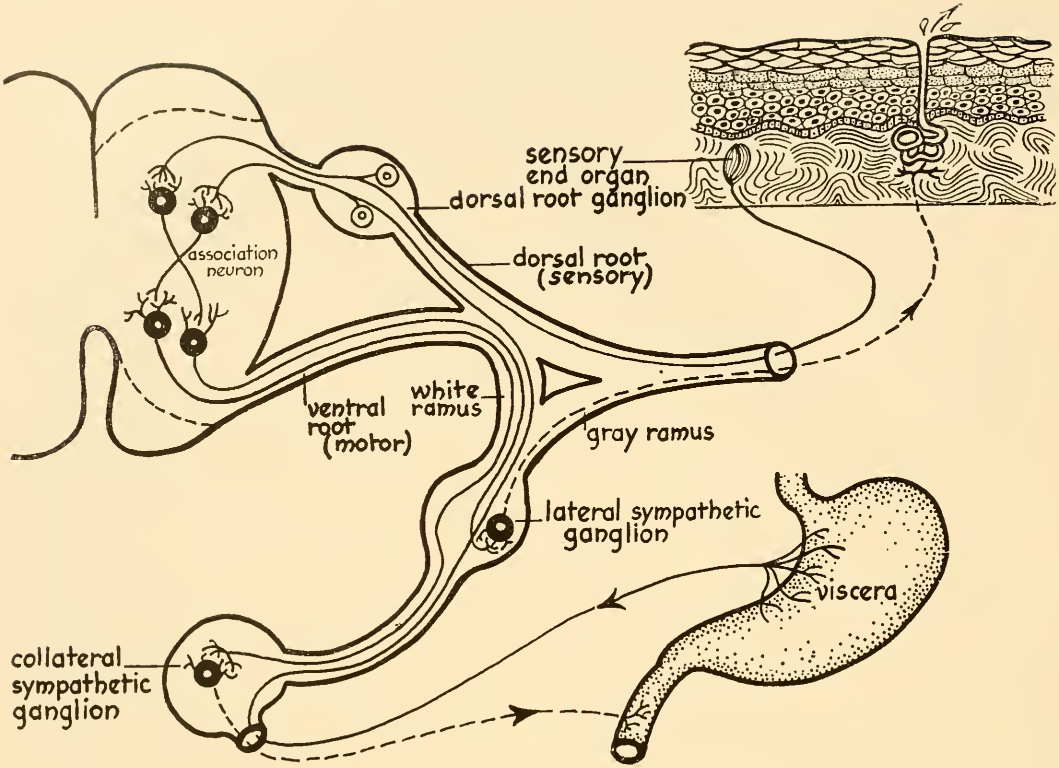


Fig. 16-23. A schematic drawing of the nerve pathways involving the autonomic nervous system. Impulses arising from a temperature sense organ in the skin can stimulate sweating. Also impulses arising from the stomach can cause same action in other parts of the viscera.

system have a chain of at least two neurons between the central nervous system and the organ innervated, whereas in the voluntary system there is but one. The former are also without a myelin sheath.

The first autonomic cell bodies of the efferent neurons lie in the lateral portion of the gray matter of the cord, while the second neuron cell bodies lie outside of the cord in the ganglia already mentioned; sometimes the second ganglia lie directly on the organ itself some distance from the sympathetic chain. The second neuron may return to the ventral root and pass along with the spinal nerve fibers to such parts of the body as the blood vessels of the skin and sweat glands which are under the control of the autonomic nervous system. Others may pass through to a large ganglion (**collateral sympathetic ganglion**) outside the sympathetic chain where synapsis occurs with the second neuron. Fibers leading from the central nervous system to the ganglia outside the cord are called **preganglionic fibers,** those leaving the ganglion, the **postganglionic fibers.** Such a system of fibers makes it possible for stimuli to come from the internal organs and to effect a response elsewhere in the body. For example, an impulse can come from the stomach (Fig. 16-23), causing some action to occur in the duodenum, initiating a peristaltic wave, perhaps. Moreover, pain impulses might come from the stomach which, by the intermingling of the two systems (central and autonomic), project through to the cerebral cortex where they are registered as an uncomfortable feeling about which something might be done. Likewise, impulses might arise in the temperature end organs of a too warm skin and pass through the circuits (Fig. 16-23) giving rise to efferent

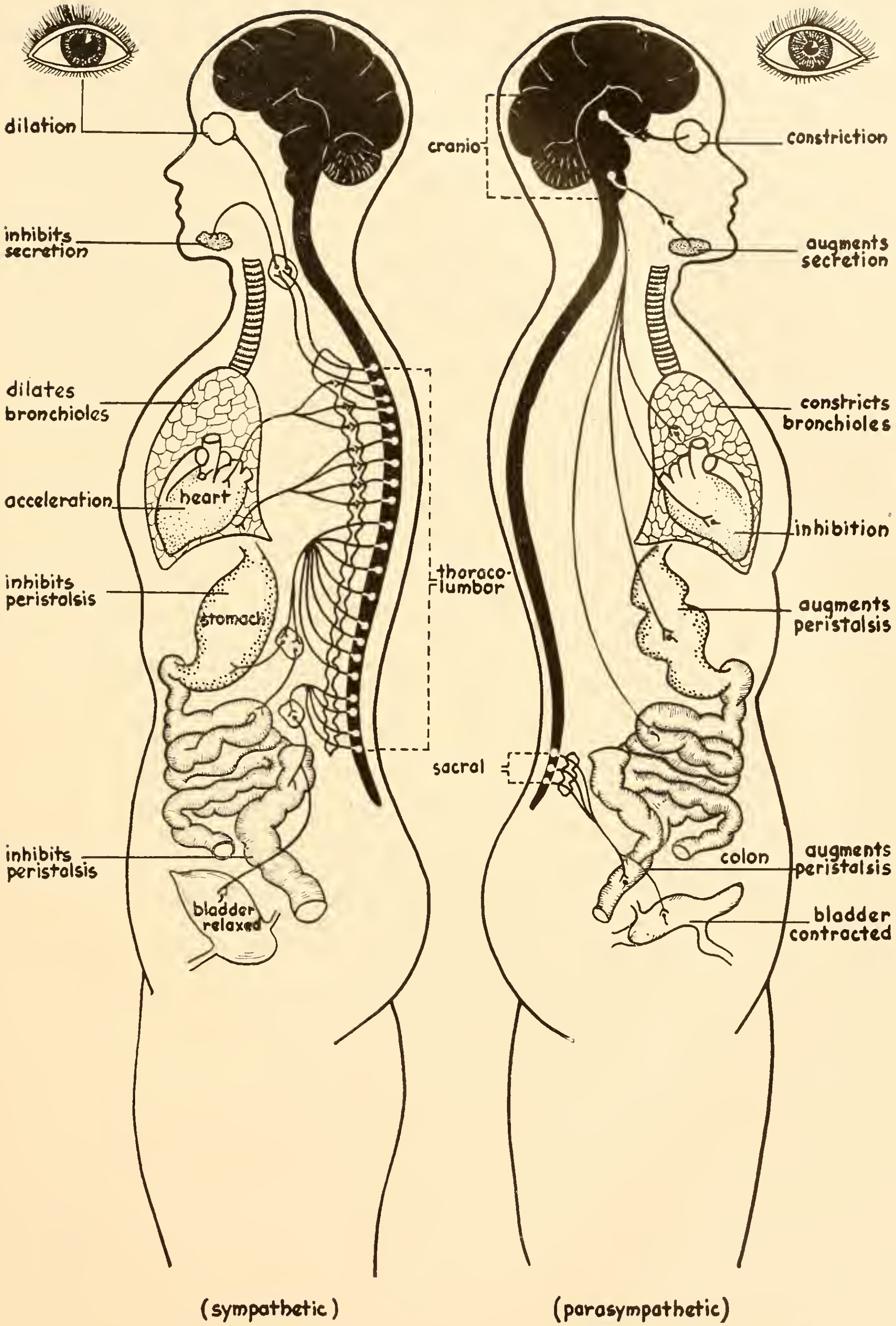


Fig. 16-24. A schematic drawing of the sympathetic and parasympathetic nervous systems, separated for clarity, to show how they function. Note that each organ is supplied with nerves that cause it to be activated or inhibited.

impulses that cause the sweat glands to pour their secretion over the skin, and thus cool the body. Thousands of these pathways are continually carrying messages to and from parts of the body, most of them unknown to the owner.

The autonomic nervous system is divided into two rather distinct parts: the **thoracolumbar** (**sympathetic**) which is composed of the double chain of ganglia already noted; and the **craniosacral** (**parasympathetic**) which originates in the posterior portion of the brain (midbrain and medulla) and the **sacral** region (Fig. 16-24). The thoracolumbar system has short preganglionic fibers and generally long postganglionic ones. The opposite is true of the craniosacral system, and in fact, the ganglia lie in some cases, such as the heart, embedded within the organ itself. These two systems send nerve fibers to all of the organs operating involuntarily so that each has a double innervation. However, the two systems produce opposite effects. For example, if the nerve from the thoracolumbar system to the heart is stimulated, the beat is accelerated, but if the nerve from the craniosacral system is stimulated the beat is slowed down. Stimulation of one nerve may cause excitation in one organ and inhibition in another, thus stimulation of the vagus (craniosacral) accelerates the heart but inhibits the stomach. The value of such a mechanism is obvious. It is the interaction of these two systems that regulates the flow of blood to various parts of the body, differing with each condition in which the animal finds itself. It also causes the pupil of the eye to dilate or constrict, depending on the amount of light that is needed for vision. These and hundreds of other routine jobs the body does quietly and efficiently and entirely without the knowledge of the owner. This system has certainly taken the drudgery out of operating the body, and has left for the higher centers the job of getting the whole organism in a position to obtain food or to do the many other things that are essential for life. If the central nervous system were burdened with the job of operating this machinery, little else could be done. It would be like requiring the President of the country to see that the proper amount of water flows through a certain aqueduct in New York City.

Biologists have been bothered by the problem as to why impulses arriving in an organ via either part of the autonomic system cause acceleration or inhibition even though the nerves appear to be identical, and what the mechanism is that differentiates between them. Some ingenious experiments have been performed to give an answer to these perplexing questions. It has been shown that a chemical (**neurohumor**) is secreted at the point of juncture between the nerve endings and the organ innervated. Furthermore, the chemical is different for the two divisions of the autonomic system, which is what one might expect if the action is the opposite. Stimulation of the craniosacral system, for example, produces **acetylcholine** at the nerve endings, and stimulation of the thoracolumbar produces **sympathin**. Thus, in order to complete the mission of delivering a message to a muscle or gland, a physical and a chemical action must take place. A substance known as choline **esterase** is present, which counteracts the neurohumor and thus prevents cumulative effects. The action of sympathin is much like that of adrenalin, the secretion from the medullary portion of the adrenal glands (endocrine) and its action is antagonistic to acetylcholine. It has no inhibitor and must be destroyed by oxidation some time after it is formed.

The discovery of specific neurohumors in the autonomic nervous system that bridge the gap between nerve endings and muscle has naturally led scientists to postulate that perhaps the same mechanism causes the bridging of the gaps between neurons in the central nervous system. Impulses passing to the synapse differ both in frequency and duration from those leaving

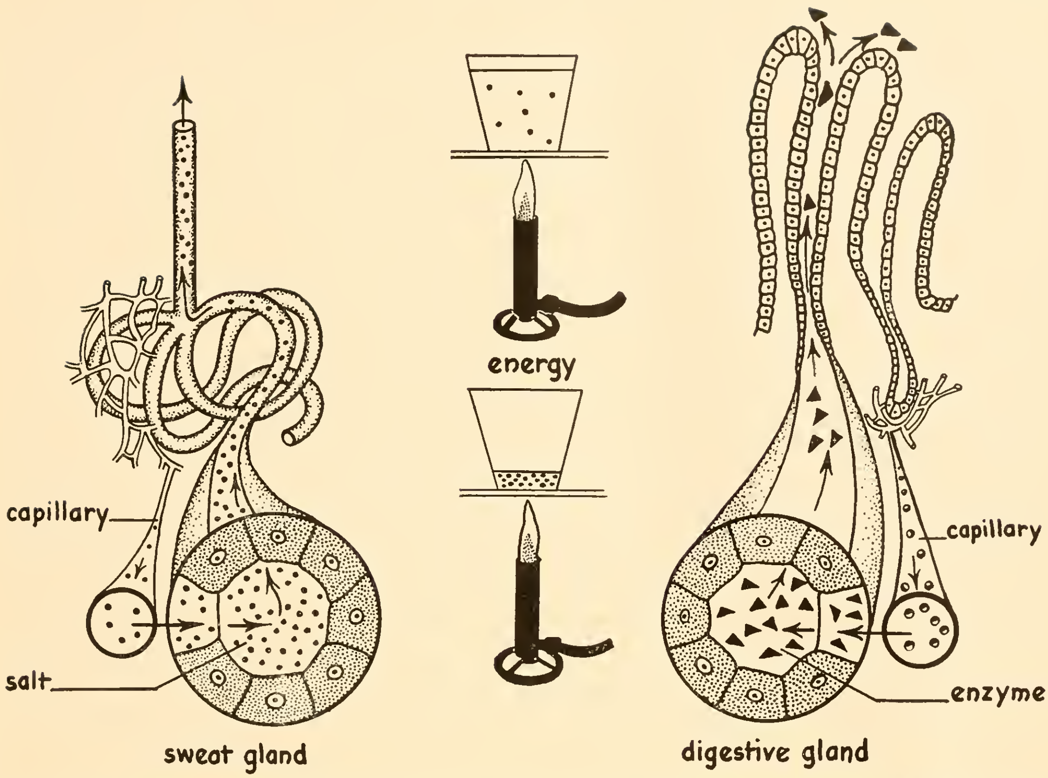


Fig. 16-25. Two different types of glands and how they function. Sweat glands merely extract the substance from the blood, concentrate it, and secrete it. Digestive glands, on the other hand, must manufacture the enzyme from raw materials supplied from the blood, and then secrete the finished product. In both instances energy is required.

the synapse, which would indicate that something happens to them as they pass through the gap. Not only is there a delay in the transmission of the impulse as it passes through the synapse but something happens in this junction which allows the impulse to cross it in only one direction. These characteristics of the synapse may indicate that the neurohumoral explanation is the correct one, although there is more work to be done on the problem before this can be stated positively.

EFFECTORS—THE ORGANS OF RESPONSE

The principal effector organs of higher animals are the **muscles** and **glands**, although there are other types of effectors in use throughout the living world. For example, there are **chromatophores**, found in a large group of vertebrates and invertebrates, that are responsible for rapid color change in the skin. Some animals possess **luminous organs** which radiate light when stimulated and still a few others possess **electric organs** that generate electrical discharges under suitable conditions. Each of these effectors will be discussed briefly with the exception of the muscles which have been treated rather thoroughly in Chapter 15.

Glands

Skin glands have already been discussed (Chapter 14) but there are other glands in the body which are stimulated directly by the nervous system. Just how a gland cell secretes is not well understood. Its job is to extract the product of secretion from the blood or lymph on one side and discharge it on the other into a lumen or tube that conducts the product to its proper place, either to the outside of the body, in the case of sweat glands, or into the digestive tract, in the case of digestive glands (Fig. 16-25). In such glands as sweat and tear glands no special substances are synthesized; their secretion is merely extracted directly from the blood. However, in the case of many other glands, the digestive and endocrine glands for example, while the raw materials are extracted from the blood stream, the final product is synthesized within the cell itself. Just how this is accomplished is unknown.

Glands respond to stimuli from the nervous system and most of them secrete only when stimulated. Some endocrine glands, however, apparently secrete continuously, although the rate may be affected by nervous excitation or by hormones from other endocrine glands. There is considerable energy utilized during glandular activity. Thus the sweat glands produce a fluid with a salt content considerably higher than that of the blood, and energy is required to increase this concentration just as it would be if heat were used to evaporate an equal amount of dilute salt water to a similar concentration (Fig. 16-25). Careful measurements of gland cells demonstrate that some respire at a higher rate than any other cells of the body, even those of the heart.

Chromatophores

Although color change is not found in human beings other than the gradual tanning of the skin as a result of exposure to sunlight, many lower animals are equipped with very efficient and often spectacular color-changing apparatus. In some animals such as the squid (Fig. 12-17) the variety and rapidity of change in color is almost fantastic. It can change from pearly white to intense black almost instantaneously. Others such as fish and reptiles change more slowly but the final product is equally dramatic. Such fish, when moved experimentally from an aquarium with a black bottom, over which they become very dark, to one of white sand, will shortly become a very light color. Furthermore, some, like the flounder, will actually produce the mottled effect of colored stones on the ocean floor. Lizards will change from the color of the bark on the tree trunk to the intense green of the leaf. The protective value of such a mechanism is obvious.

This color change is accomplished by the movement of pigment either in the effector end organ in the skin or closely associated with it. In vertebrates, the pigment is confined to single cells which are scattered throughout the skin of the animal. When light falls on the eyes of the fish, stimuli are sent to the chromatophores which adjust the amount of pigment that spreads out on the surface to obtain just the right shade of color to match the background. Blind fish remain one color no matter what the background. On a light background, the normal response of each chromatophore is to concentrate the pigment granules of the cell into compact "pin points." On a dark background the same pigment granules spread out at the surface, darkening the entire area.

Although most of the pigment cells in animals are primarily under the influence of the nervous system, some, such as those of Crustacea (Fig. 16-26) and Amphibia (Fig. 16-27), are controlled by hormones, although the initial stimulus is via the eyes. Pieces of frog skin, for example, can be stimulated to change color simply by dipping them in solutions containing specific hormones. However, under normal conditions, stimuli from the eyes excite the endocrine glands whose secretion causes the chromatophores to respond. It resembles a chain reaction.

Bioluminescence

This is often spoken of as "cold light" because very little heat is emitted and for

Fig. 16-26. The shrimp, *Grangon*, is hidden because of its ability to match its background. The chromatophores bring about a mottling effect which resembles the sand particles. In addition, it half buries itself to bring about still further concealment.

Fig. 16-27. The leopard frog changes from a light color where the spots are very prominent to a darker color where the spots are obscured. The activity of the chromatophores which are responsible for these varying colors is shown magnified in the lower figures which correspond with the frog above each one. The activity is hormone controlled.

Fig. 16-28. This is a comb-jelly (*Mnemiopsis leidyi*) found along Cape Cod. The combs are luminescent and this photo was taken using their own light.

that reason it is a highly efficient light. It has been said that if man could learn how to produce light as efficiently, a small boy could turn a generator that would light a moderately-sized city. Most of the energy in an electric light or any other kind of light is lost in the production of heat.

It is interesting to note how widespread among living things is the ability to produce light (Fig. 16-28). Indeed luminous species occur in all the major phyla, except the Platyhelminthes and the Nemathelminthes. The sea is teeming with luminescent bacteria, Protozoa, and a large variety of Metazoa. Luminous bacteria may cause a carcass or rotting log to glow in the forest on a dark night. They and other organisms may cause a brilliant display of light in the wake of a ship on the ocean at certain times of the year. The intermittent light of the common firefly has inspired the artistically inclined to describe it in verse and music. Deep sea forms as well as other animals are endowed with luminescent organs which provide light in an otherwise eternally dark world.

Luminescent bacteria usually glow continuously as long as they have sufficient oxygen, whereas the firefly flashes its light intermittently from an especially designed organ. Luminescence depends on the presence of two substances, **luciferase,** an oxidative enzyme, and **luciferin,** an organic substance present in specific luminescent organs. If these two substances are extracted from the animal and mixed in a test tube in the presence of free oxygen, luminescence occurs. Stimulation of the luminescent organs is apparently under the control of the animal that possesses it, at least in some instances. For example, the male firefly flashes its light during the mating season, a fact which may have something to do with attracting the female.

Electric organs

Powerful electric discharges can be produced by a few species of fish. They are "triggered" by stimuli coming from the nervous system. The electric eel and ray possess special "electric organs" that are composed of a great many modified muscle cells so arranged as to accumulate their individual action currents and build up a considerable voltage. In some forms as much as 400 volts have been recorded, which is sufficient to stun or even kill a small fish. When a small light bulb is placed in the circuit, flashes have been recorded. Horses wading through shallow water where the large electric eel resides have been shocked enough to throw their riders.

Muscles and glands occur in all species of the Metazoa. The additional effectors—pigmentary, luminescent, and electric—are much more restricted in their occurrence. They demonstrate how far animals may be able to modify certain parts of their bodies to perform very special functions. It is interesting to speculate how, through the millions of years of evolution, these animals have been able to select such aberrant, though practical, modifications.

CHEMICAL COÖRDINATION—THE ENDOCRINE GLANDS

An important adjunct to the nervous system in bringing about coördination of the vastly complex animal body is the **endocrine system.** This is made up of glands located in various regions of the body which secrete powerful organic compounds directly into the blood stream (Fig. 16-29). Their activity is manifest in other parts of the body. While the nervous system is responsible for quick action, the endocrine system functions in bringing about the much slower reactions which may extend over some period of time.

The glands which are known to be endocrine in nature today were described by early anatomists. Thus, Galen, in the second century A.D., described the tiny pituitary gland of mammals, although he could assign no function to it. Indeed, it was not until nearly the end of the last century that actual experimentation began to bring to light the function of these mysterious glands.

The endocrine glands and their secretions

The endocrines evolved after the nervous system, so it might be expected that they would be found in the more highly specialized animals where the nervous system could not take care of the multitudinous jobs assigned to it. These glands are present in crustacea and insects (Chapter 11) and they may be important for coördination or other functions in animals lower than the arthropods, but as yet their presence has not been demonstrated. They are consistently found among the vertebrates, even in such low forms as the cyclostomes. The glands themselves are derived embryologically from various sources, and in their evolution have performed different functions. For example, the hormones that control chromatophore activity in the amphibia can exercise no comparable function in birds and mammals because they have no chromatophores. Yet, the hormone is still present, as can readily be demonstrated by the injection into a frog of the proper extract. Undoubtedly, such recently acquired hormones as those that stimulate lactation in mammals are derived from similar hormones present in lower vertebrates where they perform a different function. There has been a long, slow, biochemical evolution of these complex substances which have an intricate interrelationship in the higher animals today. This very complex relationship has been the subject of a tremendous amount of research during the past 50 years.

The vertebrates have seven clearly recognized endocrine glands: the gonads, pan-

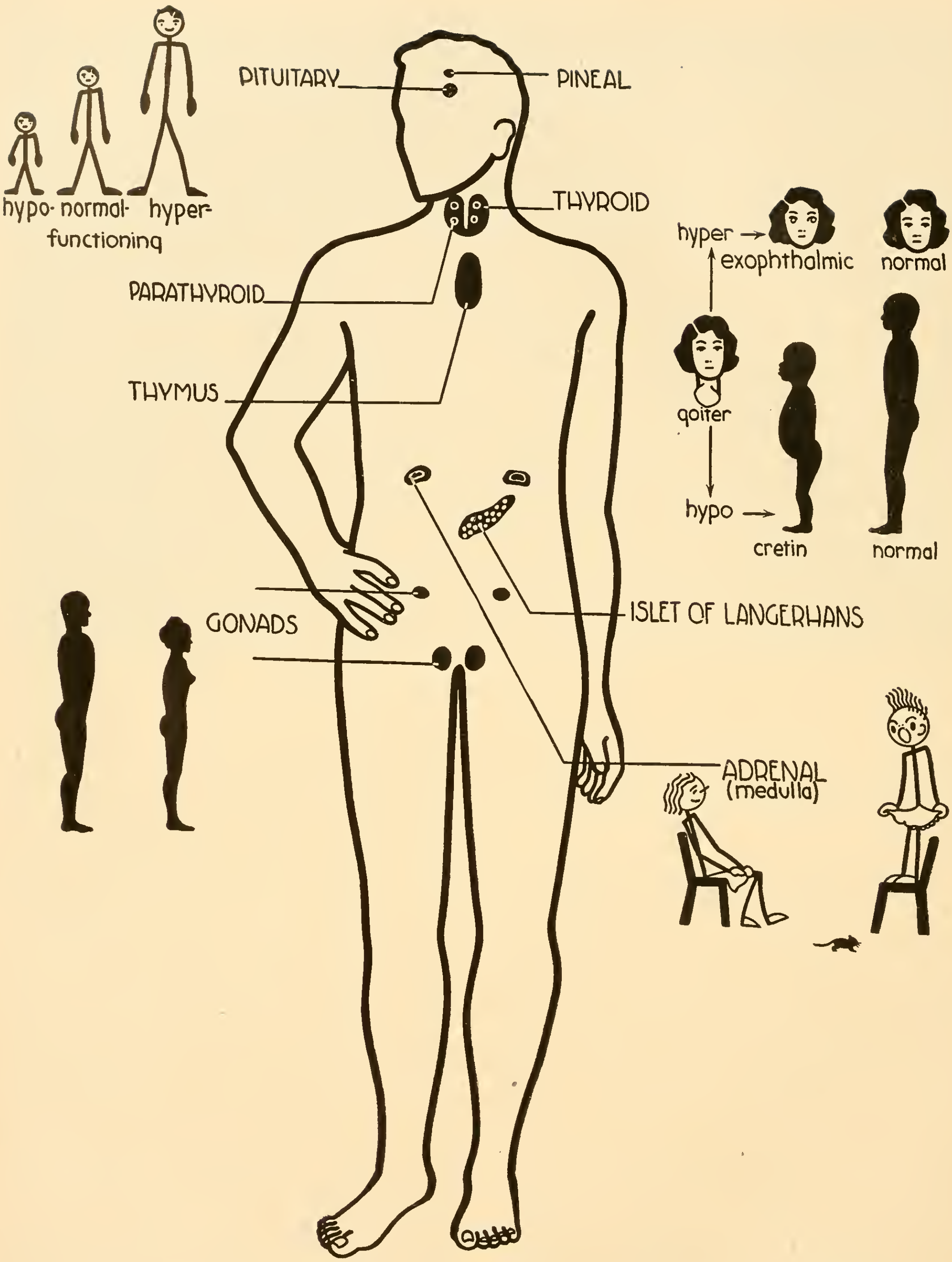


Fig. 16-29. The location of some of the endocrine glands and some of the results of their malfunctioning.

creas, duodenum, thyroid, parathyroids, adrenals, and pituitary. Although they are referred to as ductless glands, the first two do have ducts, although the endocrine secretion does not leave the gland through the ducts but instead enters the blood stream directly. These two, together with the duodenum have two separate glandular functions. The gonads function in the production of eggs and sperms in addition to their endocrine function of producing hormones that are responsible for the secondary sexual characteristics. The pancreas produces digestive enzymes in addition to insulin, and the duodenum has several functions besides producing secretin. Moreover, a single gland such as the pituitary produces several hormones, each with a strikingly different function. Other endocrine glands may be found, although this appears much less likely than the possibility of discovering new functions for the glands already known.

From the very beginning of experimental work in **endocrinology**, as this phase of biology is called, the techniques of discovering the function of a suspected gland have been much the same. The gland is removed. If changes appear in the animal's normal function and if these can be reversed by replacing the gland or its extract, then it is reasonably certain that the gland has an endocrine function. A more complete understanding can be had by using extracts, for if the gland has multiple functions, as in the case of the pituitary, various fractions of the extract can be used and these separate functions more clearly defined. Sometimes it is desirable to inject extracts into the normal animal to study the possible effects of oversupply of a hormone. In human beings, the occasional dysfunctioning of endocrine glands because of tumors or other abnormalities has given physicians and biologists abundant material to study and, in some cases, to conduct experiments. Results of experimentation on lower animals have also revealed a great deal of information that has been applied directly to the alleviation of many endocrine aberrations in man.

The ultimate goal in experimentation with endocrines is to find the exact chemicals that are involved and to be able to prepare them in the laboratory. Once the chemical structure of these substances is known, they can be synthesized and used in animals with deficiencies to restore normal conditions. This has been accomplished for a few hormones but there is still much to be learned. Before this book comes off the press a new endocrine gland may well have been discovered or a new function attributed to one already known. We will briefly survey the seven that are fairly well known.

The duodenum

Two British physiologists, Bayliss and Starling, found that the highly acidic food passing from the stomach into the duodenum stimulated the walls of the latter organ to produce a substance which circulated in the blood stream to the pancreas, causing it to secrete its products into the digestive tract. This substance they called **secretin**, designating it also by the name **hormone**, a name which has since come into general usage for this class of substances. We shall learn more about secretin in the chapter on digestion. With their pioneer work, the field of endocrinology was initiated.

Pancreas

This compound gland has ducts and its most obvious function is that of producing digestive enzymes which are drained off to the duodenum through the pancreatic duct. The digestive function of the pancreas will be discussed in a later section; here we are concerned only with the portion of the pancreas that produces the hormone **insulin.**

The story of the discovery of insulin is one of the more fascinating sagas in the annals of biological science. As far back as 1890 it was known that if the pancreas were removed from a dog, death followed in a few weeks. The salient point that came out in the early experiments was the appearance of large quantities of sugar (glucose) in the urine of such operated dogs. The two German workers who first performed these operations noticed that ants were attracted to the cages of these dogs and found that it was the sugar in the urine which was attracting them. This reminded them of human diabetes, a disease that had been known for centuries. A long series of experiments followed by workers all over the world, and it was soon proven conclusively that the small groups of cells in the pancreas, called the **Islets of Langerhans**, produced a hormone called insulin that was responsible for retaining and storing sugar in the body. If these islets were destroyed, as in the case of human diabetes, sugar no longer was retained in the liver and other tissues, but poured out through the kidneys into the urine and was lost from the body. This was a great discovery but what could be done about it now that the cause of this dread disease was known?

The first step was to try to find a substitute for the non-functioning islets. Feeding the whole pancreas to depancreatized dogs failed to produce the slightest effect. The hormone was digested in the alimentary tract; consequently, it never got into the blood stream where it could be carried to the liver and tissues in which it would work. The next step was to inject an extract into the body, but because of the difficulty encountered in getting a pure product, no satisfactory results were obtained for 20 years. During this long period experimenters were attempting to obtain a pure hormone from the whole glands of various animals, mostly domestic animals such as cattle, sheep, and hogs.

It occurred to a young Canadian physician, Dr. Frederick Banting, that perhaps the digestive enzymes produced by the pancreas destroyed the insulin before it could be extracted. This was later shown to be true. Banting reasoned that since the embryonic pancreas was known to produce the islet tissue before the enzymes appeared in the pancreas, if such glands were used, perhaps the hormone could be isolated in an active state. In 1922, he and three other men—Best, McLoed, and Collip—working together, set out to isolate the hormone. After a great deal of labor, they eventually prepared a product which caused no ill effects on the dogs when injected under their skin and which cured their diabetes. It was a short step to the treatment of humans, where success was immediate. The thousands of diabetics then had, for the first time, some means of staving off an early death from a disease that had always been fatal.

Insulin was produced in more concentrated and more purified form during the ensuing years until today the product is responsible for the near-normal lives of hundreds of thousands of men, women, and children. Someday it may be possible to take the hormone by mouth, but at present it still must be injected under the skin at rather frequent intervals depending on the severity of the disease.

The nature of diabetes. Without treatment a diabetic suffers from insatiable thirst, excessive urination, a gradual loss in weight, general body weakness, and finally a coma which terminates in death. During this course the sugar in the blood and urine is found, by measurement, to be abnormally high (as much as 8 per cent in the urine), the liver loses its glycogen and finally, in the coma state, acetone and partially degraded fats also appear in the blood and urine. Before death the acetone may reach such concentrations that it can be detected on the breath. All of these symptoms are immediately relieved with the administration of insulin.

The first, most obvious function of insulin is to maintain normal carbohydrate metabolism in the body. For some reason, in the absence of insulin the liver fails to store glycogen and glucose is oxidized very poorly. Strangely enough, the abstinence from carbohydrates in the diet does very little good in preventing any of the symptoms. In fact, it seems that without insulin the body mobilizes all of the sugar at its disposal and discharges it from the body via the urine. Even the amino acids are deaminized at an abnormally high rate, so that the sugar residue is added to the already heavily sugar-laden urine. Furthermore, the fats are withdrawn from storage and only partially oxidized, leaving the unoxidized fractions in the blood and urine. It seems that all the forces of the body are put forth to produce sugar which is then wastefully thrown away. Death is the inevitable answer to such a course, unless insulin from an external source can intervene.

In some diseases of the pancreas the islets are stimulated to produce more than the normal amount of insulin. The results are the same as when a diabetic gives himself too much insulin. The blood sugar is dropped to such a low level that the brain becomes irritable and finally the person goes into the severe condition called **insulin shock.** Most diabetics are familiar with the possibility of this condition and accordingly carry sugar or some other sugar-containing substance that can be taken quickly to overcome the lowered blood sugar level. Because of his liability to insulin shock or coma, either of which may render him unconscious, it is advisable that the diabetic carry among his possessions a card or tag identifying his disease, so that in event of collapse his condition will not be mistaken for some other malady or even drunkenness.

The gonads

The testes and ovaries are also compound glands whose primary function is the production of sperms and eggs. In addition, they have very important endocrine functions which have developed in the evolution of vertebrates primarily for the purpose of caring for both the gonadal products (eggs and sperms) and the early embryo. Such a process becomes highly complex in mammals where the young are few in number and are cared for both within the body of the mother long before birth and for some time after they have made their appearance in the outside world. To aid in its functioning an intricate system of hormones, intricately adjusted to one another, has thus been evolved.

The gonads' primary function of producing eggs and sperms will be discussed later in Chapter 21 and only such anatomy as is necessary for an understanding of their endocrine function will be given at this time.

The testes. Located among the sperm-producing tubules of the testes is a special type of tissue (interstitial) which produces a hormone, **testosterone,** that is secreted directly into the blood stream. This stimulates the production of the **secondary sexual characteristics** in all male vertebrates, characteristics which are associated with maleness. They are the very obvious traits which separate the male from the female both morphologically and physiologically. The comb and brilliant plumage of the cock, the thick neck and massive body of the bull, and the beard of man are all secondary sexual characteristics. The absolute proof that these characteristics are associated with the testis can be demonstrated by **castration,** or removal of these glands, an ancient custom practiced by man not only on his domestic animals but in some cases also on his fellow man. The castrated cock shows none of the brilliant plumage of the normal male; the steer is quite different both in its anatomy and behavior from the bull; the gelding has none of the fire nor cantankerousness of the stallion. In ancient times it was customary to castrate slaves, producing **eunuchs** who would then be docile, subservient beasts of burden and trusted keepers of the harem. When it was desired to retain the soprano voice of a

Fig. 16-30. The removal of the single ovary in birds results in the subsequent development of testes and male characteristics. In these photos the chickens on the extreme ends are female and male respectively. The animal in the middle had its ovary removed at seven weeks of age and shows a well-developed male comb. Autopsy showed two fully formed testes.

particularly talented youth, castration did the trick, and thus choirs could be produced with remarkable musical qualities. Occasionally, the accidental loss of the testes in a young boy has resulted in an adult with a high-pitched voice, lacking a beard, obese and with little of the ambition and the usual emotional characteristics associated with the male. Castration after maturity, however, seems to initiate few, if any, of these changes.

The onset of interstitial tissue activity is associated with puberty when pubic hair, change of voice, and increased size of the genitalia occur.

If testosterone is injected into a castrated animal or a testis is transplanted into some part of the body where it can grow and secrete testosterone into the blood stream, the male secondary sexual characters will be restored. Such injections given to a castrated female will cause it to develop masculine characteristics. A perfectly normal egg-laying hen can be induced to become a functional father rooster with comb, wattles, and crow and all by castration followed by a series of injections of testosterone. By removing the single ovary from a seven-weeks old chick a normal "rooster" will result (Fig. 16-30). This can be accomplished in female birds because they possess a residual testis and no external genitalia. Sex reversal in mammals is limited to the secondary characteristics only.

Occasionally the testes in mammals fail to descend normally into the scrotal sac as they should do during the last few weeks of gestation. This condition is known as **cryptorchidism** and males in which it occurs are invariably sterile. If, however, the testes are brought down into the scrotum by surgery, they very soon become functional and produce viable sperm. A cryptorchid is perfectly virile in every way except fertility, that is, he possesses all of the normal characteristics of the male including sex drive. This is because his interstitial tissue is unimpaired, so that testosterone is produced in proper amounts to allow for normal development of his masculine characteristics. Upon microscopic examination, these testes will show perfectly normal interstitial tissue but degenerate non-functional sperm-producing tubules. Experiments show that if the normal testes of mammals are placed back into the body cavity or heated to the internal temperature of the animal the sperm tubules degenerate. Therefore, sterility of the cryptorchid is due to the higher temperature existing in the body as compared to the scrotal sac. This is difficult to correlate with the fact that the internal testes of birds are fertile and the temperature is even higher than that of mammals. In the long evolution of mammals one fails to note the advantage of placing these organs, upon which the race depends for its perpetuation, in such a hazardous position when they would be much safer housed within the body cavity as are their counterparts, the ovaries.

Radiations of various kinds, such as x-rays, if given in large doses have a lethal effect upon the sperm-producing portion of the testis. In smaller doses the effect may be simply to alter the genes which ultimately might produce far greater casualties in the human race than mere sterility in a few individuals. At any rate, people who work around x-ray machines must guard themselves carefully or they will become sterile, although none of their secondary characteristics will be affected.

Chemically, testosterone is well known and is found to be similar to one of the female hormones. Other related testicular hormones are collectively called **androgenic compounds** and seem to be generally distributed throughout the body. They are probably substances which are utilized in the production of testosterone or they are products of its breakdown, because they are found in the urine.

After the testes had been associated with male vigor, the intriguing idea of transplanting them or injecting their extracts into the body of a senile male caught the imagination of early biologists. Long ago, Brown-Sequard, a famous physiologist, injected himself with testicular extracts which he professed renewed his vigor. This initiated a long series of such experiments both on animals and on man himself. The results have all been disappointing, and today it is believed there are no beneficial effects from either the administration of testosterone or the grafting of testes. It can be concluded that testosterone does initiate and maintain the secondary sexual characteristics and probably contributes to sexual behavior and urge. In man, however, the latter function is so complexly interwoven with psychological reactions that it is difficult to determine just how much effect it really has.

The ovary. A far more complex battery of hormones is produced by the mammalian female generative apparatus than by the male. This is due to the recently acquired though intricate mechanism of caring for the developing embryo, both before birth and immediately thereafter. These hormones are produced in the ovary, although others probably occur in various parts of the genital tract.

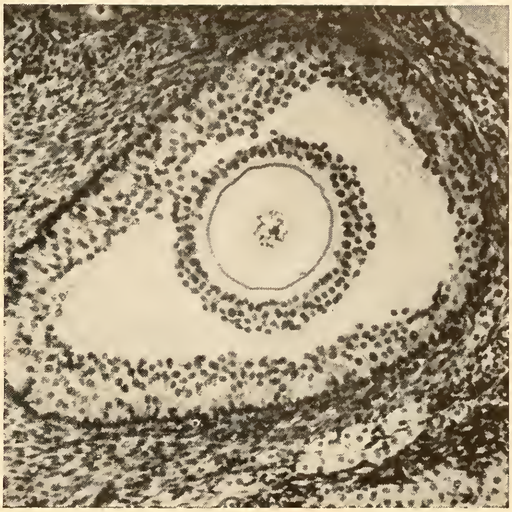


Fig. 16-31. A Graafian follicle from a rat, sectioned to show the egg.

At birth and throughout the early life of a female the potential eggs lie dormant in the outer region of the ovary. From puberty on they begin to grow. As an egg grows, there develops about it a fluid-filled space, and the entire structure is called a **Graafian follicle** (Fig. 16-31). These follicles produce a hormone, **estrogen,** which is the counterpart of testosterone in the male. The influence of estrogen in the blood stimulates the onset of changes both in body contours and in the female organs which finally result in the mature human female. A similar situation occurs in all mammals. Before completion of maturity occurs, another hormone, **progesterone,** must be produced by a special part of the ovary called the **corpus luteum.** After the rupture of the Graafian follicle and the liberation of an egg (Fig. 16-31), the cavity left fills with this tissue which, in turn, produces pro-

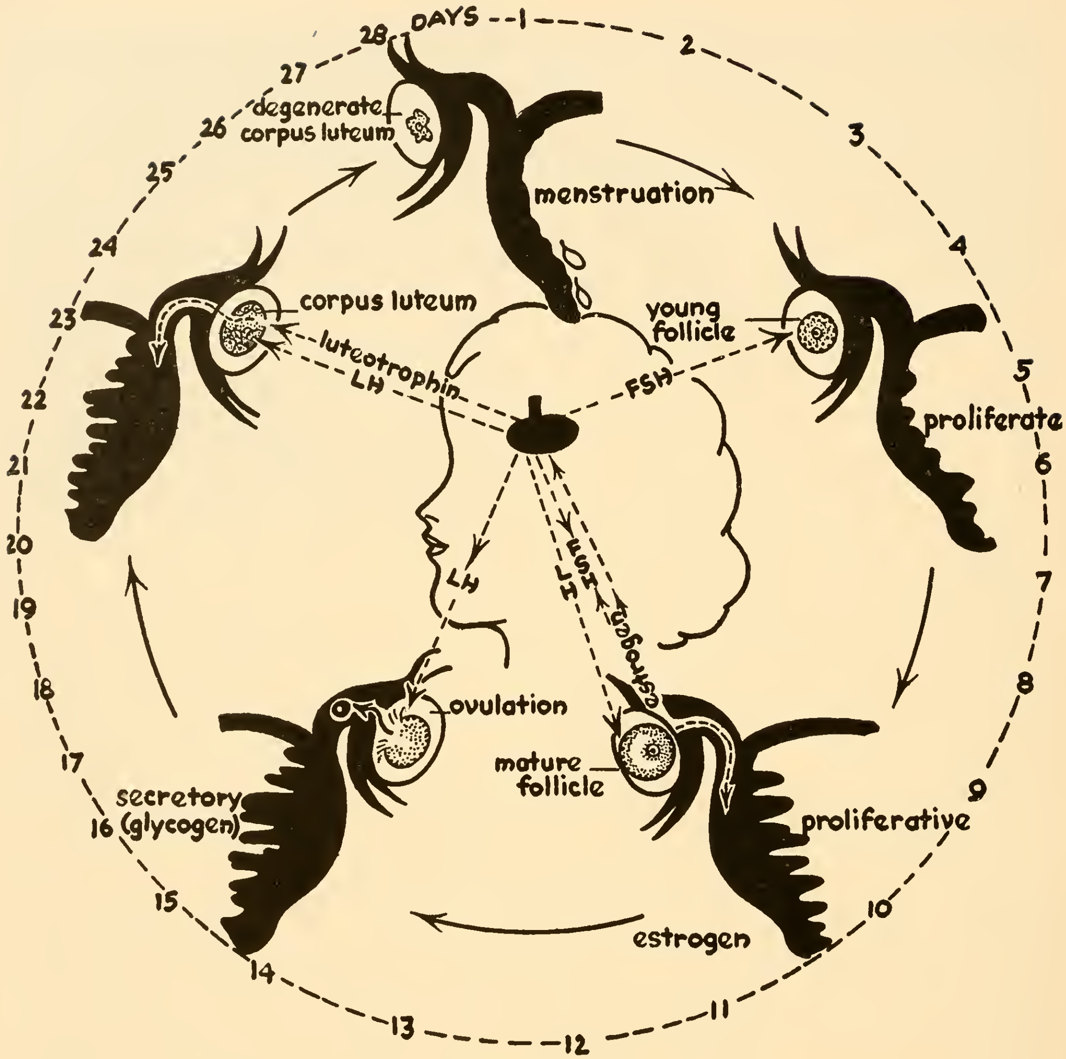


Fig. 16-32. The events that occur during the menstrual cycle in man are graphically outlined.

gesterone. Once this hormone is released the menstrual cycle is initiated in man.

The **menstrual cycle** in man and other primates has its counterpart in the **estrus** or "heat" cycle in other mammals. It involves a distinct rhythmic cycle of sexual activity during some part of which the female is receptive to the male. Such a cycle is completed every 14 days in guinea pigs, twice a year in dogs, and once every 5 days in rats. In humans and anthropoid apes the estrus cycle is complicated, involving a periodic sloughing off of the highly vascular lining of the uterus every 28 days by menstruation. In other mammals the uterine lining returns to the resting state with no sloughing off or bleeding. The word *menstruation* comes from the Latin *mensis*, which means month. The menstrual flow consists mostly of the epithelial lining of the uterus together with the incorporated gorged blood vessels. The course of events that lead up to this dramatic event are rather well known, but just *why* it must occur, since it is not found in lower mammals, lacks an immediate explanation.

Since we are dealing with a cycle, description can start at any point in it (Fig. 16-32). The termination of the menstrual flow may arbitrarily be taken as the starting point for this discussion. At this point a new Graafian follicle begins to form in the ovary and as it grows in size it produces more and more estrogen. Maturity is reached in about 12 to 18 days at which time a rupture occurs in its wall and the egg is released. This marks the end of estrogen production from this structure but not of the hormone itself. The empty follicle is quickly converted into the corpus luteum, which continues to produce in increasing amounts the closely related hormone, **progesterone**, from the 15th to the 26th day. These hormones, in addition to bringing on the changes already referred to at puberty, are thus also responsible for the rhythmic menstrual cycle. The production of both estrogen and progesterone have a stimulating effect on the walls of the uterus, causing it to proliferate and to become highly vascular in preparation for the fertilized egg, if and when it makes its way into the uterine cavity. What happens from this point forward depends on whether or not the egg is fertilized.

If the egg is **not fertilized** the corpus luteum suddenly retrogresses and progesterone is reduced to zero during the 25th-27th days of the cycle. This results in the sloughing off of the uterine wall known as the menstrual flow, which continues over a period of 4-5 days. Another Graafian follicle then begins to grow and the cycle is started over again. All this is complicated by the pituitary hormones which will be discussed a little later. It might seem that a rather elaborate preparation is made each month for the event of pregnancy and that an unnecessary waste results when fertilization fails to occur. One speculates why something a little less pretentious might not be satisfactory until it became certain that the great climax, fertilization, had taken place. But, even though there seems to be little justification in its complicated machinery, this is the way it is set up.

If the egg is **fertilized** as it passes down the oviduct, the corpus luteum is retained and goes right on producing progesterone until just a few days before the end of gestation. The zygote is implanted in the uterine wall wherever it happens to touch. In fact, the highly vascular wall is so receptive to tiny particles that almost any small object is readily picked up by it at this time. The walls also produce mucus rich in glycogen, which probably acts as a source of energy for the early stages of the embryo until it gains a secure foothold and can withdraw nourishment through its placenta. With the developing stages of pregnancy, progesterone continues to cause further accommodations of the uterine wall for the enlarging embryo. It also causes the mammary glands to increase in size, prevents any further Graafian follicles from forming, and inhibits uterine contractions. As the end of pregnancy approaches, the corpus luteum ceases to produce any more progesterone and the uterine wall, which has during this time become an accessory in producing the hormone, reduces its output. This precipitates changes which are similar to the beginning of menstruation, that is, in the absence of progesterone the uterine wall begins to degenerate, therefore becoming incapable of nourishing the fetus any longer. Furthermore, without the inhibiting effect of progesterone, the muscles of the uterine wall begin powerful contractions which eventually result in expelling the fetus. The production of milk by the mammary glands occurs after birth due to another hormone, **lactogen**, which is produced by the pituitary gland and will also be discussed later.

It takes some time after the birth of the offspring for the hormones to readjust themselves and the menstrual cycle once again to reëstablish itself. This usually does not occur until the amount of lactogen from the pituitary subsides, which means, of course, that the offspring has ceased to rely on the mammary secretion as its principal source of food. Once lactation ends altogether the menstrual cycle begins again.

The thyroid

The thyroid, together with the remaining glands, are purely endocrine in function. The thyroid has various shapes in different vertebrates but in man is bilobed and lies on either side and under the larynx (Fig. 16-29). The two lobes are connected by a narrow strip of tissue, called the **isthmus,** passing across the trachea. The presence of the gland can be determined by merely feeling it with the fingers.

This gland was seen, naturally, by early anatomists, and its importance suspected because they noted that in certain individuals it became enlarged, seeming even to cause their death. At the beginning of the Christian Era the Greek physicians prescribed the drinking of sea water as a cure for **goiter** (the term used for the swollen gland). Later, others gave their patients products of the sea, such as dried seaweed leaves, which undoubtedly gave some relief because all sea products are rich in iodine, the important ingredient in the production of the thyroid hormone, **thyroxin.** The exact function of the thyroid was not known until replacement experiments in 1885 demonstrated that the gland did produce a hormone. This was isolated in pure form in 1916 and synthesized in 1927 by Harington and Barger, two English investigators. When this substance is administered to an animal deprived of its thyroid, the animal remains perfectly normal in every respect. If it is denied such treatment, stark metabolic changes occur which, if prolonged, may terminate the life of the animal. What is the specific function of this gland?

It is generally agreed that the thyroid gland secretes thyroxin, which controls the level of basal metabolism, that is, the rate of burning foods and formation of nitrogenous wastes, as well as the degree of irritability. Thyroxin must be produced at a uniform rate in order that these important processes proceed at what is spoken of as a normal level. If more or less is produced, these processes accordingly increase or decrease in speed with accompanying symptoms that are very definite and easily recognized. A diseased thyroid merely produces too little or too much of its secretion.

Underactivity. When the gland fails to produce the proper amount of thyroxin the effects are somewhat more pronounced in a young animal than in an adult. For example, if the thyroids are removed from tadpoles or pups the animals will not mature properly. The tadpoles will not metamorphose into frogs and the pup will not mature into an adult dog. Likewise in human beings, if a child has a deficient thyroid he becomes a **cretin.** Such a child is small and badly formed, with pudgy, puffy skin and swollen tongue, and his mental development is at a rather complete standstill. If given thyroxin in the early stages of the disease, the child responds remarkably well and can grow into a normal adult. Obviously, if a human cretin is allowed to live for twenty years without treatment, thyroxin will do him little good because his body tissues have completed their development and can be changed but little.

If the thyroid becomes atrophied for some reason and fails to produce an adequate supply of thyroxin in the adult, a familiar disease known as **myxedema** results. The obvious symptoms of the disease are general loss in vigor, reduction in mental activity, increase in weight, and a thickening of the skin to give it a puffy appearance. Less obvious symptoms are a drop in basal metabolism, the improper burning of food, sometimes as much as 40 per cent below normal, a slowing of the heart rate, and a lessening in the sex drive. It seems that the entire machinery of the body slows down. The administration of proper amounts of thyroxin or thyroid extracts restores the rate of metabolism to its normal level, and subsequently all symptoms of the disease disappear. Sometimes in surgery too much of an overactive gland is removed and the patient may then find that he is suffering from myxedema and must take thyroxin all the rest of his life. Fortunately, the digestive enzymes have no effect on thyroid extract, thyroxin, or even the dried gland in contrast to insulin, a fact which permits administration by mouth, an important detail in the treatment of any disease.

Fifty years ago the presence of an unsightly enlarged thyroid was very commonplace in certain parts of the world. Surprisingly, these regions were rather well-defined and in them even the domestic animals had goiters. An examination of the soil and water showed that there was a marked deficiency of iodine. Along with this discovery, the thyroid secretion was found to be remarkably rich in iodine; it was not difficult to fit the two together and conclude that goiter appeared in regions where there was very little iodine available in the food products and water. These areas were spotted over the world. In the United States they are concentrated along the St. Lawrence River and Great Lakes regions. For example, in 1924, 36 per cent of the school children in Detroit showed incipient endemic goiter, but within 7 years after the addition of potassium iodide to table salt the incidence had dropped to 3 per cent. In view of this experience, it has been proposed that the word *salt* be legally recognized in Michigan as iodized salt and that the sale of any other salt in food stores be prohibited.

The presence of a goiter does not necessarily mean that the gland is under- or overactive. It does mean, however, that there is some sort of disturbance in the thyroid output. It may be compensating for the lack of iodine and does this by producing more thyroid tissue in an effort to supply sufficient thyroxin to keep the body at a normal basal metabolic level. Such compensating action is not uncommon in other parts of the body, for example, an enlarged heart muscle. If the thyroid cannot maintain a normal level of thyroxin, myxedematous symptoms may be evident. If it can supply the proper amount there are no symptoms of the disease, although the individual harbors the greatly enlarged gland on the front of his neck which is at least inconvenient, if not embarrassing.

Overactivity. For some unknown reason, the thyroid sometimes begins spontaneously to produce more thyroxin than the body needs, and this may be accompanied by a slight enlargement of the gland. It differs from the simple goiter described above because while it may not be enlarged, or only slightly so, its output is far greater. Obviously, abnormally high amounts of hormone in the blood stream increase the rate of burning foods (30 per cent or more) and speed up all the bodily activities. More food is consumed, yet there is a wasting away of the body. Profuse sweating occurs, the heart is overworked, and external heat cannot be tolerated. All this step-up produces a highly irritable and nervous individual who is continually on the move but accomplishing very little. The action is like running an automobile at top speed with the brakes set. It is clear that such activity will soon result in the destruction of the organism itself.

The control of such a condition, which is called **exophthalmic** (from the fact that it sometimes causes the eyes to bulge out of their sockets) or **toxic goiter,** is by destroying a part of the cells that produce the hormone (Fig. 16-33). This is easily accomplished by surgery and such operations are very successful. In this age of the atom a new method has been discovered which is sometimes employed when for some reason or other it is inadvisable to operate. It is the use of radioactive iodine. Iodine, when subjected to atomic radiations, becomes radioactive itself. Such a form is called an **isotope.** Since the thyroid picks up about 80

Fig. 16-33. A case of hyperthyroidism.

per cent of all the iodine taken into the body, it can be determined beforehand the exact amount that will be delivered to the gland shortly after swallowing isotopic iodine. Furthermore, radiations are known to destroy thyroid tissue; therefore, by feeding radioactive iodine "cocktails" to the patient, a certain amount of success has been had in destroying a part of the gland. Its more satisfactory use, however, is in the treatment of cancer of the thyroid.

The parathyroids

In the early studies of the thyroid much confusion resulted because in removing the gland the four tiny parathyroids embedded in the thyroid were inadvertently removed also (Fig. 16-29). The symptoms that followed this were not only the result of thyroid deficiency but also of parathyroid deficiency. The small parathyroid glands were discovered in 1891 and many years later their true function was determined.

If the parathyroids are removed from an animal, injected extracts of a hormone (**parathormone**) produced by the glands will keep that animal in good health. If no extract is given, the animal suffers from severe muscular tremors, cramps, and finally convulsions. The composite symptoms are called tetanus, and without treatment the animal passes into a coma and death soon follows. The parathyroids or their extracts are essential for life in mammals, including man. The value of the parathyroids seems to be in maintaining proper levels of calcium and phosphorus in the blood. When the glands are removed the blood calcium level falls rapidly, which correlates with the symptoms of the disease. Administration of calcium will prevent symptoms of parathyroid deficiency. If the glands produce an overabundance of the hormone, the calcium level in the blood then rises too high and even the calcium of the bones is sacrificed, so that a weak, twisted skeleton is the result, rendering the unfortunate individual a cripple.

The adrenals

The adrenals are located on the upper inner edge of each kidney, as one might guess from their name (Fig. 16-29). Their combined weight is no more than an ounce, and each is composed of two parts, an outer covering called the **cortex** and an inner dark-colored mass called the **medulla.** The gland is therefore a composite one and each part has a separate origin, the cortex coming from the mesodermal lining of the coelom whereas the medulla is derived from a part of the neural tube. One might expect structures of such different origins to possess different functions and they do.

The medulla. The medullary portion of the adrenal produces a single hormone called **adrenalin,** or sometimes **adrenin** or **epinephrine.** Adrenalin has been analyzed chemically and its formula determined. It has also been synthesized from sources other than adrenal glands. Related synthetic compounds such as **ephedrin** produce similar effects when administered to animals. If the medullary portion of the adrenals is removed from an animal, death does not follow nor is the animal markedly affected by its loss. If injections of medullary extract are given to such an animal or one with intact adrenals characteristic changes occur rather rapidly. The heart action becomes stronger and the blood vessels to the skin and viscera constrict, sending most of the blood to the muscles, brain, and lungs. The hair "stands on end," the pupils dilate (wide-eyed), and the skin blanches. The spleen constricts, forcing its reserve of blood out into the general circulation, and simultaneously the blood's ability to clot is stepped up. More glycogen in the liver is converted to glucose, so that the total amount in the blood is definitely increased. This chain of events prepares the body for undue stress such as occurs in a fight or a sudden retreat. The body is made ready to function to the maximum of its ability in case a sudden burst of energy is needed. Provision against possible injury is afforded by the increased speed of blood coagulation. This whole series of effects is similar to excitation of the sympathetic nervous system. Thus, both the nervous system and the adrenal medulla play an important rôle in fear and anger. Knowledge of this fact has lead to the so-called "emergency theory of adrenal function."

The cortex. The **cortex** of the adrenal is essential for life, although when even such a small portion as one-fifth of the total gland tissue is left, life is undisturbed. Its product or products are not as simple as adrenalin. They are numerous; in fact, over 20 such compounds have been isolated in recent years. The first substance, isolated in 1930, was called **cortin** and was effective in treatment of people suffering from Addison's disease, which is the name identified with a deficiency of this portion of their adrenals. Since that time, many compounds have been produced, the best known and most effective being **cortisone.** It is interesting to note that all of these are steroid (fat-like) compounds which are closely related to the gonadal hormones, testosterone and progesterone, and, as will be seen below, produce some effects on the gonads as well as other parts of the body.

If the cortex fails to function, marked changes occur which are fatal if uninterrupted by treatment. The carbohydrate metabolism is greatly affected, as indicated by a drastic drop in blood sugar, because of the inability of the enzymes to convert the proper amounts of proteins to carbohydrates and then to convert the latter to sugar in the liver. Salt (NaCl) is lost from the blood and tissues at a rapid rate which reduces the entire blood volume and with it the blood pressure. As Addison's disease progresses, the sexual functions fail due to an actual atrophy of the Graafian follicles and the seminiferous tubules.

If, on the other hand, the gland becomes overactive as a result of irritation caused by a tumor, changes of a different kind occur. In males, the maleness is greatly enhanced, accompanied by excessive hair growth. If it happens to a very young male child the sex organs may become fully mature (except the testis) within the first or second year of life, and the hair, musculature, and voice resemble that of an adult man. These are very rare cases, fortunately. In females, the situation is even worse. If the overactivity occurs in an adult woman the changes are all toward maleness; the beard grows (the bearded lady in the circus), the body becomes more muscular, and the voice deepens. Even the female sex organs begin to atrophy and become nonfunctional. These effects of the cortical hormones are not well understood, in spite of the sudden burst of experimentation resulting from the recent discovery that cortisone, when given in controlled doses, has a beneficial effect on a large number of diseases, among them arthritis. Because the hormone's beneficial effects cover such a

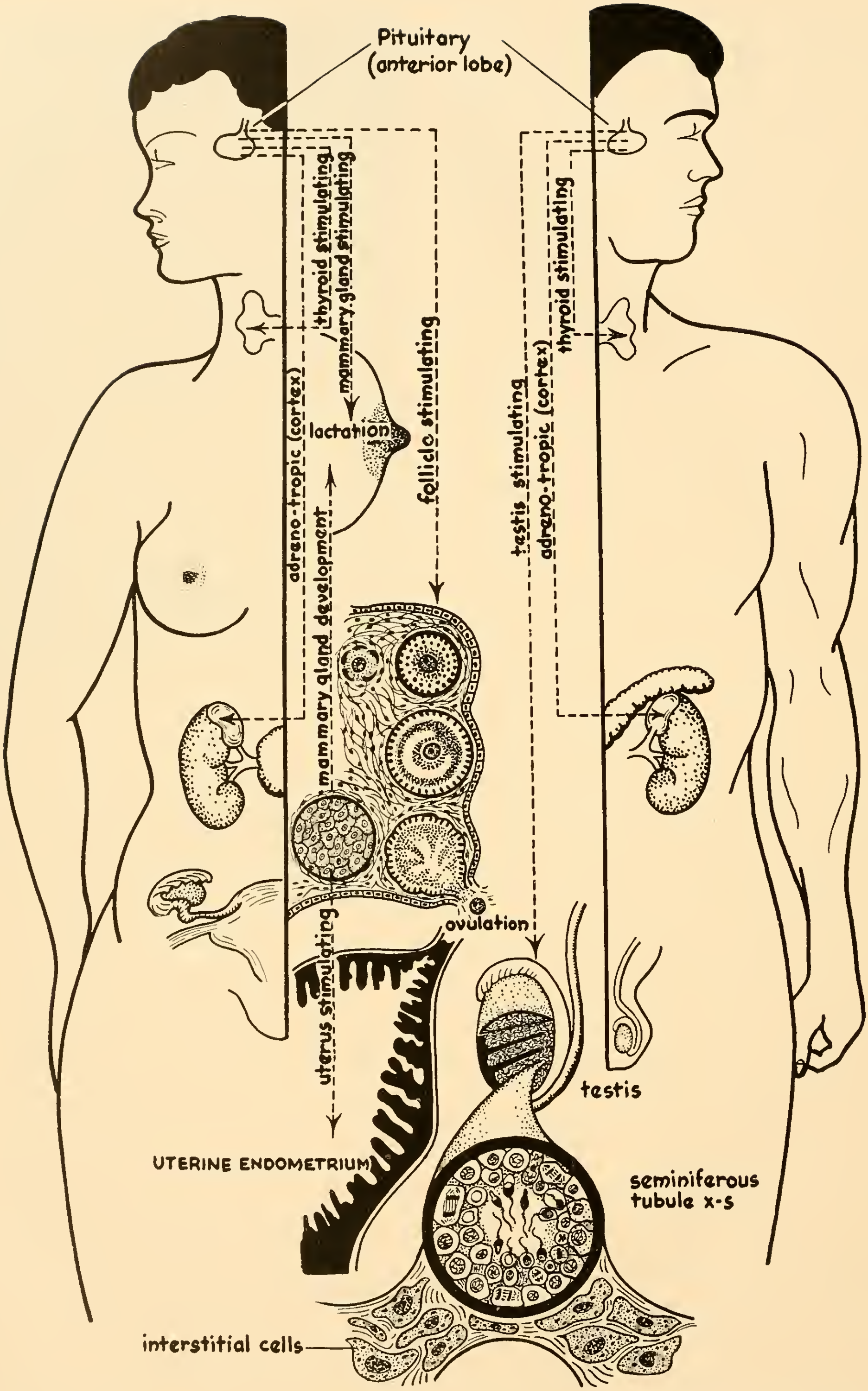


Fig. 16-34. A schematic sketch showing the various hormones produced by the anterior lobe of the pituitary and the other endocrines affected by them

wide variety of diseases, some biologists believe that we have an entirely new approach to the study of organic disease. However, it is too early to draw any conclusions from these observations.

The pituitary

The last and perhaps the most complex of all the endocrine glands is the **pituitary**, or **hypophysis**. Located in approximately the middle of the head, it lies in a bony capsule and is attached to the base of the brain by a slender stalk, the **infundibulum** (Fig. 16-34). Like the adrenals, the hypophysis is a double gland, composed of two principal lobes: the **anterior**, which arises embryologically from an outpocketing of the roof of the pharynx; and the **posterior**, which originates as a solid outgrowth from the floor of the brain. The point of contact with the brain through the infundibulum is retained while all connections with the pharynx are lost very early in embryological development. The anterior lobe is the larger of the two, although the entire human pituitary would compare favorably in size with a large pea. Because of its inconvenient location and complexity research has been arduous and relatively slow, although very recently interest has been renewed through the discovery of some new, therapeutically important, extracts.

Although it is very difficult to operate on the pituitary in man, experimental animals such as the frog and rat lend themselves to such surgery. By perforating the roof of the mouth the pituitary can be neatly removed and subsequent effects observed. When this operation is performed on a young mammal, growth is inhibited at once, sexual maturity never occurs, and both the thyroid and the adrenal cortex atrophy. With the injection of pituitary extracts, the animal develops normally and the associated symptoms never appear. From these observations it is clear that the pituitary certainly gives rise to more than

Fig. 16-35. Case of giantism. The men on either side are of normal height.

one hormone and that its influence is far-reaching in the animal body.

The anterior lobe. Five well-known hormones are produced by this lobe, and there may be others. The five are named according to the part of the body that they affect, with the addition of the suffix *trophin:* **somatotrophin** (growth), **thyrototrophin** (thyroid), **corticotrophin** (adrenal cortex), **gonadotrophin** (gonads) and **mammotrophin** (mammary). Each of these will be considered briefly in this order.

Somatotrophin effects. The function of the pituitary was brought to the attention of early anatomists by the fact that an enlarged gland was always associated with giantism. These huge men (Goliath, whom David slew, was undoubtedly one) reach a height of nearly 9 feet and are rather well proportioned, with the exception of the extremities which are longer than normal. (Fig. 16-35). An examination of the an-

Fig. 16-36. A case of acromegaly. Note particularly the protruding lower jaw, massive brows, and the enlarged hands.

terior lobe of the pituitary always reveals a greatly enlarged organ, sometimes reaching the size of a hen's egg. On the other hand, when the gland fails to produce the proper amount of hormone a midget results (Fig. 16-35). It is to be noted that giants or midgets are produced only when the gland either overfunctions or underfunctions in the young child.

Both dwarfism and giantism can be produced in animals simply by removing the pituitary in the first case and supplementing with grafted pituitaries or extracts in the second. Dogs can be forced into giants by placing glandular material under the skin or injecting purified extracts of the anterior lobe of the pituitary. If the gland is removed in a pup, growth takes place very slowly, if at all, and the dog becomes a midget. In human beings with overactive anterior lobes, removal is the only remedy known so far. In pituitary midgets injections of refined extracts is beneficial.

If increased activity occurs after maturity has been reached, as it occasionally does when a tumor forms on the pituitary, the person does not then become a giant, although deep-seated changes do occur. Since the body has already ceased growing the effort to produce a giant by further increase in size is restricted to the regions of the joints and the face. Consequently, a person so afflicted becomes barrel-chested, beetle-browed, and long-jawed, while the feet and hands grow very large (Fig. 16-36). Such a condition is spoken of as **acromegaly.**

Thyrotrophin effects. Very little is known about the relationship between the pituitary and the thyroid except that thyroxin will not supplant hormones from the pituitary in correcting pituitary deficiency. A hormone from the pituitary probably initiates or stimulates the thyroid to produce varying amounts of thyroxin.

Corticotrophin effects. The adrenal cortex and its production of cortisone are directly under the control of a specific hormone from the pituitary called **adreno-cortico-tropic-hormone** or **ACTH,** for short. This substance has only recently been isolated in sufficiently pure form so that it can be used in treatment of patients. Its action parallels cortisone in every respect, which proves that its action is through the adrenal cortical hormone. Therefore, ACTH must control the cortisone output. By increasing the ACTH, cortisone is also increased.

An interesting sidelight on the discovery of ACTH came from a common observation, namely, that during pregnancy arthritic women recover from their rheumatism. Shortly after the child is delivered the disease returns. Both cortisone and ACTH have the same remitting effect as pregnancy. Apparently, the added burden of child-bearing stimulates a greater output of ACTH which, in turn, stimulates a greater production of cortisone, the combined action of which improves the arthritis. Just what the specific action is on the disease itself is not known.

Both of these hormones have proven beneficial in cases of extensive body injury such as that caused by severe lacerations or burns. They serve to muster all the body's potentials toward regenerating new tissue as well as preventing shock and the other symptoms associated with severe trauma.

Gonadotrophin effects. A young hypophysectomized animal never becomes sexually mature, and if the operation occurs after maturity there is prompt atrophy of the sex organs. There is thus a close and important relationship between the pituitary and the sex glands. There are at least two gonad-stimulating hormones produced by the anterior lobe of the pituitary gland: one is called FSH (follicle-stimulating hormone) and the other LH (luteinizing hormone). Both are complex proteins and have only recently been isolated in pure form. If no FSH is produced, Graafian follicles fail to form in the female and seminiferous tubules cease to function in the male. Without LH none of the Graafian follicles will release their eggs, nor will the interstitial tissue of the testis produce testosterone. Restoration of these two hormones to a hypophysectomized animal allows normal development of the sexual organs and in the female insures normal functioning all the way to pregnancy and full term development of the fetus.

It should be pointed out here that the placenta, in addition to secreting hormones that supplement those of the ovary, also produces a gonotrophic hormone resembling LH. This is produced in such large quantities early in pregnancy that it appears in the urine. Some enterprising endocrinologists have taken advantage of this fact by developing a pregnancy test which is quite accurate. It consists of injecting small quantities of concentrated urine under the skin of a male frog. If LH is present in the urine—as it will be even in a pregnancy no more than two weeks old—sperm will be shed by the frog. Similar but not so simple tests have been devised using rats and rabbits.

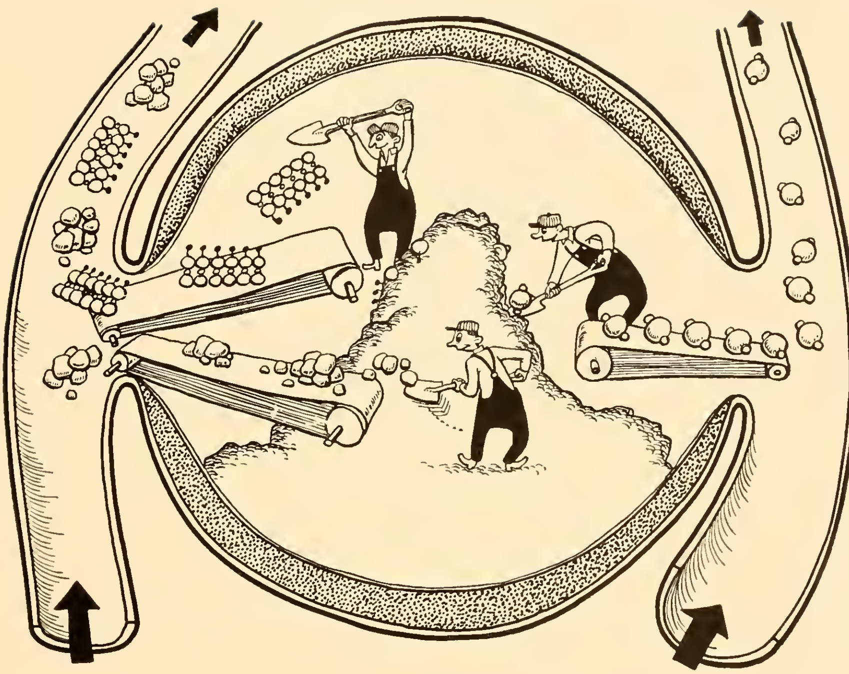
As was pointed out in an earlier section on the gonadal hormones, the mammary glands develop under the impetus given them by estrogen, progesterone, and possibly another hormone. Even after they are fully formed, lactation (secretion of milk) will not occur unless still another hormone, **lactogen,** is produced by the pituitary. This is sometimes referred to as the "maternal instinct" hormone, because it will produce certain mothering behavior in animals which normally do not possess such instincts, an old male dog, for example. If such an animal is given this hormone in sufficient quantities over a period of time it will not only mother pups but will also produce milk to feed them.

The posterior lobe. The posterior lobe functions in maintaining the proper water balance in the body, among other things. If it is damaged or removed, water is not reabsorbed in the kidney tubules. This results in a great urine flow (from 3 to 10 gallons per day), a disease known as **diabetes insipidus.** Such an afflicted person must drink tremendous quantities of water to offset this great loss.

No hormones have been purified from the posterior lobe, but some crude extracts have been prepared which, when injected into animals, cause a powerful contraction of the uterus and a constriction of the small arteries, resulting in a general rise in blood pressure. One of these fractions has some therapeutic value in increasing uterine contractions during labor. Much less is known about the hormones produced by the posterior lobe of the pituitary, perhaps because they are not so striking in their effects as are those from the anterior lobe.

In this chapter we have seen how the many parts of a complex animal are coördinated into an integrated whole. We shall examine in the next few chapters the organ systems responsible for the energy that keeps the machine going, using man again as the principal animal for study.

CHAPTER 17



THE DIGESTIVE SYSTEM

The business of procuring food and of extracting the energy that resides in it is one of the most important activities confronting animals. This is true because all animal activities require energy which can be obtained only by releasing it from the food where it is stored. All animals, from amoeba to man, have made special provisions for bringing about this conversion. The first steps in this complex energy-releasing mechanism are ingestion and digestion of food.

A large variety of means have been devised by animals to accomplish these ends. The amoeba engulfs its food to form a tiny vacuole in which the food is finally dissolved or digested and absorbed into the surrounding cell protoplasm (Fig. 17-1). In ascending the animal scale—to hydra with its spacious gastrovascular cavity, to the earthworm with its internal tube, to the vertebrate with a more elaborate tube—we see the evolution of a complex digestive apparatus of higher animals. Whereas the digestive enzymes in the earthworm are secreted solely from the walls of the tube, in the vertebrate there are, in addition, special glands some distance away from the

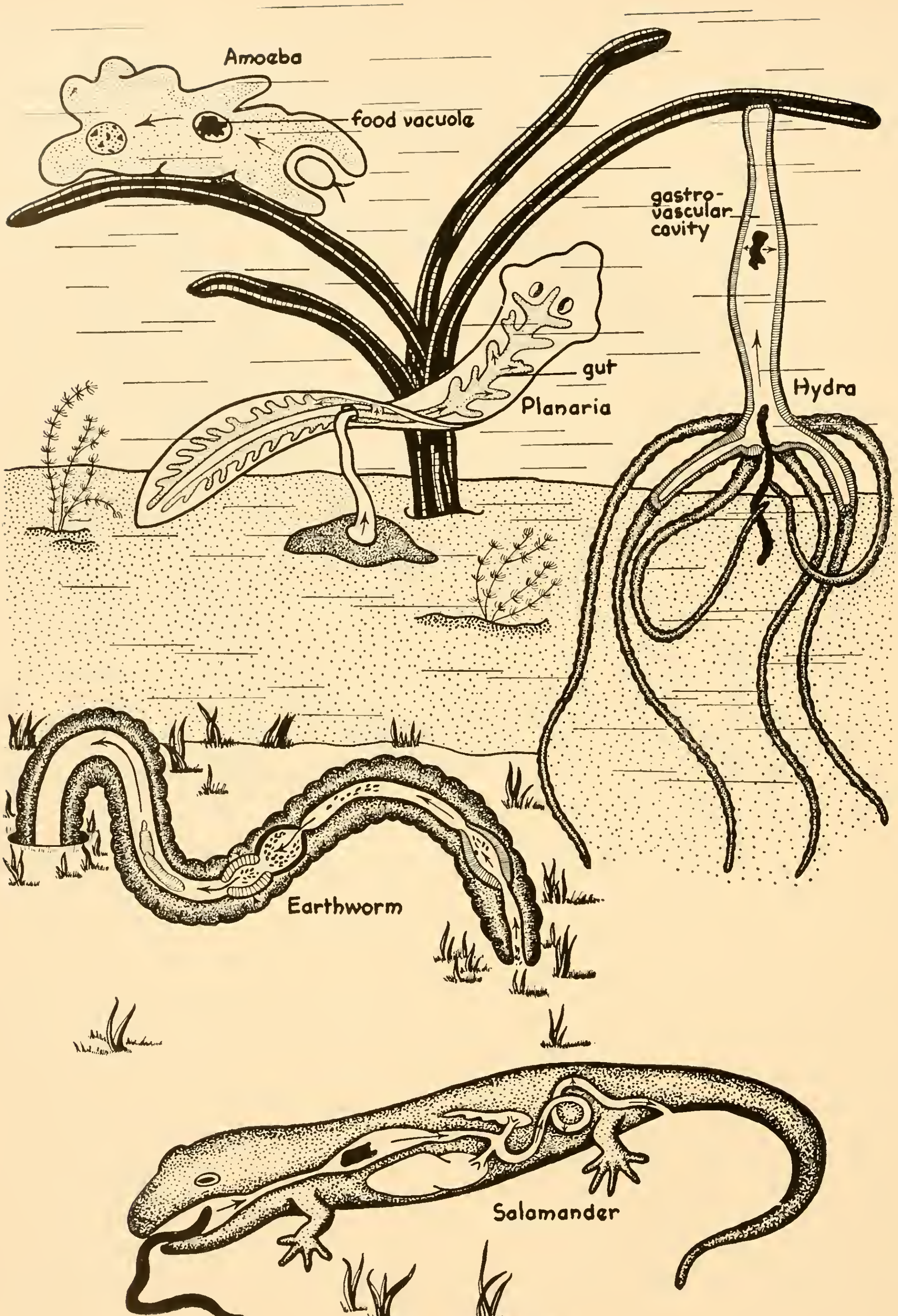


Fig. 17-1. Some of the ways animals handle the problem of digestion.

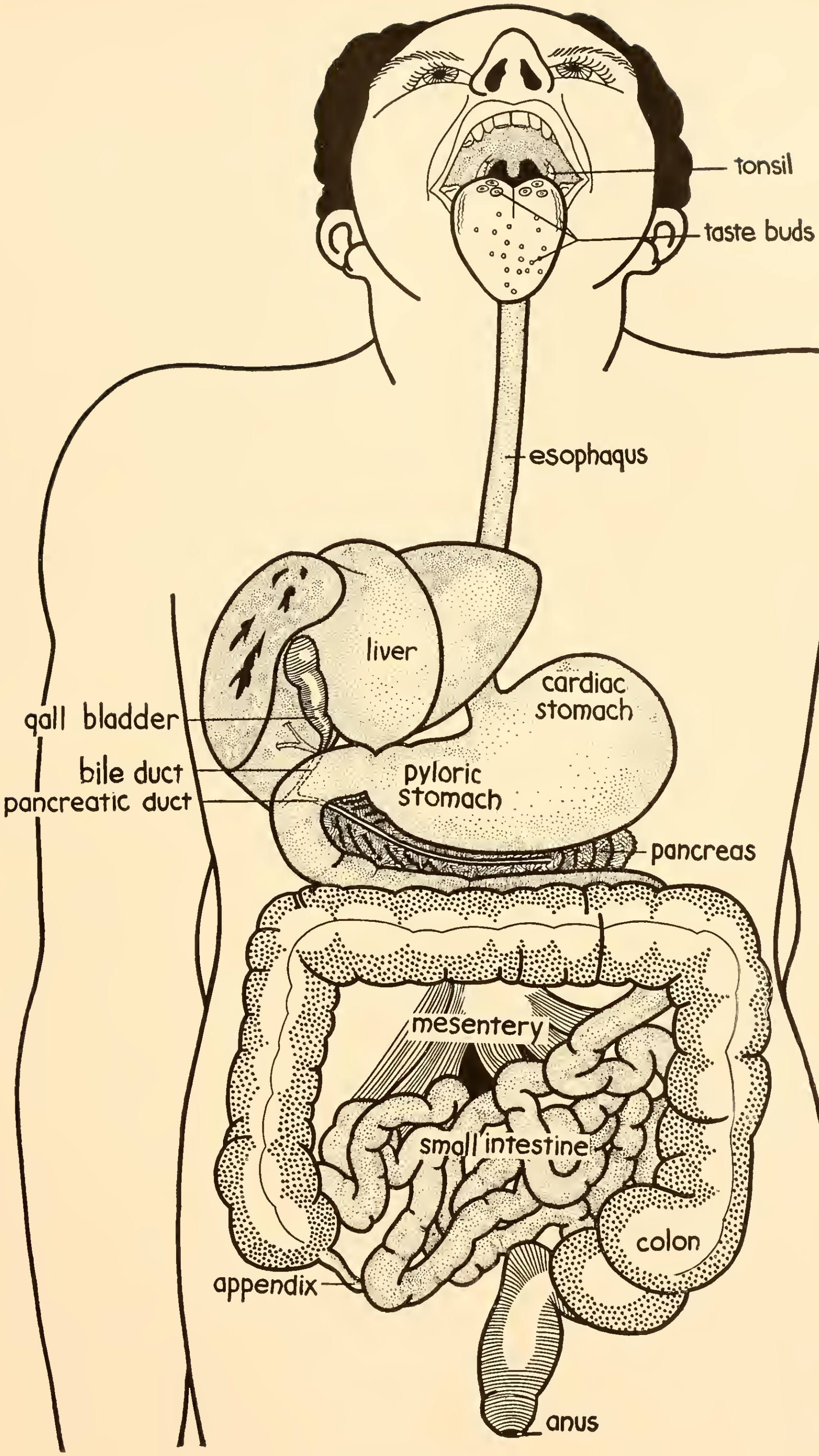


Fig. 17-2. The human digestive tract.

gut, and their secretions are carried to the gut through a duct. It must be remembered that while the digestive apparatus itself has become more complex with the increasing bulk of the animal housing it, the fundamental principle of digestion remains unchanged from amoeba to man. The sole purpose of digestion is to break down the large food molecules until they become soluble and thus transportable to distant parts of the animal body for use by the protoplasm there.

Now that the purpose of taking food into the body is understood, a "tour" through the digestive tube will be taken (Fig. 17-2).

THE MOUTH

Food is taken into the **oral cavity** through the mouth, where it is crushed into smaller particles by the teeth. During this procedure it is thoroughly mixed with **saliva,** a secretion from the three pairs of **salivary glands** (submaxillary, sublingual, and parotid) (Fig. 17-4). The tongue arises from the

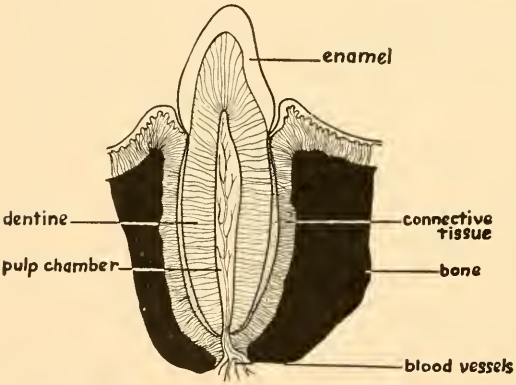


Fig. 17-3. A mammalian tooth in sectional view to show its internal structure. A part of the jaw is also shown to indicate how the tooth is fastened to the bone.

floor of the oral cavity where it functions as a handy organ in moving the food about and pushing it to the back of the mouth when it is to be swallowed. The tongue is not only highly sensitive to chemicals, as has already been pointed out, but also to touch. A small baby always wants to put things in its mouth, the apparent purpose being to satisfy its acute sense of touch. The use of the tongue in forming words needs no further comment. The oral cavity is lined with mucosa which secretes mucus, thus keeping the lining moist at all times; this, together with saliva, aids in lubricating the food so that it can slide down the esophagus without too much friction. The teeth are such important structures both from the utilitarian and esthetic points of view that further consideration should be given them.

The teeth

It should be recalled that teeth arise from the ectoderm and that they are actually modified scales similar to those found in the shark (Fig. 14-4). The tooth consists of the **crown** which protrudes into the oral cavity, the **neck,** a narrow region where the gum comes into contact with it, and the **root** which is firmly cemented in a socket in the jaw bone (Fig. 17-3). The crown is covered with hard **enamel** which affords a good grinding surface. Under this is the **dentine,** which is softer, and lying at the center is the **pulp** chamber which contains the nerves and blood vessels. The tooth is porous and is nourished as long as it is alive. Because of its porous nature, a tooth can be anesthetized by simply applying an anesthetic to the crown, a recent method employed by dentists.

Man has two sets of teeth during his lifetime. The first set, the **milk** teeth, begin to appear in the first year of life and are fully formed by the eighth year. Before they are all well established, however, the front ones start falling out because of the pressure of the second set coming from underneath. So, during the first twelve to sixteen years of life the individual is experiencing a continual loss and replacement of his teeth. The second set, when fully formed, is composed of 32 teeth, eight on each side of both the upper and lower jaws. There are two front cutting **incisors,** one **canine** next (proceeding posteriorly), then two **premolars**, used in grinding food, and finally three **molars** which are the heavy grinders. The last molars, the **wisdom teeth**, may appear late in life or not at all.

Teeth that are so perfectly formed in lower vertebrates and primitive man seem to have difficulty withstanding the inroads of civilization. It has long been known that the white man has notoriously bad teeth while his primitive brother usually has perfect teeth throughout his lifetime. In recent years much research has been done to solve this perplexing and distressing problem. A high carbohydrate diet has been thought to be responsible for tooth decay, but natives of many of the South Sea Islands live almost exclusively on a starchy diet and yet their teeth are unusually well preserved. However, when sugar (sucrose) replaces starch in the diet, dental caries (decay) appear. Along with this change to sugar there is a marked increase in the numbers of an acid-forming bacterium (*Lactobacillus acidophilus*) in the mouth. If sugar is withheld from the diet for some time the bacteria disappear and there is no further decay of the teeth. It is rather well confirmed today that it is the sugar in the diet that causes dental caries, and since sugar occurs only in small quantities in nature, it can be considered an unnatural food for all animals including man. Teeth are not designed to withstand the action of acids produced by the bacteria, hence decay is prevalent among sugar-eating people, which includes much of the civilized world. Fluorine in the water is known to be of value in preserving teeth, probably owing to the fact that in addition to the hardness of the enamel it produces, it retards the growth of bacteria in the mouth.

Digestion in the mouth

The only part of the saliva that has to do with food breakdown is the enzyme **ptyalin**. It acts directly on starches and converts them to maltose, a disaccharide (double) sugar. This is a very active enzyme, for if only a few drops of saliva are added to a suspension of starch kept at body temperature, it will be converted to maltose in about 20 minutes. This demonstrates one of the most remarkable properties of an enzyme, for to accomplish the same conversion in the laboratory would require drastic treatment with powerful acids for many hours. Ptyalin has the power to break the large starch molecules into the much smaller maltose molecules, leaving only one more step to the glucose stage when, as a simple sugar, it can be taken into the body tissues and burned. The way most people eat, ptyalin has only a momentary chance to function before the food departs for the stomach, although its action does continue during swallowing and for a short time in the stomach.

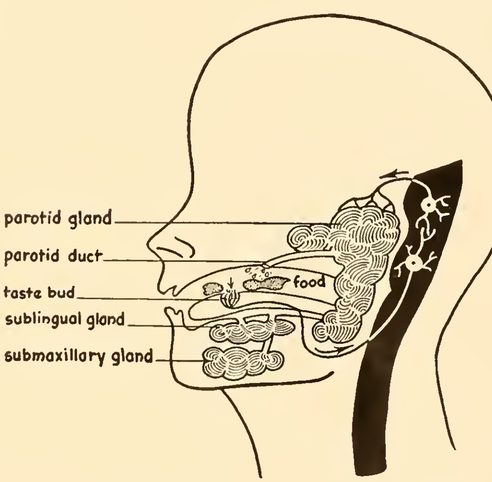


Fig. 17-4. The salivary glands secrete saliva when end organs in the tongue and mouth cavity are stimulated. The nerve pathway is shown here.

The flow of saliva into the mouth is controlled by nerves which respond to stimuli coming not only from the taste buds on the tongue but also from end organs in the walls of the oral cavity that are sensitive to the presence of food itself and to the mechanics of chewing. Impulses travel from these end organs to the brain stem to be

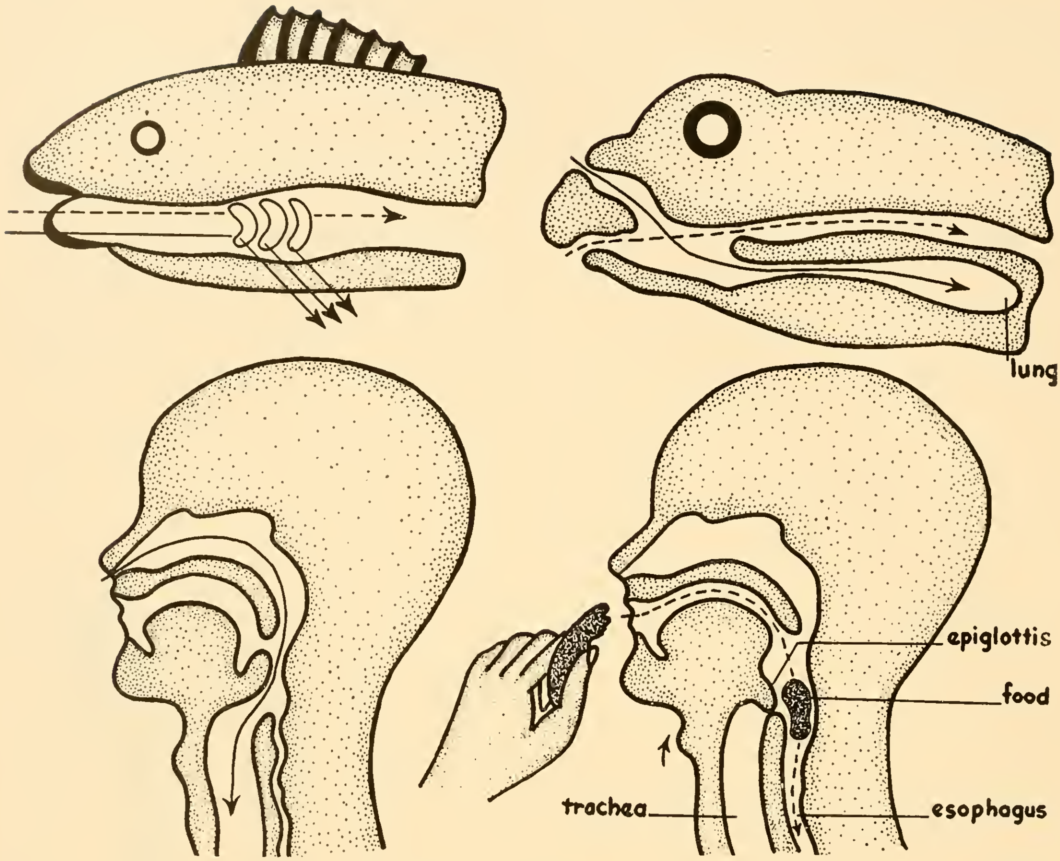


Fig. 17-5. In fish (upper left) the food and water portal of entry is the mouth. In land-dwellers the air and food passageways cross as shown here in the amphibian (upper right) and man. The left lower figure shows the condition of the larynx during breathing and the lower right figure shows it during the act of swallowing food.

routed back along the efferent nerves to the salivary glands (Fig. 17-4) which are stimulated to pour saliva into the mouth through ducts. This is not the only way salivation (secreting saliva) can be induced, as any hungry person knows who smells, sees, or even thinks about food. Such responses are called **conditioned reflexes** and are acquired by learning. From past experience one knows the appearance, odor, and taste of food and so one responds reflexively by increasing the salivary output when any or all of these sense organs are stimulated. Salivation is an important response because it prepares the mouth cavity for food before it is introduced.

Swallowing

The problem of getting food from the mouth cavity to the stomach in vertebrates has an interesting evolutionary history. The difficulty arose when animals migrated onto land and the breathing and food paths were forced to coincide. Water, the oxygen-containing medium, passes into the mouth and out the gill clefts in fish, while the food enters the mouth also and merely continues straight ahead into the esophagus (Fig. 17-5). No difficulty was experienced with such a mechanism. However, when vertebrates moved out on the land the oxygen-containing medium, air, took a new pathway because the lungs evolved from the floor of the mouth cavity. This meant that both food and air must pass through the pharynx and could only be accomplished by providing some way of closing one when the other was functioning. The apparatus is very simple among amphibians but becomes more complex in the higher forms, particularly in mammals. Here an elaborate system of nerves and muscles have evolved to provide a smooth crossing of food and air. The inadequacies of this system are familiar to anyone who has experienced the difficulties resulting when particles of food get into the air passages.

Let us see how the process of swallowing takes place in man. When the food reaches a pasty consistency in the mouth, it is forced into the pharynx (back of oral cavity) by the tongue where a series of events follow in rapid succession which propel it to the stomach through the small esophagus. When food or fluids reach the pharynx a chain of impulses is initiated which brings about the pulling forward of the larynx and a tipping of the epiglottis to prevent food from passing into the trachea, together with a simultaneous opening of the upper end of the esophagus (Fig. 17-5). Once all this is started, the food is beyond recall. When it enters the esophagus a peristaltic wave carries it quickly to the stomach. Peristalsis is accomplished by the thick muscles which make up the wall of the esophagus. The presence of food in this collapsed tube causes the longitudinal muscles to relax just in front of the bolus (ball) and at the same time causes the circular muscles to constrict just behind it with the result that the food is pushed along the tube (Fig. 17-9). This is a rapid action, requiring only 5 to 6 seconds for food and less for fluids. Furthermore, it has nothing to do with gravity because a horse can swallow uphill, as indeed it must almost always do, and even a human can drink in an inverted position if he desires. Swallowing is initiated only by the presence of food or fluids in the pharynx; thus it is impossible to swallow twice in rapid succession when no foods or fluids are taken into the mouth. Yet when one drinks fluids one can swallow continuously. This means that swallowing can only occur when food or fluids are in the pharynx.

THE STOMACH

After passing through the esophagus, the food drops into the stomach, which is a saclike expansion of the digestive tube designed not only to store considerable food (about two and one-half quarts) but to start the digestion of proteins (Fig. 17-2). It is a thick-walled muscular sac lined with **gastric glands.** These are minute, slender pockets in the soft mucosa with tiny openings through which the gastric juice flows into the cavity of the stomach. In addition to the circular and longitudinal muscle layers of the esophagus, the stomach possesses an oblique layer. With this elaborate system the stomach becomes an efficient mixing or churning organ.

The stomach is usually divided into two general regions: the **cardiac region** which immediately follows the esophagus, and the **pyloric region** which is followed by the small intestine. The anatomy and activity of the two portions vary somewhat. The portals of entry and exit to the stomach are guarded by valves consisting of thickened circular muscles which, when strongly contracted, completely close both of these openings. Such valves in a tube are called **sphincters.** Besides these two in the stomach, the **cardiac** at the entrance and the **pyloric** at the exit, there are two others along the digestive tube: one where the small intestine joins the colon (**ileocaecal**) and the other at the end, the **anal** sphincter. These valves are important in retaining the food in its proper place until digestion is complete.

As food is swallowed the stomach gradually expands until full; the reverse process takes place as digestion is completed and the food is moved along to the small intestine. Fluids such as water pass through the stomach in a few minutes, whereas more solid foods remain from 3 to 5 hours, depending on their nature. Some foods digest more slowly than others, for example, those rich in fats. The food is retained in the stomach and churned until it resembles a thick soup, which is called the **chyme**. Peristaltic waves begin in the cardiac region and move toward the pyloric end, so that the food is constantly being forced into that end. So long as the pyloric valve remains closed, the food cannot pass into the intestine, but must continue to be mixed back and forth until the proper consistency is reached. The pyloric valve then opens intermittently, allowing small amounts of the chyme to pass in spurts into the upper end of the small intestine.

These movements are under the influence of the autonomic nervous system. Parasympathetic fibers reach the stomach through the vagus nerves and their action increases the intensity of the peristaltic waves and augments the flow of gastric juice. The opposite action is brought about by impulses coming through fibers from the sympathetic system. Undue emotional strain during a meal excites the sympathetic fibers excessively, thereby slowing up stomach activity, which is not conducive to good health. For this reason, meal time is no time to discuss weighty or controversial problems.

Provision has been made in most animals for removing anything taken into the stomach that does not "set well." This is particularly true in carnivores, who are apt to eat slightly decayed food that might be toxic. Regurgitation, as this chain of events is called, is just the reverse of swallowing, culminating in a complete evacuation of the stomach. Just prior to the major event a deep breath is taken in order to hold the diaphragm down; a convulsive contraction of the abdominal muscles then follows which presses the stomach up against the rigid diaphragm. The sphincter leading into the esophagus relaxes and the stomach contents are expelled almost explosively. The action also resembles swallowing in that once it starts it continues until the job is done, regardless of the will of the owner. This safety mechanism is a feature of importance in the survival of a species.

Digestion in the stomach

The millions of tiny glands in the walls of the stomach secrete **gastric juice**, a highly acidic, watery fluid that contains the protein-splitting enzyme, **pepsin**. Between 400 and 800 cc. of gastric juice are produced during the digestion of an average meal. The flow of gastric juice, like the flow of saliva, is under the influence of the nervous system, at least in part. Everyone has experienced "mouth watering" when hungry and within sight or smell of good food; the stomach "waters" the same way and probably at the same time. Just how this functions was an attractive subject for investigation even for early biologists, and in recent years research has been so fruitful that the entire mechanism is rather well understood. Let us follow briefly the history behind these discoveries.

At the time of the signing of the Declaration of Independence in this country, a clergyman in Italy attempted some experiments on the activities of his own stomach. This amazing Spallanzani swallowed small metal cages containing bits of meat and after these were left in his stomach for varying lengths of time they were retrieved by means of an attached string. He noticed that the tiny bits of meat had disappeared and concluded that they must have gone into solution and therefore were digested. Another notable series of experiments, begun about 40 years later and continued for many years, was performed by an American army surgeon, Dr. William Beaumont, who had the good fortune of treating a man

(Alexis St. Martin) with an unusual bit of accidental stomach surgery. This Indian had been shot through the stomach with a shotgun, and the remarkable thing about the accident was that the load had not only torn away the abdominal wall over the stomach but had also taken a part of the stomach as well. Beaumont plugged the wound with a wad of cotton and waited for his patient to die. To his surprise the patient not only recovered but the stomach wall healed to the abdominal wall in such a way as to leave a permanent opening, or fistula, as such openings are now called. This gave Beaumont an unusual experimental subject for the study of the functions of the stomach. For years afterwards he kept St. Martin close at hand so that he could observe how digestion progressed under all sorts of conditions.

Since that time there have been many cases where the esophagus has been closed because of the accidental swallowing of some strong chemical, making it necessary to provide the person with a fistula in order that he might receive nourishment. Many of Beaumont's observations have been confirmed and a great deal more has been learned. The famous Russian physiologist, Pavlov, produced artificial fistulas in dogs and then studied the rate of flow of the gastric juice under various psychical conditions (Fig. 17-6). In such fistulas a small compartment of the stomach is separated off from the remaining portion, but the circulation and nerves remain intact so that the fistula will respond normally. With such an experimental animal Pavlov was able to show conclusively what factors influenced gastric secretion. Another operation which supplemented the findings with artificial fistulas involved the severing of the esophagus and the bringing of the cut ends to the surface of the neck (Fig. 17-6). His discoveries from this experiment were of great importance. For instance, he showed that if a dog were fed a meal which never reached the stomach, since the cut esophagus led to the outside at the neck, about one-fourth of the normal flow of gastric juice took place. He showed further that this was due to reflexes, because the flow ceased when all of the nerves to the stomach were severed. However, if he placed

Fig. 17-6. Artificial openings into the digestive tracts of two dogs to illustrate how Pavlov performed his basic experiments. The left dog is eating a "sham meal," while the right one is secreting gastric juice from a "Pavlov pouch" into a container.

food directly into the stomach without the dog seeing or smelling it, about one-half of the normal flow of gastric juice took place. While the flow in this case was somewhat reduced by cutting the nerves to the stomach, a considerable secretory activity continued. This could mean only that there must be a hormone produced by the lining of the stomach which circulates in the blood and stimulates the gastric glands, at least in part, to secrete. This hormone, **gastrin**, has since been identified. With this type of experiment Pavlov established the principle of "**conditioned reflex**" which is the basis for much of modern psychology.

The stomach contents are very acidic (pH 1.2-0.3) because of the high concentration of hydrochloric acid in the gastric juice. This is apparent to anyone who has eaten too heartily and sometime later complains of a "sour" stomach. The same taste is even more evident when food is regurgitated. The acid functions in providing a favorable medium in which the enzyme, **pepsin**, can do its best work, and it probably has a bactericidal effect on detrimental bacteria which may be taken in with the food.

When pepsin leaves the gastric glands it is in the inactive state, called **pepsinogen**. When this substance comes in contact with an acid medium, it is transformed into pepsin and is then able to attack the large protein molecules, breaking them down into smaller ones. Pepsin is called a **protease** (the suffix *ase* is used to identify an enzyme) because it breaks proteins down into **proteoses** and **peptones** which are soluble. The reaction may be expressed thus:

$$\text{Protein} + \text{water} \xrightarrow{\text{pepsin}} \text{proteoses and peptones}$$

Pepsin, like all digestive enzymes, functions by adding water (hydrolysis) to the protein molecules, thus breaking them into small molecules. This is the initial stage of protein digestion. The ultimate goal is the amino acid stage, but that must wait until the food reaches the small intestine.

Mammals possess another enzyme, **rennin**, in their gastric juice which has a very specific action, namely, the curdling of milk. This has been evolved because the young mammal depends on milk for the early part of its post-natal existence, and were there no curdling of the milk in its stomach, much of the protein (**caseinogen**) would pass far into the intestine, just as any other fluid does, before protein digestion could start. Rennin, therefore, converts the soluble protein caseinogen into insoluble casein, which permits its normal digestion in the stomach and later in the small intestine.

Like other parts of the body, the stomach is subject to many ills but it seems to suffer especially from emotional strain. In some people happiness seems to center around the contentment of their stomachs. Everyone is familiar with the difficulty experienced in eating immediately following the reception of good or bad news. This is owing to stimulation coming through the autonomic nervous system. Continued emotional strife can even produce organic damage, such as erosion of small areas of the stomach lining (gastric ulcers). Frequently this malady clears up "miraculously" when the emotional strain is removed. In stubborn cases of ulcers or cancer, parts, or even the entire stomach in extreme cases, may be successfully removed. This type of surgery has progressed remarkably in the last two decades but, needless to say, not to the stage where a goat's stomach can replace that of man—contrary to an idea staunchly believed by many people.

THE SMALL INTESTINE

The small intestine is a narrow tube with a length of over 23 feet which extends from the stomach to the colon or large intestine. Although it is possible to get along without a part or all of the stomach, it is absolutely necessary that the small intestine remains essentially intact, because it is here that all digestion is completed and **absorp-**

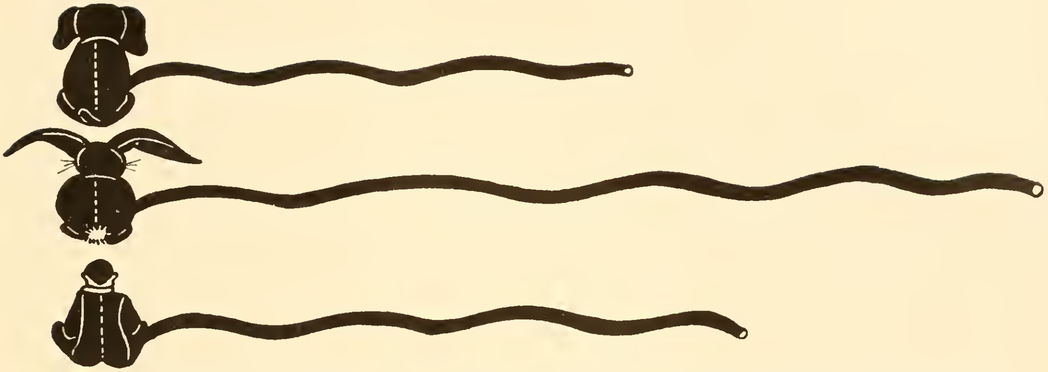


Fig. 17-7. The length of the digestive tracts of animals varies with the diet, as shown in these figures. The carnivore (dog) has the shortest track (with respect to trunk length), the herbivore (rabbit) has the longest, while the omnivore (man) has a gut of intermediate length.

tion of the end products of digestion occurs. The small intestine is divided into three parts that differ slightly from one another in their anatomy. The first 10 inches is the **duodenum**, into which the ducts from the **liver** and **pancreas** empty. This is followed by about 10 feet of a region known as the **jejunum**, which is particularly rich in intestinal glands. The remaining portion is the **ileum**, and is characterized by the vast number of tiny finger-like projections of its lining, the **villi** (Fig. 17-10). These structures increase the surface area of the intestine tremendously, thereby making possible the adequate absorption of digested food substances. The small intestine is thus adapted to retain food for a considerable period of time in order that digestion may be completed and absorption take place. In this respect, it should be recalled that carnivores possess shorter intestines than herbivores because meat digests more rapidly than do plant materials (Fig. 17-7).

The entire gut is supported by a dorsal **mesentery** which holds such parts as the stomach and duodenum in place but at the same time allows the rest of the small intestine considerable freedom of movement. In lower vertebrates there is evidence that a ventral mesentery was once present which held the entire digestive tract in a line from mouth to anus. As the gut increased in length this ventral support was lost. Actually, it no longer performed any particular function, since the animal lived in a horizontal position where its gut hung like clothes from a line. However, when man decided to walk on his hind legs, the dorsal mesentery could not continue to support the gut as well as previously, and so the gut had a tendency to slide posteriorly into the pelvis. In youth, the abdominal muscles are adequate to compensate for this deficiency but as age advances the gut tends to sag more and more, resulting in the pot-belliedness of advancing years. It requires a great amount of physical effort to keep it in place, a price that a tired body and a genial philosophy will not condone.

The liver

This, the largest gland in the body, is located on the right side just under the diaphragm (Fig. 17-2). It is tunneled with spaces and with vessels which are filled with large quantities of blood, and because of its construction will not tolerate injury. Fatal internal injuries suffered in car accidents frequently involve the liver. Unfortunately, the steering wheel of the automobile is located over this area of the body, and since any sudden stopping of the car throws the victim against the wheel, the liver, being the most vulnerable organ in that area, is most apt to be damaged.

Bile, which is drained from all parts of the liver by tiny tubules, accumulates in one large duct, the **bile duct,** which eventually joins the pancreatic duct just before the two empty into the duodenum (Fig. 17-2). However, there is a storehouse for the continuously secreted bile, the **gall bladder,** which is located in a hollow on the under side of the liver. It is a thin-walled sac connected to the bile duct by a small duct of its own. Between meals the bile accumulates in this sac and when bile is needed the walls contract, forcing the stored bile into the duodenum in large quantities.

In so far as digestion is concerned, the only function of the liver is the production of bile. In a sense, bile is an excretory as well as a secretory product because the residue from broken-down red blood cells accumulates in it and is thus eliminated from the body, at least in part. Bile also contains considerable quantities of sodium bicarbonate, which functions in alkalizing the chyme in the duodenum. The organic constituents of bile are **bile pigments, bile salts** and **cholesterol,** each of which has specific functions.

The bile pigments, **bilirubin** (red) and **biliverdin** (green), are responsible for the color of bile. While in man bile is straw-colored, in other vertebrates it ranges from green to red with all intermediate shades. When mixed with the chyme in the gut, the bile pigments undergo further chemical change, turning to dark brown or black, thus contributing the brown color of **stools.** The first sign of faulty bile elimination is the gradual loss of this color, and when the bile fails altogether the stools are gray in color.

Of the numerous constituents making up bile, only the **bile salts** function in digestion. They are responsible for emulsifying the fats in the food so that the fat-splitting enzyme from the pancreas can work more effectively. They also seem to **activate** this enzyme, because without them the fats are poorly digested and appear in large quantities in the stools. They are conserved by reabsorption in the lower end of the small intestine and circulate in the blood back to the liver to be used over again.

The organic compound **cholesterol** seems to be important in the bile only because of the trouble it sometimes causes. It does not accumulate if the concentration of bile salts is sufficiently high to keep it in solution. However, if the bile salt level drops, cholesterol will sometimes precipitate out in the gall bladder, forming **gall stones.** These are harmless in themselves but if one is forced into the tiny bile duct as the gall bladder contracts in emptying it may occlude the tube and produce trouble. Peristaltic waves in the tube wall attempt to pass the stone along and this causes extreme pain. If the contractions are successful the stone eventually passes into the intestine where it will do no more harm. If, on the other hand, it remains lodged in the duct, bile fails to reach the intestine and all the symptoms resulting from an absence of bile in the gut ensue. The stools lose their color, fats fail to digest, and the bile pigments, since they are excretory wastes, accumulate in the blood and eventually in the skin, causing it to bronze, or **jaundice.** Removal of the stones is a simple surgical operation and when accomplished the person is usually restored to health very quickly.

The pancreas

This long, flat, light-colored organ lies between the stomach and duodenum, and by means of its **pancreatic duct** connects with the bile duct. The gland has two functions: endocrine, which has already been discussed, and digestive. It produces several digestive enzymes, all of which are essential to complete the digestion started in the mouth and stomach. In addition, the **pancreatic juice,** like bile, contains large quantities of sodium bicarbonate, which functions in neutralizing the acid chyme from the stomach. Even with this large amount of sodium bicarbonate the chyme remains slightly acid during its trip through

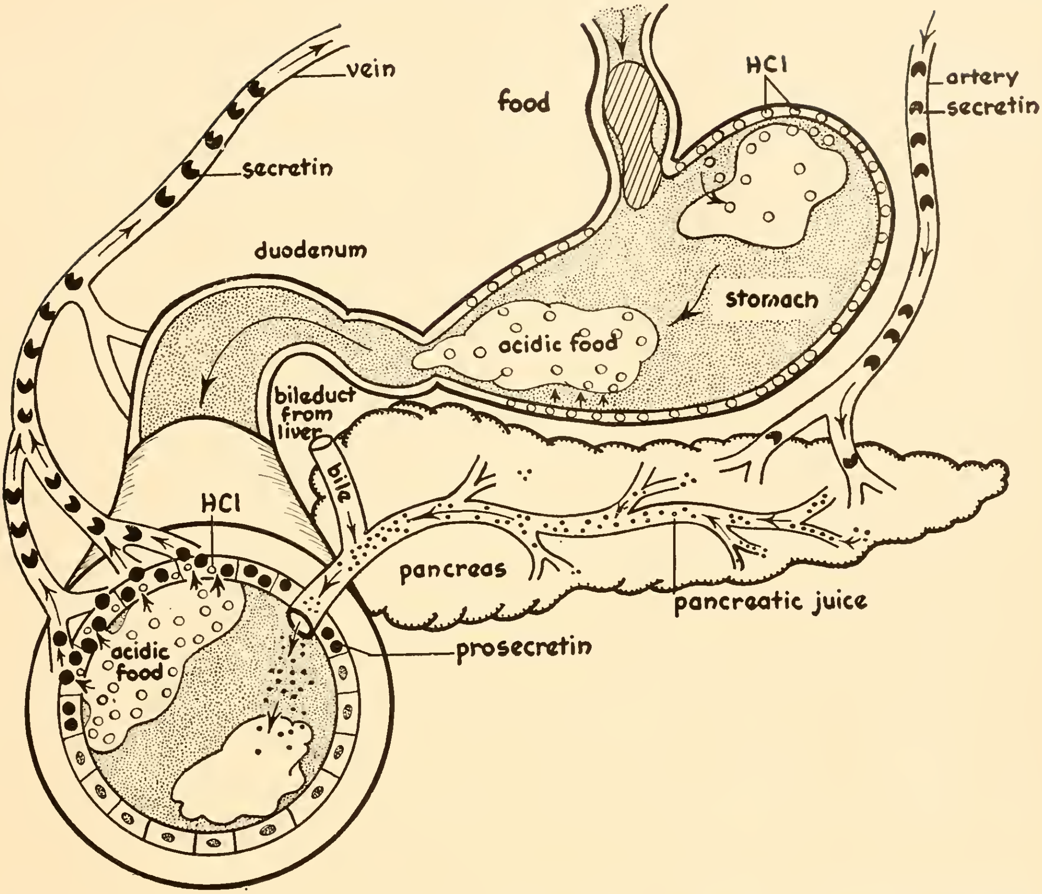


Fig. 17-8. The hormonal control of the secretion of pancreatic juice. The acidic food causes prosecretin (block spheres) in the duodenal lining to be converted to secretin (black spheres with a notch) which circulates in the blood, eventually reaching the pancreas where it stimulates the flow of pancreatic juice.

the small intestine, a fact contrary to earlier beliefs.

The pancreatic juice contains a starch-splitting enzyme (amylase), **amylopsin,** a protein-splitting enzyme (proteinase or protease), **trypsin** (secreted as inactive trypsinogen), and a fat-splitting enzyme (lipase), **steapsin.** It should be noted that the only true lipase in the entire tract is steapsin; hence, if this fails there is no chance for fat digestion. The other two enzymes are approximately duplicated in the secretions of the mouth and stomach, so that in a depancreatized animal protein and carbohydrate digestion progresses at a fair rate while fat digestion fails altogether.

Control of pancreatic juice and bile flow

The pyloric sphincter relaxes when the content of the stomach reaches a certain consistency, though precisely how this is controlled is not well understood. Once the chyme reaches the duodenum, however, the control of the bile and pancreatic juice flow is rather well known. The wall of the duodenum contains a substance called **prosecretin** which, when brought into contact with hydrochloric acid, is converted to a hormone called **secretin.** Some of this gets into the blood stream where it circulates to the pancreas, causing it to deliver pancreatic juice (Fig. 17-8). The proof of the action of secretin can be had by simply injecting an extract from the wall of the duodenum that has come in contact with hydrochloric acid into an animal which has had all of the nerves to the stomach and pancreas cut in order to rule out nervous control. The result is copious secretion of pancreatic juice.

Bile secretion is stimulated by a somewhat similar mechanism. The presence of fats and acid in the duodenum causes the formation of a hormone named **cholecystokinin,** which circulates in the blood and causes the gall bladder to contract and deliver its contents.

Digestion in the small intestine

As the chyme spurts through the pyloric spincter into the duodenum, it is eventually mixed with bile and pancreatic juice, together with secretions from the intestinal wall called **intestinal juice.** The intestinal juice contains enzymes that are functional in the final stages of digestion. The chyme is rendered less acid by the highly alkaline nature of both bile and pancreatic juice, even though it may never reach the neutral stage. Trypsin, as it comes from the pancreas, is in an inactive form called trypsinogen but is converted to the active trypsin the moment it comes in contact with the intestinal juice. The substance responsible for this conversion is **enterokinase.** Trypsin attacks any complete proteins that have survived the effects of pepsin in the stomach, as well as proteoses and peptones, breaking them down to peptides, thus:

$$\text{Proteoses and peptones} + H_2O \xrightarrow{\text{trypsin}} \text{peptides}$$

These peptides need still further treatment by enzymes in the intestinal juice before they are fit for absorption.

Amylopsin takes up where ptyalin left off in carbohydrate digestion, because nothing happens to these food substances in the stomach. Ptyalin, as was pointed out earlier, does not have a full opportunity to do its work so that considerable starch reaches the small intestine. Therefore, amylopsin is called upon to break these down into **maltose,** just as ptyalin did, only it does the job more effectively because it has more time.

$$\text{Starches} + \text{water} \xrightarrow{\text{amylopsin}} \text{maltose}$$

Further degradation of maltose must take place before absorbable glucose is formed.

Steapsin does the complete job of digesting fats from the complex fat molecule down to fatty acids and glycerol:

$$\text{Fats} + \text{water} \xrightarrow{\text{steapsin}} \text{fatty acids} + \text{glycerol}$$

In this final stage absorption can take place.

The work now left for the intestinal juice enzymes is to complete the digestion of proteins and carbohydrates. In the case of peptids, this is accomplished by **erepsin** which degrades them to **amino acids,** ready for absorption. The carbohydrates now in the disaccharide forms of **maltose, sucrose,** and **lactose** are acted on by the corresponding enzymes maltase, sucrase, and lactase (collectively called invertases) respectively which degrade them to simple sugars that are also readily absorbed by the intestinal wall.

Small intestine movements

While the chyme is in the small intestine (5-10 hours) it is in constant motion. The purpose of this movement is to mix it thoroughly, and thus insure proper digestion and absorption. One of the most important sources of our knowledge about these and other movements of the alimentary tract has come through x-ray pictures taken during various stages in digestion. If a person consumes a meal heavily laden with barium (or bismuth), it can be readily followed through the digestive tract because barium is opaque to x-rays. When observed with a fluoroscope, such a mass appears as black shadows on the screen, and if pictures are taken, the contours of the alimentary canal can be made out very easily. This is common practice in determining abnormalities or diseases of the digestive system.

There are two types of mixing movements in the small intestine: **segmental** and **pendular.** Both are confined to the limits of a single loop of the gut. The segmental movements start by constricting at regular intervals throughout the loop (Fig. 17-9). Relaxation appears in 10 minutes or so and another series of constrictions occur which are between the first series. This results in the breaking up and mixing of the masses of chyme. It is supplemented by the pendular movements, which consist of mild peristaltic waves that move the chyme back and forth within the intestinal loop but do not go beyond it. The chyme is moved progressively along the gut by means of peristaltic waves that occur both gently and in sudden rushes. The action is a slow progressive movement with a sudden rush, at times, of the entire contents from stomach to colon. The combined movements result in a continuous progression of the chyme through the small intestine until it reaches the colon, or large intestine.

THE LARGE INTESTINE

The small intestine joins the colon in the lower right region of the abdominal cavity (Fig. 17-2). The opening is guarded by the **ileocaecal sphincter.** Chyme that passes into the colon is still in a very fluid state, but as it passes through this region of the digestive tract much of the water is reabsorbed. The reabsorption of water is a conservation measure, for if it were retained in the gut the intake of water by mouth would necessarily be much greater. Such demands would impose insurmountable problems for an animal that needed to go any distance for its source of water. Since the chyme moves very slowly through the colon (12-14 hours) there is ample time for the water to be reabsorbed. During this time bacteria grow so abundantly that they constitute about half of the weight of feces. They cause no harm and probably do very little good in the gut of man. In some herbivorous vertebrates, however, they are thought to be beneficial, aiding the digestion of cellulose.

The sac-like **caecum** at the beginning of the colon terminates in a finger-like evagination called the **vermiform appendix** because it is worm-like in appearance (Fig. 17-2). This is a remnant of a once functional portion of the caecum. Herbivorous animals possess a very large caecum in which a certain amount of bacterial digestion takes place. The appendix in man sometimes becomes infected, and since it does not drain well, the infection may reach such proportions as to burst the peritoneal lining, liberating the contents of the appendix into the coelomic cavity. This is serious because

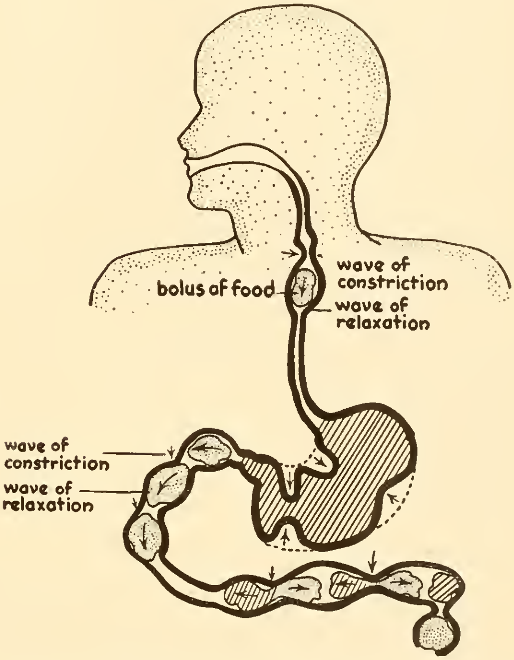


Fig. 17-9. Food moves along the digestive tract by peristalsis. The motion is rapid in the esophagus, where its purpose is to get the food to the stomach as soon as possible. In the stomach and remainder of the gut there are two kinds of movements. One that moves the food along, as shown in the duodenum above, and the other which brings about a mixing of the food (segmental and pendular) as shown in the stomach and lower intestine.

the bacteria then attack the extensive lining of the visceral organs, resulting in a general infection that can be fatal. However, with the use of antibiotics and a surgeon's skill there is usually little danger today of such an infection proving fatal.

From the region of the caecum the colon extends anteriorly along the right side as the **ascending colon,** crosses to the left side as the **transverse colon,** passes down the left side as the **descending colon,** then bends in an S-shape (**sigmoid flexure**) to become the **rectum.** The digestive tract terminates in the **anus** which is closed by two powerful muscles, the **anal sphincters.**

Colon movements

The chyme, which is now referred to as **feces,** is gradually moved through the colon by mild peristaltic waves as well as periodic, over-all massive contractions. When feces reach the rectum, which is normally empty, a desire to defecate becomes very pronounced. During defecation a large peristaltic wave moves over the entire colon, aided by voluntary contractions of the abdominal muscles.

Failure of regular bowel movements, commonly referred to as constipation, is the subject of much discussion and more misinformation. If feces are not regularly eliminated from the lower bowel, they tend to accumulate and the mere pressure caused by their presence may produce headaches and the usual symptoms associated with constipation. Similar symptoms can be elicited by simply packing inert material, such as cotton, in the lower bowel. Therefore, no toxins are produced during constipation, although this is usually thought to be the case. The various cathartics that are so well advertised to relieve this condition act in various ways. Some, such as cascara, stimulate the reflex centers in the brain which, in turn, initiate peristaltic contractions; others such as epsom salts (magnesium sulfate) are not readily absorbable, and since they are taken in high concentrations there is a tendency for water to remain in the digestive tract. Castor oil as well as magnesium sulfate strongly irritate the nerve endings in the lining of the gut which bring about violent peristaltic activity reflexively. Usually a controlled diet will relieve constipation without resorting to these artificial means. Much of the catharsis to which people subject themselves is not only unnecessary but harmful.

Absorption

Once the food is digested it is *absorbed* into the blood stream and carried to all parts of the body to provide the material for energy release and for growth and repair. With the exception of alcohol, which is absorbed in the stomach, nearly all organic and inorganic compounds are absorbed in the small intestine. Elaborate provisions have been made to facilitate the process of absorption. In the first place, the small intestine is 23 feet long and, secondly, the **villi,** previously referred to, multiply the surface area of the lining at least 10 times. Consequently, there is a great expanse of surface area into which the chyme comes in close contact, giving every absorbable particle an opportunity to find its way into the blood stream.

The important anatomical unit that facilitates absorption is the **villus** (Fig. 17-10). It is a thin-walled projection lined with capillaries and with a central space, the lymph vessel or **lacteal.** As the watery chyme bathes the villi, an osmotic equilibrium is constantly strived for between the blood and the intestinal contents, but since the blood is moving rapidly through the capillaries, the flow of absorbable materials is toward the circulating blood. Therefore, the end products of protein and carbohydrate digestion, together with inorganic salts and water, are absorbed directly into the blood stream and are transported via the hepatic portal system directly to the liver. The products from the breakdown of

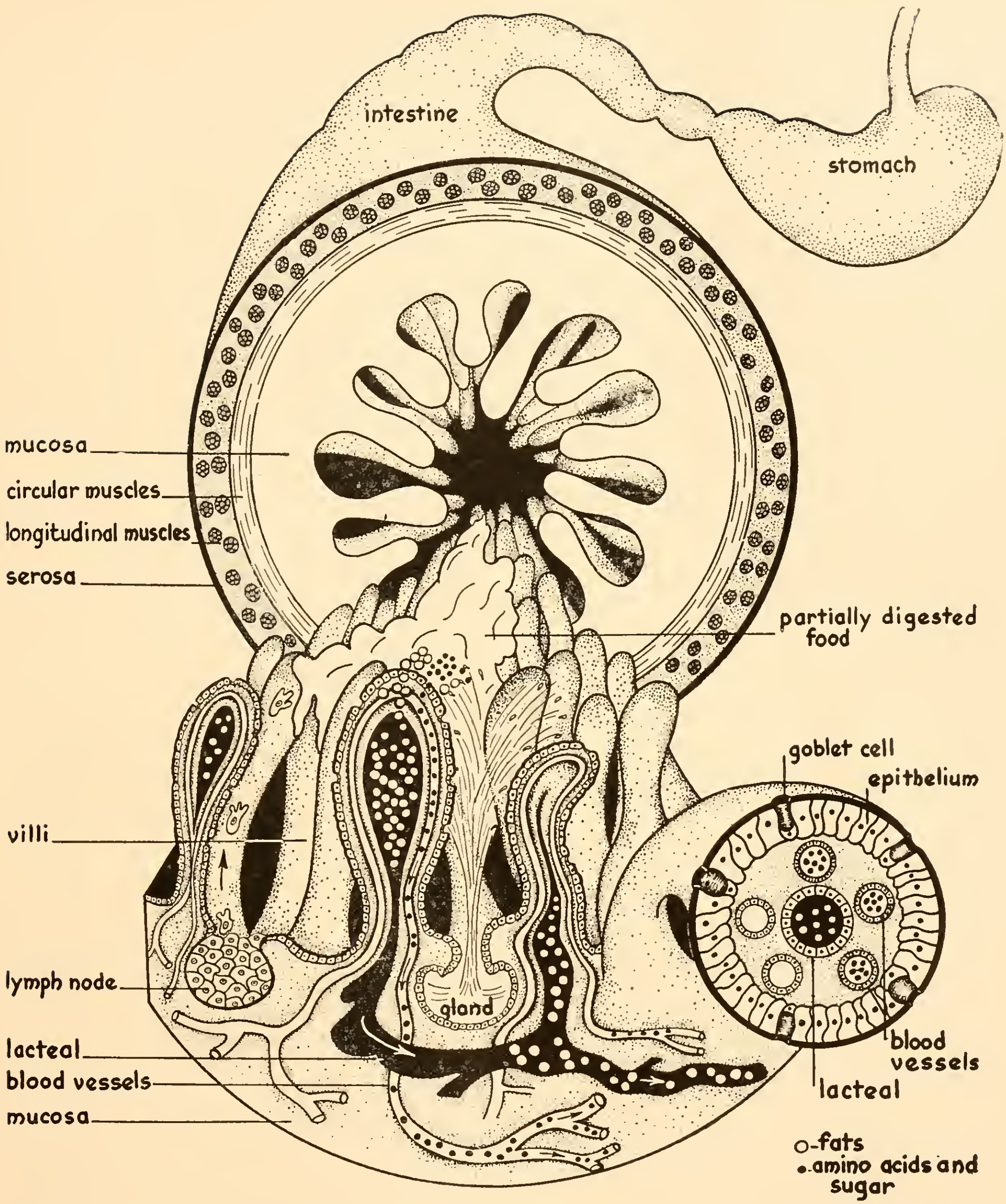


Fig. 17-10. A cross-section of the intestine with the villi greatly enlarged to show how absorption takes place. Amino acids and sugars are shown entering the capillaries of the villi. Likewise the fatty acids and glycerol, which become fats upon absorption, are taken into the lacteals of the villus. One villus is shown contracted while the other is gorged with fat. This "pumping" action aids in moving the lymph.

fat (fatty acids and glycerol), however, pass through the mucosa and at once recombine into large fat molecules which are slowly taken up by the lacteals. The lacteals join with the lymphatic system and eventually pass into the general circulation. The end result is that all food products eventually reach the blood stream, where they are distributed to all parts of the body. Once the food is in the blood or lymph, the next task is to bring about its distribution to all parts of the body and to provide oxygen so that it can be burned to release energy, which is the ultimate goal.

FOOD

Now that we have seen how food passes through the digestive tract and is digested, we shall discuss briefly the kinds of food necessary for the continued health of a human being.

Food must provide the body with the proper amounts and kinds of substances from which it can synthesize its own parts. Just as the carpenter or mason must have lumber, bricks, cement, and other materials, so must the body have its building materials. The digestive process breaks down the large, complex molecules to small or, simpler ones that can be rebuilt into the specific molecules needed for human protoplasm. The process of reconstruction will be taken up later. What concerns us now is the kinds of food which, when reduced to the simple state, will provide all of the essential materials in sufficient quantities to build and maintain the body. Returning to the house analogy, if the carpenter does not have enough lumber and nails, or the mason enough bricks and cement, they will be forced to cut corners and produce a house that will not function as it should. Similarly, food must contain all of the essential substances if the body is to be properly constructed. Food must also supply a source of energy to maintain the body at a constant temperature and to permit movement. Therefore, food must include oxidizable materials, or materials that can be converted into substances that will burn. Let us consider the kinds of food that contain these two types of materials.

Foods for building

The simplest of these are the inorganic salts. The analysis of any animal will reveal a considerable amount of iron, calcium, phosphorus, and other minerals. Moreover, the animal body excretes minerals every day, in man about 30 grams. This means that the animal must get these from somewhere and, of course, the only source is through the food supply.

The minerals that are most apt to be deficient in human diet are calcium, iron, and iodine. Calcium is essential for building bone and should be maintained at a high concentration in the diets of children and pregnant women. The old adage that a woman loses a tooth with each child may have some truth in it because the demands of the fetus for calcium are great and calcium can come only from the mother's blood. If her diet is deficient in calcium, her teeth may be sacrificed to obtain the vital element. Although calcium is present in small amounts in vegetables and cereals, it is particularly rich in milk—hence, the constant urge for an adequate supply of this food for children. Iron is necessary for the formation of hemoglobin, the chief constituent of the red corpuscles, and a low iron diet will result in anemia. Meats and eggs are rich in iron, as well as many kinds of fruits and vegetables, and ordinarily, under normal circumstances, it is not necessary to supplement the diet for this mineral. Iodine is required for the proper functioning of the thyroid gland, as was pointed out earlier. Near and at the seashore, and in regions covered by the sea in past geological time, this element is in adequate supply in the water and food grown in the region. Sea food in particular is always rich in it. In other areas, however, particularly those remote from the sea, the iodine is not sufficient for an adequate diet and must therefore be supplemented.

While sodium chloride (table salt—NaCl) is probably adequate in most meats, it is less abundant in plant products; for that reason, food is usually salted during cooking and the salt shaker forever adorns the table, just in case. Salt is essential for normal body maintenance. Hydrochloric acid, for example, is produced in the cells of the stomach, using the Cl from the NaCl. With severe sweating there is a gradual loss of salts, and if prolonged will result in "miner's cramps," where large muscles go into painful spasms. The victim suffers from extreme thirst but the more water that is taken the more severe the spasms, because the salt loss is proportional to the water loss. During the recent war where so much work was done in the tropics, it was found that by eating salt tablets the symptoms could be avoided.

Since the body is primarily water and since approximately 2000 cc. are normally lost each day, it follows that this important substance must also be replaced continuously. One can survive many weeks without food but only a few days without water.

In addition to minerals and water, the protoplasm-building proteins must be present in the diet in considerable quantities. Larger amounts of protein are essential for the growing body than the 50 grams per day required by the adult. This amount must include all of the amino acids (about 10) that the human body cannot synthesize from simpler compounds. These are the so-called "essential amino acids." There are many others that can be manufactured by the intracellular enzymes, providing the raw materials are available. Some proteins, such as those derived from milk, meat, eggs, and wheat, contain all of the essential amino acids, whereas others, such as those from gelatin and corn, lack one or more. A diet including only one of these two proteins would be inadequate. It is therefore best to eat a variety of proteins in order that all of the amino acids be supplied in sufficient quantity for proper growth and repair.

Foods for energy

All of the energy utilized by the body must come from the food brought into it. Very little energy is derived from breaking the large molecules of protein, carbohydrate, and fat down to absorbable size during digestion. The bulk of the energy comes from further breakdown by oxidation of these absorbed products in the cells. When carbohydrates, fats, and proteins are burned to the same end products, either in the body or artificially outside the body, they deliver the following numbers of calories per gram: proteins and carbohydrates—about 4 calories; fats—about 9 calories. As far as energy requirements are concerned, one food is as good as another. Carbohydrates, of course, burn readily to supply energy. One can also derive all required energy from protein alone by conversion of a part of it (about 40 per cent) to glucose and burning it. With fats the situation is different. For some reason, when over 50 per cent of the caloric intake is fat, oxidation is impaired, and fats burn best when there is an adequate amount of carbohydrate present in the tissues.

Accessory foods—the vitamins

The discovery of vitamins has a long and fascinating history. When man first began to isolate himself from natural fresh foods and to live on stored or dried foods the "deficiency diseases" made their appearance. Among the many diseases that appeared, **scurvy** was the best known, and the first for which a remedy was worked out. That was some 350 years ago, long before anybody knew anything about vitamins, or much else concerning nutrition. A British navy captain discovered that when his men were down with scurvy after many months at sea, their fresh foods exhausted, they recovered almost miraculously, if the ship docked where fresh fruits were available. He, therefore, took fruit, particularly citrus fruit, aboard and discovered that small daily rations kept his men from getting the dreaded scurvy. It has been said by some that the use of this knowledge was responsible in part for the success of the British navy. Within the present century a great deal has been learned about this vitamin, as well as many others that have since been discovered.

Vitamins are effective in extremely small quantities, so small that they cannot be considered energy-producing in the sense that proteins, carbohydrates, and fats are. They are specific, relatively simple organic compounds which must be included in the diet for normal health. If they are absent over a period of time, definite symptoms appear which grow progressively worse, terminating in death. Animals vary in their vitamin needs. Rats, for example, can synthesize vitamin C and man can exist without thiamine. In the latter case, however, this vitamin is manufactured by bacteria living in his digestive tract. By trial and error experiments the vitamin requirements have been determined for most laboratory animals, such as the rat, mouse, guinea pig, and rabbit, so that they can be employed in vitamin research. However, in recent years it has been found that microorganisms, such as certain species of bacteria and Protozoa, also require vitamins, and their needs are so precise that these tiny organisms have become very important in determining not only the presence of particular vitamins in foods but also the amount present. This method, called **microbiological assay,** is becoming more important as further studies are made on nutrition.

Vitamin research is moving so rapidly today and becoming so complicated that only a bare minimum can be presented here —enough, it is hoped, to provide the reader with sufficient knowledge to approach the problem of feeding himself in an intelligent manner. Some of the better-known vitamins are listed in Table I, together with their sources and the diseases caused by their absence from the diet.

Vitamin A. This vitamin is derived from the orange-colored pigment of plants called **carotene.** Strangely enough, the vitamin itself in pure form is colorless. Carotene is present in all green plants and it is most abundant in those that are yellow or red. Carrots, for example, are rich in vitamin A. Some animals have a tendency to store it in great quantities in their livers. This is particularly true of such fish as the shark, cod, and halibut, hence the well-known names—shark-liver oil, cod-liver oil, halibut-liver oil. Note that it is found in the oil of these livers. Its fat or oil solubility is one of its characteristics.

In severe cases of vitamin A deficiency, rarely observed in this country, the eyes become infected and the cornea becomes very dry and ulcerated. Another symptom is the inability to see at night, which is called **night blindness.** The retina of the eye cannot synthesize **visual purple** in the absence of this vitamin and consequently does not respond to dim light (see p. 401). It is true of vitamin A, as it is with most of the others, that severe symptoms resulting from a marked deficiency rarely show up among Americans because of our diversified diet. Mild cases, on the other hand, are relatively common but can be corrected simply by supplementing the diet with vitamin A.

B vitamins. This is a group of vitamins that are abundantly found in high-protein foods such as meat, liver, nuts, whole grains, and particularly yeast. In the early days of vitamin research, a single B vitamin was described; now a large number, upwards of 12, are known to belong to this group which is sometimes referred to as the **B complex.** They do not all function directly in nutrition, however.

Thiamine (B_1) produces dramatic results when administered to a laboratory animal, like a pigeon, with marked symptoms of **avitaminosis, polyneuritis** in this case. Within 30 minutes the completely helpless animal regains its posture and appears normal in every respect. Severe thiamine deficiencies in man produce **beriberi**, a disease that was common among the rice-eating peoples of the world when modern methods of removing the hulls were introduced. The thiamine was in the hulls, and hence was lost in the processing of the rice. The processing of wheat today is just as impractical from a nutritional standpoint. Nearly all of the vitamins are removed from the wheat grain when it is processed into the white flour that is demanded by the American housewife. Present-day methods of milling have become a little more scientific, however, for an effort is now made to put the vitamins back in again. It seems a rather ridiculous procedure to go to the labor and expense of removing many nutritious parts of the rich wheat kernel, and then be obliged to restore them for the sole purpose of keeping the flour white. About all that is accomplished is the production of a white but nutritionally inferior flour at a higher price.

Riboflavin (B_2). When deficient, this leads to skin disorders in man as well as in laboratory animals. Small amounts taken daily will often restore the skin to normal appearance.

Niacin. This is the primary pellagra-preventing vitamin. **Pellagra** is a disease which affects the skin and the digestive tract, and is fatal in severe cases. It is found in certain areas in the South where the diet consists almost exclusively of molasses, meat, and corn. Small amounts of yeast, which contains niacin as well as other members of the B complex, will cure the disease very quickly. This is probably the only severe vitamin deficiency disease that is prevalent in this country today.

Table I

IMPORTANT VITAMINS

Name	*Good Sources*	*Effects of Marked Deficiency*
Vitamin A ($C_{20}H_{30}O$) Carotene	Yellow and green vegetables, fish-liver oils, butter, eggs	Severe night blindness, xerophthalmia
Vitamin B_1 ($C_{12}H_{16}N_4SO$) Thiamine	Whole grains, yeast, meats, outer coats of cereal grains	Beriberi, stunted growth
Vitamin B_2 ($C_{17}H_{20}N_4O_6$) Riboflavin	Same as B_1	Skin defects
Vitamin B_6 Pyridoxine	Same as B_1	Uncertain in man
Niacin ($C_6H_5NO_2$)	Same as B_1	Pellagra
Vitamin B_{12}	Same as B_1	Pernicious anemia (?)
Vitamin C ($C_6H_8O_6$) Ascorbic acid	Fresh citrus fruit juices and vegetables	Scurvy
Vitamin D ($C_{28}H_{44}O$) Calciferol	Butter, eggs, fish-liver oils	Rickets, faulty calcium metabolism
Vitamin K ($C_{31}H_{46}O_2$)	Most leafy vegetables	Increased clotting time of blood

Vitamin C (ascorbic acid). Vitamin C is found abundantly in citrus fruits and fresh vegetables. Cooking destroys it rapidly and stored foods soon lose their vitamin C content. The chief symptoms of scurvy are due to the weakening of the walls of the capillaries and small arteries, causing the characteristic bleeding at the joints, gums, and under the skin. Dental caries are supposed to be due, in part, to a low vitamin C intake.

Vitamin D (calciferol). This vitamin is most abundant in fats that have been exposed to ultraviolet light. Such fats are said to be irradiated. Often milk is advertised as being irradiated, which means that some of the fatty substances have been changed to vitamin D. Exposing fats to sunshine will do the same thing; even exposing one's own body to the sun produces this vitamin, hence the name, "sunshine vitamin." When vitamin D is deficient in the diet of children there is failure of proper deposition of phosphorus and calcium in the developing bones, causing the disease known as **rickets.** A rachitic child has a malformed skeleton. Fortunately very few rachitic children have been seen in recent years, compared to two decades ago. In climates where there is a great deal of sunshine the vitamin deficiency is rarely seen. However, in northern climates during the winter months children are very apt to deplete their stores of vitamin D. For that reason, it is important that children's diets be supplemented with this vitamin during this season.

Vitamin K. Vitamin K is produced by bacterial action in the digestive tract and if interfered with in any way, the vitamin K content of the blood drops, and with it the ability to clot properly. This vitamin seems to play a part in the synthesis of **prothombin,** an essential factor in coagulation of the blood. When bile fails to reach the digestive tract, as in gall stone occlusions, the bacteria do not produce vitamin K in sufficient quantities to allow normal clotting of blood, thus making surgery hazardous. Today the surgeon does not worry, because a few treatments of vitamin K restores the clotting time and bleeding is no problem. It is also given before childbirth in order to prevent unusual hemorrhaging.

Recently, many other vitamins have been discovered, some of which seem to be important in the treatment of disease, and which may or may not have a direct relation to nutrition. For example, **folic acid** and **vitamin B_{12}** are important in the treatment of pernicious anemia, a serious blood disease. It has been found that as little as 1 microgram (1,000,000th of a gram per day) of vitamin B_{12} is adequate to keep a pernicious-anemia patient in good health. As other vitamins are discovered and as the mechanism of their operation in the body is explored, it may be that important new remedies will be found for some age-old diseases. This is a rapidly advancing and fascinating field of research today.

In summing up this problem in a nation where most people are not confronted with the problem of how to get enough food but what kind of food to select, good advice is to eat a highly varied diet. Such a diet should be particularly rich in fresh vegetables and fruits, with an ample supply of meat, and lesser amounts of the foods high in carbohydrates, such as potatoes, bread, and so forth, which add weight but which have few vitamins. Eat sufficient, but not too much, food. A slightly underfed rat is the healthiest, and there is reason to believe that the same holds true for man.

The use of alcohol

It may seem questionable whether the controversial subject of the use of alcohol and tobacco belongs in a general book on zoology, but because of their widespread use, a discussion of these topics is included. So much emotionalism has been connected with the use of alcohol, in particular, that it has been very difficult for a non-scientific person to obtain an unbiased account of the whole problem. Perhaps a few scientific facts about the use of alcohol by man are in order.

Is it a food or poison? The answer is that it is both a food and a poison, depending on the conditions under which it is consumed. It can also be considered a drug because it falls under the definition, "any substance which, when introduced into the body, modifies the activity of the body organs otherwise than by increasing the supply of available energy."

Carefully controlled experiments with rabbits show that alcohol (ethyl alcohol) can be utilized as a source of energy in the body. It is not stored, however, as is glucose (glycogen), but must be burned completely to carbon dioxide and water. Over 90 per cent of ingested alcohol burns, delivering large quantities of energy to the organism. As it burns, other foods are saved and stored. Consequently, the use of alcohol is often accompanied by a tendency to add weight.

It is extremely difficult to discover whether the use of alcohol is definitely poisonous when used in considerable quantities over long periods of time. Personal accounts add data to both aspects of the problem, but they are so flavored with emotion that it is virtually impossible to appraise them accurately. Many diseases, such as **general paresis** and various kidney and heart ailments, which formerly were thought to be brought on by drinking, we now know with certainty cannot be traced to the use of alcohol. Experiments with both laboratory animals and man have demonstrated rather conclusively that moderate amounts of alcohol taken more or less continuously over long periods of time have no deleterious effects on any of the organs of the body, nor on the ability to reproduce, nor on longevity. Salt, sugar, and many other substances that are essential foods, however, can produce harmful effects, even death, when taken in high concentrations.

Heavy drinking does seem to affect body structures and functions, primarily because of the secondary effects produced by the habits of the drinker. A heavy drinker usually has very bad eating habits, becoming undernourished, particularly with respect to vitamins. He treats himself badly, with irregular hours of sleep, careless exposure to undue heat, cold and infection, especially venereal infections. Such maltreatment in even a non-drinker would be seriously detrimental to health. With the body in such a state of lowered resistance, it is very apt to fall prey to infections of various sorts which may terminate the life of the individual. In this respect, certainly, heavy drinking is very undesirable from the point of view purely of health. Even more important are the pronounced effects on behavior. After prolonged heavy use of alcohol, an individual becomes morose and disagreeable to a point where he is unfit to live with. Under these conditions homes are broken up and the drinker sinks from one level to another until there is nothing left but his alcoholic habit. Because the possibility of becoming an "alcoholic" is always imminent, a young person should give careful consideration to that first drink. He must weigh the short-lived euphoria that he might derive from it against the possibility of becoming an alcoholic.

The reason why people become addicted to alcohol is probably that some deep-seated, nervous instability and emotional conflict tied up with an unconscious feeling of insecurity exists which may extend back into their childhood. The solution to the problem of these deep, emotional disturbances is being intensely studied today. Some progress is being made by the medical profession, but, strangely enough, equal success in treating alcohol addicts has been had by fellow sufferers who have bound themselves together in an organization known as "Alcoholics Anonymous." Their goal is total abstinence, and this is attained by sympathetic understanding from the only ones who really understand them, namely, fellow alcoholics. The organization has grown rapidly since it was started a decade ago and its record of success is impressive. It should be called to the attention of anyone who believes his habit of alcoholism is getting out of control.

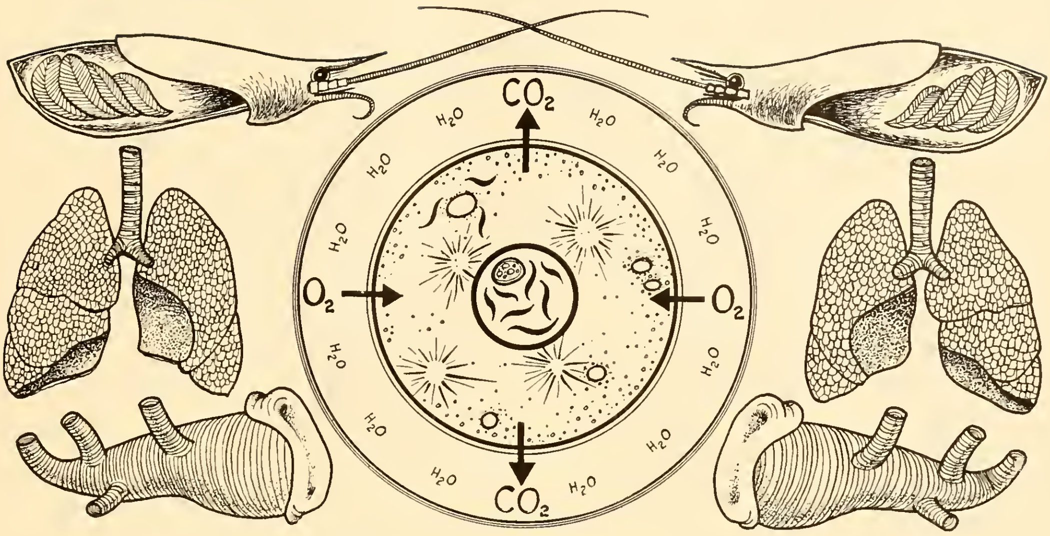
The use of tobacco

A brief discussion of the tobacco habit will be considered, not because it has anything to do with nutrition (in this sense it differs from alcohol), but only because it is often associated with alcohol in the layman's mind. One may become nauseated by too much smoking but he does not become inebriated so that he loses control of his higher faculties. At this point, it might be well to point out that one can form a deleterious habit of drinking cokes, coffee, or tea, all of which contain caffeine. Even cocoa contains theobromine, likewise a stimulatory drug. It seems that through man's evolution he has constantly sought out concoctions containing substances which either stimulated or depressed him thus changing his behavior to a greater or lesser degree. Even today the drug-containing beverages are the most popular. Such drugs as marihuana and cocaine derivatives have to be denied the general public by law because their effects are so drastic, and their habit-forming power so great. It is a strange paradox that man must be protected from destroying his life by drugs and poisons of various kinds—something a lower animal would never do. What price civilization!

It is common knowledge that the young adult who first starts to smoke is likely to become nauseated and very ill; with persistence he becomes tolerant to the tobacco toxins and derives pleasure from the experience. However, his initial contact with tobacco indicates clearly the poisonous nature of the various irritating substances, nicotine included, that are volatilized during the smoking process. Whether its prolonged use is detrimental is even more questionable than alcohol. Tobacco has certain definite physiological effects, such as the contraction of the capillaries at the finger tips and a slight increase in the heart rate, but whether or not these are injurious has not been definitely proven. Experiments with rats, exposed for several generations to both tobacco smoke and to nicotine injections, showed no ill effects. Man does not always respond as the rat does, so that final conclusions cannot be had from these experiments.

Why people smoke in ever increasing numbers is difficult to say. Certainly little satisfaction can be obtained from the direct answers of the smokers themselves. The chief reason is probably to relieve tension. This is accomplished by the simple manipulation of the tobacco and all the mechanical gadgets associated with it. If nothing else, it is an expensive habit, especially for young college people who generally cannot and should not afford it.

CHAPTER 18



THE BREATHING SYSTEM

In the previous chapter we saw how the energy-rich food is broken down and absorbed into the blood stream, ready for distribution to all of the cells of the body where it is used for growth, repair, and energy release through burning. In order that burning can occur, **oxygen** must be present, because all energy obtained by a living organism is through oxidation. Each cell, then, must not only have a supply of fuel and building materials but it must also have oxygen to burn the fuel. The function of the breathing system in animals is to provide a means of getting oxygen out of the air and into the vicinity of the cell so that it can be utilized. Another function is the elimination of CO_2. In animals with considerable bulk, where the cells are a great distance from the surface, the circulatory system performs the job of distributing the oxygen, thus working hand in hand with the breathing system to solve this complex problem of oxygen supply.

The definition of respiration, as generally accepted today, is not breathing but the actual burning of the food in the cells, releasing energy and the waste product, carbon dioxide. Breathing, on the other hand, is merely part of the mechanism by which cells obtain oxygen. Lungs, gills, and other structures are designed to remove oxygen from the air or water and to pass it on to some sort of transportation system by which it can reach every individual cell. It is important that the distinction between breathing and respiration be kept in mind during the following discussion.

All animals from amoeba to man respire

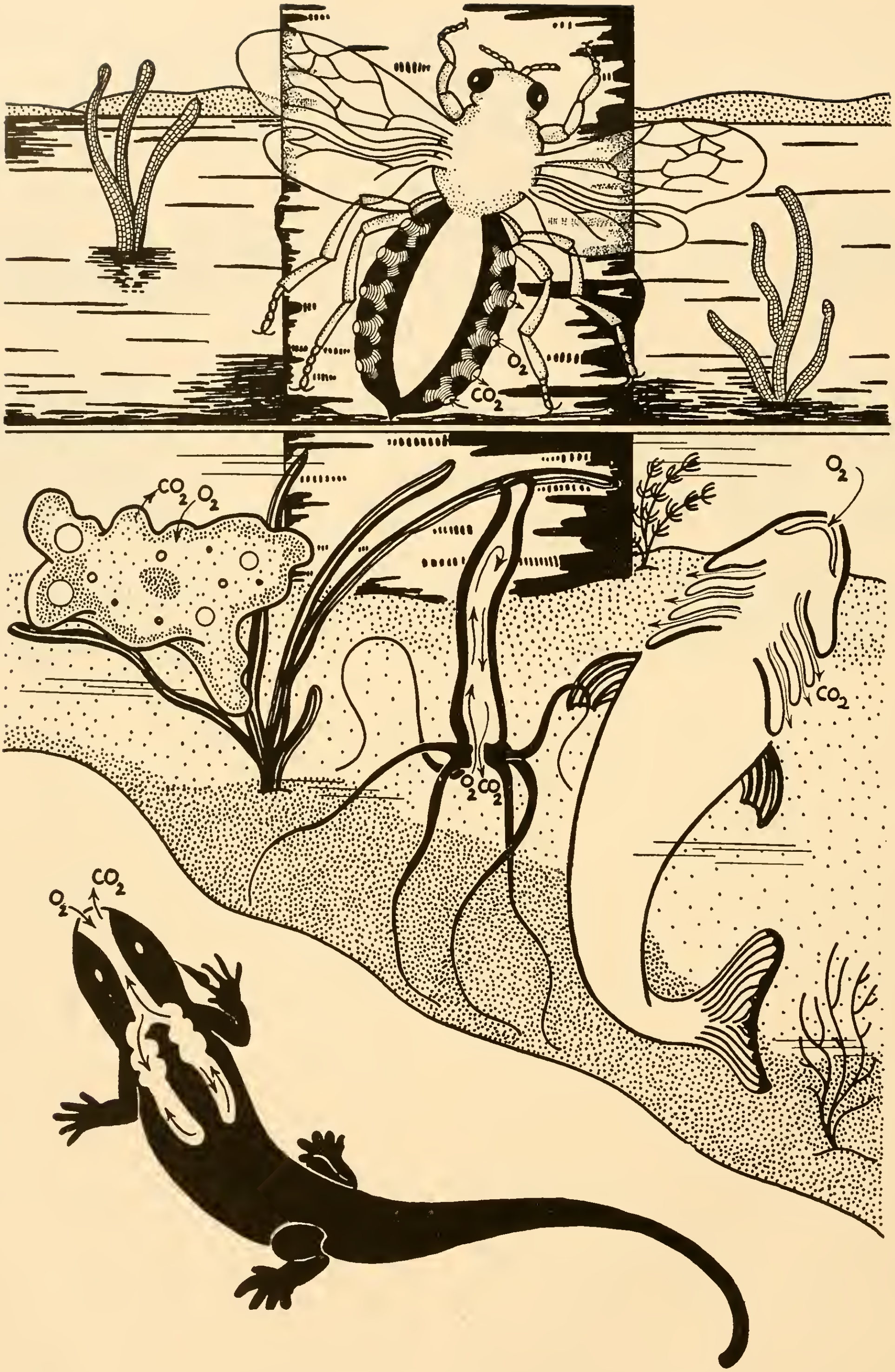


Fig. 18-1. A few of the ways various animals breathe. Special organs are unnecessary for amoeba and hydra. Water dwelling forms, such as fish, have gills, whereas animals that breathe air have trachea (insects) and lungs (adult amphibians, reptiles, birds, and mammals).

the same way, at the **cellular level.** The methods employed by different animals to bring oxygen to the cells are highly varied and become extremely complex in large animals. Such a system may be compared to the ventilating system of a large building. The larger and more complex the building, the more intricate the system becomes, and each new expansion of the edifice means the addition of more powerful blowers and an ever increasing number of ducts. A point might even be reached when it would be impossible, or at least impractical, to attempt to provide ventilation to all parts of the building. In animals, likewise, the problems become more complex with increasing size, which has doubtless been one of the factors in limiting the size of animals. Otherwise, they might grow forever. In earlier chapters, reference has been made to the breathing systems of the various animal groups, and here they are brought together in a comparative manner (Fig. 18-1).

Unicellular animals such as amoeba have no special devices for breathing. They take oxygen through the outer covering and lose carbon dioxide the same way, by the simple process of diffusion. The same is true of hydra. In planaria, however, the body is much more complex, and tissues between the body wall and the gastrovascular cavity are remote from the surface, so that diffusion is much less efficient. This definitely limits the size of the animal. Modifications had to be evolved, therefore, before any increase in bulk could occur. In the earthworm this was accomplished by the introduction of a circulatory system which carries oxygen from the skin (the breathing organ) to all cells of the body (Fig. 10-17). Insects solved the problem very differently. They devised a unique system of tubes (trachea) which carries oxygen directly to each cell (see p. 226). In many higher forms, such as larger crustacea, mollusks, and the lower vertebrates, special breathing organs in the form of gills have evolved; while in the higher vertebrates, beginning in the Amphibia, lungs have developed. Gills and lungs are intricate structures designed to provide a tremendous surface area which makes possible rapid gas exchange. Gills are designed to function in water, lungs in air. They are essentially alike in having thin-walled surfaces which are highly vascularized by capillaries in order that the blood can come close to the oxygen-containing outer environment. For a more detailed account, we will use the breathing system of man.

HUMAN LUNGS

The lungs of man, like those of all vertebrates, arise in the embryo from an outpocketing of the floor of the pharynx. When fully formed, they fill the entire **thoracic cavity.** The complete breathing system consists of the **nasal chambers, larynx, trachea, bronchi, bronchioles,** and **alveoli** (Fig. 18-2). The nostrils are the normal portals of entry for air, and they open into the spacious nasal chambers which are especially adapted for warming the incoming air. The surface area is greatly increased by sheets of bony tissue, the **turbinates,** that hang down into the nasal passages. These are covered with a layer of mucous epithelium that is kept constantly wet by the mucus-secreting glands located in this layer of tissue. It is also highly vascularized, giving warmth to the entire nasal chamber. The result is that as air passes through these passages it is not only warmed to approximately body temperatures but is also humidified to some extent.

Another important feature is the provision made to filter particulate matter out of the incoming air. The nose is lined with hair which strains out the larger particles, and smaller bits which pass the hair are caught in the mucus secretion and eventually discharged with it. Proof of the efficiency of this mechanism is noted by observing the color of the nasal secretions

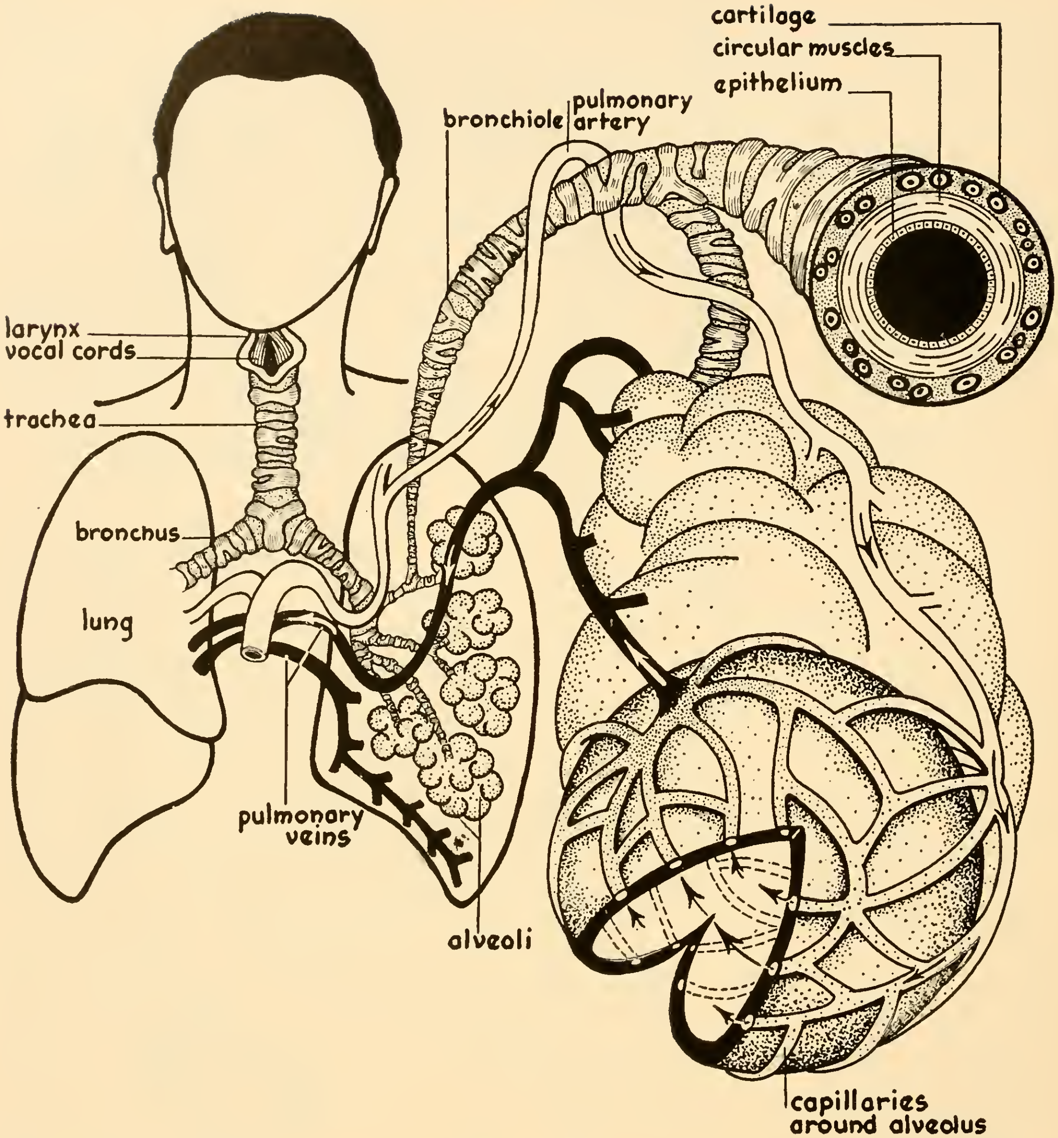


Fig. 18-2. A schematic view of the breathing system of man with one alveolus and associated parts greatly enlarged.

after working in dust-laden air. The mucus secretion also has some hygienic value, because bacteria are caught by this mechanism as well, thus preventing them from reaching the lungs where they might cause disease. However, some bacteria and viruses may establish themselves in the nasal areas, as in the case of head "colds." Later they may make their way into the deeper portions of the respiratory tract where characteristic symptoms appear. The nasal secretions have some bacteria-destroying action, and in head colds the cells of these areas are stimulated to produce large amounts of mucus to prevent the organisms from getting a foothold. This reaction accounts for the "running nose" at the beginning of a cold. Unfortunately, this is frequently carried to such extremes, that swelling of the walls closes the air passages, forcing the victim to breathe through his mouth. This makes him liable to infection from the same or other organisms in the lungs, since the air has not been filtered in the nasal passages as it normally would be.

Once past the nasal passages, the air is carried down into the **pharynx** and into the **larynx** on its way to the lungs. The larynx, or **voice box**, is a cartilaginous enlargement of the upper end of the **trachea.** It offers a rigid support for the **vocal cords,** which are stretched bands of tough tissue that vibrate to produce a sound when they are tightened and air is forced over them. While the initial sound comes from the vocal cords, the ultimate sound produced is highly modified by the nasal chambers and mouth cavity. These resonating chambers, together with their movable parts (soft pallate, tongue, and cheeks), are responsible for the **quality** of the voice, either speaking or singing. Any interference with these passages has a marked effect on the quality of the voice, a familiar phenomenon in anyone suffering from a cold.

Immediately beyond the larynx is the **trachea,** a single tube whose walls are kept from collapsing by means of cartilaginous rings. The "windpipe," as it is sometimes called, lies at the front of the throat where the rings can be felt through the skin. The trachea passes into the chest cavity where it divides into two **bronchi,** one going to each lung. These subdivide into **bronchioles** which after many divisions terminate in tiny blind sacs, the **alveoli.**

In the alveoli the actual exchange of gases takes place. All of the mechanism up to this point functions in getting the air to and from these alveoli. The combined surface of all the alveoli of the human lungs is over 1000 square feet, and all of this is in intimate contact with capillaries. The lungs are covered by a thin layer of epithelium called the **pleura** and the spaces between the alveoli and bronchioles are filled with elastic connective tissue. The lungs remain partially inflated at all times. When removed from the thoracic cavity they collapse to only a fraction of their inflated size, because of the constant tension on the walls of the bronchioles. But, even in this contracted condition they resemble a sponge in consistency and will readily float in water.

THE BREATHING MECHANISM

The lungs completely fill the thoracic cavity, which is lined with pleura identical to that covering the lungs. These two layers normally lie close together with no actual space between them, but when deflated, the space that results is known as the **pleural space.** The two surfaces are held together because there is no air in the pleural space. In other words, there is a partial vacuum in which the pressure is below that of the outside atmosphere. Therefore, if the walls of this closed cavity move out so as to enlarge the cavity, the walls of the lungs must follow. This creates a decreased pressure in the lungs themselves which, in turn, causes air to rush into the low pressure region deep in the alveoli. The opposite effect results when the cavity is reduced in size. The cavity can be increased and decreased in size by simply raising the ribs (Fig. 18-3) and then allowing them to return. Simultaneous with the raising of the ribs, the dome-shaped **diaphragm** is pulled downward and flattened. The ribs are raised by the contraction of the muscles lying between them (intercostal muscles) and when these muscles are relaxed the ribs fall back into position. At the same time, the diaphragm is returned to its dome-shape by a ligament that keeps it in this position. Therefore, **inspiration** is brought about by the contraction of muscles, **expiration** by relaxation. As a result of these two actions the air in the alveoli is changed.

Under extreme exertion the abdominal muscles also are involved in the breathing movements. On inspiration they relax in order to allow the diaphragm to descend farther, thereby compressing the abdominal organs. In forced expiration the abdominal

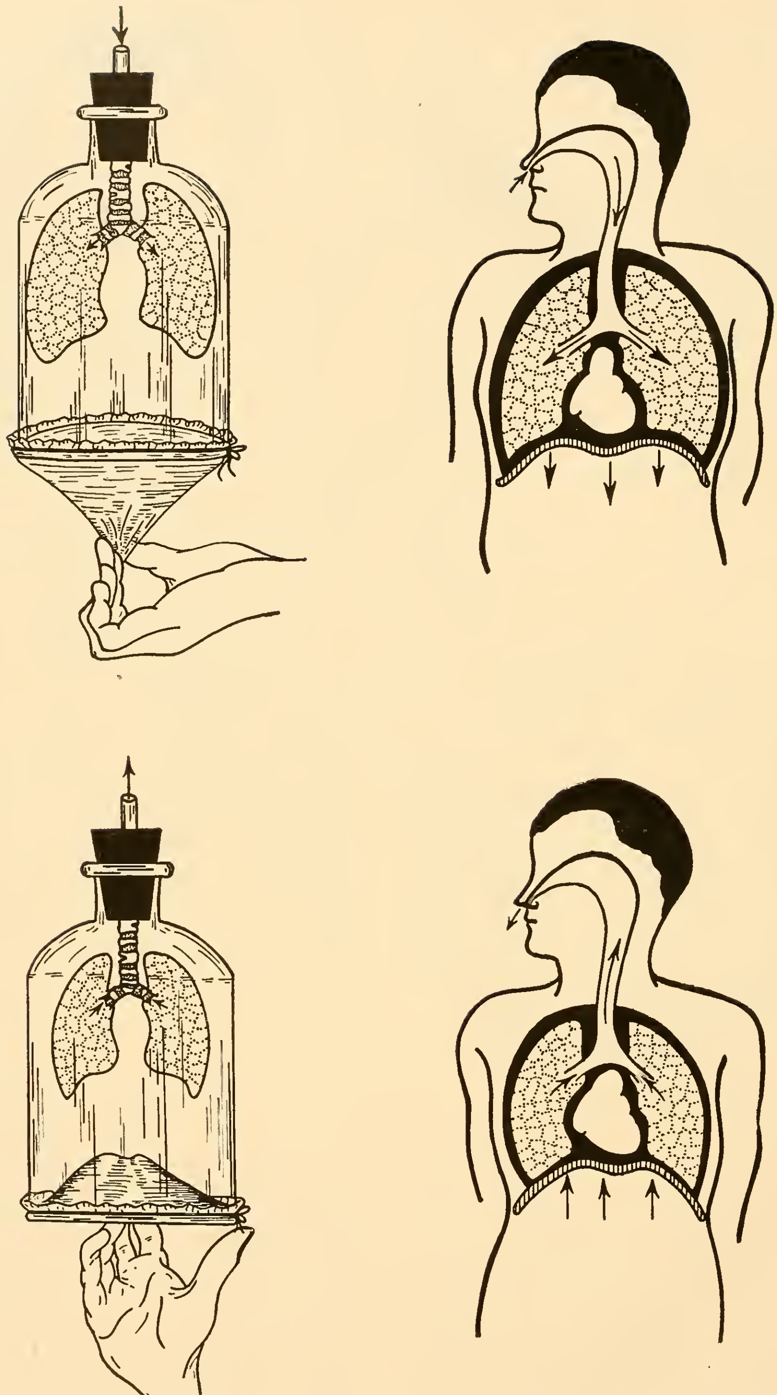


Fig. 18-3. In breathing the thoracic cavity increases and decreases in size by alternate raising and lowering of the ribs, together with a corresponding elevation and depression of the diaphragm. This can be shown experimentally by placing the lungs and trachea of a dog in a bell jar and covering the open end with a rubber membrane. By pushing up and down on the membrane, simulating the movements of the diaphragm, air passes in and out of the lungs.

muscles contract in order to help push the diaphragm upward. These muscles also play an important part in coughing and sneezing. Preceding these actions, the air passages are voluntarily closed and the muscles contract to build up a pressure within the lungs. This is followed by a sudden opening of the passages, resulting in an explosive discharge of air which is designed to dislodge any foreign matter that may have gotten into the air passages.

Accidental puncturing of the thoracic cavity brings about the collapse of the lung because when air within the pleural cavity

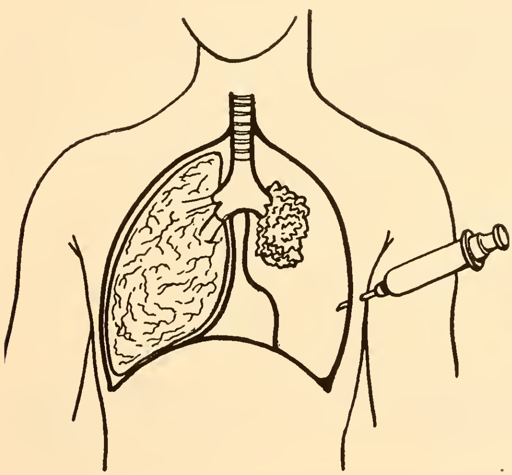


Fig. 18-4. Lungs can be deflated by simply forcing air into the pleural space as shown here.

reaches the same pressure as the outside air, the lung contracts, as pointed out above. Such a lung is non-functional and if both lungs collapse at the same time, suffocation follows. Fortunately, there is a partition between the lungs so that one can be deflated while the other functions normally. It even becomes necessary sometimes to collapse one or the other lung artificially in such diseases as tuberculosis. This is easily accomplished by simply forcing a hollow needle between the ribs into the pleural space and allowing sterile air to enter (Fig. 18-4). When the needle is withdrawn the lung will gradually fill the space again after about two years as the air is slowly absorbed into the tissues and eventually carried away in the blood.

In some diseases, particularly poliomyelitis, the motor nerves to the breathing mechanism fail to function, resulting in death from suffocation if some artificial breathing mechanism is not brought into immediate action. This apparatus, commonly called an "iron lung," is merely a device that creates a partial vacuum over the chest region, thus replacing the non-functioning

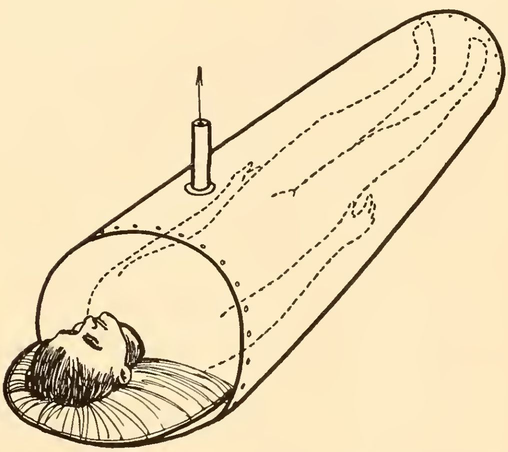


Fig. 18-5. In such diseases as poliomyelitis the motor nerves to the breathing mechanism fail. The iron lung is a device that substitutes for the action of the breathing muscles. A partial vacuum is produced in a rhythmic manner over the entire body, but its specific effect is on increasing and decreasing the thoracic cavity, simulating normal breathing.

muscles (Fig. 18-5). Its use must be continued as long as the muscles remain inactive. Frequently the nerves regenerate, in part at least, so that gradually they are able to carry impulses to the breathing muscles and normal breathing is restored.

LUNG CAPACITY

It is a familiar fact that breathing is slow and shallow when one is at rest, either sitting or lying down but rapidly becomes faster and deeper with exertion such as running. It is also well known that when resting one can take in a great deal more

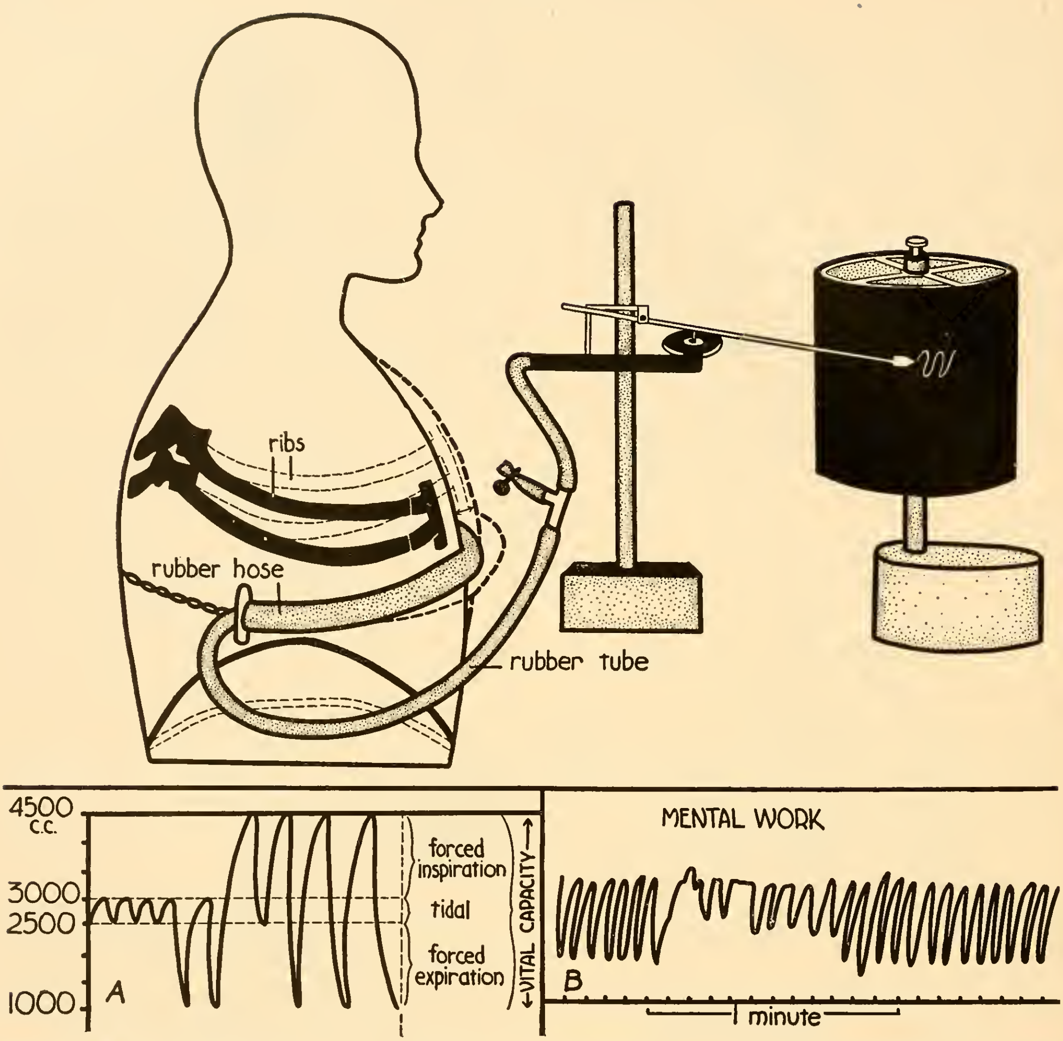


Fig. 18-6. Breathing movements can be recorded by such a device as shown here. The movements alter the air pressure in the rubber hose which is transmitted via the rubber tube to the rubber membrane which in turn influences the movement of the lever, the tip of which inscribes the magnified movements on the smoked drum. With this instrument the tracings shown in *A* and *B* were made. See the text for an explanation of *A*. The tracings in *B* are a result of mental work. A student was given a problem in mathematics to solve which required one minute. How his breathing was influenced during this mental work is shown in the tracing.

air at the end of a quiet inspiration and can force out a great deal more air at the end of a quiet expiration. These facts indicate that the lungs have a great deal more capacity than is used in non-strenuous work. This constitutes a reserve that is always available when needed.

In quiet breathing, about 500 cc. of air is breathed in and out. This is known as **tidal air**, reminiscent of the tides (Fig. 18-6). Upon forced inspiration, 1500 cc. more can be taken into the lungs. This is known as **complemental air.** Forced expiration can deliver about 1500 cc. of air, known as **supplemental air.** Therefore, complemental air together with tidal and supplemental air amounts to about 3500 cc., the total capacity that can be taken in and forced out under conditions of heavy exertion. This amount is called **vital capacity.** There is some variation in this quantity, depending on the size, age, sex, and training of the individual. Athletes usually have slightly more vital capacity than do nonathletes, women slightly less than men.

Some air, about 1000 cc., is always left in the lungs even after forced expiration. This **residual air** is present to some extent in lungs that have been removed from the body. If the lungs of an unborn child are placed in water they do not float, whereas those of the newborn who has taken a breath do. This test sometimes has legal significance in suspected cases of infanticide.

CONTROL OF BREATHING

Because the demands for oxygen vary with activity, the rate and depth of breathing vary to meet these demands. It is possible to change the rate of breathing voluntarily, although one does not need to think in order to breathe. One can hold his breath for some time, with considerable distress, but eventually he will be forced to breathe again in a normal fashion. The rate of breathing is altered by a number of conditions arising from within as well as from without the organism. Such conditions include emotional as well as physical strain (Fig. 18-6).

Breathing is a result of the coördinated action of a great many muscles which require a rather precise controlling mechanism called the **respiratory** or **breathing center**. This consists of a group of specialized cells located in the **medulla** (Fig. 18-7). Bursts of nervous impulses leave this center over the **phrenic** nerves to the diaphragm and over the **cervical sympathetics** to the rib muscles, causing both to contract, resulting in inspiration. The rate at which these contractions occur depends on several factors influencing the respiratory center. If the carbon dioxide content of the blood

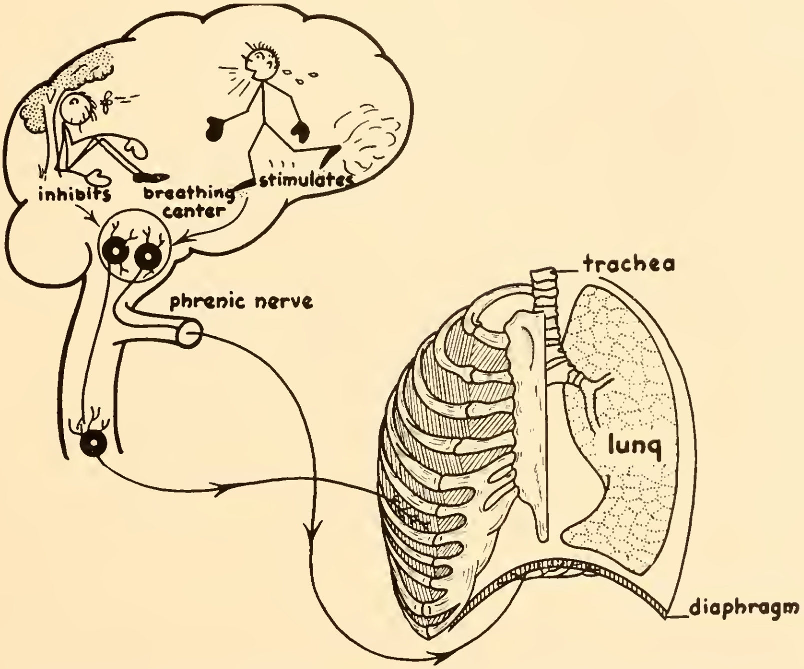


Fig. 18-7. The rate of breathing is controlled by the breathing center which is sensitive to carbon dioxide in the blood. During activity the increased carbon dioxide content of the blood stimulates the breathing center to bring about increased rate of breathing. The opposite effect prevails when at rest.

rises, as it does in exercise or emotional stress, the impulses are quickened. If, on the other hand, the carbon dioxide is diminished, the impulses will likewise be farther apart. If the phrenic nerve is severed or destroyed through disease such as poliomyelitis, the impulses fail to reach the diaphragm and this muscle ceases its contractions. The same is true of the other motor nerves going to the rib muscles. It is possible by taking a series of deep inhalations and exhalations to reduce the carbon dioxide content of the alveoli to a point where breathing can be held in abeyance until the gas again reaches a sufficient concentration to stimulate the respiratory center. For the same reason, a newborn child will take its first breath only after the carbon dioxide has reached a certain level. When its placental circulation is cut off the gas begins to build up in the blood. Occasionally, even then breathing will not start. This can be remedied oftentimes by forcing air containing 10 per cent carbon dioxide into the lungs.

One of the problems of breathing that was not understood for a long time was how the respiratory center could send out these bursts of impulses in a rhythmic fashion. It has been discovered by clever surgery that if all of the sensory nerves leading to the respiratory center are severed, inspiration will occur but not expiration. In other words, the muscles of the diaphragm and of the ribs will contract but will not relax, because a steady stream of impulses continue to come to them. This means that the respiratory center must be inhibited periodically so that the bursts of impulses coming to the breathing muscles are interrupted. This is accomplished by sensory endings in the walls of the alveoli and other parts of the lungs (Fig. 18-8). When air is drawn into the lungs, the stretching of the walls presses on the nerve endings, causing impulses which inhibit the respiratory center. Such is the device by which the lungs are alternately filled and emptied.

The respiratory center is also inhibited by impulses coming to it from many other

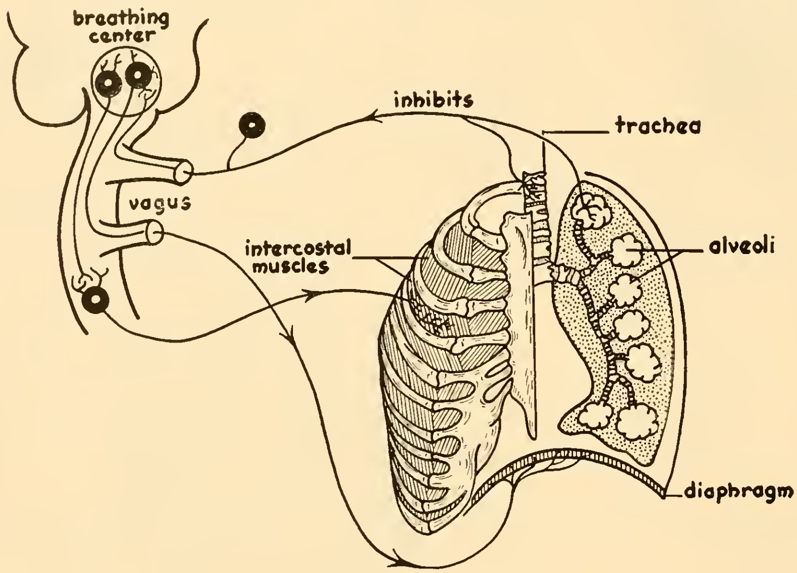


Fig. 18-8. The rhythmic movements in breathing are controlled by the breathing center also. Sensory nerve endings lying in the alveoli send impulses to the center which inhibit its action when the alveoli are stretched on inspiration. During the period of inhibition, no motor impulses come from the center to the muscles, hence they relax, resulting in expiration.

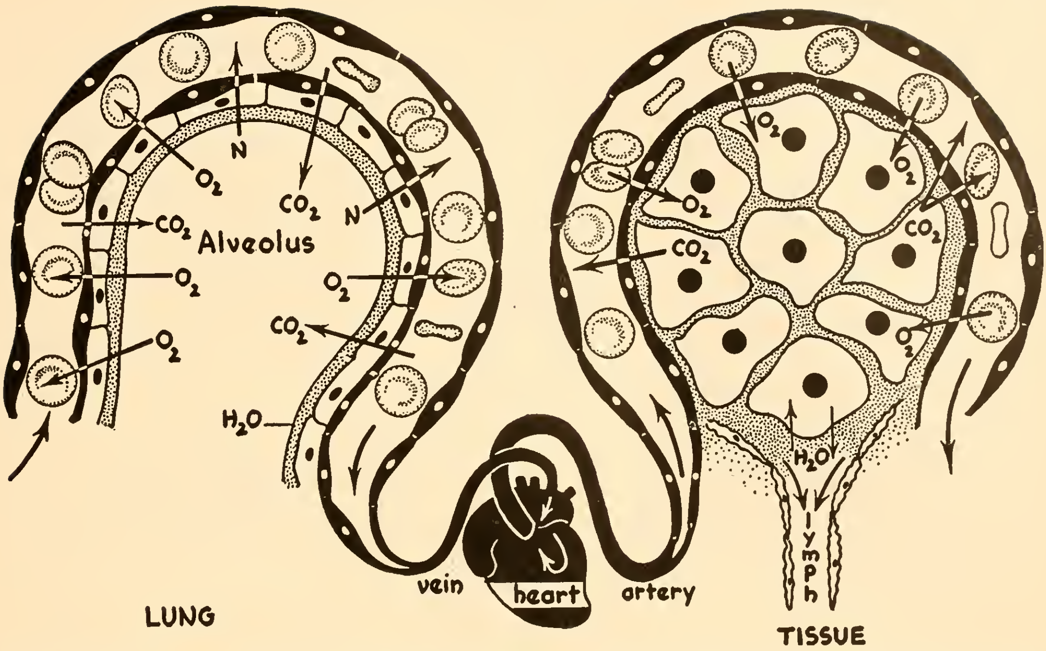


Fig. 18-9. This is a schematic representation of how respiration occurs in the alveoli (external) and in the tissues (internal). An explanation is found in the text.

parts of the body. Receptors lie in the walls of the larynx and pharynx which are sensitive to foreign bodies or harmful gases. For example, when a particle of food gets into the larynx, breathing ceases at once to prevent the passage of the particle farther into the delicate respiratory tract. This is followed by a closing of the epiglottis until considerable pressure is built up in the chest cavity. It then lets go explosively in the form of a cough as already described. Likewise, if irritating gases such as chlorine are drawn into the pharynx, breathing ceases instantly with the closing of the air passage by the epiglottis. Here is another safeguard to prevent injury to the extremely sensitive and delicate lining of the respiratory tract. Severe pain and sudden chilling will also inhibit the respiratory center. One also "catches his breath" because of the action of these nerves on the respiratory center. Thus we see how this mechanism is tuned to the job of protecting the important breathing organ so that its function may go on uninterrupted throughout life.

GASEOUS EXCHANGE

The exchange of CO_2 and O_2 in the alveoli of the lungs is called **external respiration**, in contrast to the exchange at the tissue cells which is referred to as **internal respiration**. By measuring the amount of oxygen and carbon dioxide in expired air as compared to that of the atmosphere, it is easy to demonstrate that some exchange has taken place, as shown in the following figures:

	Inspired Air	*Expired Air*	*Difference*
Oxygen	20.0%	14.5%	5.5%
Carbon dioxide	0.04%	5.5%	5.5%
Nitrogen	79.0%	80.0%	1.0%

Water and other gases have not been taken into account in the above approximate figures. It is noted that atmospheric air has lost approximately 5 per cent of its oxygen and has picked up approximately 5 per cent carbon dioxide in passing through the alveoli of the lungs. Blood passing near the alveoli has lost most, but not all, of its car-

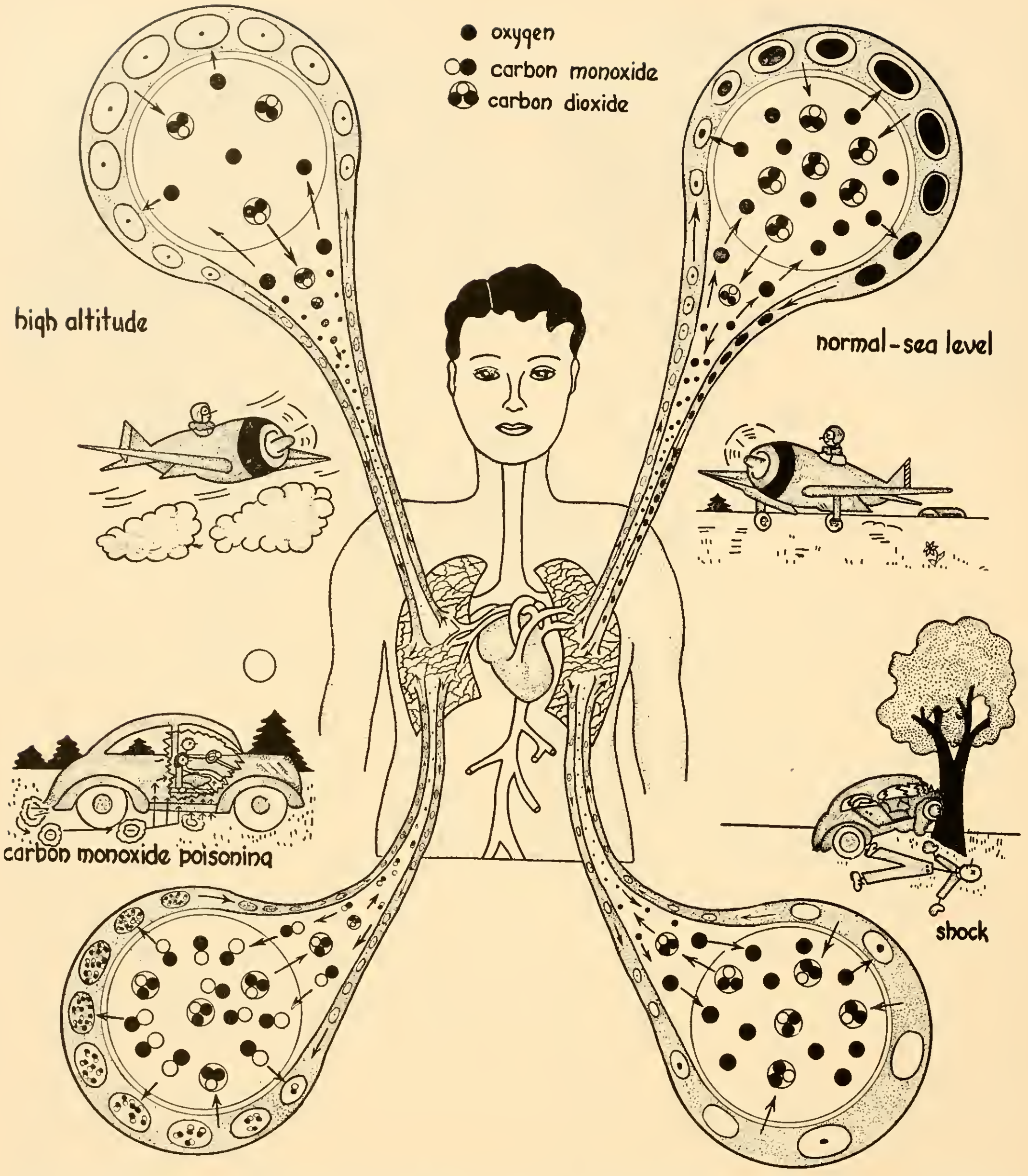


Fig. 18-10. There are several physical and chemical factors in the external environment that influence respiration. Under normal atmospheric pressures (sea level) the gaseous exchange in the alveoli is adequate. At high altitudes (beyond 14,000 feet) the air pressure is so reduced that an insufficient amount of oxygen passes into the blood to maintain consciousness. In shock (a physiological response caused by serious lacerations or trauma) the blood pressure drops so low in the alveoli that circulation is inadequate to pick up enough oxygen to maintain normal body activities. In the presence of carbon monoxide (CO) a stable compound (methemoglobin) is formed in the blood, thus rendering hemoglobin incapable of carrying oxygen. If prolonged, breathing of CO can be fatal.

bon dioxide and has taken on a load of oxygen. Just how is this done?

The oxygen molecules in the air dissolve in the watery mucus covering the lining of the alveoli and pass directly through by diffusion to the blood which is flowing very close to the walls of the alveoli, in fact, only two cells away (one cell layer in the capillary wall plus one cell layer in the alveolar wall) (Fig. 18-9). Oxygen passes from the alveolar air to the blood by simple diffusion, since the concentration of the oxygen molecules is much greater in the alveoli than in the blood. Although oxygen molecules are moving freely across the membranes in both directions, there are more going into the blood than are going into the alveoli, hence the net movement is toward the blood stream. Conversely, the carbon dioxide moves in the opposite direction for exactly the same reason. The inert nitrogen gas remains approximately the same during breathing. The over-all result, then, is that the blood leaving the lungs is rich in oxygen and low in carbon dioxide, whereas expired air is rich in carbon dioxide and low in oxygen. With the continued breathing movements there is a continual exchange of these gases, and interruptions cannot be tolerated, at least for any prolonged periods of time.

The amount of oxygen in the alveoli depends on the amount in the air, which changes with atmospheric pressure. At sea level it is 760 mm. of mercury, of which about 150 mm. represents the **partial pressure** of oxygen. There is a gradual drop in pressure as one rises above the earth's surface and with this comes a drop in the pressure of oxygen in the alveoli, even though the breathing rate and depth are increased. At about 14,000 feet, no matter how fast or deep the breathing, symptoms called **mountain sickness** appear. These are due directly to a shortage of oxygen in the tissues, resulting from too little oxygen in the alveoli and hence too little in the blood (Fig. 18-10). Airplanes at or above 14,000 feet must, therefore, supplement the oxygen supply. This is done in passenger liners by pressurizing the entire cabin to that of about 4000 feet, no matter how high the plane goes. People who live at high altitudes (10,000 feet) soon become acclimatized to the rarefied air by producing more red corpuscles, thus increasing the oxygen-carrying capacity of the blood.

In the tissues, where internal respiration occurs, exactly the opposite condition prevails with respect to the movement of the two gases (Fig. 18-9). The oxygen diffuses from the blood into the tissue cells because the amount of oxygen is higher in the blood than in the tissues, and the carbon dioxide diffuses out of the tissues into the blood for a similar reason. Not all of the oxygen leaves the blood at the tissues, however. Only about 7 cc. out of a possible 19 cc. (per 100 cc. of blood) actually diffuses into the tissue cells.

GASEOUS TRANSPORTATION BY THE BLOOD

The value of the blood as a transporting agent for oxygen and carbon dioxide can be determined easily by measuring the amount of these gases that will be dissolved in equal quantities of blood and water. It will be found that for both O_2 and CO_2 many times more will be picked up by blood than by water. This is owing primarily to that amazingly complex organic compound called **hemoglobin.** Plasma is little better than water in its capacity to carry these two gases. For example, only 0.2 cc. of oxygen and 0.3 cc. of carbon dioxide will dissolve in 100 cc. of plasma, whereas the same amount of whole blood will absorb 20 cc. of oxygen and 50 or more cc. of carbon dioxide. If it were not for hemoglobin, the blood would need to circulate 35 times faster than it does to accomplish the same job.

About 98 per cent of the oxygen is carried in combination with hemoglobin and the rest is dissolved in the plasma. The molecules unite in a one-to-one ratio, that is:

$$\underset{\text{(purple)}}{\underset{\text{Hemoglobin}}{Hb}} + O_2 \underset{\text{(tissues)}}{\overset{\text{(lungs)}}{\rightleftarrows}} \underset{\text{(scarlet)}}{\underset{\text{Oxyhemoglobin}}{HbO_2}}$$

Obviously the reaction must be a reversible one, because the oxygen must be as readily released to the tissue cells as it is taken up in the alveoli in the lungs. Hence blood leaving the tissues contains largely hemoglobin, whereas that leaving the alveoli contains primarily oxyhemoglobin. The color difference in these two explains why systemic veins are purplish in color while arteries are bright red.

Hemoglobin is no less remarkable in its ability to facilitate the carrying of large quantities of carbon dioxide. This gas is immediately converted to carbonic acid (H_2CO_3), which would become a serious problem if it were not transformed to a harmless carbonate during its journey to the lungs where it is eliminated from the body. Carbonic acid would render the blood very acid and this we know does not happen, for the blood has a relatively constant number of hydrogen and hydroxyl ions (pH 7.45) at all times. If, however, the alveoli become unable to eliminate carbon dioxide as in disease (pneumonia), the carbonic acid will build up in the blood which will then become more acid than usual (it will still be alkaline), resulting in a condition called **acidosis.** Tissues cannot tolerate this acid condition for long and soon will die. Carbonic acid in the blood is immediately converted to a carbonate by uniting with sodium or potassium ions that are furnished by oxyhemoglobin when it is converted to hemoglobin in the tissues. This is a complex and involved process but one that again emphasizes the remarkable nature of this one compound, hemoglobin, which is spread so abundantly throughout the animal world.

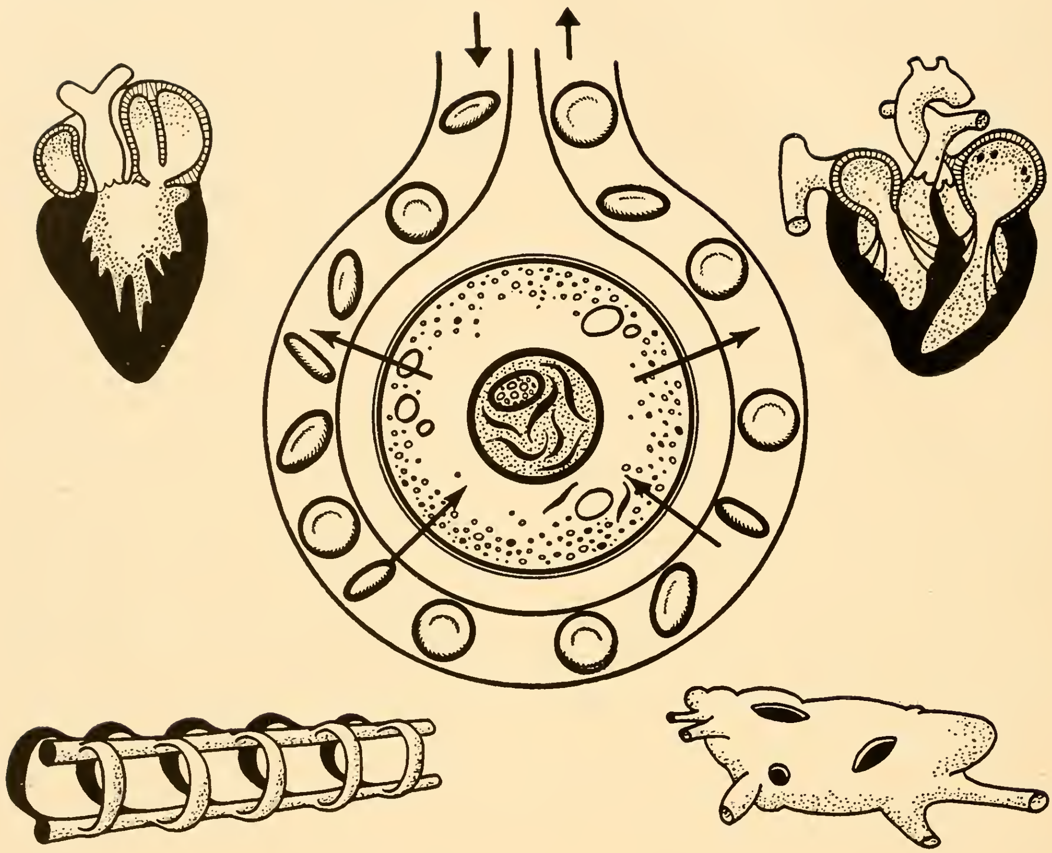
For all chemical purposes, nitrogen plays no part in respiratory exchange in man. However, it does produce some effects which become important only under unusual conditions. In probing into the various corners of his environment man has gotten into trouble with this abundant and omnipresent gas. Trouble starts when he leaves the earth's surface very far, either up into rarefied air or down into the depths of the sea with its tremendous water pressures. Gases under pressure remain in solution as long as the pressure is maintained, but the moment the pressure is decreased they will come out of solution in the form of bubbles. This familiar fact is observed when the cap is removed from a bottle of "coke"—bubbles of carbon dioxide rise rapidly from within the fluid because of the release of pressure.

At sea level there is an atmospheric pressure of 760 mm. of mercury exerted on all parts of the body, inside and outside. Minor differences in pressure, such as those due to altitude changes encountered in driving across the country, have little or no effect, because the change is gradual and the gases in the blood and tissues have a chance to adjust themselves in an undisturbing manner. However, if the change is sudden, that is, if one suddenly ascends to 20,000 feet in the matter of a minute or two, these dissolved gases begin to form bubbles in the blood which float about and become lodged in the blood vessels, plugging them and thus cutting off the circulation in parts of the body. This results in violent pain which sometimes causes the person to bend over, hence the name "bends." This discomfort is also experienced by deep sea divers when they begin to surface after being submerged to a considerable depth in the sea. Divers must surface slowly to avoid the "bends," although there are considerable differences in individuals, some suffering more acutely than others. With the advent of high speed rocket planes in recent years the necessity for preventing "decompression sickness," as it is referred to now, has become more important than ever. Research has revealed that helium, another inert gas, leaves the tissues much faster than nitrogen and for that reason has been employed to prevent the sickness. Aviators breathe the gas a few minutes before taking off, thus replacing the nitrogen in their tissues, and when they reach high altitudes they do not suffer from decompression sickness.

The matter of ventilation in living quarters has gone through various stages in the past 100 years. It was once thought that night air was bad and that all windows must be battened down tight at night or one would certainly "shiver with the ague." It has since been learned that the "badness" in the night air was mosquitoes and the ague was due to the malarial parasites residing in the body of the mosquito that were transmitted by its bite to people. Then someone mistakenly identified tuberculosis with a lack of ventilation, so people went into a period of living out in the open. Windows were flung open at night and it was considered in the interests of good health to be covered with snow the following morning while still lying in bed. Today a more sane approach to the problem of ventilation has come about, based on scientific facts.

It is true that oxygen is withdrawn from the inspired air and that in an air-tight room after a considerable period of time all of the oxygen would be used up. But who lives in an air-tight room? Most houses are so porous that the exchange through windows, doors, and even walls and roof is adequate to take care of all of the oxygen needs of the people residing within. This air turnover likewise rids the room of the accumulated carbon dioxide. However, everyone is familiar with the "stuffiness" common in crowded theaters and other gatherings. This feeling probably arises from the increased humidity and temperature that comes from rebreathed air, mingled with the usual variety of body odors. Circulating and drying the air restores it to outside freshness. To insure comfort it is necessary only to see that the air in the house is circulated, and this is the principle of air-conditioning which has become popular in recent years. This information should give comfort to the householder both in keeping his body warm and his budget intact.

CHAPTER 19



THE TRANSPORTATION SYSTEM

In the previous two chapters we have seen that as animals grow larger, some sort of transportation system becomes imperative to insure food and oxygen reaching the cells. Above the simple Metazoa such a system has evolved in the form of a circulating fluid in which the food and oxygen are transported.

Amoeba and hydra have no need for such transportation because all of the cells are in direct contact with the external environment (Fig. 19-1). To some extent this is also true of planaria. However, its deep-lying cells, such as those in the mesoderm, may receive their oxygen and food from a fluid, **hemolymph,** that bathes all of these internal cells. There is no means of circulating the fluid except by the body move-

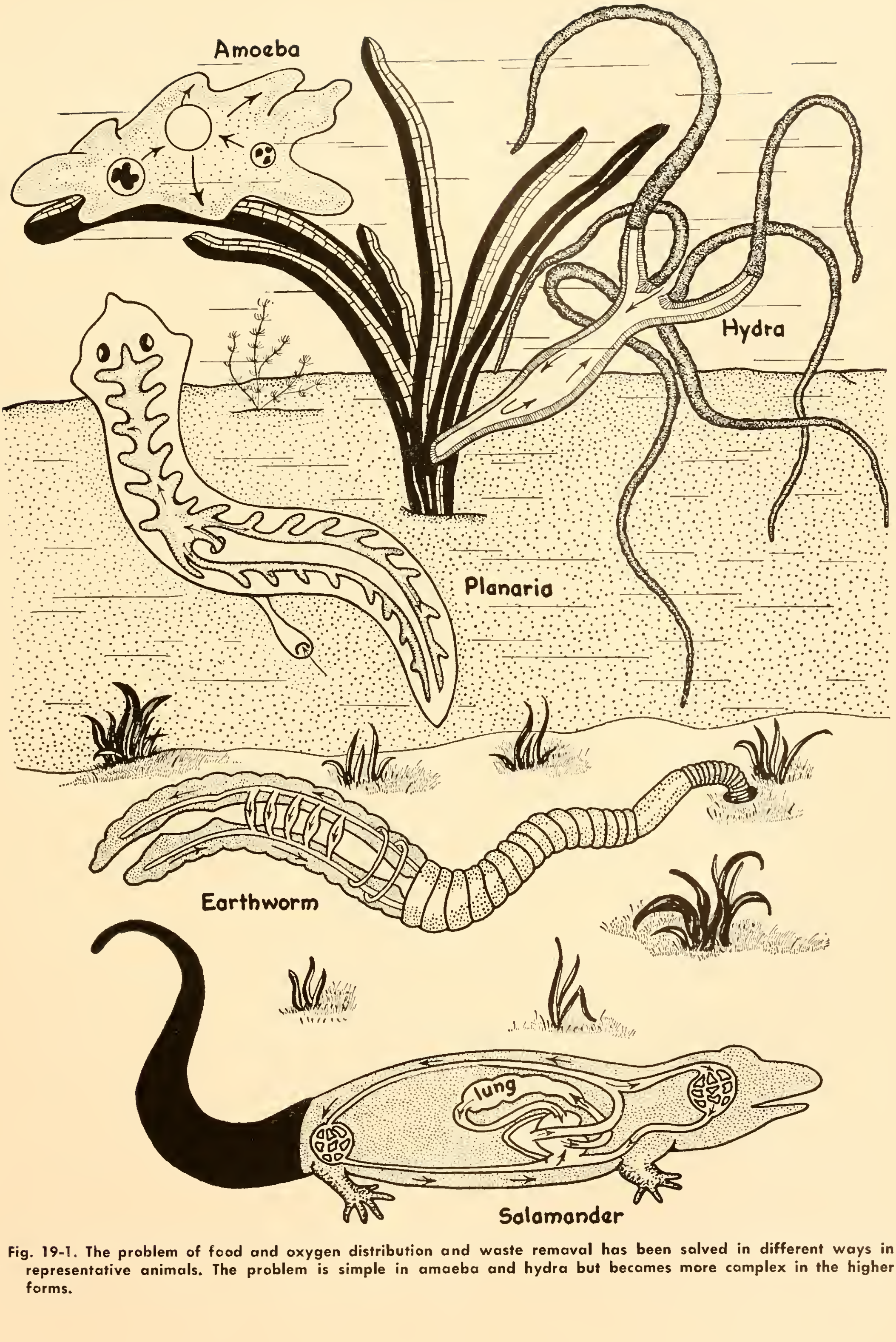


Fig. 19-1. The problem of food and oxygen distribution and waste removal has been solved in different ways in representative animals. The problem is simple in amaeba and hydra but becomes more complex in the higher forms.

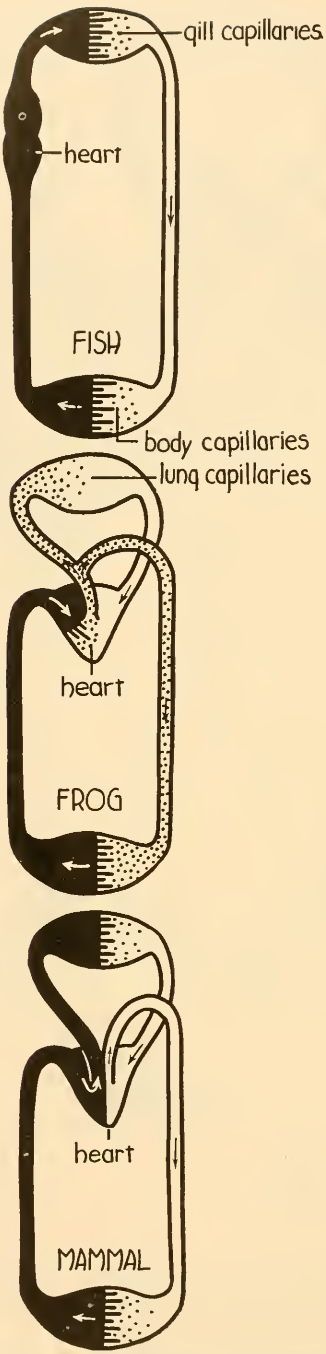


Fig. 19-2. A schematic portrayal of the evolution of the vertebrate circulatory system. While the simple two-chambered heart was satisfactory for an aquatic form, it could not handle the problem of transporting oxygen in sufficient quantities for the active air-breathing land dwellers. The second heart (pulmonary heart) had its beginnings in the amphibians and reached its full-fledged condition in the higher reptiles, birds, and mammals.

ments. Because this is so slow, the animal itself responds feebly to its environment; hence these are all slow-moving creatures.

Although a rudimentary circulatory system is found for the first time among the nemertines (Fig. 10-8), it was not until the annelids appeared that a well-differentiated system of closed tubes was established as an essential organ system. The circulatory system of the earthworm, for example, is a well-defined, efficient system. Like all transport systems, it is composed of a circulating fluid, **blood,** confined to closed vessels which at some point break up into very tiny tubules. These tubules have walls only one cell layer thick and they are in close association with all of the cells of the body. A pump is provided to keep the fluid flowing continuously. Once such a system was established, the bulk of the animal could increase very greatly with safety and this is exactly what happened, as demonstrated by the great dinosaurs of the past and the huge whales of today.

Evolution in the vertebrate circulatory system is one of the many interesting changes that accompanied the transition from aquatic to terrestrial existence as described in an earlier chapter. This can be briefly summed up with the aid of a sketch (Fig. 19-2). In fish, the circulatory flow of blood was between the respiratory organ (gills) and the body tissues. The two-chambered heart forced the blood through arteries into the gill capillaries where external respiration occurred. These capillaries coalesced to form arteries which carried blood to tissue capillaries in all parts of the body where internal respiration took place. The capillaries then united to form veins which conveyed the blood back to the heart—a very simple system.

When vertebrates made the transition to land life, a circuit to care for the newly acquired lungs was established. This meant the construction of a new heart superimposed on the old one. The beginning of this development is seen in amphibians where

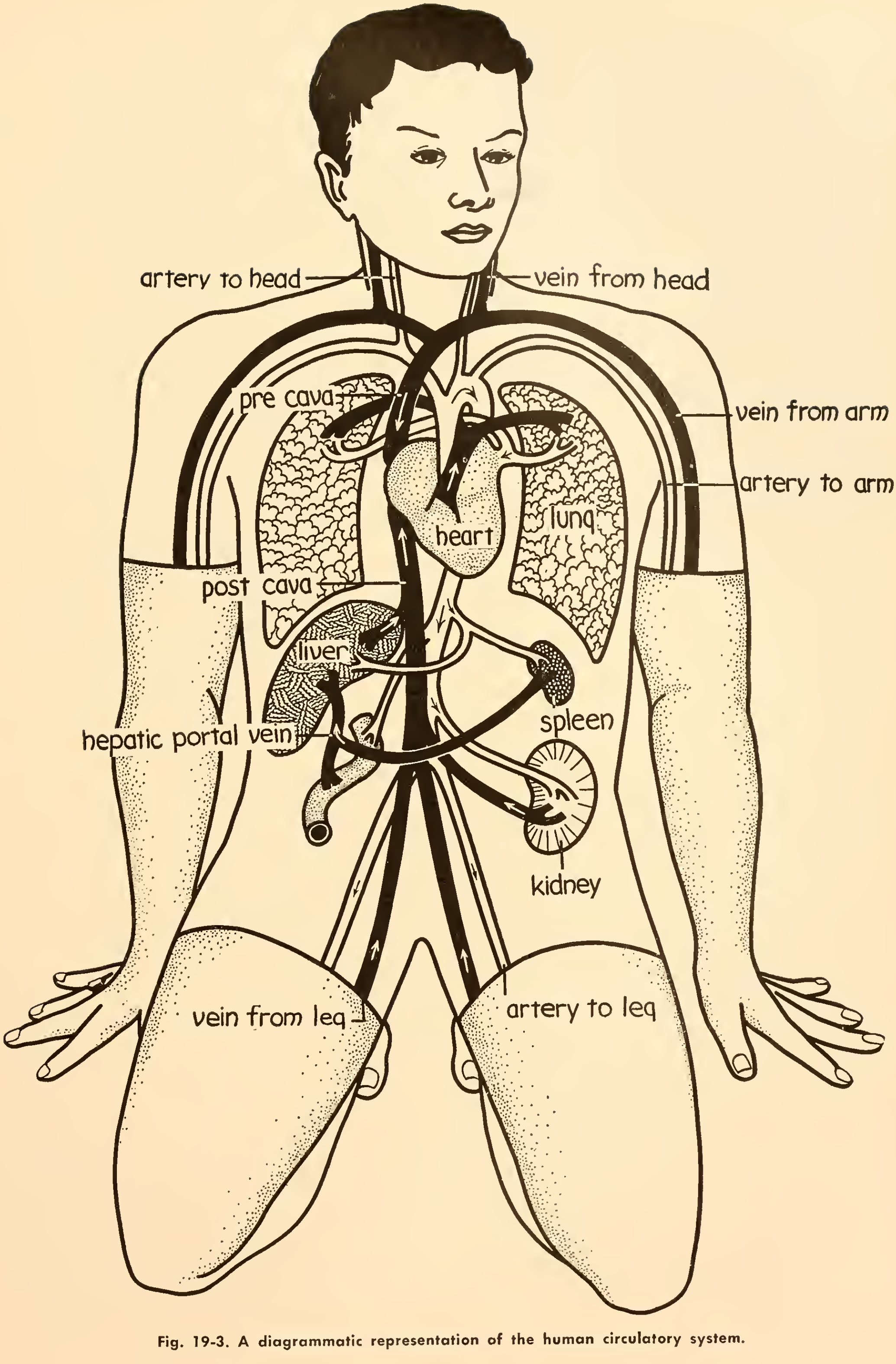


Fig. 19-3. A diagrammatic representation of the human circulatory system.

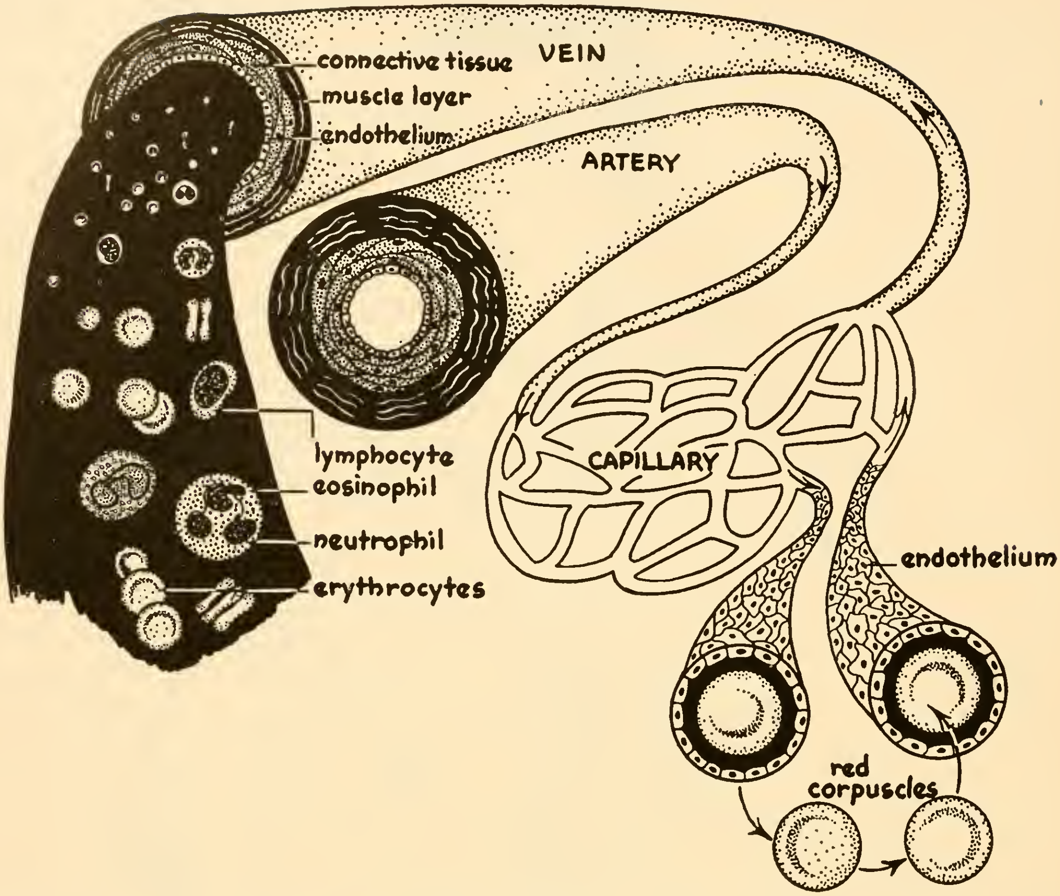


Fig. 19-4. Arteries and veins differ only in thickness of their walls, whereas capillaries are composed only of the layer of cells that lines the larger vessels. In this figure the arrows indicate the path of the blood. Some of the various cellular components of the blood are also shown.

a second auricle, together with a pulmonary circulation, appeared. This was only a partial solution, for the oxygenated and reduced blood became somewhat mixed. In a further step forward, a complete two-chambered heart appeared in the higher reptiles. This proved so satisfactory that it was retained in both mammals and birds. Once the two hearts were formed, the vertebrates were fully equipped for success on land and evolution was extremely rapid, as evidenced by the tremendous variety of land forms. Let us examine the circulatory system of man as an example of this system in land vertebrates.

THE MACHINERY OF HUMAN CIRCULATION

The over-all design of circulation in man (Fig. 19-3) is similar to that of air-breathing vertebrates in general, differing only in such minor details as the number and location of vessels.

The functional part of circulation is the circulating fluid, **blood,** the medium that carries food and oxygen to the cells. The elaborate mechanism of the heart, arteries, veins, and capillaries is merely a mechanical device to circulate the blood so that its contents may reach every cell in the body.

Before studying the blood itself, let us examine the machinery of circulation.

THE VESSELS

These consist of a closed system of tubes, large and small, which convey the blood continuously within a circuit. The large vessels carrying blood away from the heart are known as **arteries**; the large vessels bringing blood back to the heart, known as **veins**. The tiny intermediate vessels are **capillaries**. The last are the most important, since it is through their walls that the real work of the circulatory system goes on, and for this reason they will be considered first.

The capillaries

These tubules, often so small that blood cells pass through single file, have walls composed of a single layer of cells. These same endothelial cells continue as the lining of the larger vessels (Fig. 19-4). The capillaries form a network throughout all the tissues of the body, so vast and complicated that a pin prick anywhere usually punctures one, causing blood to ooze out. Because of their thin walls, dissolved substances in the blood can readily pass into the tissues, and conversely, waste substances in the tissues can readily diffuse into the blood and be carried away. In an active animal such as man it is essential that this exchange be a rapid one. Even in the relatively sluggish frog, whose capillaries can be easily observed in the web of its foot, blood cells race through the capillaries in a fraction of a second and yet this is sufficient time for the important processes of exchange to occur.

The arteries and veins

On either end of the capillaries are larger tubules, **venules** (little veins) at the end toward the heart and **arterioles** (little arteries) at the end coming from the heart. These venules and arterioles become larger and larger as the heart is approached, where they are designated as veins and arteries. There is no structural difference between the two except that the walls of the arteries are thicker and stronger than those of the veins (Fig. 19-5). Both are composed of three layers of tissue. The inner **endothelium** layer is the same tissue that makes up the whole of the capillary wall. As a matter of fact, it lines the entire circulatory system. The outside layer of both arteries and veins is made up of a tough **connective tissue** so that it readily stretches to permit an increase in diameter, but does not easily rend. Between the two is a **smooth muscle layer** which regulates the diameter of the blood vessel, thereby controlling the amount of blood flowing through it. These muscles (**vasoconstrictors**) are under the influence of the autonomic nervous system and the state of their contraction depends on the need of various tissues of the body for food and oxygen. For instance, following a meal the muscles in the walls of the blood vessels going to and from the viscera relax, allowing more blood to flow to and from these organs. On the other hand, during violent exercise they contract in this region but relax in the muscles and respiratory system. By such regulation the various parts of the body are supplied with the proper amount of blood at all times.

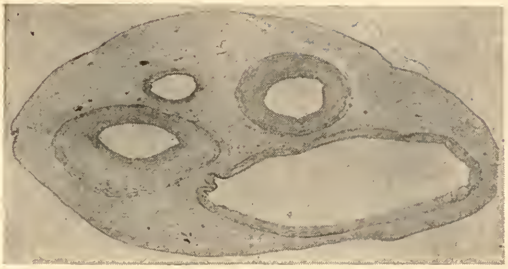


Fig. 19-5. Cross-section of the human umbilical cord to show the construction of an artery and vein. The largest opening is a vein. Note the thin wall as compared to that of the two smaller arteries just above it. Veins and arteries are similar in structure except that the muscle layer in the latter is heavier.

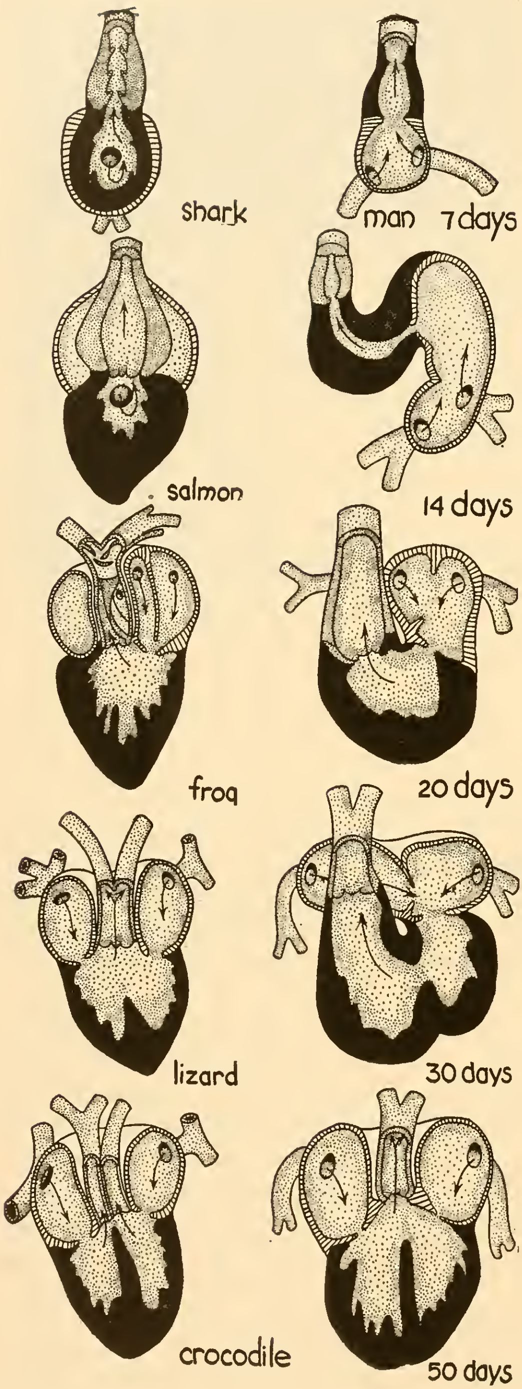


Fig. 19-6. The phylogenetic development of the vertebrate heart from the shark through the reptile is shown on the left. This is recapitulated in the embryology of the human heart shown on the right.

The walls of the arteries need to be stronger than those of the veins because the blood is under considerable pressure when it leaves the heart and this pressure alternately rises and falls with each contraction of the ventricles. Since the capillaries need a continuous flow there must be some means of absorbing these high and low pressure levels, and this is taken care of by the elastic arterial walls. When the pressure rises suddenly, as it normally does, the walls stretch, absorbing the pressure. Between beats, then, the resilience of the walls forces the blood through the capillaries at an even flow. If this were not true the blood would gush through at high pressure and stop altogether between beats when the heart is at rest. Indeed, something approximating this happens in advancing years when the walls of the vessels grow hard due in part to deposition of salts. When this occurs, the pressure of the blood rises so high that the brittle vessels are apt to burst and cause damage by cutting off the blood source to vital organs.

THE HEART

The pumping mechanism of animals has had a long history of evolution from the simple pulsating tubes of the annelid to the highly efficient organ of the vertebrate. Much of this history has been portrayed in earlier chapters, and with respect to vertebrates can be summed up briefly by comparing the hearts of several adult forms (Fig. 19-6). The history is correlated with the transition from aquatic to land life. The primitive heart of the shark, as well as the more elaborate one of the salmon, are two-chambered pumps that function satisfactorily where gills are the breathing organs. With the advent of lungs, a second heart was formed over millions of years of evolution. Today we see how this probably happened in the adult forms of the frog, lizard, and crocodile. The story is also nicely re-

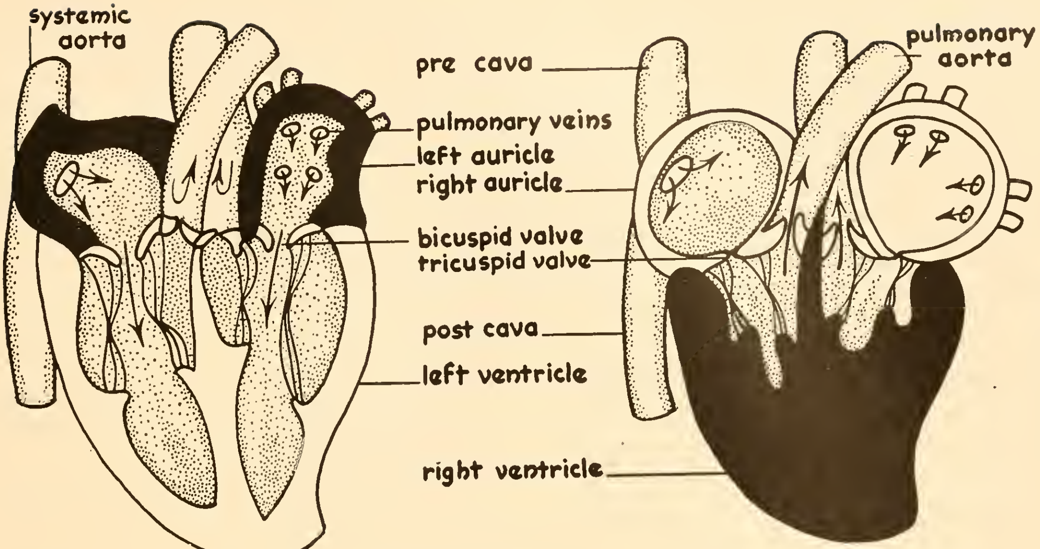


Fig. 19-7. The human heart is shown here cut so that the chambers and valves can be seen. The contracting portions are indicated in solid black, whereas the parts that are relaxed are left white. The two figures demonstrate the way the parts operate during the cardiac cycle.

capitulated in the developing mammalian embryo (Fig. 19-6).

The adult human heart is a muscular organ composed of four principal chambers, two **auricles** and two **ventricles**, and a system of valves beautifully designed to keep the blood going in one direction (Fig. 19-7). The auricles are thin-walled, sac-like chambers whose principal function is to collect sufficient blood from the great veins to fill the ventricles quickly the moment they are empty. The ventricles, on the other hand, are thick-walled chambers whose sole function is to keep the blood forever on the move throughout the vast network of vessels. The left ventricle is thicker and larger than the right because its task is a bigger one, namely, forcing the blood throughout the body, whereas the right heart merely keeps the blood moving through the lungs. The two hearts, however, are intimately associated and beat simultaneously even though their circuits are distinct and separate. The left auricle and ventricle are separated by a pair of flaps, called the **bicuspid** (mitral) **valve;** similarly, the right auricle and ventricle are separated by three flaps, the **tricuspid valve.** These flaps of tough tissue are held rigidly in place when under pressure by tiny cords that extend to the inner muscular walls of the ventricles.

The ventricles open into large arteries, the left into the **systemic aorta** and the right into the **pulmonary artery.** Very near the openings are half-moon-shaped valves, the **semilunar valves,** which prevent the blood from returning to the ventricles once it is forced out. Each valve is composed of three thin-walled cups that fit very tightly together when under pressure. These, as well as the other valves, are arranged so that the blood can pass only in one direction. This, then, is the pump that keeps the blood circulating continuously throughout life.

The blood path through the heart

Blood passes from the pre- and postcavas into the right auricle, the walls of which then contract (**systole**), forcing the blood through the mitral valve into the right ventricle (Fig. 19-7). Actually, when the ventricle empties and begins to relax (**diastole**), the blood requires very little force to flow into the ventricle, hence the muscular walls of the auricles are thin. The ventricle fills completely, then suddenly contracts with sufficient force to exceed the pressure in the pulmonary artery, thus opening the semilunar valves which allow the blood to pass to the lung capillaries. The blood then returns to the left auricle by way of the four pulmonary veins. The path taken by blood passing through the left heart is similar to that of the right, although the force with which it leaves is greater because the blood must go throughout the body as a result of the impetus received from the muscle of the left ventricle. It passes over the semilunar valves of the dorsal aorta and out to the capillaries of the body, eventually returning to the right auricle again through the vena cavas. This complete circuit is sometimes called the **cardiac cycle.**

How the heart is nourished

It is obvious that such an active muscle as the heart must receive an ample supply of oxygen and food continuously. Even though tons of blood flow through the heart chambers, none of it reaches the heart muscle because there are no direct connections to the muscle from the chambers. The heart has a system of blood vessels of its own, however, called the **coronary circulation.** This rather strange name was given to it because the vessels reminded early anatomists of a crown, since they encircle the top part of the heart. The two **coronary arteries** leave the dorsal aorta just above the semilunar valves (Fig. 19-8) and pass throughout the heart muscle, ultimately becoming capillaries. Blood returns through a system of veins (**coronary veins**) which coalesce and eventually empty into the right auricle via the **coronary sinus.** Approximately one-fourth of the total blood pumped out by the left ventricle passes through the coronary circulation. This is an extremely important system because the slightest impairment, such as a tiny clot of blood lodging in it, profoundly affects heart action. This is one form of heart attack. Sudden death results when the stoppage of blood is sufficient to hinder seriously the contraction of the muscle.

Listening to the heart during health and illness led more alert physicians many centuries ago to recognize that certain sounds could be associated with heart malfunctioning. The characteristic "lubb-dup," as heard with the stethoscope, is caused by the closing of the various heart valves to prevent the blood from rushing back into the auricles from the ventricles and back into the ventricles from the great arteries. The low "lubb" sound is due to the closing of the mitral and tricuspid valves during the initial stages of ventricular systole, whereas the sharp "dup" which follows the first sound very closely is caused by the sudden closing of the semilunar valves in the arteries. There is a brief pause during which time the heart rests and the auricles fill. Any abnormalities in the closing of these valves can be detected by various "murmuring" sounds that are easily recognized by the trained ear of the physician. During some kinds of infectious diseases, and perhaps allergies, the edges of the valves become inflamed and injured; upon healing they frequently do not fit as well as they once did, resulting in the so-called "heart murmur." Such an injured heart can, however, increase its size and output so that even with faulty valves it may still be adequate. Such a heart is often spoken of as a "compensated heart" and within limits may function normally for many years.

The work of the heart is almost unbelievable when it is compared to that accomplished by other muscles of the body. Starting long before birth, indeed, when the embryo is no more than 25 days old, it continues its ceaseless contractions until old age; during all this time it does not falter, and its only rest comes between systoles. Beating at 70 times per minute, over 100,000 per day, and nearly 40,000,000 per year,

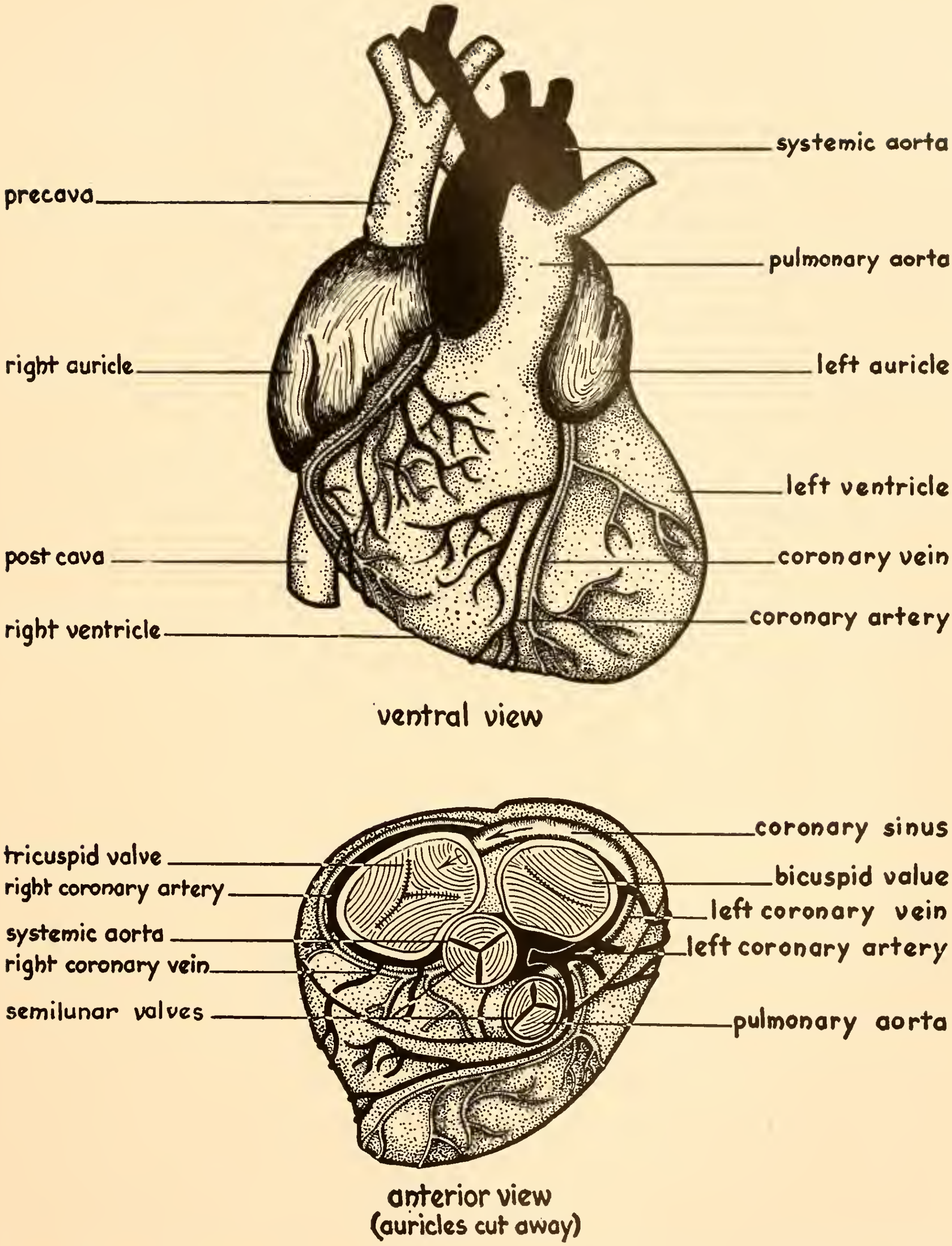


Fig. 19-8. The heart is here shown in ventral and anterior view with the auricles cut away in order to illustrate the nature of the coronary circulation.

the heart does enough work in one year's time, as computed by the physicist, to lift its owner nearly 100 miles above the surface of the earth. When working at full

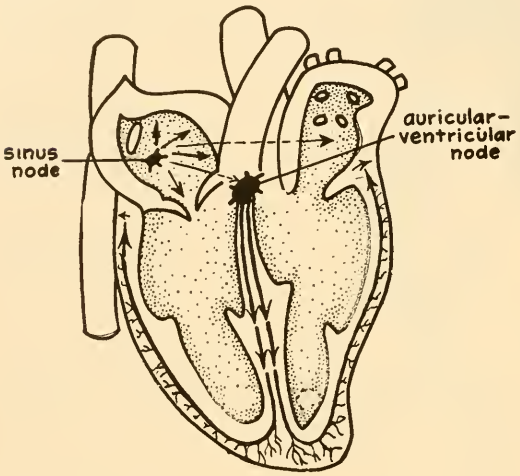


Fig. 19-9. The sequence of the contraction of the various chambers of the heart is under the influence of the sinus node and the auricular-ventricular node. The beat is initiated in the sinus node, from which it travels over the heart as indicated by the arrows.

capacity, a normal heart can deliver an amount of blood equivalent to that coming from an ordinary household faucet turned wide open! It is truly a remarkable organ.

Control of the heart

The heart muscle will function in an apparently normal fashion when removed from the body that houses it. Histologically, cardiac muscle is unlike either smooth or striated muscle (Fig. 4-5). The nuclei lie deeply embedded in the muscle fiber like smooth muscle, but cross-striations are present, much like voluntary muscle. Most important, however, all of the fibers are directly connected to other fibers so that the entire mass of muscle fibers is continuous, forming a syncytium.

Skeletal and smooth muscles contract only on stimulation by nervous impulses or endocrine secretion. The vertebrate heart, on the other hand, may be removed from the body and if placed in the proper nutrient fluid at the proper temperature will continue beating for hours. Moreover, the rate of pulsation may be quite normal even though it is isolated from any nervous or hormonal control. This might seem to indicate that the heart is not influenced by either of these types of control but a check of one's own pulse under varying conditions of excitation or physical exertion quickly shows that such is not the case. This means only that the **intrinsic** nature of the heart muscle is to contract in a rhythmic manner. The rate of this beat, however, may be attended by outside factors. This can be demonstrated in an excised heart. When placed in a cold fluid it slows down, whereas in a warmer one it speeds up. Therefore, temperature affects its rate. Certain drugs do the same.

The manner in which the heart beats has been determined rather precisely in studies of the excised heart. It has been shown, for example, that if the heart is subjected to reduced temperatures in various parts, its rate of beat is changed only when a specific region is cooled. This region lies near the base of the great veins where they enter the right auricle (Fig. 19-9). There is a discrete bundle of specialized tissue lying here called the **sinus node** or "pacemaker" which is responsible. This is clearly shown by the following experiment. If an excised heart is clamped in the region between the auricles and the ventricles, the former continue their rhythmic beating whereas the latter remain quiet. This demonstrates that impulses pass from the pacemaker through the auricles to the ventricles. We have learned further that in passing from auricles to ventricles the impulses travel over a bridge called the **auricular-ventricular-node** (Fig. 19-9). In the contraction of the heart as a whole, the auricles beat first, the ventricles second. Nerve pathways in the heart have been traced from the auricular-ventricular-node down through the septum between the ventricles and anteriorly through the muscle, and each beat is syn-

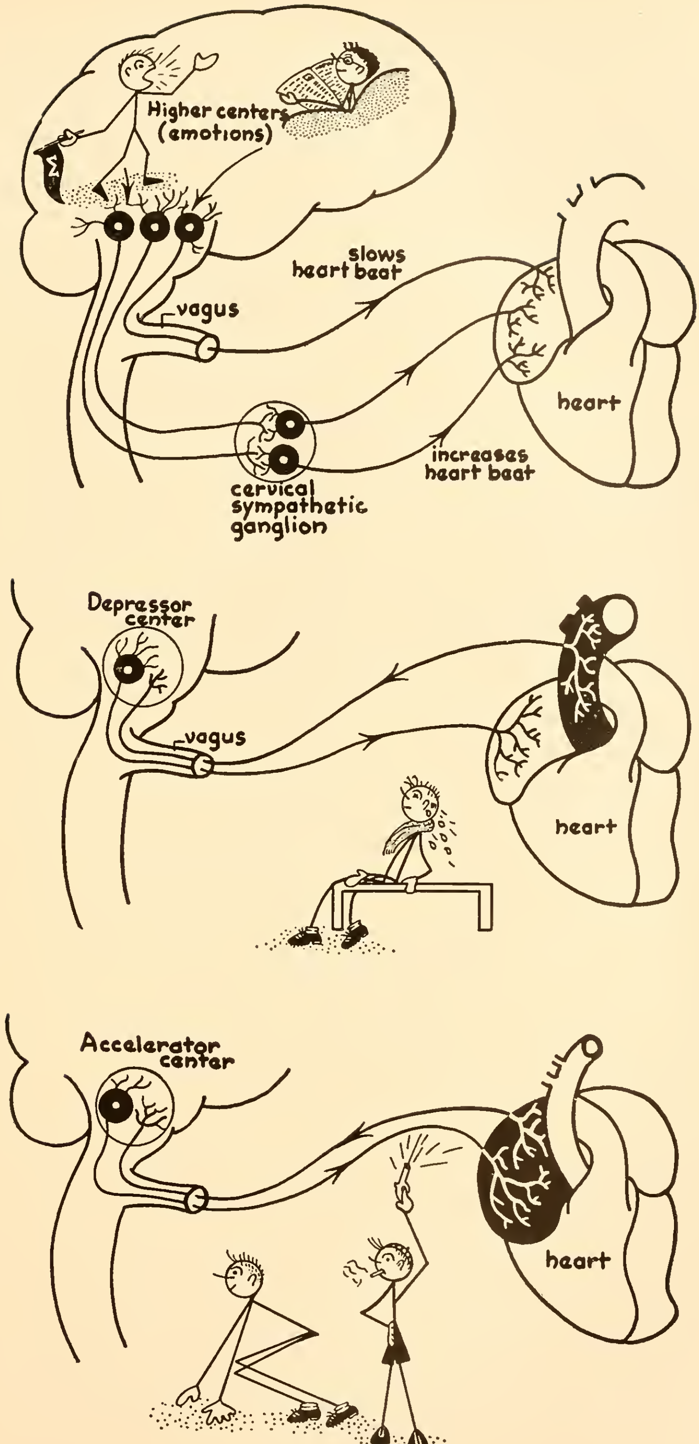


Fig. 19-10. The rate of heart beat is under the control of the cardiac center in the medulla. The upper figure demonstrates how emotions control the beat. The middle and lower figures show how the rate is regulated according to physical needs.

chronized with an impulse that follows this pathway.

Even though the heart will beat autonomously in the intact animal, its beat is carefully regulated by two sets of motor nerves which carry impulses directly to the sinus nod (Fig. 19-10). Branches from the vagus (cranial-sacral) may inhibit the beat, whereas many branches from the thoracolumbar autonomic system in the cervical region may accelerate it. These are influenced by emotions, a fact familiar to all.

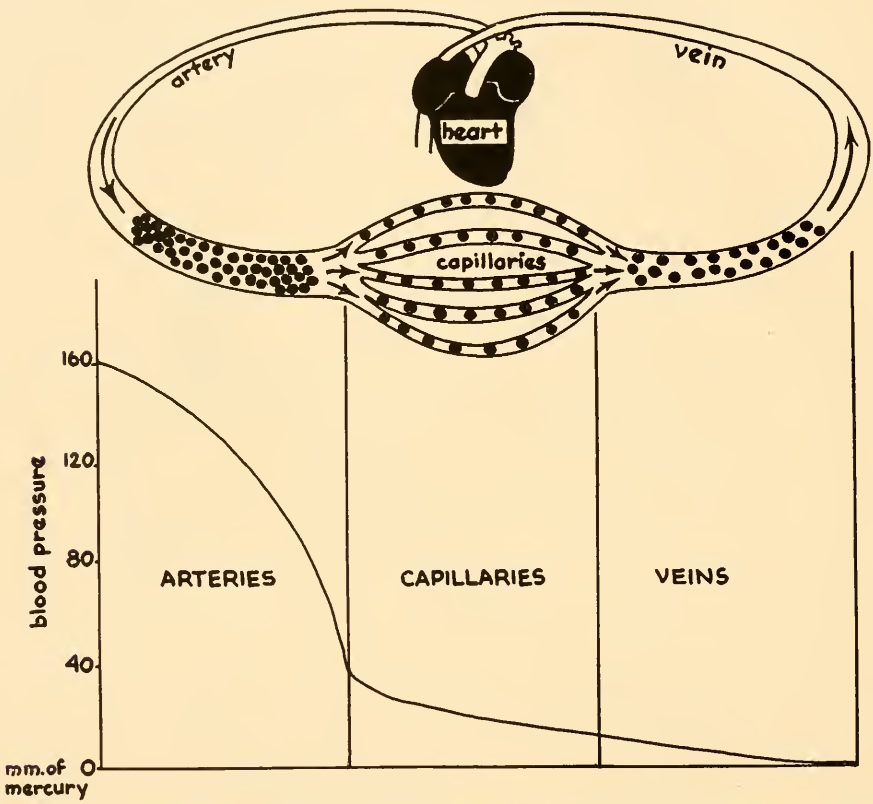


Fig. 19-11. The blood pressure falls rapidly in the arteries but declines at a much more gradual rate in the capillaries and veins. It is highest when leaving the heart and lowest in the large veins that empty into the heart, as indicated by this sketch.

Additional sources of regulation come from two groups of sensory endings close to or in the heart itself. One group originates in the aortic arch and terminates in the **cardiac center** (depressor center) in the **medulla**, and these nerves are called **depressors** because they slow down the heart beat by stimulating the vagus when the pressure is unnecessarily high in the aorta. Such action occurs following exercise when the muscles no longer need a large volume of blood. A second group arises in the right auricle and terminates in the **cardiac center** (accelerator center). When the large skeletal muscles are in vigorous action, blood flows into the right auricle in greater amounts than normally. As a result the walls are stretched, stimulating the accelerator nerves to make the heart beat faster with the result that the muscles receive the additional blood they need. Thus, by the combined action of these sets of governors, the heart is able to maintain a rate that supplies all parts of the body with an adequate amount of blood under highly variable circumstances.

It was brought out in an earlier chapter that when a muscle contracts, a minute electrical impulse is set up which can be detected with delicate instruments. This fact has been employed in diagnosing heart difficulties. The instrument employed is the **electrocardiograph.** It records slight electrical changes that occur when the various parts of the heart muscle contract. A normal heart produces a characteristic series of peaks and valleys. Any deviation in this pattern indicates abnormality, the exact nature of which can be discerned rather accurately.

BLOOD PRESSURE

If a vein is severed the blood oozes out in a gentle flow, whereas if an artery is cut it shoots out in spurts which are synchronized with ventricular systoles. It is obvious that the blood is being forced along under pressure, and that the arterial pressure is much higher than the venous pressure. The highest pressure is maintained in the aorta. As the blood passes through the thousands of miles of capillaries, the pressure gradually falls, owing primarily to the friction of the walls of these tiny tubes (Fig. 19-11). By the time it reaches the veins, much of the pressure has been spent and, in fact, when it reaches the large veins entering the right auricle it has a slight negative pressure. In other words, the blood is "sucked" into the heart.

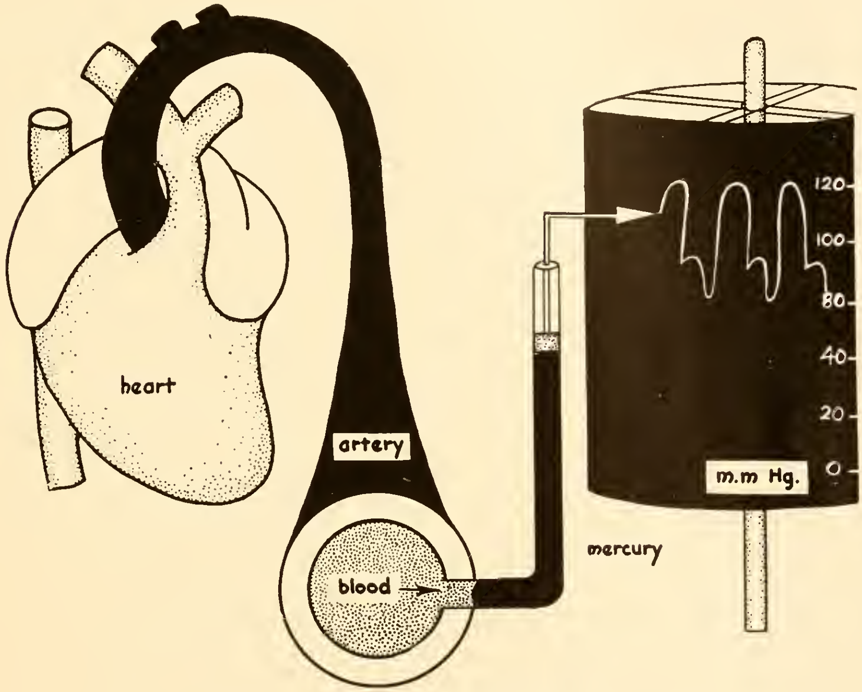


Fig. 19-12. Blood pressure readings can be obtained in this manner. With such a device much information can be gained about the circulatory system.

The pressure in the arteries rises and falls with each heart beat. This can be easily observed by "taking the pulse," which can be felt at the wrist or any other artery that comes near the surface. The artery swells and collapses in a rhythmic manner. This interested an eighteenth-century English clergyman, Stephan Hales, to the point of experimentation. He placed a crude canula (a small brass tube), connected to a long glass tube, into the carotid artery of a horse and noted that the blood rose to a distance of over 9 feet. He also observed that the blood rose and fell gently in the tube with each heart beat. He therefore concluded that the pressure in the artery was sufficient to maintain a column of blood 9 feet high, and that the variation in height was due to the contracting ventricle.

Blood pressure is measured even today in a similar manner, although with more refined instruments. For experimental purposes, where blood pressure recordings are desired over some period of time, the blood from an artery is allowed to flow into a tube fitted to a recording device (Fig. 19-12). Continuous recordings can be made in this manner. This would be a rather formidable way to observe the blood pressure of a patient in the physician's office and there would be few who would submit to such treatment. The years following Hales' discovery led to much experimentation, and before the turn of the nineteenth century, other methods had been devised to obtain blood pressure without entering an artery.

The most successful method is universally employed today. It consists simply of placing a rubber bag that can be inflated around the upper arm where it will squeeze the arm artery until no more blood can be forced through it. The bag is attached to a mercury **manometer,** an instrument that records the pressure in millimeters of mercury. Mercury is used because it is a heavy fluid and changes in pressure can be recorded with a small instrument. Water could be used but the instrument would be very inconvenient because the tube would have to be several feet long. Once the blood is prevented from going through the arm artery, the pressure in the cuff is slowly released, barely allowing blood to pass through at the highest pressure, called **systolic pressure** because it is the point of greatest force due to ventricular systole. This can be heard through a stethoscope placed over the artery at the elbow. As the pressure is released still further, more and more blood flows through the artery and the sound becomes louder and louder, suddenly falling off sharply. The pressure reading just before this point is reached is referred to as the **diastolic pressure,** because the blood is moving during the entire cardiac cycle and it therefore records the pressure which is maintained in the arteries when the semilunar valves are closed. In other words, it is the lowest pressure in the arteries or when the heart is at rest. A great deal of important information can be obtained by the physician about the condition of the arteries and heart by taking blood pressure readings, and they have become a routine part of medical examinations.

THE BLOOD

It is interesting to recall that not too long ago it was considered sound medical practice to withdraw blood (blood-letting) from the veins during disease, while today such a procedure would be considered "fatal," if not for the patient, certainly for the doctor who attended him! Medical practice today is to conserve the patients' blood, or even add to it by transfusion in certain types of illness and in cases of serious injury. Many thousands of lives were saved during the recent war because stored blood could be given to injured men.

In spite of earlier blood-letting customs, blood has been held in high regard from ancient times and today still plays a part in rituals of many primitive tribes. Such terms as "blood lines" in breeds of domestic animals or "good or bad blood" or "blue blood" denote the hereditary importance that has been attached to blood. Despite such common beliefs, it is now known definitely that there is no difference of this sort either between the bloods of individuals or of various races of man alive today. Any efforts to perpetuate this fallacy are based on emotion rather than fact.

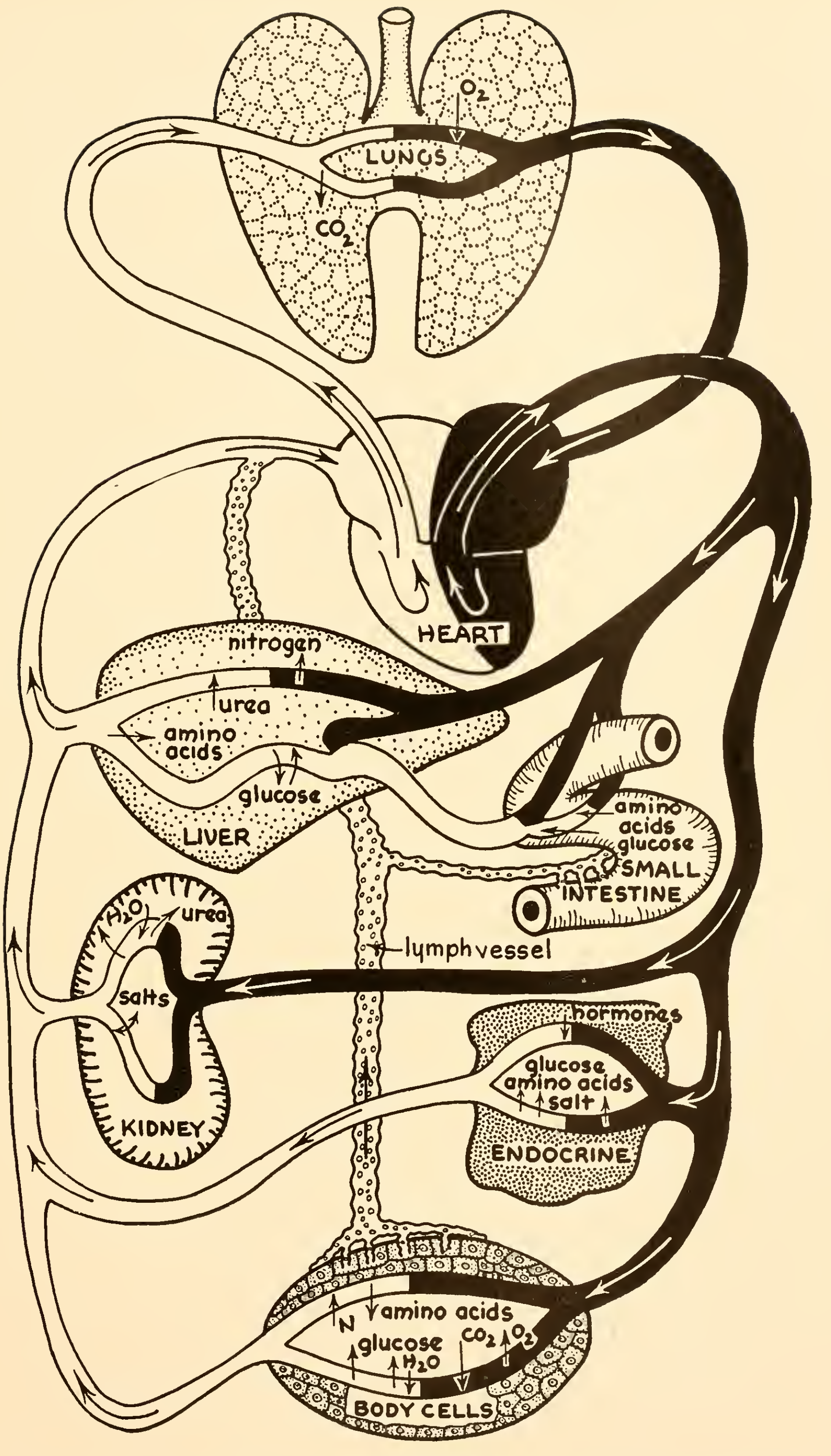


Fig. 19-13. The blood performs many functions as it flows through the body, some of which are portrayed in this sketch. Note what happens to the blood as it enters and leaves each organ.

The more we learn about blood, the greater its importance becomes. Let us review its function in nutrition and metabolism by following it on a routine trip through the body (Fig. 19-13). Blood leaving the left ventricle goes to the liver, digestive tract, kidney, and body tissues. The blood coming from the liver contains more urea, that from the kidney less urea, that from the intestines more amino acids and glucose, and that from the general body tissues less food and more waste products. Moreover, all of the blood leaving these organs is low in O_2, which must be replenished in the lungs at the same time that CO_2 is lost. The urea which is formed in the liver must make a complete circuit through the lungs before it reaches the kidneys, where it is extracted from the blood. Fats are absorbed into the lymphatic system which eventually joins the blood system, making possible the distribution of this food. As the blood passes through the endocrine glands, food products are absorbed and converted into hormones which are then secreted into the blood. The performance of all of these functions and many more makes blood truly a most remarkable fluid.

Closer examination shows that blood is a tissue like muscle, nerve, or bone, even though it exists in a fluid state. The fluid portion of the blood is called the **plasma.** Floating in the plasma are certain **formed elements** consisting of **erythrocytes** (red blood cells), **leucocytes** (white blood cells) and **platelets.** In addition, the plasma carries a load of a large variety of substances, some of which still are not well understood. Like all tissues, blood is mostly water, about 80 per cent; the 20 per cent of solids consists of approximately 18 per cent protein and 2 per cent other chemical substances. When the formed elements are separated from the plasma, they are found to make up nearly one-half of the volume (45 per cent). The total amount of blood in a normal person is 5-6 liters, or approximately 8-10 per cent of his body weight. One can lose somewhat less than half of this amount and survive, but a special mechanism for **coagulation** or **clotting** is present to prevent blood loss.

Blood clotting

The survival value of any mechanism that prevents the loss of blood is obvious. Blood coagulates even more rapidly in the earthworm, for example, than in man. The blob of jelly-like substance on the windshield of a speeding car demonstrates the rapidity with which the insect's blood coagulates. Animals have very short clotting times when compared to the three minutes required for man's blood to clot, for the speed with which the clot forms often spells the difference between life and death.

The exact series of chemical reactions that takes place in forming a blood clot are not completely understood, although a great deal of work has been done on the problem. The clot is made up of a mass of threads of a protein called **fibrin,** which enmeshes red blood cells so that a semi-solid plug is formed. It starts as a small clot but grows rapidly until it is of sufficient size to fill the opening in the vessel. If the vessel is too large or the pressure too great from behind, as in the large arteries, the clot fails to stop the blood flow and death of the animal results. Ragged injuries produce better and faster-forming clots than do clean cuts, the explanation of which will follow shortly.

There are several observations on blood that need to be known before the clotting mechanism can be understood. If blood is collected in a vessel containing sodium citrate or oxalate, it fails to clot; and if it is allowed to flow into a paraffin-lined vessel, it clots only very slowly. In the first instance, the chemicals must have blocked the clotting action of the blood and in the second, the nature of the paraffin surface must have been involved. It is now known that the sodium citrate or oxalate combines with the calcium in the blood, removing it from solution. Therefore, calcium must be essential for clotting. The smooth paraffin is similar to the lining of the blood vessels; therefore, rough surfaces such as often formed in ragged injuries must aid in the formation of clots.

If freshly drawn blood is stirred vigorously with stiff bristles, fibrin shortly begins to collect on the bristles, and if the stirring continues all of the fibrin can thus be removed, leaving what appears to be perfectly normal blood except for its failure to clot. This is called **defibrinated** blood. There must have been a precursor protein, much like fibrin, that was in solution in the blood but which became insoluble with the stirring. This is known as **fibrinogen.** The problem is: Why did fibrinogen become fibrin? What initiated the chain reaction?

Something must happen when the blood is taken out of the vessels, because clots do not normally form within the circulatory system itself. Careful chemical analysis has revealed another substance, **thrombin,** in the plasma which is responsible for the conversion of fibrinogen to fibrin. Obviously, thrombin cannot occur freely in the blood stream, or clots would form within the vessels. This happens only rarely and even then only under pathological conditions. Again experimentation has revealed a precursor, **prothrombin,** that is normally present in the blood. The next problem is: What starts prothrombin to form thrombin?

Another careful search has demonstrated that the platelets and probably other tissues of the body contain a substance or group of substances, called **thromboplastin,** which are essential in starting this long chain of reactions. It was stated earlier that calcium was also essential, because if it is removed from the blood no clot forms. Just what the relationship is between these substances is not clear at present. Probably when a hemorrhage occurs, the broken cells in the vicinity of the injury, together with the disintegrated platelets, release thromboplastin. Thromboplastin, reacting with calcium in the blood in some unknown manner, produces prothrombin which converts to thrombin and this, in turn, changes fibrinogen to fibrin. Summarized:

Hemorrhage $\rightarrow$ thromboplastin
thromboplastin + calcium + prothrombin $\rightarrow$ thrombin
thrombin + fibrinogen $\rightarrow$ fibrin
fibrin + red blood cells $\rightarrow$ clot

Earlier in the chapter on nutrition there was mention made that vitamin K had something to do with blood clotting. If it is formed in too low levels in the digestive tract the clotting time increases dangerously, so much so that surgery is inadvisable until large quantities of this vitamin are given to restore the normal clotting time. The above discussion does not include anything concerning this substance. It is now thought that vitamin K is associated with prothrombin formation, and hence its effect on clotting time.

A blood-clotting defect that has been known for a long time and has been the concern of certain royal families because of its sex-linked inheritance is **hemophilia** (see p. 602). The "blood" of the once royal house of Spain was "tainted" so that this defect appeared frequently in the sons, being passed to them by their mothers who did not suffer from the disease themselves. The slightest wound could be fatal in such afflicted people because the blood clotted very slowly. Analysis of their blood determined that it was normal in all respects except that the platelets did not disintegrate as readily as in normal blood. Just why they are less fragile or what to do about it still remains an unsolved mystery.

Red blood corpuscles

Red blood corpuscles are the most numerous and most conspicuous of the formed elements of the blood (Fig. 19-4). A blood smear will reveal them as tiny, circular, biconcave disks without nuclei. All vertebrates except mammals possess nucleated erythrocytes; just why nuclei are absent in the latter group is difficult to understand. However, it must be admitted that since the red blood cell lives only about 120 days and never reproduces, it would seem to be a waste of effort to utilize the space in the cell for a nucleus when it could be occupied more profitably by **hemoglobin**, the oxygen-carrying pigment. The erythrocytes possess nuclei when they first form in the red marrow of the bones, but lose them just before entering the blood stream. The cells are a light yellow in color under the microscope, although in combined numbers they render the blood a typically red color. Normally there are from 4,500,000 (women) to 5,000,000 (male) cells per cubic millimeter of blood. This number varies with disease and nutritional deficiencies. A drop either in the number of red cells or their hemoglobin content results in **anemia**, which can be serious if prolonged because the blood is unable to supply the cells with the proper amount of oxygen.

The red cells are formed and destroyed at a tremendous rate, about two and one-half million per second. Destruction occurs in the spleen and other specialized tissues. In a normal person the cells must be produced at the same rate as they are destroyed. Since one of the chief elements of hemoglobin is iron, there must be a continual supply in the diet. The amount is small (0.01 gm. per day) and most diets contain an ample amount. However, it is now known that copper is also essential for proper hemoglobin formation. The need for copper lies in the production of an enzyme necessary for hemoglobin formation. Some serious deficiencies in the bone marrow cause a drop in hemoglobin production, resulting in fatal anemias. Recently these have been arrested by administering

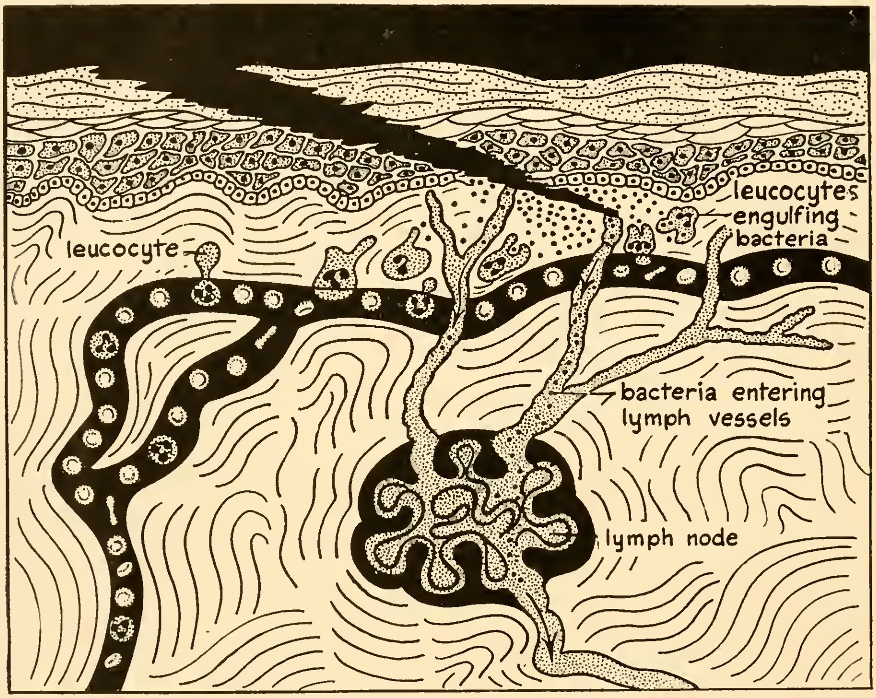


Fig. 19-14. With a break in the skin, the leucocytes (certain kinds) move out of the blood vessels into the injured area where they engulf and destroy any invading bacteria. Bacteria that are not eliminated by the leucocytes may find their way to the lymph nodes where they are usually destroyed. If, however, they get past these barriers they are free to invade the entire circulatory system and the entire organism.

very small doses of two of the B-vitamins, **folic** acid and vitamin B_{12} (p. 472). These vitamins are extracted from liver, which was a logical place to find them, since large doses of liver extract were used for years to lessen the symptoms of this particular disease.

The oxygen and CO_2 carrying capacity of erythrocytes has been discussed earlier (p. 487).

White blood cells

White blood cells are called **leucocytes** because they are colorless. They are not so numerous as the red corpuscles, and there are several different kinds, all with nuclei (Fig. 19-4). They can be distinguished by the way they take certain stains, and when counted they serve as an excellent criterion for determining certain kinds of diseases. They usually increase rapidly in number (normal count is about 7000-9000 per cubic millimeter) during an infection, because some of them (neutrophils and monocytes) act as scavengers and attack the bacteria by engulfing and digesting them (Fig. 19-14). Such a process is termed **phagocytosis.**

White blood cells have the ability to move like an amoeba, and in a localized infection they migrate between the cells of the capillary walls out into the infected region where they do their work. Pus is primarily leucocytes. They probably also aid in healing by transforming into other types of cells in order to repair damaged tissue. Other functions have been assigned to them, but considerable information is still needed to understand their complete rôle in the body.

The plasma

The fluid portion of the blood, the **plasma,** has many and diverse functions besides that of carrying prothrombin and fibrinogen, already referred to in blood clotting. It may be recalled that it carries the food essentials—amino acids and sugars—as well as the wastes, urea and carbon dioxide. Such ions as Na, K, Ca, Cl, and several others are also present in plasma, and all perform specific functions in maintaining a stable internal environment for the organism.

The plasma also transports a very interesting and important group of substances called **antibodies.** Their presence was discovered many years ago, in Pasteur's day, and their significance has become more and more important, although as far as their exact nature is concerned we know little more today than was known when they were first discovered. It is best to describe an actual experiment in order to understand their production and what they do, even though how they are produced and how they work is unknown.

Antibody production

It was learned in the chapter on digestion that proteins must be degraded to amino acids before they can pass into the blood stream. Any more complex compound of this sort initiates deleterious reactions. For example, if rattlesnake venom is injected into the blood, serious complications follow; hence the value of venom as a defensive and offensive mechanism. If, on the other hand, a very tiny amount of the venom is injected into a large animal, as a horse, the reaction is not severe, and if the injections are gradually increased at short intervals the horse will eventually tolerate a tremendous dose; enough that, had it been injected in one initial dose, it would easily have killed the animal. Just what has taken place to protect the animal from this poison?

The snake venom is a **foreign protein** and, like any foreign protein, initiates a reaction in the body of the horse. The reaction produces a substance that can combine with the snake venom and neutralize its effect. This substance is called an **antibody** and the snake venom is the **antigen.** Any foreign protein can act as an antigen. In fact, this is the only way we have of separating and classifying specific proteins, for it is more delicate than any chemical tests known. Proteins are so complex that the structural formula has never been written for one of them. There are probably millions of them, and each animal possesses its own specific proteins for which there is no chemical means of separation. Using an animal for a test tube, it is possible to determine by experimentation the many different kinds in a very precise manner, even to determining from what animal a bit of blood or tissue originated. This has many practical applications, such as identifying whether or not a specimen of blood is from man or a lower animal. This is done by withdrawing the blood from an animal that has previously been injected with a foreign protein, for example, egg albumin, and then separating out the cells by whirling the blood in a centrifuge (an instrument for increasing gravity). If some of the original albumin is then added to this clear serum, a white precipitate will form. This reaction will occur for only one protein and no others; it is, therefore, highly specific.

One interesting use of this reaction was employed by Nuthall of England years ago in the classification of animals. He built up antibodies in experimental animals against the blood of other animals. For example, he might inject the blood of the ape into a rabbit and after a time draw off a sample of the blood from the experimental animal, centrifuge out the cells, and to the clear serum add some of the serum (antigen) of a closely related animal, say a gibbon. He discovered that the closer the animals were related, according to the usual system of classification, the heavier was the precipitate that formed. In this case, the serum of the gibbon would give a rather heavy precipitate, whereas the serum from a pig would give much less, and that from a snake none at all. Interestingly enough, he was able to confirm the classification based on morphological structures.

The graded precipitate of the **precipitin reaction,** as this is called, is a distinct value not only in the relationships pointed out in the preceding paragraph but in determining the closeness of the chemical relationship of different proteins.

Undoubtedly antibodies are formed in tissues other than the blood, but just where is not known. They do appear, however, in the plasma, and since this is a readily available tissue, most of our knowledge of antibody formation has come from studies of the blood. It might be thought that antibody formation could occur in a test tube. What an excellent way to prepare it, if this were true! Unfortunately, it forms only in the living organism. Where it has practical significance, as in preventing certain diseases, it is produced in large animals such as the horse.

Blood types

From the foregoing discussion on the relatedness of animals, it might be expected that all animals of the same species have the same specific proteins. In general this is probably true. However, there are minute variations of which we have become aware primarily through our efforts to transfuse blood from one person to another. They have also been called to our attention in plastic surgery, where attempts are made to graft tissues from one person to replace the destroyed tissues of another, as in case of severe burns, for example. One wonders why the healthy, intact organs of people dying in accidents could not be saved and transplanted in the bodies of those who are dying because the same organs are no longer functioning properly as a result of some organic or infectious disease. So far we have been limited to blood and corneas of the eyes in this regard, primarily because of the specificity of proteins of individuals. In other words, the proteins of one person are slightly different from those of another, so that such transplants are incompatible and will not "take." However, even with blood some difficulties have been encountered.

Blood types M and N. By injecting the red blood corpuscles of a person into a rabbit, a specific antibody is built up in the rabbit which when mixed with more red cells of the same individual will cause them to agglutinate or stick together in clumps, a reaction that is easily visible under the microscope, or even by the naked eye for that matter. This is a clear-cut test, not greatly unlike the precipitin test, which can be used to determine whether or not all human blood is identical. This has been done in thousands of people and it is now known that blood is not all alike. In fact, the evidence today indicates that there are a great many different kinds of blood types. We shall consider only a few, at this moment, the M and N forms.

By testing thousands of human beings it has been discovered that there are two different kinds of proteins in the red blood cells that will cause antibody formation in rabbits, the M protein and the N protein. Every human being possesses either one or the other or both. Fortunately, these proteins do not produce their corresponding antibodies in the blood, which makes it unnecessary to determine which of these types a person has before a transfusion is permitted. However, this knowledge has had some value in determining questionable cases of parenthood. It so happens that the type of protein, M or N or both, is inherited in a definite Mendelian fashion.

The Rhesus factor. Recently another group of red cell proteins have been discovered, designated as the Rhesus or simply the Rh factor because it was first discovered in the Rhesus monkey. A survey of various populations showed that it occurs in about 85 per cent of the people. If a person possesses the protein he is said to be **Rh positive,** whereas if his red cells do not contain the factor he is **Rh negative.** Normally there is no anti-Rh in the serum, and of course no difficulty is encountered unless

Fig. 19-15. If Rh positive blood is transfused into an Rh negative person, anti-Rh is built up in the latter's blood. If, at some later time, another transfusion of Rh blood is given, complications may arise because the anti-Rh will bring about the clumping of red cells.

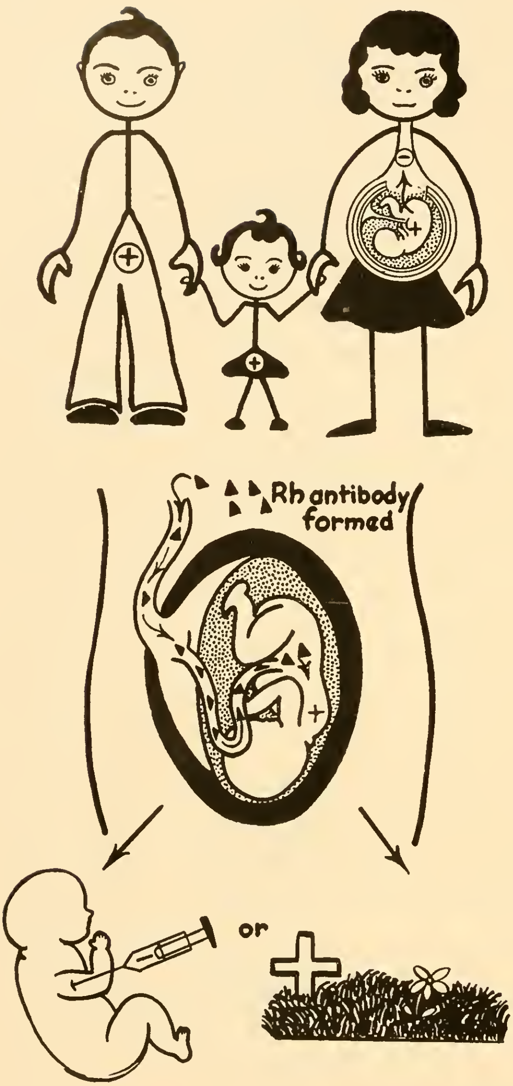


Fig. 19-16. Complications may arise when an Rh positive man marries an Rh negative woman, as indicated in these figures. The explanation is given in the text.

for some reason or other the blood of an Rh positive and an Rh negative are mixed. Under these conditions the protein containing the Rh factor acts like a foreign protein in the Rh negative person giving rise to the anti-Rh antibody. If, then, at some subsequent period such a person receives another transfusion of Rh positive blood, agglutination of the donor's red cells will occur because the anti-Rh is present in the recipient's serum (Fig. 19-15). Such clumped blood cells will produce serious reactions and even death. For this reason, before blood transfusions are given, the Rh condition of the blood is determined and a history of any previous transfusions is important.

The Rh factor also explains the cause of a disease of newly born infants called **erythroblastosis fetalis.** This disease is responsible for the death of a small percentage of babies shortly after birth, and was heretofore a complete mystery. It is now known that the Rh positive factor is inherited as a **dominant,** and the Rh negative factor as a **recessive.** This means that it will appear in either half or all of the offspring of an Rh positive father and an Rh negative mother. When the developing fetus of this combination inherits the Rh positive factor from its father it is possible that trouble will follow (Fig. 19-16). Normally the blood of the mother does not come into direct contact with the blood of the fetus, but occasionally a very small number of red cells apparently do get into the maternal circulation, perhaps by the accidental breaking of small capillaries in the placenta. Once Rh positive red cells get into the mother's circulation, Rh antibody is produced. Since the antibody is present in the serum, it can easily diffuse through into the fetal circulation, causing damage to the red cells of the developing fetus. Such a child, when born, will be highly deficient in red blood cells, which results in a severe jaundice, and unless immediate treatment is given will die. The child may be saved by numerous blood transfusions during the first few weeks of life.

The situation is not as serious as it might appear as attested by the small number of babies born with this disease. This is owing, perhaps, to the fact that not all cases of pregnancy result in a mixing of the fetal and maternal blood. Furthermore, not enough antibody is generally produced to cause trouble on the first pregnancy so the condition does not usually show up until the second and subsequent pregnancies. Since only 15 per cent of the population are Rh negative, and half of these are women, the chance combination of an Rh positive man with an Rh negative woman is not great. Although it is important to know the Rh condition of the mother before and during the pregnancy, it is not sufficiently important to cause alarm on the part of an Rh negative woman who is contemplating marriage to an Rh positive man.

It is important, however, to know the Rh factor condition of a young girl about to receive a transfusion. Suppose an Rh negative girl receives large amounts of Rh positive blood in a transfusion. She may develop such a high concentration of anti-Rh that it might be impossible for her to ever bear an Rh positive child. Furthermore, if at some subsequent time another transfusion were necessary and she were given Rh positive blood again, she would suffer a severe, perhaps even fatal, reaction. Concern for the type of transfusions used is not confined to the female alone. Rh negative males can also suffer severe reactions if transfused intermittently with Rh positive blood. As a result of this recent information, blood is routinely typed for the Rh factor.

Other blood types. At the turn of the century, Karl Landsteiner, an American Nobel Prize winner, gave us the first explanation of why people sometimes suffer severely when they are transfused with blood from another person. These occasional catastrophies made the blood transfusion business a rather risky procedure to be used only as a last resort. Landsteiner showed that the red cells of the blood contained two proteins, called **A** and **B**, and that they existed in people singly, in combination, or not at all. Persons could accordingly be classified into groups, depending on the nature of their blood: those with protein A were placed in blood **Group A**, those with B in blood **Group B**, those with both proteins in blood **Group AB**, and those with neither protein in blood **Group O**. The serum of each of these groups contains the antibody for other groups but not for its own, that is, the serum of Group A has anti-B but not anti-A, Group B has anti-A but not anti-B, Group AB has neither antibodies, and Group O has both. These antibodies are naturally present in the serum of people, and their kinds must be known in any case before blood can be transfused without possible ill effects.

The groups are readily determined by cross-matching according to the scheme shown in Fig. 19-17, where it is apparent that the only safe transfusions are between people of the same blood group. In practice, however, it has been found that this is not altogether true. Persons with Group O have been called **universal donors** because it is possible to transfuse their blood into people with any of the other groups without ill effects. The reason for this is twofold. In the first place, the erythrocytes have no **antigenic** proteins, so there can be no reaction between them and the antibodies in the recipient's plasma. Secondly, the introduced anti-A and anti-B antibodies are diluted so rapidly by the recipient's plasma that they have very little opportunity to cause the erythrocytes to agglutinate. Of course, if the blood is added too rapidly or in too large quantities, some agglutination might occur. Like the other blood groups studied so far, these groups are inherited in a definite manner, which will be considered in a later chapter.

Other functions of the blood

Among the many functions of the blood must also be included body defense, pH and temperature regulation, and water balance. These will now be briefly considered.

Body defense. In addition to the phagocytic action of the leucocytes already referred to, the blood and tissues of the body employ the antigen-antibody reaction to destroy invading microörganisms that produce disease. Bacteria as well as animal

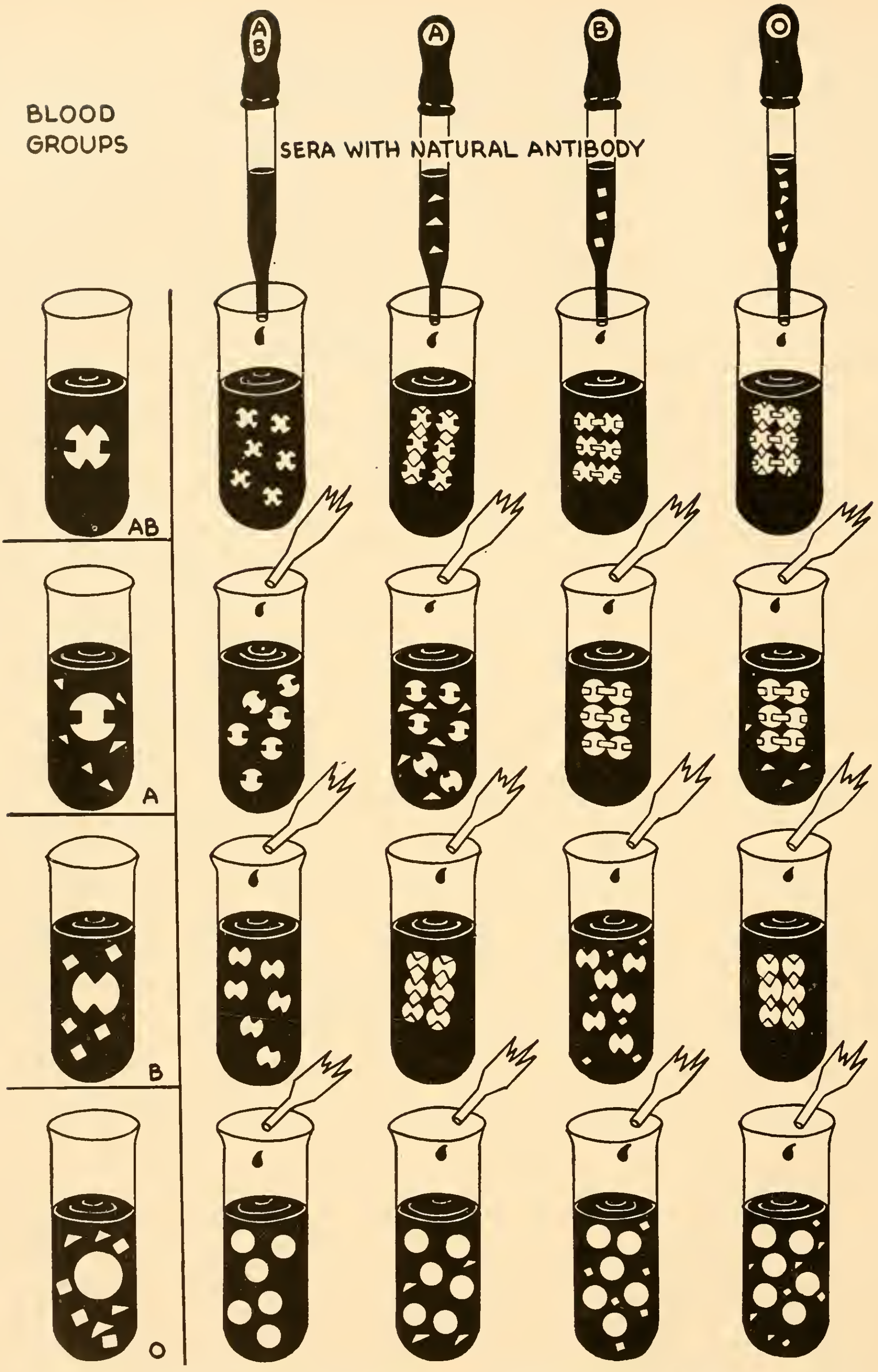


Fig. 19-17. A schematic representation of the various blood groups (A, B, AB, O) and what happens when they are mixed. Agglutination occurs when the red cells of a certain type are mixed with the sera containing a specific antibody. The antibodies are indicated by specifically shaped particles that fit into the spaces cut out of the circular discs which represent the red blood cells. When they fit agglutination occurs. See text for a further explanation.

parasites are protein in nature and therefore induce antibodies when they get into the blood stream and other tissues. The parasite is toxic to the host, so **antitoxins** are produced that will either destroy the parasite or render it helpless so that the leucocytes may engulf and destroy it more easily. Often the parasite gives off a protein product which is also toxic to the host and again an antitoxin is built up against this product, so that it is neutralized and can no longer harm the body. The end products of this reaction are removed from the body through various channels.

The production of antitoxins is spoken of as **immunity**, a very familiar term. Once the antibodies have been produced, they are active for some time against a second invasion of the parasite. How long they are active seems to be specific for the parasite. For example, immunity against typhoid fever may last a year or two, whereas one may never expect to have a second case of whooping cough, the antibodies for which last throughout the lifetime of the individual. Immunity built up by the actual participation of the parasite in question is called **active immunity**. A similar immunity can be produced artificially by introducing a weakened or even a dead strain of the parasite into the body so that it will bring about antibody formation but will not cause the disease or, if it does, only in a very mild form. This is the method employed in immunizing against smallpox, for example. Another method is to employ an altered toxin, such as that used in building up active immunity against diphtheria. The toxin taken from the diphtherial organism is treated so that it has lost none of its antigenic properties but is no longer toxic to tissues in the body. This substance is called **toxoid**. Upon receiving a small quantity of toxoid, antibodies (antitoxins) are produced, so that if at any subsequent time the diphtherial organism enters the body its effect will be neutralized at once and it will be unable to obtain a foothold. This type of treatment has made cases of diphtheria very rare and they could be nonexistent if everyone were thus protected.

Sometimes, as in the case of advanced tetanus, it is necessary to build up the supply of antibodies immediately. There is not sufficient time to allow the body to produce them in the usual slow manner. It is possible, then, to add them directly by injections of antitoxin that has been previously produced in a horse. This type is called **passive immunity**, because the person himself contributes nothing toward the production of the antibody. Passive immunization is short-lived, which is its chief disadvantage, but in certain diseases it can save a life. It is wiser to prevent the appearance of the disease by active immunization rather than attempt to cure the disease once it has struck—hence the popularity of immunization programs in our schools and the absolute enforcement of such programs in the armed forces.

Acid-base balance. All of the cells of the body are very sensitive to the amount of acid or base that is present in their environment, and can withstand only very slight changes in the concentration of hydrogen ions. Since the blood controls the internal environment, it follows that it, too, must be very constant. Such is indeed the case. In whatever part of the body the **hydrogen ion concentration** or **pH** of the blood is measured, it will be found to be remarkably constant, being slightly alkaline (pH 7.45). This may seem difficult to understand in view of the many compounds being "dumped" into and withdrawn from the blood continuously. It is made possible by substances in the blood, appropriately called **buffers**, which maintain a constant pH. They combine with both acids and bases so as to prevent any important change in the relative number of hydrogen and hydroxyl ions. The most important buffers in the plasma are the proteins, phosphates, and carbonates. Acids that form in the cells as a result of metabolic activity are passed through the cell membrane into the blood where the buffers absorb the extra hydrogen ions, thus preventing an excess and hence an increase in acidity. Carbon dioxide coming into the blood from all the cells promptly forms carbonic acid and then carbonate, both of which would make the blood intolerably acid if it were not for the buffers. The carbon dioxide is lost in the lungs, an important factor in removing acid conditions from the blood. Likewise, acidic substances are removed from the circulation in the kidneys. All of these factors work together in order that the blood can remain constant as far as the acid-base balance is concerned.

Water balance. Water is constantly being added to and withdrawn from the blood because it is the only way that this important compound can be delivered to and taken away from the body cells. This is extremely important, since all life processes are maintained in a water medium within the cells. Therefore, they must have the proper amount at all times. Water is taken into the blood from the digestive tract and lost through the skin as sweat or through the kidneys as urine. Excess water is normally lost through the urine, so that a delicate water balance is maintained in every cell of the body at all times.

Temperature regulation. Because the body is exposed to widely varying external temperatures, several different mechanisms have been provided to regulate the body temperature. The added muscular contraction brought about by shivering in mammals causes a greater burning of the sugar, thus raising the temperature of the entire body. When the body is exposed to low temperatures, the skin becomes pale and cold, owing to the contraction of the capillaries (vasoconstriction), thus preventing blood from coming close to the external surface where it would be unduly cooled. The opposite effect, flushed skin, is noted following violent exercise or during particularly hot weather. This is because the dilated capillaries (vasodilated) in the skin allow the warmer than normal blood to come near the surface where it can lose its excess heat. This control of the size of the skin capillaries is very important in the temperature regulating mechanism. In addition, the sweat glands pour out water which, by evaporation, provides an important cooling device.

Certain special provisions have been made in some animals for increasing surface area to make the cooling process more effective. For example, elephants and rabbits are thought to employ their large ears for this purpose as well as for collecting sound waves. Bats are thought to rely on the circulation in the skin of their wings for heat regulation. Man, of course, covers his body with various fabrics, the color and texture of which is changed depending on the temperature. Hair and feathers are excellent insulators against temperature change. Thus the bodies of the warm-blooded birds and mammals are reasonably well suited to withstand the varying temperatures they encounter in their particular environments.

The lymphatic system

A swelling following a blow on any portion of the body is gorged with a fluid called **lymph**, which is much like plasma except that it does not contain so much protein material. It does, however, contain some white cells, principally **lymphocytes.** Lymph fills all of the spaces between and around cells and thus bathes every cell of the body. It functions as a medium between the capillary and the cell, a continuum through which food, oxygen, and wastes can enter and leave the cells.

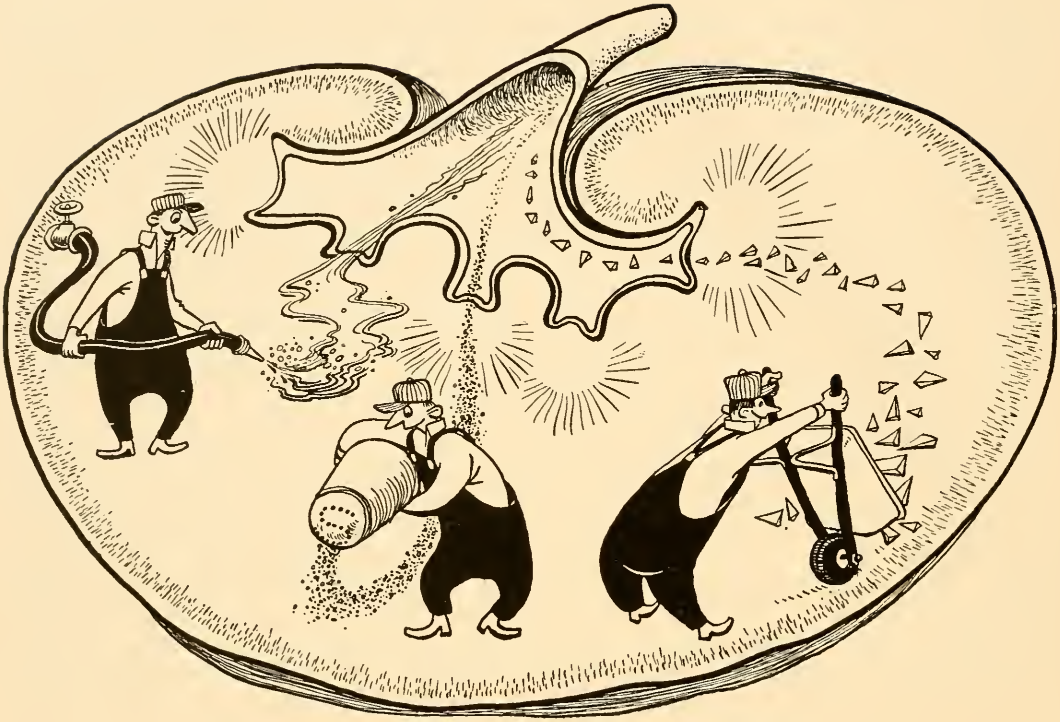
Lymph passes out through the capillary walls around the cells, and from there moves slowly on into a system of vessels which coalesce and eventually reach the circulatory system in the neck region where the large lymph vessels join the large neck veins. This is as intricate as the venous system and resembles the latter in many respects. It merely is an alternate route by which water and wastes from the cells can reach the general circulation. In other words, it resembles a "sludge pump" in its action.

The lymph glands which produce the lymphocytes of the blood lie along the lymph channels, through which they are dumped into the blood. The lymph glands have another function, namely, as filters. Foreign particles such as dust, debris, and bacteria float in the lymph and finally make their way to the lymph glands where considerable phagocytic activity goes on. This can be so active as to produce noticeable swelling of these glands, particularly under the arms if the source of infection is in the hand, or in the groin if the difficulty arises from some portion of the leg or foot. They function in stopping the infection before it gets into the general circulation where it may do a great deal of damage. Carbon particles are inert, so that those entering the body from air laden with coal smoke will lodge in the lymph glands, contributing a dark color to them if the person has lived in cities where smoke is abundant.

There is no pumping station in the lymphatic system of man, although such mechanisms are present in some of the lower animals. The movement of the lymph is due to the continual massaging of the lymph channels by the contracting muscles, both visceral and skeletal. The contraction of the villi in the intestinal walls, as well as the negative pressure created at the point of entry into the large neck veins, aid in bringing about lymph movement. Any stoppage of this movement results in swelling, as in the case of certain roundworms that invade the lymph glands, thereby clogging them so that the lymph cannot pass through. In such cases a leg may weigh as much as 100 pounds (p. 183).

We have seen how the circulatory system provides for the needs of the individual cells in a complex animal. Let us now determine what happens to the food elements that have been carried to the cell. Obviously, they must be utilized in construction, repair, and the releasing of energy through oxidation. These will be considered in the next chapter.

CHAPTER 20



METABOLISM OF FOODS AND DISPOSAL OF WASTES

In the preceding discussion it was shown how food and oxygen were delivered to the individual cells in a complex animal. The next step is to consider the processes by which energy is derived from this food—energy which is essential in bringing about movement, growth, production of heat, as well as all other living processes. This most important series of processes, called **metabolism**, goes on within the cell, providing energy to keep it active and material out of which new protoplasm and new cells can be constructed. The **catabolic** processes involve oxidation by which energy is released, and the **anabolic** processes involve the synthesis of new molecules for the construction of new protoplasm. Together, these destructive and constructive processes constitute metabolism.

METABOLISM

Constructive metabolism

Every cell of the body must rebuild or replace itself from time to time. During the growing stage of the whole animal, and in some cases during adulthood, cells also duplicate themselves. This means that protein must be synthesized in each cell, and this is done by the utilization of the amino acids that come to the cell from the blood stream. The proper amino acids are selected and put together, by means of specific enzymes, into the protoplasm of the particular animal. The amino acids are synthesized into proteins by **dehydration,** that is, by the loss of water, just the reverse of the process of **hydrolysis** that occurs in digestion. This is a simple process that passes easily from one stage to the other in the presence of proper enzymes, though it is not so easy outside of the cell.

Each cell builds its own specific proteins from the amino acids that are available to it. The proteins of every species of animal differ from those of every other. The enzymes within the cell determine the proportions of different amino acids and how they are to be fitted together to produce specific proteins. The source of any particular amino acid, such as glycine, does not matter, since it is the same whether it be from a cow, oyster, or plant. As it combines with others, however, the resultant protein is highly specific. This relationship may be compared to bricks in a house. The red bricks are all alike no matter from which brick yard they came, and they only become distinctive when they form a part of a particular house. They are then part of a pattern, which in this case is Jones's house, not Johnson's or Stoopnagle's. It follows that all of the necessary amino acids must be present in the blood if this constructive work is to go forward. For some reason while animals, man included, can build certain amino acids within their own cells, they cannot construct others. The amino acids they build are called **non-essential** amino acids, and are not needed in the diet although they can be utilized if available. The amino acids they are unable to produce must be provided in their diet. These are the **essential amino acids** referred to earlier. For example, if a person tried to live on gelatin alone he would starve, because several of the essential amino acids are not present in this protein. By a combination of foods, which is usual in the diet of most animals, all of the essential amino acids are made available. The ultimate source of the essential amino acids must be plants, because they alone are able to build all of them.

The complex carbohydrate, **glycogen,** is synthesized in the liver, muscles, and other tissues of the body from **glucose.** Much of the glucose that comes to the liver through the **hepatic portal vein** is converted into glycogen by the loss of water (**dehydration**), a process not greatly unlike the one which forms proteins from amino acids. As was pointed out in an earlier chapter, glycogen is stored and used as it is needed by the tissues. Glycogen can also be formed from proteins and fats by a process that is not completely understood at present.

Fats are produced in much the same way as glycogen and protein, that is, by the union of fatty acids and glycerol with the loss of water (dehydration). Proteins and carbohydrates can be converted to fats also, but here again the process is not too well understood. Proof of this lies in the fact that carnivores do produce fat even though they eat very little of it. Likewise, to the sorrow of many people, fat can be produced and stored from carbohydrates such as sugar.

Hormones are also synthesized by animal cells. Vitamins, on the contrary, must be derived from the diet, because there seems to be no means of producing them within the animal cell itself. This is another instance where animals depend entirely on the plant world for an essential food substance.

There is thus less synthesis of organic materials in animals than in plants. By far the most complex metabolic activities of animals are the destructive forces, those which release the energy that is necessary to sustain life in all of its complexities.

Destructive metabolism

All of these complex organic substances absorbed by animal cells are capable of delivering a vast amount of energy if degraded to the simpler substances from which they came. The plants built them up into complex molecules by utilizing energy received from the sun, and all of this energy is available when the reverse process occurs. The animal cell complements the work of the plant cell. The latter builds up the energy, whereas the former releases it, all for the sake of perpetuating animal life on the earth.

In bringing about the degradation of complex molecules to simple ones, animal cells have employed a long list of chemical reactions, some of which are still only vaguely understood, if at all. The chief reaction employed by animals to release energy is **oxidation**, a familiar process in the world outside of cells as well. This may be defined as (1) the addition of oxygen, (2) the loss of hydrogen, or (3) both.

In the burning of glucose the following initial and final products are indicated:

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

This reaction involves many steps between the initial and final stages, in fact, over twenty-five enzymes are essential, meaning there must be at least that many separate steps in this degradation in which energy is released at almost every step.

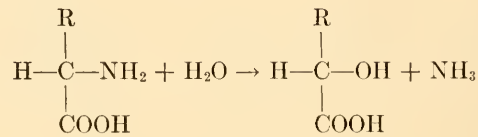
This oxidation process is little different, as far as the energy release is concerned, from similar burning in a test tube. The one significant difference is the temperature at which the oxidation proceeds. It occurs at body temperatures in the cell, which is possible again only by the presence of the numerous enzymes.

Fats, likewise, can be burned to release energy. Ordinarily they are not drawn upon as a source of energy and it is only after days of starvation that they do come into the picture. Then they burn to carbon dioxide and water, but in a slightly different manner from glucose.

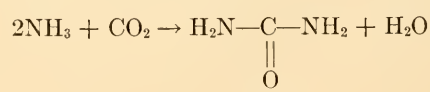
$$2C_{51}H_{98}O_6 + 145O_2 \rightarrow 102CO_2 + 98H_2O + \text{energy}$$

Needless to say, enzymes also play their indispensable rôle in this reaction. One peculiar thing about the oxidation of fats is that they will not burn well except in the presence of glucose. In other words, they must burn simultaneously, though the reason why is not clear.

Proteins can also be utilized for energy, although their chief function is in the construction of protoplasm. Amino acids do not burn directly but must first be stripped of their amino groups (NH_2). This is done in the liver by the addition of water and the formation of ammonia and a *deaminated* compound. The process is known as **deamination:**



The ammonia forms ammonium hydroxide immediately by uniting with water. This is a strong alkali which is normally produced in considerable quantities and if allowed to accumulate would upset the acid-base level of the blood, causing a serious condition that could not be tolerated by the organism. Therefore, the ammonia must be removed from the blood as fast as it forms; this is also done in the liver where it is converted into urea which is neutral in its reaction. This is accomplished in the following manner:



(urea)

The kidneys then remove the urea from the blood and pass it into the urine of which it makes up a considerable part. The more protein that is taken into the body, the greater is the urea output in the urine, so that the examination of the urine of an animal gives some clue as to the nature of its diet.

The remaining portion of the original amino acid is finally either burned completely to CO_2 and H_2O, delivering large amounts of energy, or is converted to glucose which eventually oxidizes in the usual manner.

The metabolism of the animal is destructive for the most part. Of course, most of the energy is expended in the mere business of keeping alive—moving about, producing heat, ingesting, digesting, distributing food, and disposing of wastes. But even the synthesis of fats, glycogen, and proteins depends on energy derived from the destructive forces in the cell. And, as the animal increases in size, a tremendous amount of organic matter must be torn down in order to synthesize sufficient protoplasm to provide for growth. So the cycle goes on. What the plants build up, the animals break down, each complementing the other. It had to be thus or there would have been no animals, and had there been no animals, the world would soon have been overrun with plant products which would have tied up all of the available CO_2 and other critical compounds in the form of organic molecules.

DISPOSAL OF WASTES

Once the food products are metabolized, the resulting waste products must be promptly removed from the body. Retained, they act as toxic substances, causing death of the animal within a short time. The elimination of these wastes is very simple in the unicellular animals like amoeba (Fig. 20-1) and even in multicellular ones like hydra. Indeed, wherever all or even most of the cells are still in contact with water in the external world, there is no problem, for the CO_2 and nitrogenous wastes diffuse through the cell membranes into the surrounding water. When many of the cells of the animal body lie deeper, the elimination of metabolic wastes requires special organs. This has resulted in the formation of the excretory systems: gills or lungs for the removal of CO_2, and kidneys for the removal of nitrogenous wastes. Sweat glands in some mammals also aid in excretion.

These systems have all been described in preceding chapters, and we shall here confine the discussion to a brief account of the major steps in the evolution of kidneys. We have seen that the first simple kidney consists of a system of tubules ramifying the body tissues, as illustrated in planaria (Fig. 20-1). Each tubule drains the tiny flame cells which selectively pick up the nitrogenous wastes from neighboring cells, and the entire system conveys those products to the outside through many pores.

The next great step is taken by the annelids, where nephridia replace the flame cells. Not only do the cells at the funnel (nephrostome) pick up coelomic fluid which contains many substances besides nitrogenous wastes, but as this fluid passes down the tubule selective reabsorption occurs along the way. This principle established in the annelids is retained throughout all higher groups.

In the vertebrates the origin of the excretory system is intimately associated with the reproductive system. Primitive cyclostomes have kidneys that are not greatly different from those found among invertebrates. They are long, thin, paired structures lying in the dorsal wall of the body cavity, one on each side of the vertebral column (Fig. 20-2). Coelomic fluid is drawn into the ciliated nephrostomes which lead into a long tubule much like the earthworm. The tiny tubules coalesce forming larger tubes, the **urinary ducts**, which terminate in the cloaca. In this animal, the eggs and sperms are shed into the body cavity and find their way out through two openings from the posterior end of this cavity into the cloaca. This is an extremely simple method reminiscent of some of the lower invertebrates. The excretory system

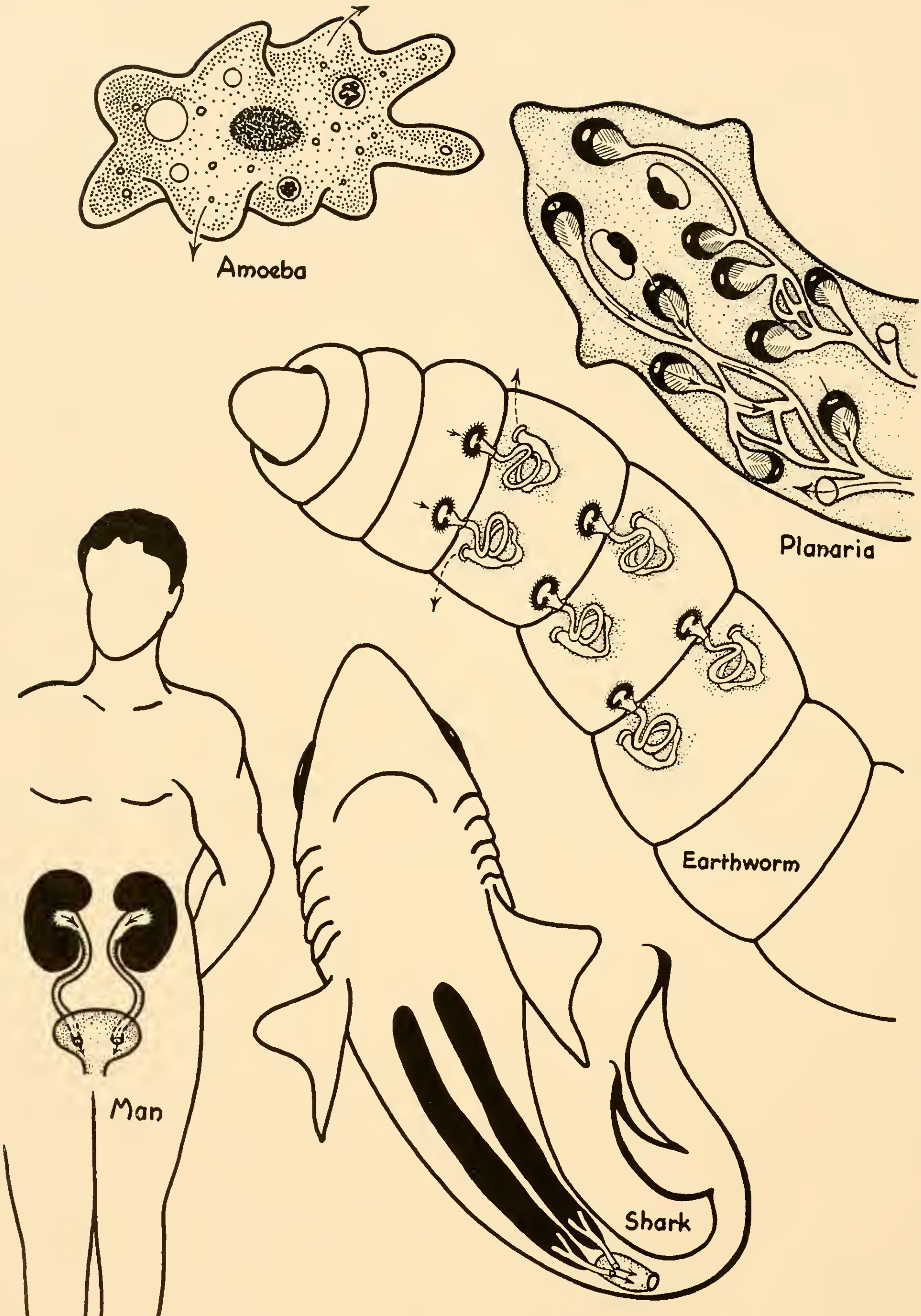


Fig. 20-1. The problem of ridding the body of nitrogenous wastes is handled in various ways by representative animals.

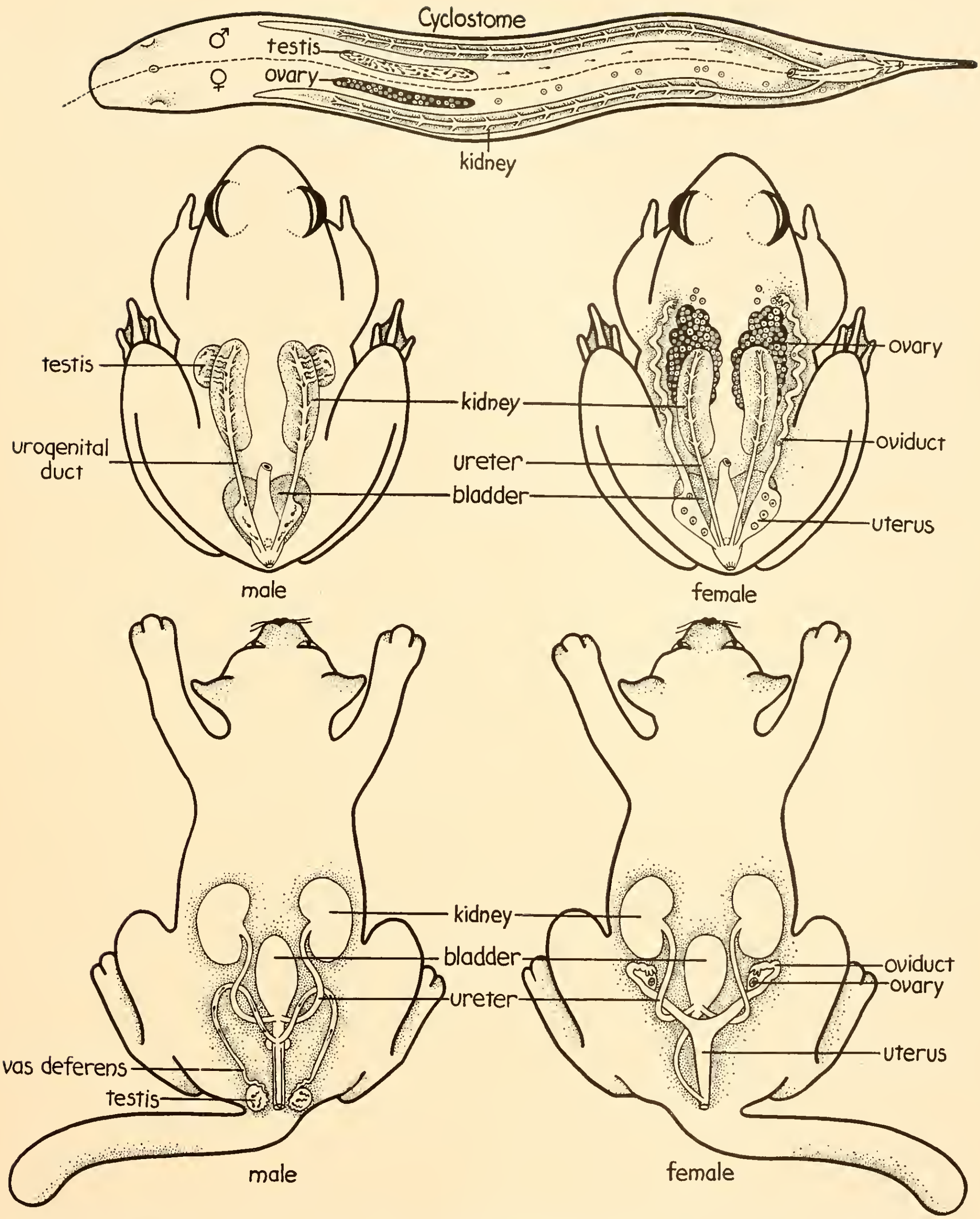


Fig. 20-2. The urinary and reproductive systems were separated in lower vertebrates (cyclostomes) but became intimately associated in higher vertebrates (fishes, amphibia, birds, and mammals). Three forms are shown here to show how this came about. See the text for details.

and the genital system are thus distinctly separated. Perhaps because this system of getting rid of the germ cells was so fortuitous, it became necessary to provide tubes for this purpose. By chance, or perhaps by proximity, the urinary ducts took over that task, and an intimate relationship became established between the excretory and reproductive systems. This was done very gradually through several groups of animals over a period of many millions of years.

Among the fishes and amphibia, the testes became connected with the upper end of the kidney by means of tiny tubules, the vasa **efferentia.** Sperms then made their way out of the body through the same tubes as the urine, namely, the **urogenital duct** (Fig. 20-2). New ducts, the **oviducts,** were formed for conveying eggs out of the body. The lower ends of these ducts became large and sac-like to form the **uteri** (singular—*uterus*) in order to accommodate the great numbers of eggs that accumulated before deposition. The uteri, too, opened into the cloaca. This seemed to be a very satisfactory arrangement, and not until mammalian evolution was well underway did further radical changes take place.

In a mammal, such as a cat, we find that the kidneys have become "kidney-shaped" and much more compact than the long thin organs of the fishes or even the thicker structures of the amphibians. As in the cyclostomes, the tubes which convey urine away from the kidneys have no affiliation with the genital system. Indeed, these ducts, the **ureters,** are new tubes which formed very late in evolution. They connect with a **bladder** (urinary), thence through a tube, the urethra, to the outside. The old urogenital ducts of the frog have lost their urinary function and have been taken over completely by the genital system. Their sole function in the mammal is to carry sperm cells. These tubes, the vasa **deferentia,** connect with the urethra, which is urogenital throughout the rest of its course to the outside of the body. The terminal portion is modified into a copulatory organ, the **penis.**

The path of the eggs in mammals is not greatly modified from that of the frog. They pass into the oviducts from the ovaries and then into the uteri, which may be paired as in the cat or fused as in man. The eggs of mammals are much smaller, of course, but they follow essentially the same path as in the amphibians and fishes. A new structure, the **vagina,** has been added which receives the penis of the male in sperm transfer, an essential for land animals.

The embryological development of the urogenital system of mammals follows basically the same course as its evolution. That is to say, at one time the kidney resembles that of a cyclostome, and a little later, that of a frog. Finally, some time before birth, the true mammalian kidney and associated organs are formed. It must be remembered that although the excretory and reproductive systems are anatomically intimately related, they bear no relationship to one another functionally. The job of reproduction and excretion are two separate and distinct functions.

The human kidney

The two kidneys in man are about 4 inches long and are located near the mid-dorsal line just below the stomach. The ureter and blood vessels emerge from a depression on the medial side. The kidneys lie in a capsule of peritoneum which excludes them from the coelom. If a kidney is sliced lengthwise, it will be seen to consist of an outside layer, the **cortex,** and an inner capsule, the **medulla** (Fig. 20-3), both of which are visible to the naked eye. At the point where the ureter leaves, there is a large cavity, the **pelvis** (not to be confused with the pelvis of the skeleton), which is a depository for the urine as it comes from the millions of tiny tubules of the kidney. The entire internal kidney is tied together with connective tissue and interlaced with blood vessels, and it is a

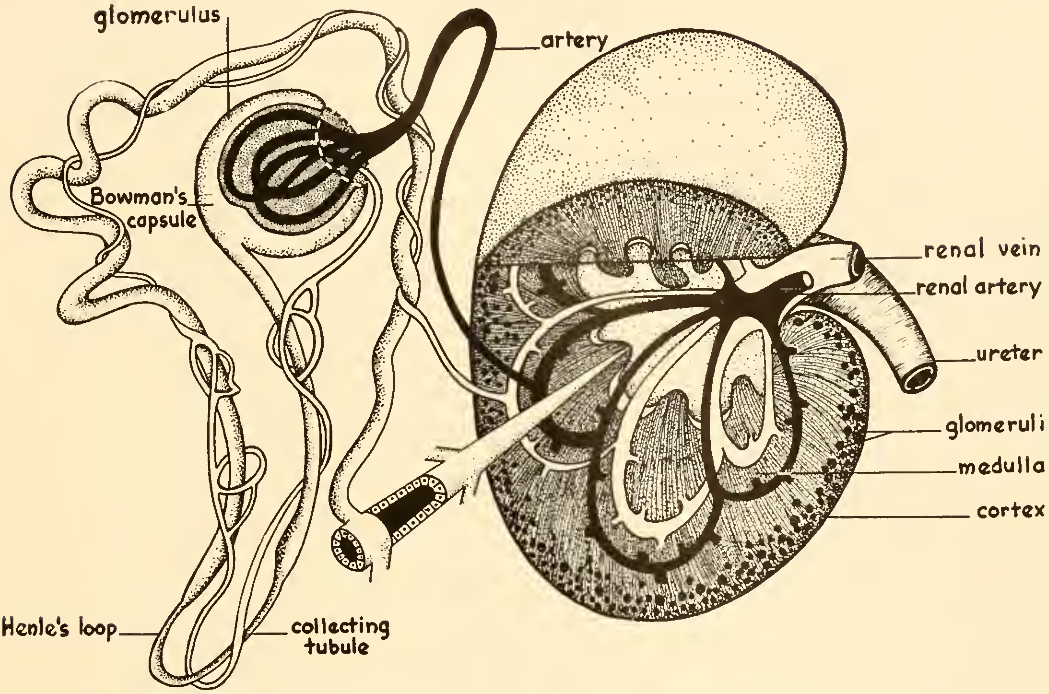


Fig. 20-3. A schematic view of the human kidney cut to show its internal structure and with a single excretory unit enlarged to show its detailed anatomy.

very complex and extremely delicate organ.

The cortex is made up of **renal corpuscles,** which are the tiny units where the excretory process begins (Fig. 20-3). Each consists of a minute ball of capillaries, the **glomerulus,** surrounded by the double-walled cup-like sac, **Bowman's capsule.** The inner wall of the capsule closely adheres to the glomerulus in order that substances may diffuse readily from the blood stream into the cavity and thence through the long tubule to the pelvis of the kidney. The medullary portion of the kidney consists almost exclusively of these tiny tubules which play an important function in the business of excretion.

Urine formation. The function of the kidney has long been known but just how urine forms has become clear only in recent years. Following through the process as it is now believed to take place, the blood passes into the kidney through the renal artery which immediately breaks up into smaller and smaller vessels until these eventually form the glomeruli of the renal corpuscles. As the blood passes through, all of the substances in the blood except the cells and proteins diffuse through Bowman's capsule by **filtration.** This is purely a physical process which depends entirely on the pressure in the blood vessels, and the amount of fluid passing into Bowman's capsule rises and falls with that pressure. The vessels coming from the glomerulus are slightly smaller than those going to it, so that the pressure remains high in these vessels. About 1 per cent of the blood volume is lost to the **capsular filtrate** as it passes through the kidney.

By some ingenious experiments with tiny micro-needles, Prof. A. N. Richards was able to examine the capsular filtrate and found that it contained urea, sugar, amino acids, salts, and so forth, in about the same concentrations as those in the blood plasma. Obviously, if all of these valuable products remained in the capsular filtrate, the animal would shortly drain its body of the essentials of life. Therefore, these products must be selectively **reabsorbed** into the blood while the fluid passes through the extremely long tubule on its way to the pelvis. This is possible because, when the blood leaves the glomerulus, instead of forming a vein, as is customary in other organs, it becomes another set of capillaries, this time surrounding the tubule that leaves Bowman's capsule (Fig. 20-3). As the capsular filtrate passes down the tubule, the valuable portions, such as the amino acids, sugars, salts, and so forth, are **secreted** back into the blood again. This requires considerable work on the part of the cells lining the walls of the tubules, as indicated by the fact that the kidney requires more oxygen than the heart when calculated on equivalent weights. The secretion is against a diffusion gradient, which accounts for the large amount of work that is necessary. If the kidney is denied oxygen, reabsorption stops, although filtration proceeds normally.

With this arrangement it is apparent that the kidney functions as an organ which selects what substances shall remain in the blood and what shall be removed. If there is too much sugar in the blood, for example, the tubules will reabsorb some of it but leave the surplus in the capsular filtrate. Under these conditions the urine will show sugar, which is what happens in diabetes. The same is true of other substances.

The kidney as a regulatory organ. Because of its ability selectively to secrete substances, the kidney is a very important organ in maintaining the proper composition of the blood and other body fluids. As we have seen, the various end products of metabolism are injurious if allowed to accumulate. The kidneys remove just the right amount of each to prevent harmful effects, and yet leave enough to maintain a proper balance of ions and molecules. The kidney figures prominently in the retention or release of hydrogen and hydroxyl ions to maintain their proper balance, and thus hold the pH of the blood constant. If the salt concentration of the blood should rise too high or fall too low, there would be a harmful movement of water which might destroy cells. This too is prevented by the elimination of exactly the right amount of salts through the tubules of the kidneys.

Many substances that are used in medicine are eventually eliminated through the urine. Such compounds as antibiotics, aspirin, and many others are removed from the body via the kidneys. Hence testing the urine is an important criterion of the effectiveness of a drug in treating a specific disease. If the drug appears in the urine shortly after it is given, it can be of little value. Antibiotics, for example, must remain in the body long enough to have a static effect on pathogenic bacteria. Frequently when searching for a new drug, it is found that the drug does the intended job very well but is lost too rapidly through the urine to be effective.

The kidney is able to return a certain amount of various substances to the blood from the capsular filtrate, but if the amount appearing in the blood is above a certain critical level, which is spoken of as the "threshold" level, the kidney no longer is able to prevent the substance from appearing in the urine. In diabetics (see p. 436), for example, the blood sugar reaches such high levels, owing to the lack of insulin, that a large amount of it appears in the urine. If, in man, the amount of sugar per 100 cc. of blood exceeds 150 mg., sugar will appear in the urine. In other words, that is the threshold for sugar. Other substances have thresholds but they would not necessarily be the same as sugar.

Blood volume is also regulated by the kidney. Following a severe hemorrhage the blood pressure drops, thus slowing up urine production and conserving body fluids. Similarly, if the blood contains too

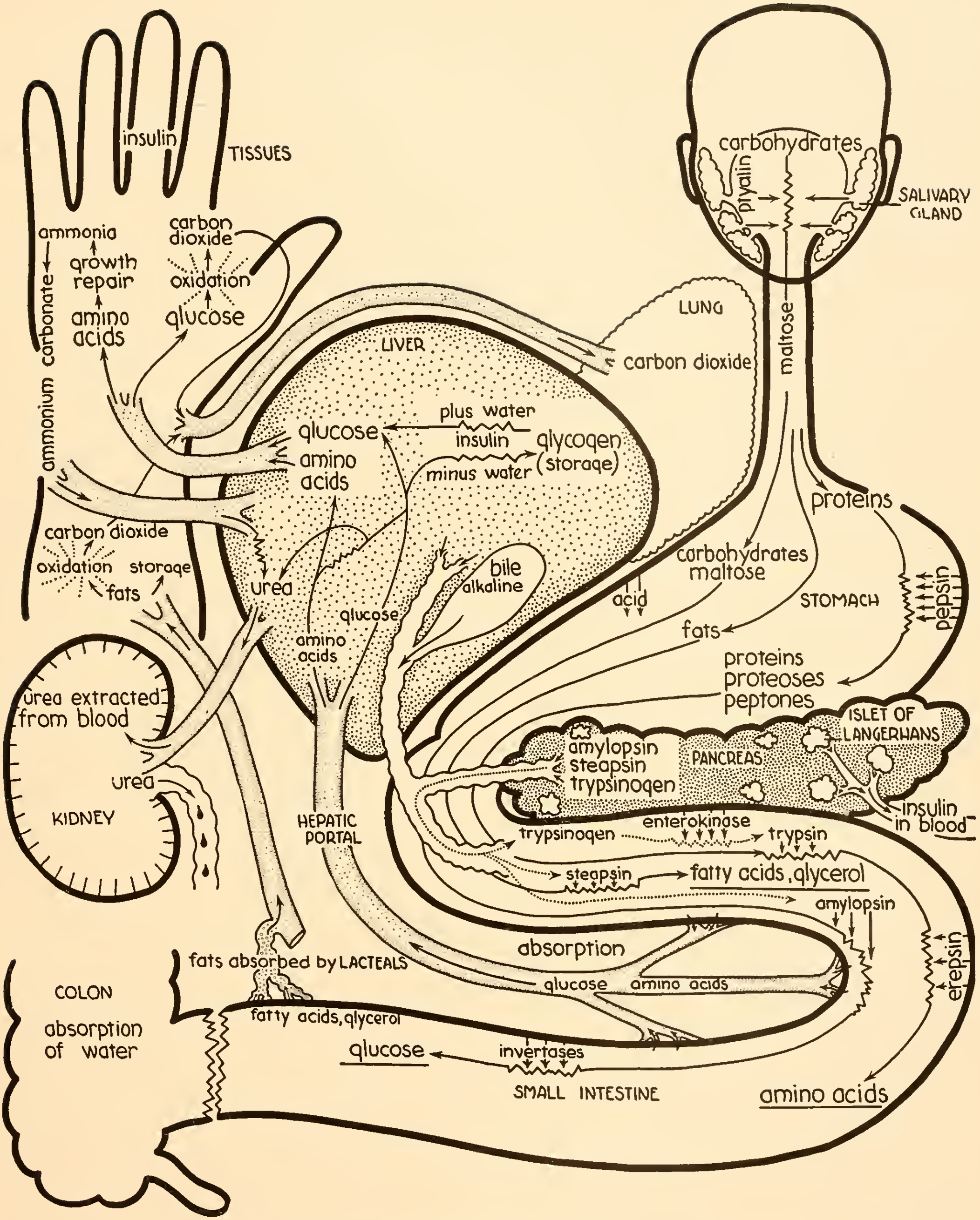


Fig. 20-4. A schematic representation of the history of food in the body.

much water the blood pressure rises and more fluids are eliminated as a consequence. The amount of urine that is excreted depends not only on the amount of fluids taken into the body but also on the amount of salt that is to be eliminated from the blood. On a salty diet the urine output is greater because more salts must be removed from the blood if a normal balance of these ions is to be maintained. Also it requires more water to pass the high proportion of solids that appears in the urine after a heavy intake of salts. In the case of diabetes there is too much sugar in the capsular filtrate and this produces a high osmotic pressure. For this reason, not much water can be reabsorbed into the blood and so a large urine output results.

Urine volume is also controlled by a hormone secreted by the posterior lobe of the pituitary (see p. 449). This substance controls the rate of water reabsorption in the tubule. If it is insufficient or completely lacking, a disease known as *diabetes insipidus* results. People suffering from this disease may have a urine output of 30-40 liters per day instead of 1.3-1.5 liters, which is average. As might be expected, they also suffer from an insatiable thirst.

A normal kidney restores all of the utilizable substances in the capsular filtrate to the blood except in cases where the retention of such substances might be harmful. However, urea and other substances are highly concentrated as the capsular filtrate flows down the tubule toward the pelvis of the kidney. Once in the bladder it is known as urine. Its concentration will vary, of course, with the amount of water included with it. This can be measured by determining its specific gravity, a routine procedure in diagnosis.

Like most organs of the body, the kidney has a tremendous latitude within which to operate, and can withstand considerable abuse and still do its job satisfactorily. Actually, only one-half of one kidney, or one-fourth of the total kidney tissue, is necessary to handle the normal business of living.

HISTORY OF FOOD IN THE BODY

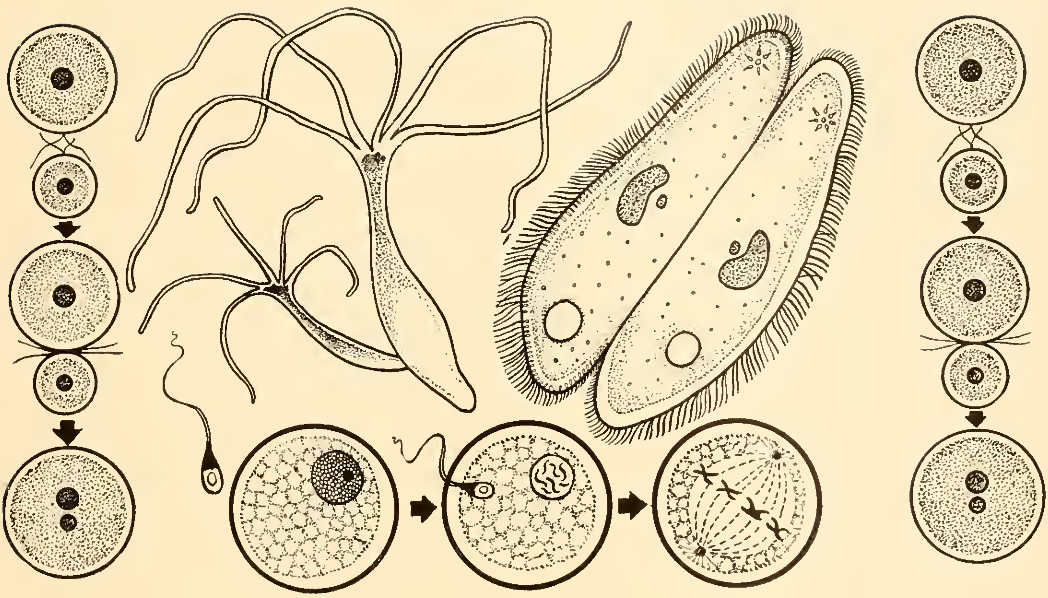
It might be well at this point to review the entire story of the food pathway through the body. This can best be done by some such scheme as that shown in Fig. 20-4.

The food taken into the digestive tract in the form of large molecules is broken down by enzymatic action into its absorbable end products: amino acids, simple sugars such as glucose, and fatty acids and glycerol. The first two are taken directly into the blood stream through the hepatic portal system, whereas the last enter the blood via the lymphatics. In the liver, under the influence of hormones, glucose is either stored in the form of glycogen (by the loss of water) or is passed out to the tissues in the general circulation. Amino acids either pass into the general circulation where they function in growth and repair or they become deaminized in the liver. Here the nitrogen-containing fragment forms urea which is eliminated through the kidneys, while the carbon fragment follows the glucose pathway.

In the tissues, glucose oxidizes to carbon dioxide and water, thus releasing the energy necessary for life. The oxidation products are eliminated through the lungs. Some of the amino acids are resynthesized into the specific proteins of the body, whereas others are broken down into their nitrogen end products, namely, ammonia and eventually urea, which is eliminated through the kidneys.

The fatty acids and glycerol resynthesize into fats the moment they pass from the gut into the lymph channels. They then flow in the blood to the tissues where they are stored or where their stored-up energy is released by oxidation, the resulting carbon dioxide leaving the body through the lungs.

CHAPTER 21



REPRODUCTION

In the preceding chapters we have considered in some detail the problems of structure and maintenance in the individual animal body. We shall now turn to the problem of reproduction of the individual or maintenance of the race. All animals reproduce, from the simplest protozoan to the most complex mammal, and, furthermore, elaborate provisions are usually made for this all important event. The methods employed by animals today must have had a long and interesting history.

Undoubtedly, the first forms of life duplicated themselves by some sort of fission, perhaps much like many bacteria and Protozoa do today. This is one form of **asexual** reproduction, so called because there is no sex involved; the cell simply divides into two parts, usually equal in size (Fig. 21-1). When animals became many-celled, some form of asexual reproduction was still retained by many of the lower forms. Hydra, for example, forms buds (Fig. 21-1) which develop into miniature hydras. Planaria, a more complicated animal, still employs fission. With increasing complexity of body structure in higher forms, this method of reproduction was lost entirely.

Sexual reproduction must have been introduced very early in the evolution of living things because we find it well established even among the single-celled plants and animals. There is a series of single-

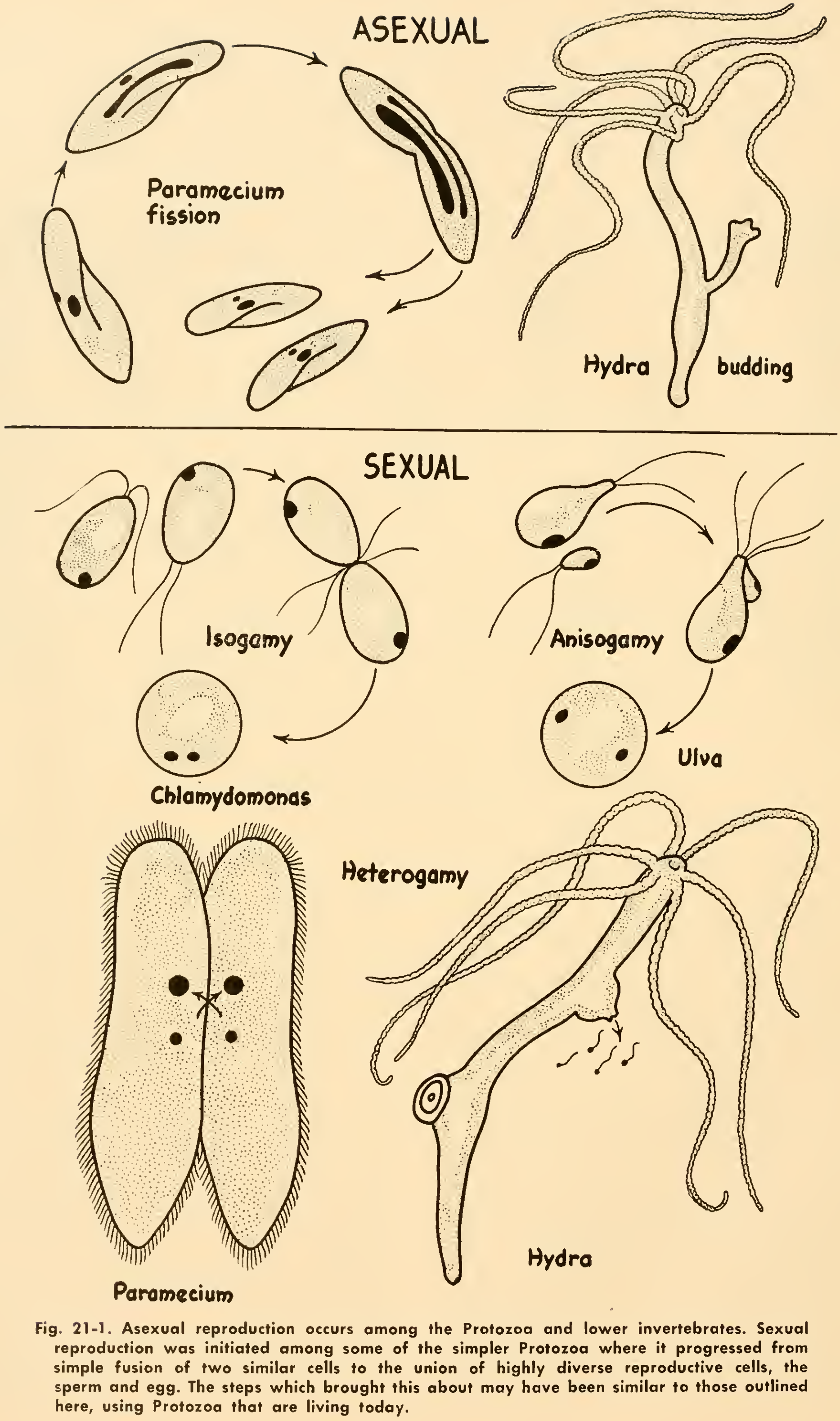


Fig. 21-1. Asexual reproduction occurs among the Protozoa and lower invertebrates. Sexual reproduction was initiated among some of the simpler Protozoa where it progressed from simple fusion of two similar cells to the union of highly diverse reproductive cells, the sperm and egg. The steps which brought this about may have been similar to those outlined here, using Protozoa that are living today.

celled green forms living today that show a graded sequence from the union of cells that are similar in size and activity to those that are quite unlike in these respects (Fig. 21-1). At certain times, individual cells of *Chlamydomonas* will fuse, forming a **zygote** which will overwinter and continue its asexual method of reproduction the next spring. Since these uniting cells are equal in size, they are called **isogametes** and their union, **isogamy.** A closely related form, *Ulva*, undergoes a similar process, although in this case the cells are unlike in size. The smaller of the two is more active than the larger and in this respect resembles a sperm. Such unlike gametes are called **anisogametes** and their union, **anisogamy.** Among the ciliate Protozoa, such as paramecium, the migrating nucleus during conjugation (see p. 119) is smaller than the immotile one that remains behind. Here there is not only a size difference but also a physiological difference—one moves, the other does not. Once the sex cells reached this relationship in their evolution, they then maintained it throughout all higher forms. The smaller sperm cell is always motile and is able to maintain sustained movement, while the egg is large and immotile. Such gametes are referred to as **heterogametes** and their fusion, **heterogamy.** After sexual reproduction became established it was retained, and while we see a rather wide range in sizes and shapes of both eggs and sperms, the fundamental plan remains unchanged in all animal groups.

The methods of bringing eggs and sperms together is relatively simple among both the lower invertebrates and the lower vertebrates. The union is purely fortuitous, although some arrangement, such as seasonal aggregations, is usually provided so that the animals will be in the immediate vicinity of one another. As long as the animals remain in a fluid environment, all that is necessary is to discharge the sex cells into the water where by sheer chance they are brought in proximity to each other. However, when animals invaded the land the whole process became much more complex. It must have taken a long time to accomplish this transition along with the many others resulting from the pronounced change of habitat. Perhaps the most interesting modifications came about among the vertebrates, some of which we have already discussed.

Care of the young

Among the vertebrates there are three ways in which young are cared for in their early development (Fig. 21-2). Some are hatched from eggs that are laid, as in the case of most fishes, amphibia, many reptiles (Fig. 21-3) and all birds. These are called **oviparous** forms. Others retain the eggs within the uterus until they hatch, and the resulting young are therefore born in a relatively advanced and active stage of development. These are said to be **ovoviviparous.** Some fish and some reptiles (snakes) are of this type. Still other vertebrates (mammals) produce small eggs without yolk that develop in the uterus and the young receive most, if not all, of their nourishment from the uterine wall of the mother. These are said to be **viviparous.** Young born thus are, of course, more or less advanced in development.

In general, fishes and amphibians give their young little or no care whatever and consequently no provisions in the way of accessory structures are found in these animals (Fig. 21-4). However, when the reptiles moved onto land, certain anatomical modifications were essential if the young were to survive in a dry environment. For one thing, the egg became very large, abundantly supplied with reserve food for the developing embryo, thus providing a means for the embryo to reach a rather advanced stage before it had to shift for itself. Besides this food reserve, the egg had to supply a fluid environment in which the embryo could develop. In other words, a

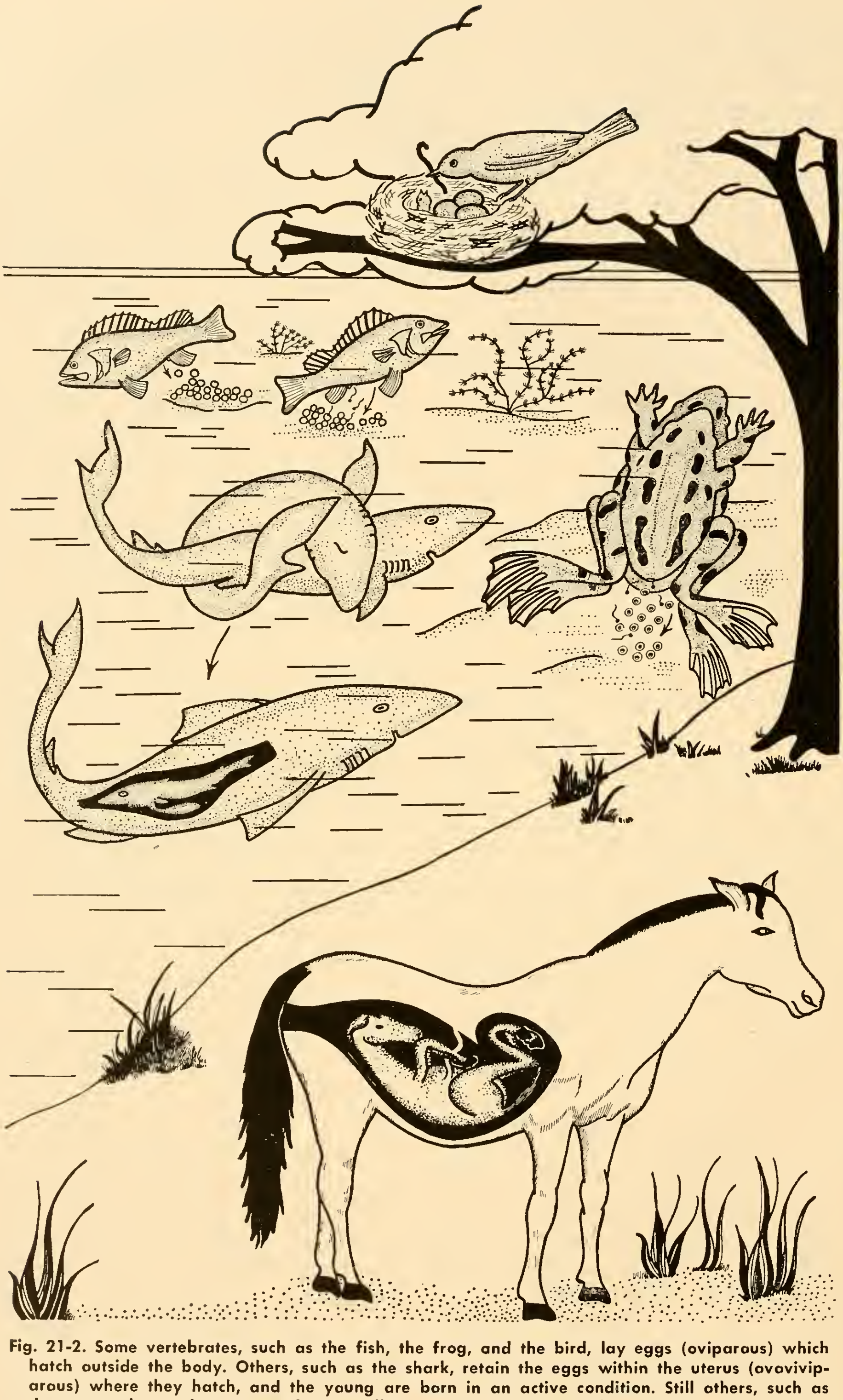


Fig. 21-2. Some vertebrates, such as the fish, the frog, and the bird, lay eggs (oviparous) which hatch outside the body. Others, such as the shark, retain the eggs within the uterus (ovoviviparous) where they hatch, and the young are born in an active condition. Still others, such as the mammals, produce young from small eggs (viviparous) and the young receive nutrients from the uterine wall.

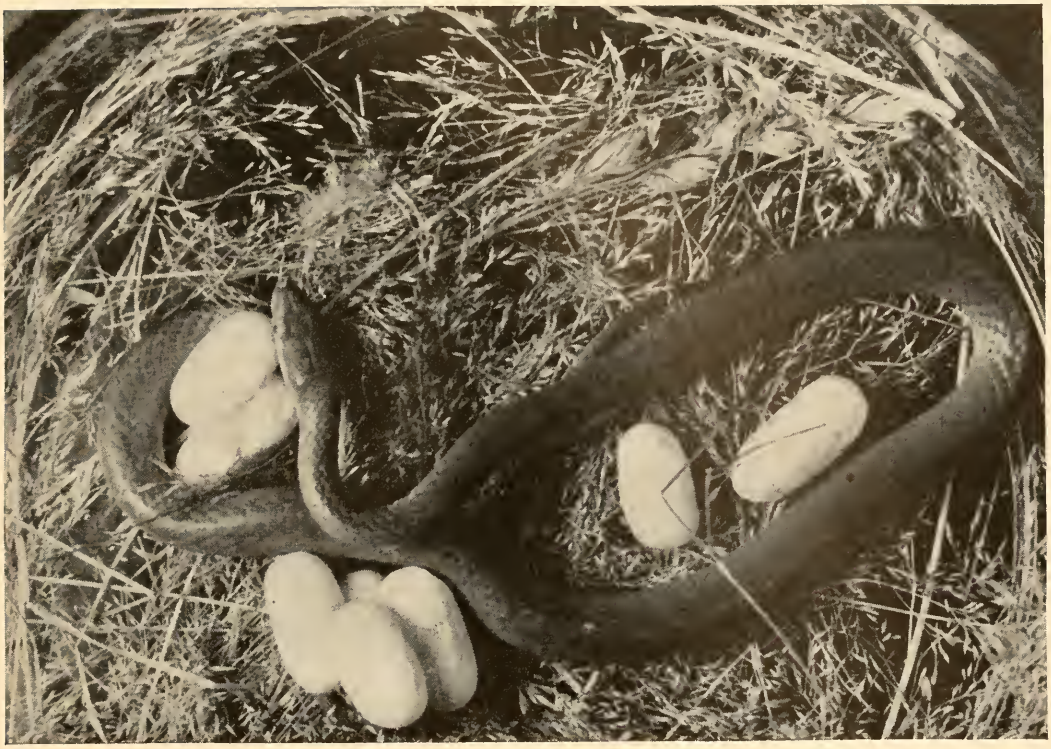


Fig. 21-3. Some snakes, such as the green snake shown here, lay eggs. The outer shell is leathery and wrinkled.

tiny bit of its ancestral aquatic world had to be incorporated into the egg. This was supplied by the introduction of the **amnion** (p. 320). Moreover, as the embryo advanced in its development it required more oxygen than could be supplied by diffusion to the embryo directly. The development of the **allantois** (p. 320) met this need (Fig. 21-4). Large eggs, together with their extraembryonic membranes, served very well for the reptiles and birds. The former reached great heights as dominant worldwide animals during the Mesozoic Era and the latter are a dominant form today.

However, the keen swift-moving mammals that were to follow developed a new approach to this problem. When their embryo began to receive nourishment from the uterine wall via a special organ, the **placenta** (p. 338), the large food reserve of the reptilian egg was no longer necessary, although the membranes of the latter were retained. Gradually the yolk disappeared, but the yolk sac, though empty, still remained (Fig. 21-4). Let us examine these extraembryonic membranes a little more carefully.

The **amnion** is an outfolding of the body wall of the embryo and is lined with peritoneum, the lining of the **coelomic cavity.** This membrane continues to grow around the embryo until the latter is completely enveloped and lies in the resulting **amnionic cavity.** The membranes fuse at their point of juncture, so that the cavity is a closed, fluid-filled sac reminiscent of the aquatic environment that was the home of all earlier embryos. Because the amnion is double-walled, an outer layer, called the **chorion,** is formed. In birds and reptiles the chorion comes in contact with the inner layer of the egg shell, whereas in mammals it comes in contact with the uterine wall and ultimately becomes a part of the placenta.

The **allantois** arises as an outpushing from

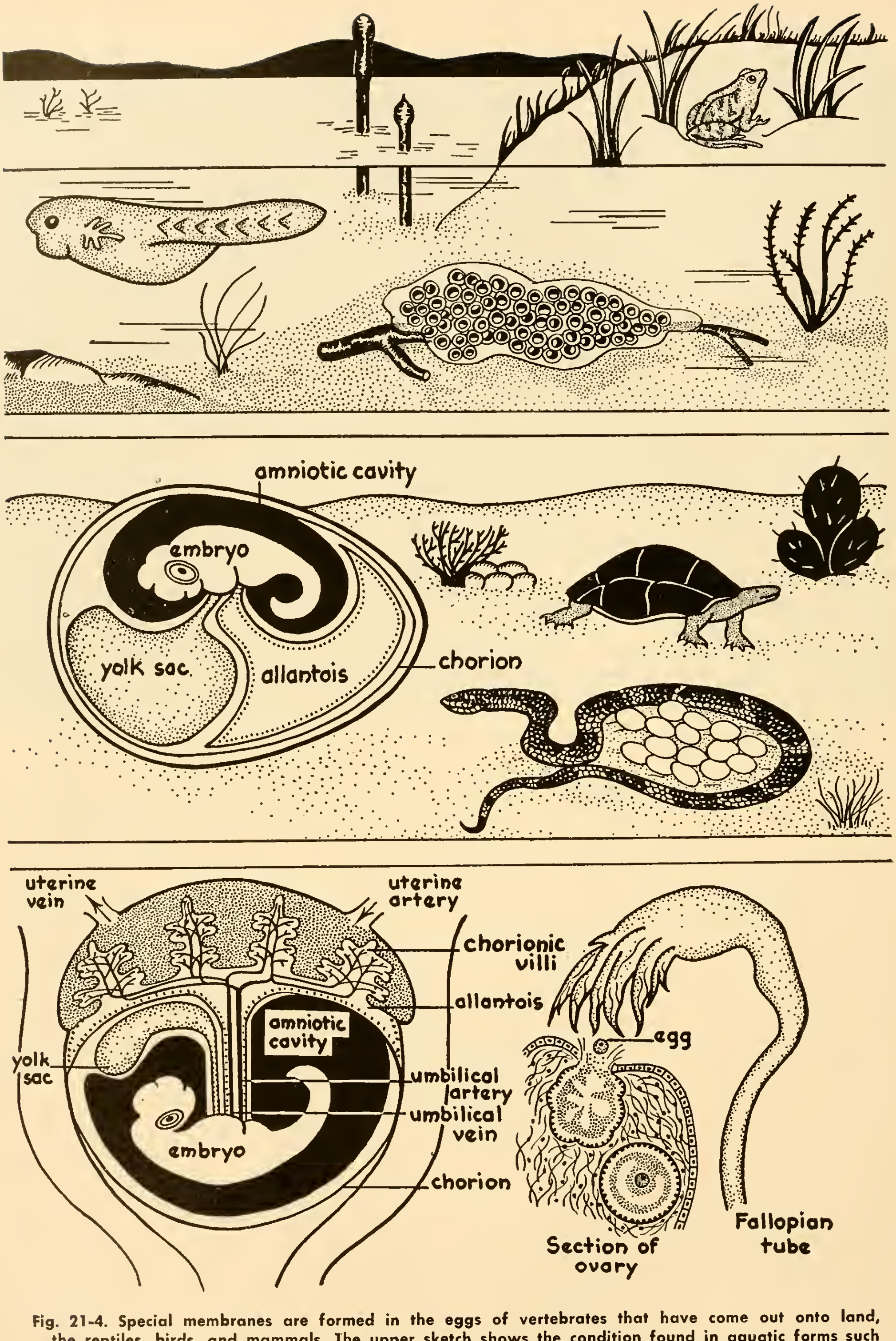


Fig. 21-4. Special membranes are formed in the eggs of vertebrates that have come out onto land, the reptiles, birds, and mammals. The upper sketch shows the condition found in aquatic forms such as fish and amphibians. The middle figure shows the formation of the amnion and allantois to make embryological development on land possible. In these eggs there is sufficient stored food (yolk) to carry the embryo throughout its early development. In the lower figure is shown the condition found in mammals where, in addition to the membranes seen in the earlier forms, the placenta has evolved, making it possible for the embryo to receive nourishment from the mother.

the posterior gut and forces its way into the extraembryonic cavity to become a large sac-like structure, the outer layer of which fuses with the chorion. The resulting intimately fused membrane then lies in close proximity with the inner surface of the shell in birds and reptiles but in mammals eventually becomes a part of the placenta. The allantois functions as a respiratory organ in picking up oxygen and giving off carbon dioxide for the developing embryo; in addition, it absorbs food materials from the large egg of birds and reptiles and acts as a repository for nitrogenous wastes.

In higher mammals the allantois, together with the chorion, comes into temporary contact with the uterine wall where the chorion sends out finger-like projections, the **chorionic villi**, deep into the wall's soft tissues. This region of contact is richly supplied with capillaries from the **umbilical artery**. Embryonic blood is sent to this region under the impetus of the fetal heartbeat and returned to the embryo via the umbilical vein. Simultaneous with the development of the chorionic villi, the uterine wall in the same region becomes highly vascularized, forming many blood spaces into which the finger-like villi dip. This entire region is known as the **placenta**, which is shed at birth. It must be remembered that there is no blood connection between the embryo and the mother; each has its own circulation which is kept distinct at all times. The placenta acts like the attachment organ of a fungal parasite—a means of extracting nourishing fluids from the "host." Through this organ oxygen is obtained, carbon dioxide is eliminated, food is absorbed, and nitrogenous wastes (urea) are discharged.

Evolution of external structures

We usually think of the need for external genitalia to facilitate the union of the sex cells as directly related to the change to life on land. To be sure, such accessory structures were essential for land life, but we must not forget that copulatory organs did evolve among fishes that never left the water. The sharks again are a striking example. The **claspers**, which are modified pelvic fins in the male shark, are utilized as an intromittant organ for carrying the sperm to the cloaca of the female (Fig. 21-2). Many bony fishes also have converted their fins into a copulatory organ. These are unusual cases among the fishes and most of them have so little external sexual dimorphism that even the best ichthyologists have difficulty in telling male from female. This is no problem for the fish, however!

Among the strict land vertebrates—reptiles, birds, and mammals—a special copulatory organ, the **penis**, has evolved. Among the reptiles it is a pair of elongated masses of erectile tissue with a groove between, the entire structure originating from the floor of the cloaca. In mammals the groove is closed to form a tube which is a direct continuation of the urethra. The terminal portion of the female tract has followed a parallel evolution by becoming transformed into a tube-like receptacle, the vagina, for the penis and seminal fluid.

Along with these changes has come the introduction of a large complex of chemical regulators (hormones) and certain nervous modifications which has made copulation not only a necessity for the continuance of the race but a highly gratifying experience. During the breeding period of large mammals such as cattle both sexes will go to great lengths, even exposure to death itself, in order to tend to the business of bringing about the union of their sex cells. Owners of female dogs are well aware of the semiannual heat cycle of their charges. This intensity of the sex drive in animals is imperative for race survival. One can imagine how long any race would last if it were lethargic in this respect. It is easy to understand how those animals with the greatest sex drive were more apt to become the parents of the next generation, whereas those indifferent in this regard might never

Fig. 21-5. Among the fishes with cartilaginous skeletons (sharks and skates), two entirely different ways of caring for the young are observed. The top picture is the partly cut away egg case of the barn door skate (*Raja stabuliformis*), showing the embryo skate lying within. These eggs are laid in marine vegetation where the long tendrils on the four corners of the egg case anchor it during the incubation period.

The lower picture is of a small shark (*Mustelus*) embryo removed from the uterus of the mother. The long umbilical cord is attached to the half empty yolk sac which supplies nourishment for the embryo during its early life. In its later embryonic life there is a "placenta" formed in which nutrients and gases pass between the fetal and maternal circulation.

become parents at all, so that with their death their indifference would also become extinct.

Evolutionary significance

Viewing the vertebrates in a general way, it is true that giving birth to active young is more advanced than egg laying. There are, however, a number of very interesting primitive vertebrates, the sharks, for example, that have progressed a long way toward producing and caring for young in much the same way mammals do. Some sharks inhabit the deep sea and never come into shallow waters to deposit their eggs in safe places. In such species, the eggs are retained in the uteri where they can be better cared for. In one small shark (*Mustelus*) tiny projections, like villi in the intestine, protrude from the yolk sac and penetrate the uterine wall from which the embryo derives nutritious secretions (Fig. 21-5). This condition certainly approaches the placenta of mammals; indeed, these sharks are called "placental" sharks. Another interesting device for extra-egg nourishment of the developing embryo is found among the rays, close relatives of sharks. In some of these animals, glandular teats grow out from the inner uterine wall and by contractions force their secretion into the mouth or spiracle of the embryo, thus resembling extrauterine feeding of mammals. In spite of these rare cases, it is generally true that evolution of the reproductive system among vertebrates has been from the egg-laying forms to those that retain and nourish their young within the uterus of the mother.

We can make one further generalization, constantly keeping in mind the occasional exception which prevents one from drawing final sweeping conclusions. Most primitive animals make headway by sheer weight of numbers; millions are produced but only a small fraction of a per cent survive to maturity. As the animals become more complex, fewer and fewer offspring are produced but the early mortality rate drops also. With smaller numbers greater parental care is given, so that the percentage of survival is much greater. The fish deposits its eggs in a scooped-out hollow on the stream bottom and immediately leaves them to the ravages of other fish. A large mammal like a horse bears young only once a year but gives the offspring great care, even to the point of sacrificing her own life (Fig. 21-2). In each case the chance for race survival may be the same. Immediately we can think of exceptions to this generalization. The codfish, for example, lays millions of eggs each season, whereas the shark may have no more than a dozen in an equal period of time, yet the shark is more primitive than the cod. Frogs and toads give their young no care whatever, but the bluegill (fish) will protect its nest of eggs viciously against all intruders. These are good examples to remind us of the caution one must exercise in stating a generalization.

THE HUMAN REPRODUCTIVE SYSTEM

Although there are minor differences in the reproductive apparatus among various mammals, they are all essentially alike, man included. One rather striking variation has undoubtedly had considerable influence on man's habits and indeed his entire social structure. That is the lack of a seasonal or periodic breeding season. The sexes are mutually attractive throughout the year. This fact probably has had some bearing on the establishment of permanent unions that could provide for offspring which required such long periods of time for growth to maturity. This is the basis of the family which, in turn, underlies our whole social order as we know it in civilized nations today. It should not be implied, however, that man is by nature fitted perfectly into the strait jacket of civilization he has fashioned for himself. In fact, he is constantly in

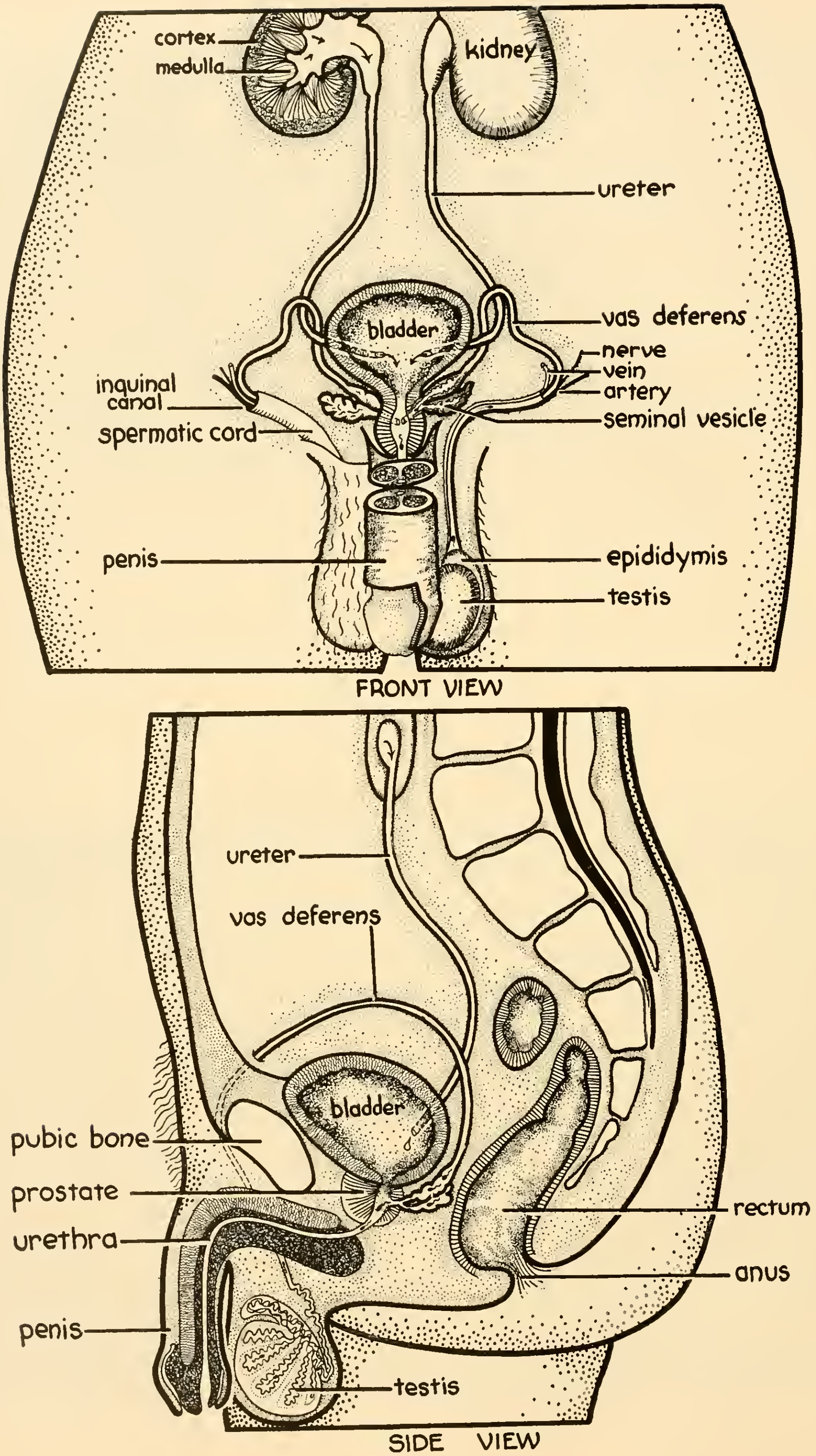
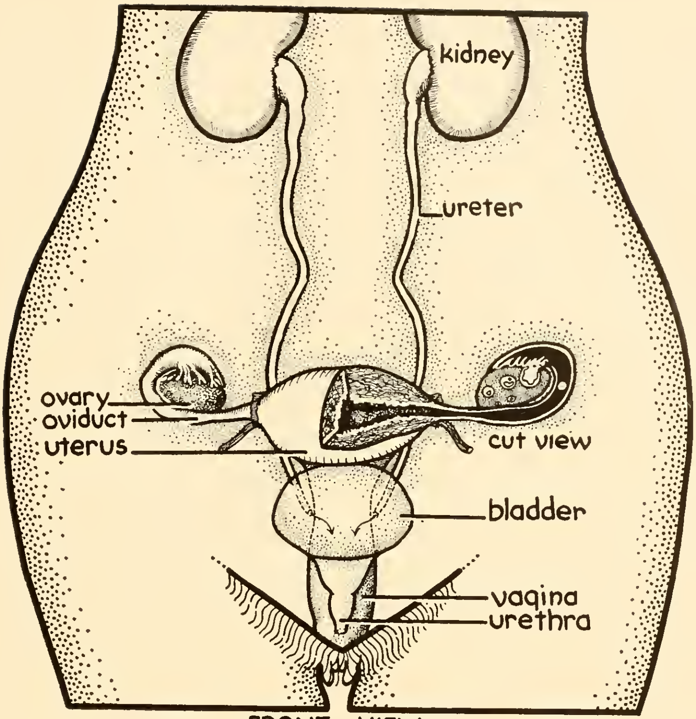
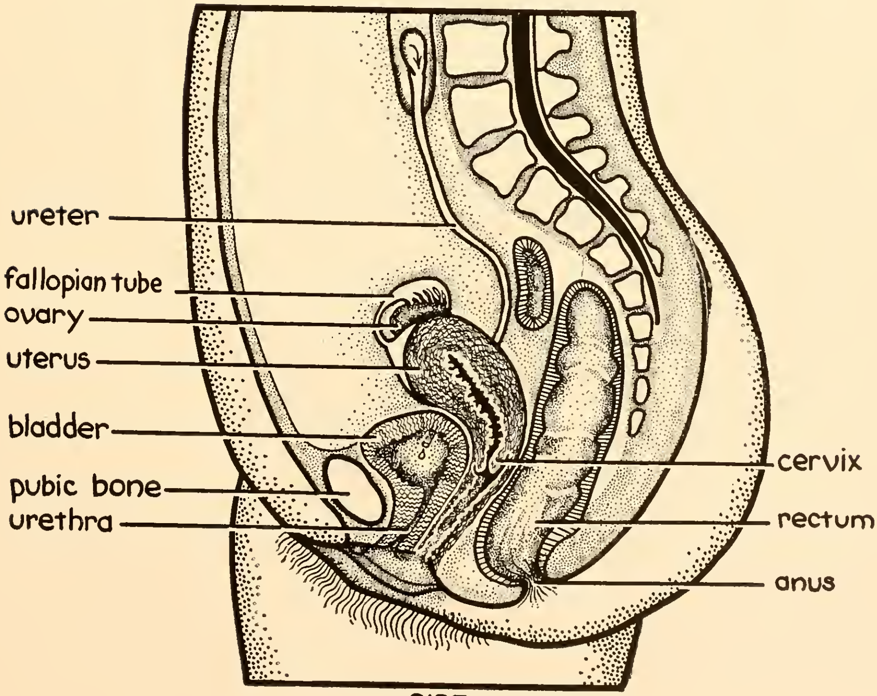


Fig. 21-6. The human male reproductive system.



FRONT VIEW



SIDE VIEW

Fig. 21-7. The human female reproductive system.

trouble with those individuals who tend to break with established convention and to follow basic instinctive urges. This applies to sex urges as well as others. It is important that we recognize these basic urges as normal and regulate our social order accordingly. This attitude has not always been maintained in the past, but as knowledge grows concerning human behavior we shall eventually reach a better understanding of what curbs can be placed on basic instincts that will benefit society and thus make for a more successful civilization.

Male

The sperm-producing glands are the **testes**, which are very similar in their anatomy to the same organ in other mammals. Sperms are produced by rapidly dividing cells located in the walls of the long, tiny, coiled tubules which, taken together, make up most of the gland itself (Fig. 21-6). The paired testes lie in a pendant sac, the **scrotum**, which is located in the pubic region. Sperm cells make their way out of the testes into the **epididymis**, a long convoluted tubule, where they mature and are stored for a time. They then pass into the **vas deferens**, a thickened sperm duct that passes anteriorly through the **inguinal canal**, finally entering the **urethra** and thence through the **penis** to the outside. Near the region where the two vasa deferentia enter the urethra each receives secretions from the glandular **seminal vesicles**. Also at this junction the **prostate gland** surrounds the urethra and pours its secretions into it. The secretions from both the prostate gland and the seminal vesicles provide a transport medium for the sperms.

The penis is composed of a special tissue with large capillaries called **erectile tissue** which, when gorged with blood, causes the organ to become much enlarged and turgid. In such condition it becomes a satisfactory organ for transferring sperms to the vagina of the female. Erection is accomplished when, under sexual excitement, the small arteries leading to the penis relax, allowing blood to fill the large capillaries; at the same time the veins constrict where they leave the organ, thus trapping blood within it. The organ becomes flaccid by a reversing of the process. The penis ends in a cap-like structure, the **glans**, which is partially covered by loose skin, the **prepuce**.

Because of the anatomical arrangement of the male generative organs, certain difficulties may be experienced, especially by older men. For example, if the prostate becomes enlarged, which it not infrequently does, elimination of urine becomes difficult because the urethra is squeezed shut. Another difficulty arises from the fact that when the testes descend through the inguinal canal into the scrotum some weeks before birth, a weakened area is left at the point where the spermatic cord perforates the abdominal wall. If, at some later time, sufficient pressure is brought to bear on this area, a small segment of the gut may be forced into this canal resulting in an inguinal **hernia**. This sometimes occurs during birth when the child is apt to be squeezed unduly while passing through the small birth canal. If further constriction occurs, the circulation to the gut may become so impaired as to kill the region, thus resulting in gangrene which can be very serious.

Female

The egg-producing **ovaries** lie deep in the lower body cavity where they function much as they do in lower vertebrates (Fig. 21-7). Their function is to produce sufficient eggs to maintain the race, and since the chances for fertilization in mammals are very good only a comparatively small number are actually generated. The cells destined to become eggs lie in the periphery of the ovary and as they mature migrate into the deeper portions (Fig. 21-8). Several layers of cells form around each egg at

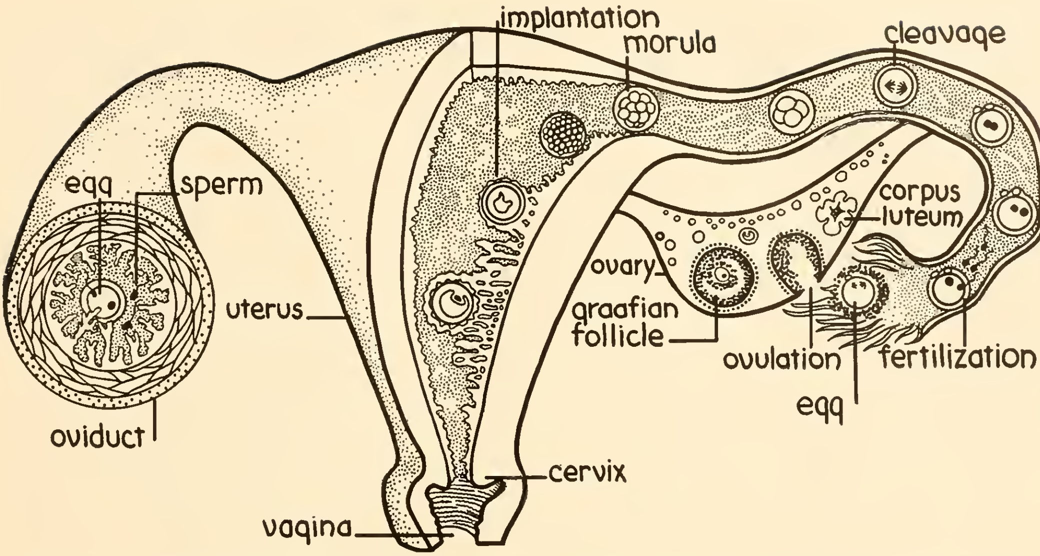


Fig. 21-8. The human ovary and uterus cut in such a way that the pathway of the fertilized egg can be followed. Note that fertilization occurs in the upper end of the oviduct. One of the oviducts is cut in cross-section in order to show the nature of its lining.

first; later a liquid-filled cavity appears, in which the egg floats, being attached by a thin stalk to the inner wall. The entire structure is now known as a **Graafian follicle.** When mature it is over 1 centimeter across and is located near the periphery of the ovary once more. The region nearest the outer edge of the ovary thins out and finally splits, allowing the follicular contents to be extruded into the body cavity, a process known as **ovulation.** The tiny egg (about 200 microns across) is carried out with the fluid and is subsequently drawn into the funnel-like terminal end of the oviduct (Fallopian tube), which is lined with beating cilia that create a current directed into the oviduct. Occasionally the egg gets "lost" in the coelom and never reaches the oviduct. If, however, it should be fertilized while outside the confines of the oviduct, which sometimes happens, the embryo may become attached to any convenient organ, including the ovary itself, and develop for some time. It usually is unable to go to full term, however, and aborts, causing severe internal hemorrhages that may be fatal if immediate care is not given.

Fertilization

The union of the egg with a sperm must occur at a rather specific time because neither is long-lived. Fertilization is most apt to occur if sperms are in the vicinity of the egg within a few hours after ovulation and it usually does not occur if more than three days elapse before the union is possible. Ovulation is definitely timed with respect to the menstrual cycle, usually occurring about the fourteenth day following the onset of menstruation. There may be rather wide variations in unusual cases, but as a rule a day or two before or after the fourteenth day will find the egg in the oviduct where it may be fertilized if sperms are in the vicinity. Sperms deposited in the upper end of the vagina make their way through the **cervix** (Fig. 21-8) and **uterus** into the oviducts in a matter of several hours. It is interesting to note that it seems to be essential that millions of sperms be supplied at once in order that only one

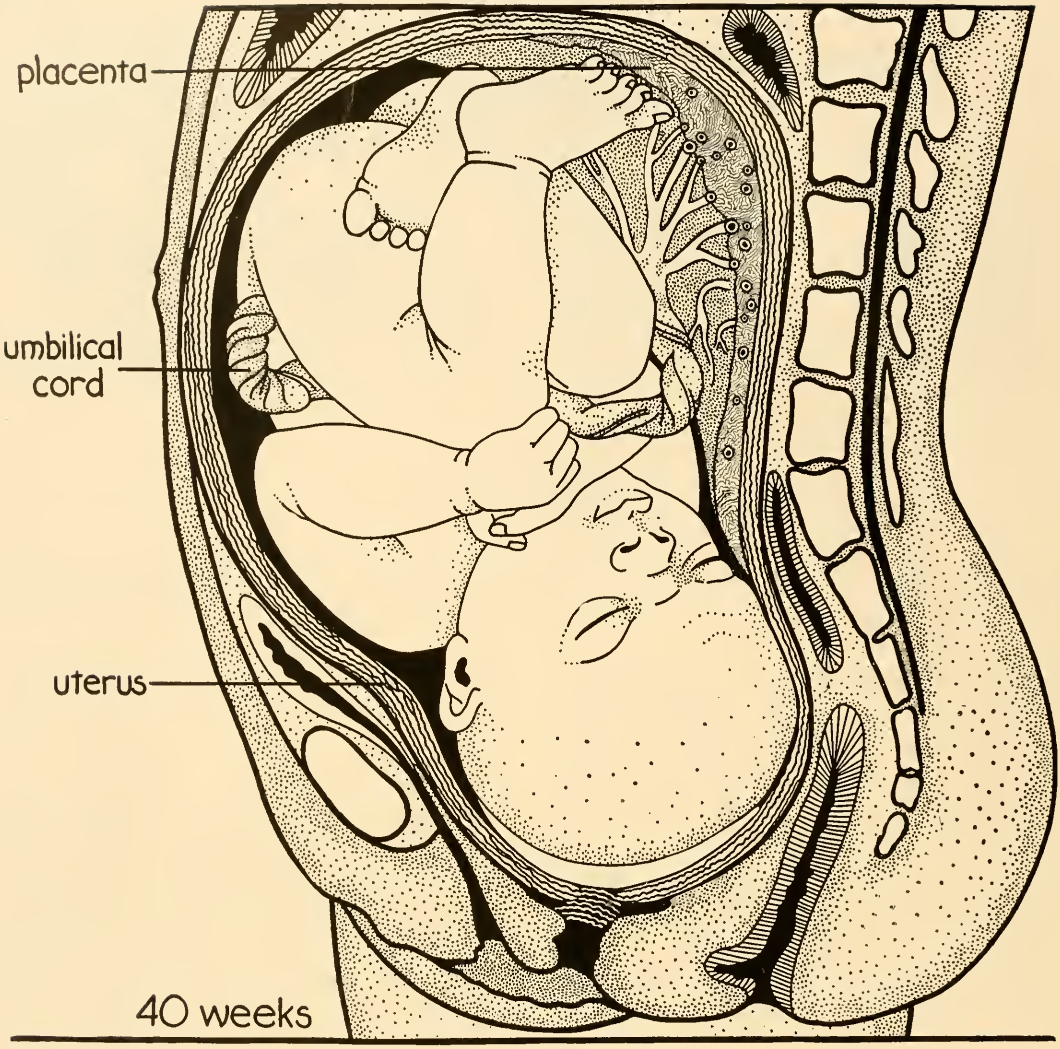


Fig. 21-9. The full-term fetus shown in its normal position just before birth.

reach its destination, even though only one is necessary for fertilization. Apparently the coöperative effort of many is needed to digest their way through the mucous lining of the female generative apparatus.

Once the egg is fertilized, it divides several times en route down the oviduct, and by the time it reaches the uterus it is a ball of cells (Fig. 21-8) and is ready for **implantation**, that is, to become attached to the uterine wall. During the time these things have been happening to the egg, the uterine wall has been preparing itself for the reception of the young embryo. When the embryo reaches the uterus, it is actually drawn into the uterine wall because of the receptive nature of the lining itself. Once implanted, the embryo grows rapidly, starting as a tiny reddened spot and finally, after approximately 40 weeks, becoming a full term **fetus** (Figs. 21-9, 21-10). This entire process is intricately linked with a complex battery of hormones which has been referred to in an earlier section (p. 439).

During intrauterine life the embryo must develop a complete set of organs—lungs,

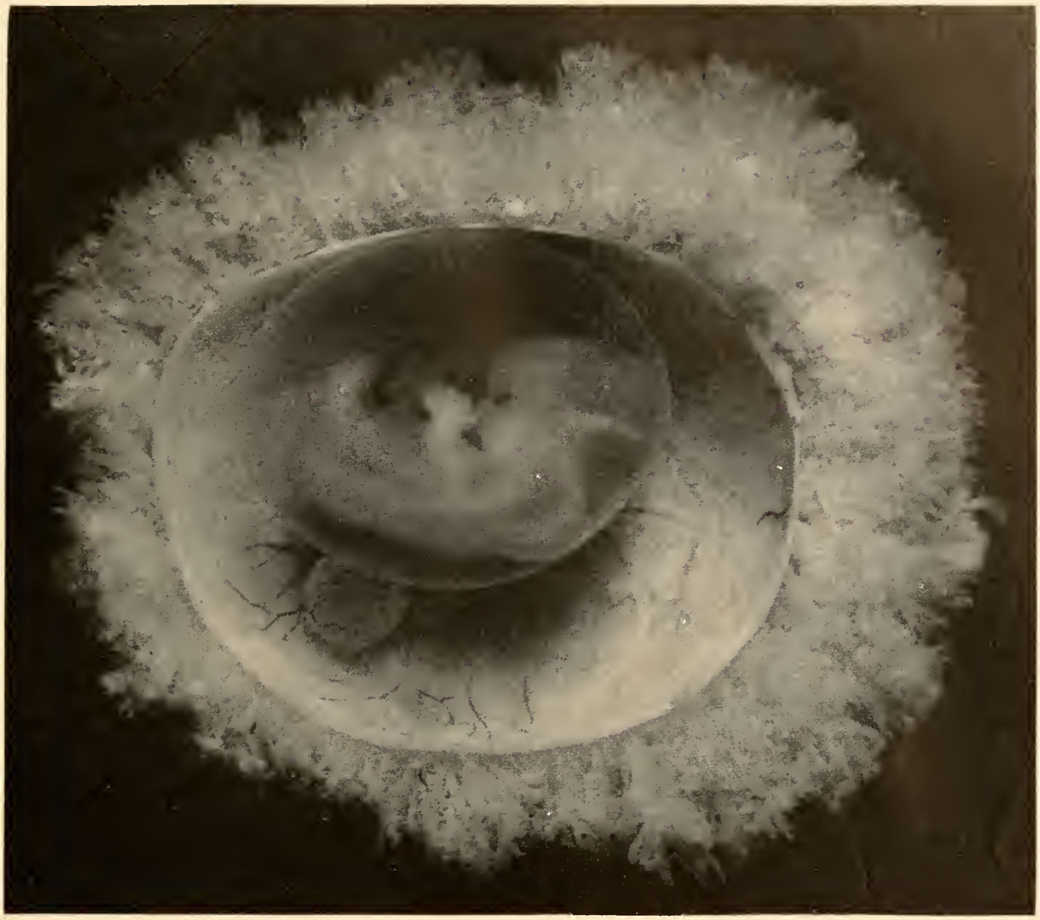


Fig. 21-10. A human embryo (about six weeks old) floating in the amnionic cavity. The spherical-shaped body in the lower left is the yolk sac. The feathery nature of the chorion is shown. The part nearest the viewer has been cut away.

digestive system, excretory system—and all except the circulatory system have never functioned but must be ready to do so within a matter of minutes after birth. All of its nourishment and oxygen have come to the embryo through the umbilical vein from the placenta, and all of its waste products (carbon dioxide and urea) have been delivered through the same organ. Its lungs have never breathed, its kidneys have never excreted, and its digestive tract has never functioned, yet within a few minutes after it is born all of these organs begin performing their jobs and, almost without exception, they function perfectly from the very start. The most dramatic change occurs in the circulation.

The blood path through the fetus is quite different from that in the adult (Fig. 21-11). Obviously, circulation of blood must start very early in the developing fetus because it is only through the circulation that nourishment and the elimination of wastes can take place. The blood must be pumped to and from the placenta at a rapid rate during **development**, hence the circulatory mechanism is one of the first organs that is well developed in the fetus. The beating fetal heart is easily detected with a stethoscope long before the child is born. Since

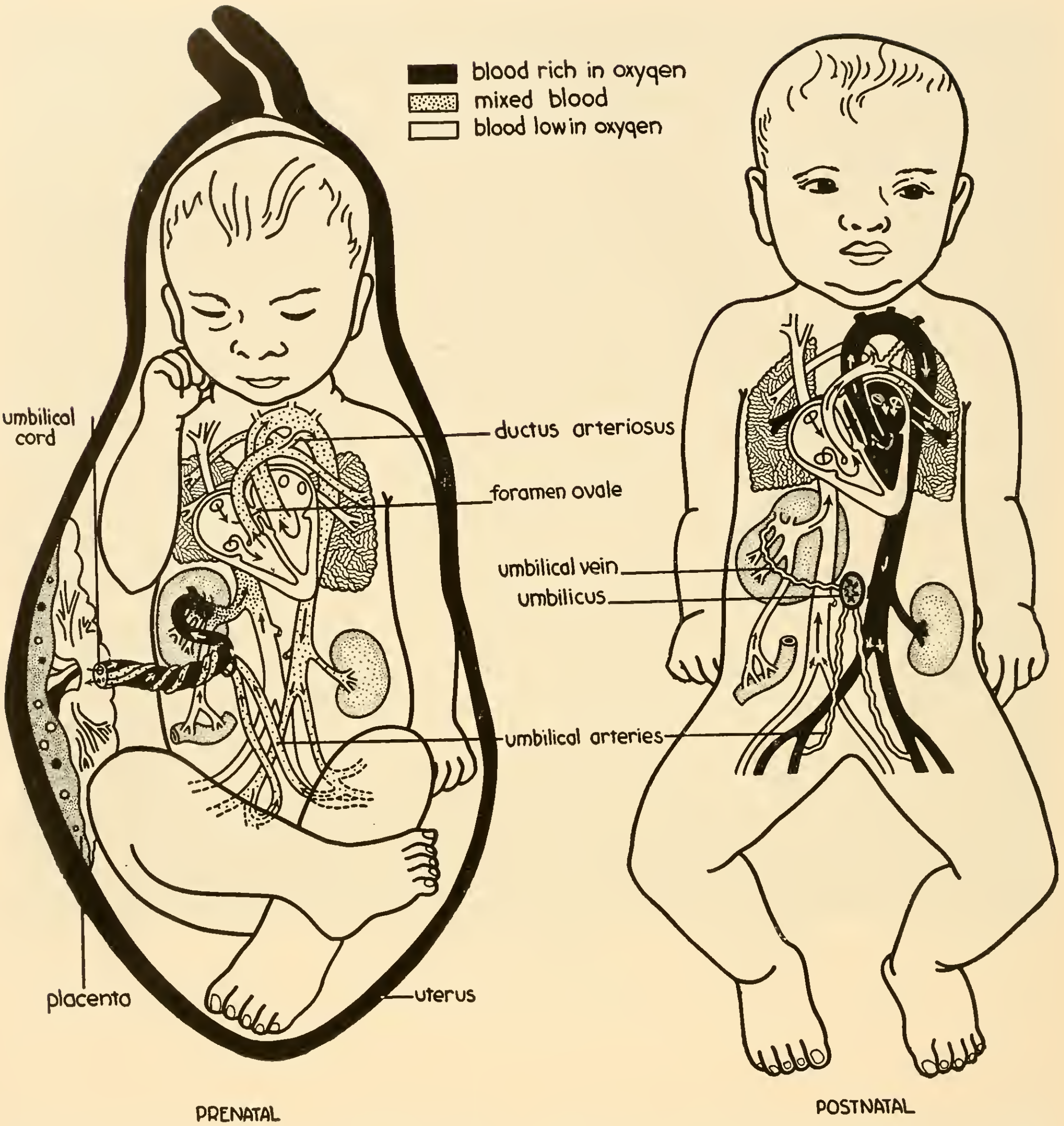


Fig. 21-11. The blood pathway is quite different during fetal life than it is after birth. These changes are indicated in these sketches.

there is no point in sending blood through the non-functional lungs, the heart has modified the main blood flow through itself, and functions essentially as a single organ rather than the double one of the adult. This temporary detour has meant that the fetal heart must be constructed on a slightly different plan than the adult heart. There is an opening between the auricles, the **foramen ovale,** which allows incoming blood from the great veins to fill both auricles simultaneously. When the blood is forced out from the ventricles, that coming from the right ventricle, which in the adult goes to the lungs, is short-circuited through a large, short connection, the **ductus arteriosus,** to the aorta. Very little blood goes to the lungs so very little comes back to the left auricle. Almost the entire output from both ventricles therefore passes out into the general circulation. This is necessary because the blood must be forced through the paired **umbilical arteries** to the placenta, which is a highly vascular organ requiring large quantities of blood. The blood flows in this path throughout fetal life, while the organ systems are being developed so that at the moment birth occurs they will function properly.

The basic structure of the human embryo is well delineated by the end of the twelfth week of intrauterine life, although there is a great deal of growth that must take place before the child is ready for the rigorous life that awaits him in the outside world. The uterine wall keeps pace with the growing embryo and the added burden gradually changes the entire body contour of the mother (Fig. 21-12). As the fetus grows it slips posteriorly, with its head low in the pelvis, and by the fortieth week of its life it is ready to be born.

Birth

The process of being born is one of the more remarkable events in the biological world (Fig. 21-13). As the fetus passes through the tight-fitting birth canal, the umbilical cord remains attached to the placenta, and until the moment the child takes his first breath nourishment and oxygen are received from this source. Upon exposure to the external world the usual stimulation coming from being chilled and from the high CO_2 in his blood causes the child to take his first breath. The partial vacuum created in the chest cavity causes the blood to be diverted from the ductus arteriosis into the pulmonary artery and lungs. This is aided by a powerful sphincter muscle surrounding the ductus arteriosis which contracts at this moment and never relaxes. The large volume of blood then makes its way back to the heart through the pulmonary veins, filling the left auricle. Since this chamber is now filled from a new source, it is no longer necessary for an opening to exist between the auricles, hence a flap of

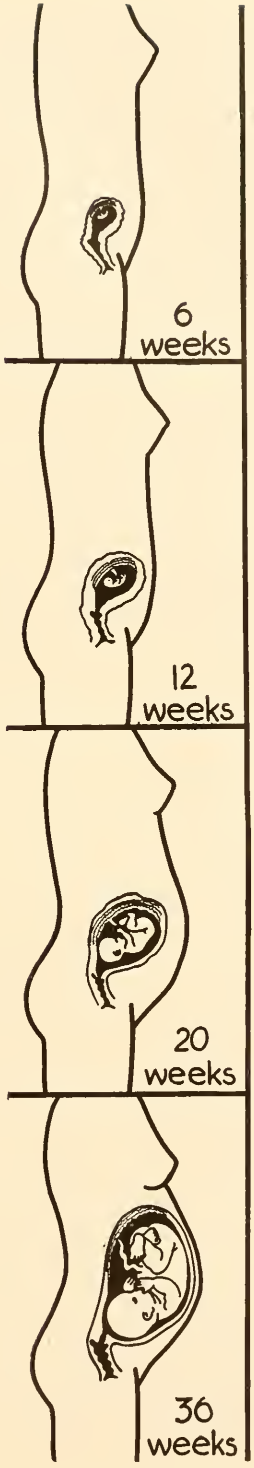


Fig. 21-12. Changes occur in both the uterus and the mother to accommodate the developing fetus.

Fig. 21-13. A series of models showing the various stages in the delivery of a baby. The placenta remains attached to the uterine wall for some time after the child is born. It is then shed and the uterus returns to its normal size.

tissue closes the foramen ovale. It requires a few minutes for this adjustment to take place, during which time the child is bluish in color, but gradually he becomes pink as the circulation is separated into its pulmonary and systemic parts. It is indeed amazing that with all its complications this process so seldom fails.

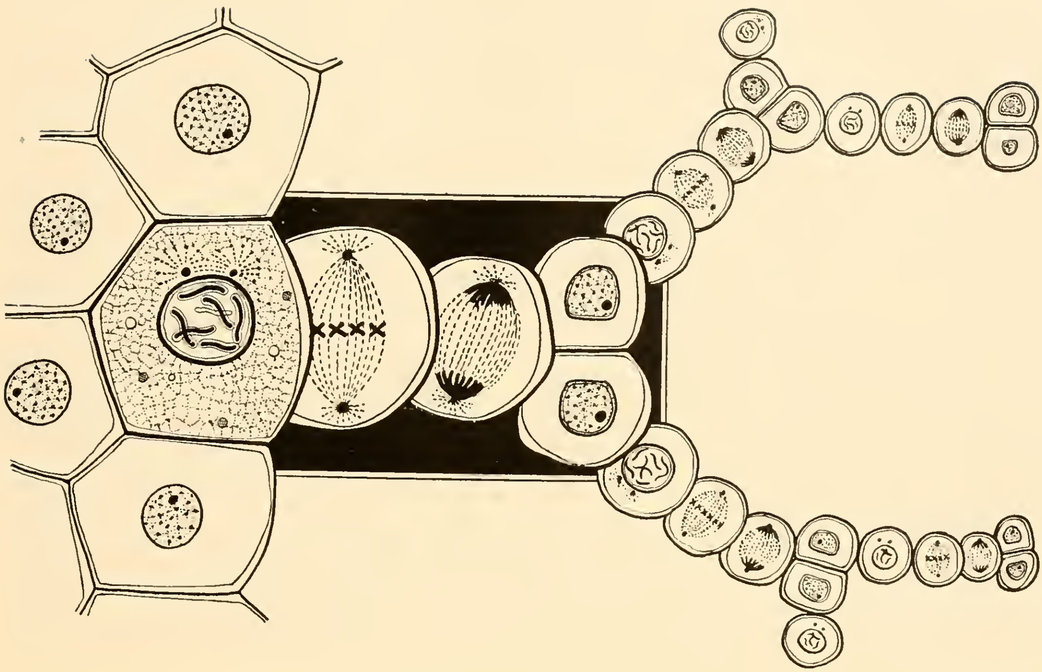
However, if the foramen ovale does fail to close or something else goes wrong with the mechanism for separating the blood, the baby remains bluish in color, a condition given the term *blue baby.* He is bluish in color (cyanotic) because the oxygenated and reduced blood are mixed, just as they are during fetal life. Some remarkable surgery has been accomplished in recent years to correct such occasional defects.

We have now completed the story of the *Rise of Animal Life,* starting with the single-celled animals and culminating our discussion with the mammals, man in particular. We have also considered in each group how the problem of perpetuation was solved, but this was always at the level of an individual, a protozoan or a mammal. We must now consider the problem of the continuity of life in its most fundamental aspects. We must attempt to answer such questions as: how do genes duplicate themselves, how do cells duplicate themselves, how can a single cell such as a fertilized egg give rise to a complex form like an earthworm or a man, and finally what underlying mechanism makes it possible for a race to continue apparently unchanged for many generations? These are some of the most perplexing problems in biology today and it is only recently that answers have begun to come forth. In the next Part, *Continuity of Life,* we shall examine some of these problems and a few of the answers as we know them today.

PART VI

Continuity of Life

CHAPTER 22



THE CONTINUITY OF CELLS

In Chapter 2 we learned the basic nature of protoplasm and that it must duplicate itself continuously. The large protein molecules in protoplasm have the power to duplicate themselves through metabolism, each kind producing others exactly like itself. Amino acids coming to the cell from without, together with those that are made by the cell itself, are built into the protein molecules of the cell in a very precise manner, so that every molecule of a certain type is exactly like every other one of that type. Just how this is done is problematical, but we are inclined to think it is through enzymes. As long as the proper amino acids continue to be present in the surrounding environment, the huge protein molecules continue to be formed. This is the beginning of a duplicating mechanism that is found among all living things and is the basis for the continuity of life.

DUPLICATION OF GENES

We must rely on chemical means to understand duplication of protein molecules but it is possible actually to see evidences of duplication of the huge protein molecules or aggregates of molecules which we call genes. Genes are confined to chromo-

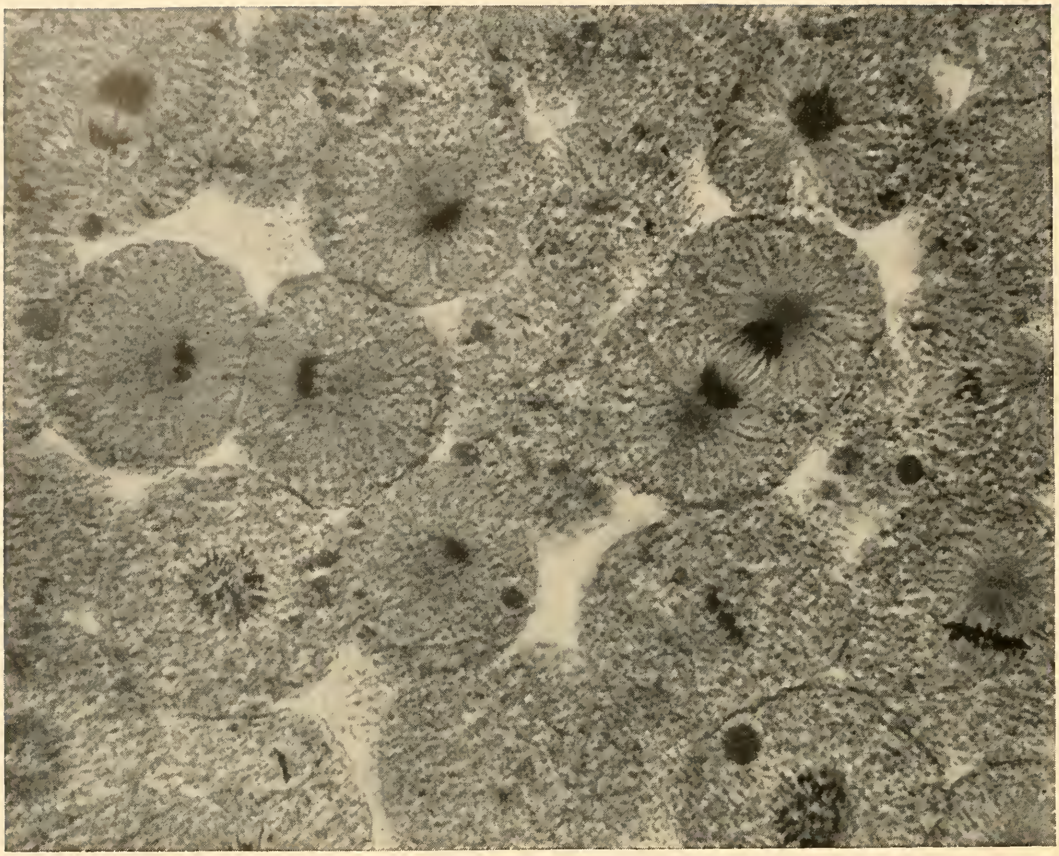


Fig. 22-1. Mitosis in the whitefish early embryo.

somes, which under the most powerful light microscopes appear to be string-like masses of dark-staining bodies (Fig. 24-4). The most careful studies with both light and electron microscopes lead us to believe that the genes are arranged in a linear fashion within the chromosomes which are enclosed in a thin sheath.

When reproduction occurs in a chromosome, a new string of genes forms alongside the original, and it is an absolute duplication of the first in every detail. The new chromosome apparently forms by accumulating the proper constituents from the surrounding protoplasm under the influence of the original chromosome. It is as if the chromosome were a template from which another, exactly like itself, can be produced; the newly formed one then becomes a template itself from which another can be formed, and so on. Just how this is done is still unknown.

DUPLICATION OF CELLS—MITOSIS

The duplication of genes and chromosomes is the first step in the ultimate duplication of cells. This is immediately followed by a division of the cytoplasm, resulting in two cells equal in respect to the genes which each bears. This process is called mitosis. The most significant aspect of cell division is the remarkably equal distribution of the chromosomes to the daughter cells. This is essential because the genes control the future metabolism and ultimate success or failure of the cell. This is beautifully illustrated by removing small portions of the cytoplasm of an egg and following the nucleated part in subsequent development. Such an egg will produce a normal embryo. However, if a chromosome is removed from the nucleus of an egg cell, will differentiate the chromosomes from other regions of the cell. Excellent preparations have been made of a large variety of dividing cells. Among them the early embryo of the whitefish affords some of the best material (Fig. 22-1). Let us study this

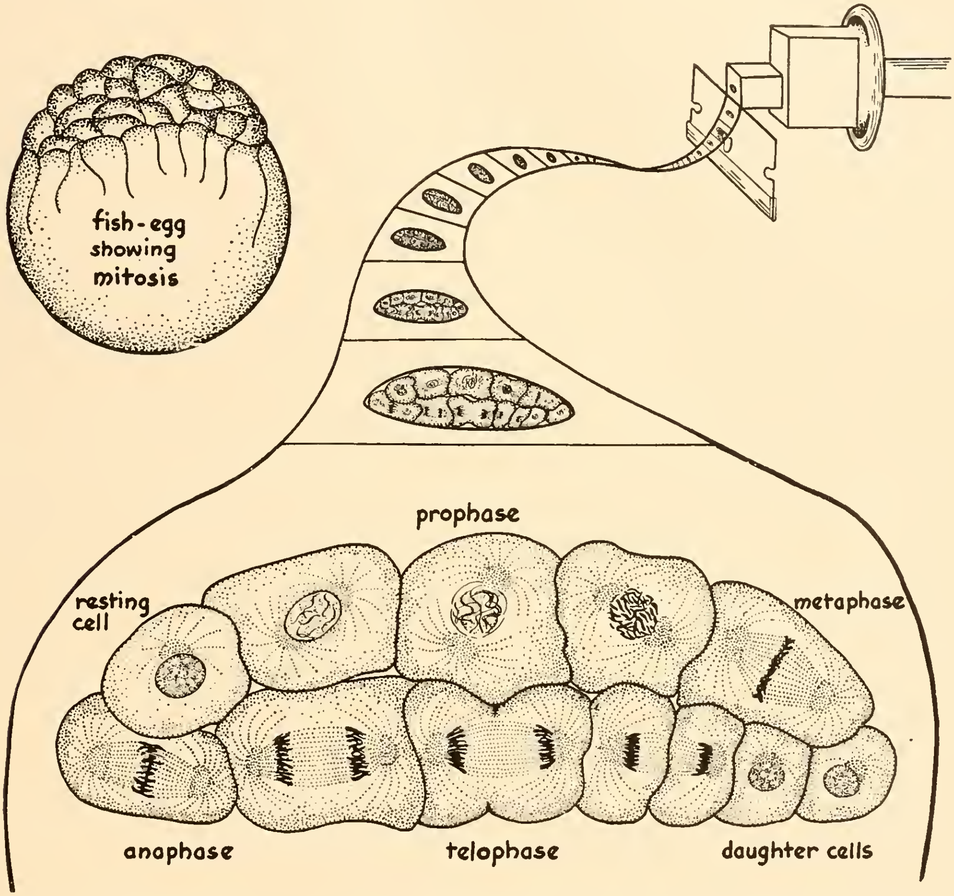


Fig. 22-2. Cell division can best be seen in embryonic tissues such as the early whitefish embryo (upper left). This tissue is killed, stained, and placed in a paraffin block. Then very thin slices (6-8 microns) are cut. These form a ribbon as shown here. When properly stained and mounted on a microscopic slide, the activity going on within the individual cells can be studied. The five stages in mitosis are schematically represented here.

it probably will not develop at all. Even if it should develop to some degree, the resulting embryo would be abnormal. Chromosomes are irreplaceable because the genes of which they are composed are vital to the life of the entire cell.

The process of cell division can best be seen in large cells that have been cut into thin slices and stained with some dye that particular form as representative of animal mitosis in general.

Biologists have agreed, for convenience, on five steps or phases which cells go through during the duplication process (Fig. 22-2). It must be remembered that there is no hard and fast line of demarcation between these phases because the process is a continuous one. They merely denote approximate stages. The so-called "**resting**" **phase**, or **interphase**, indicates the stage when there is little or no apparent activity in the nucleus. Actually, however, it is during this phase that growth is going on at a rapid rate and metabolism may in reality be at its peak. Under the microscope the chromosomes in this phase are sacculated and the chromatin appears to be dispersed.

The first signs that cell division is imminent are the separation of the **centrioles** (not seen in whitefish cells) and the gathering of the chromatin into what appears to be a fine thread. This is called the **early prophase.** Later, when the centrioles have reached the opposite poles of the cell, the nuclear membrane fragments and disappears. Simultaneous with this event, **astral rays** radiate out from the centrioles and fibers extend from one centriole to the other, forming a **spindle.** By this time, the chromatin has thickened and the chromosomes first appear visibly paired, although duplication has occurred at some earlier stage. The chromosomes move about rather haphazardly at this time but finally settle at or near the middle of the cell. This terminates the prophase and introduces the **metaphase** in which the chromosomes align themselves along the **equatorial plane** of the spindle, each pair being associated with a single spindle fiber. The paired chromosomes then are seemingly pulled toward opposite poles by the spindle fibers. There is considerable controversy as to just how they reach the poles, but all observations show that they are attached to the spindle fibers and probably manage to reach the poles of the cells through the influence of these structures in some manner not thoroughly understood. This migration stage is designated the **anaphase.** Finally a new nuclear membrane forms around the chromosomes which assume their characteristic dispersed condition observed at the beginning in the interphase. This is the **telophase.** The cytoplasm cleaves and finally the daughter cells are completely formed, ready to undergo a growth period before the next division is initiated.

While there are individual variations among animal cells, the process of mitosis is essentially the same in all cells. Many plant cells do not have centrioles and they separate the cytoplasm in a manner different from animal cells, but division of the nuclear elements is the same.

Factors regulating mitosis

Cells divide at varying rates in the different tissues of the body, some undergoing mitosis at extremely short intervals whereas others divide only rarely. For example, sperm cells are produced continuously at a tremendous rate in the mammalian testis, millions every day. Likewise, red blood cells are manufactured at the rate of 2½ million per second, meaning that an equal number of mitoses must occur. On the other hand, some cells such as those in the bones and nervous systems are rarely replaced, hence mitoses occur only rarely in these tissues. All of the cells in an embryo are undergoing rapid cell division but as the organism matures the tempo gradually slows down. Biologists have been and still are puzzled over the problem as to what controls this rate of cell division.

It is common knowledge that cells in the region of an injury divide more rapidly than those in the uninjured area. Obviously, the increased rate is essential if the wound is to be closed. Some biologists have been able to demonstrate the presence of a "wound hormone" produced by injured and dead cells which is thought to stimulate mitoses. This has been demonstrated in plants and it is thought that a similar mechanism may operate in animals.

There is also a purely physical reason why cells must divide when they reach a certain size. If small pieces of cytoplasm of an amoeba are cut away periodically the cell fails to divide at all. It seems that a certain ratio between the surface area of the nuclear membrane and the amount of

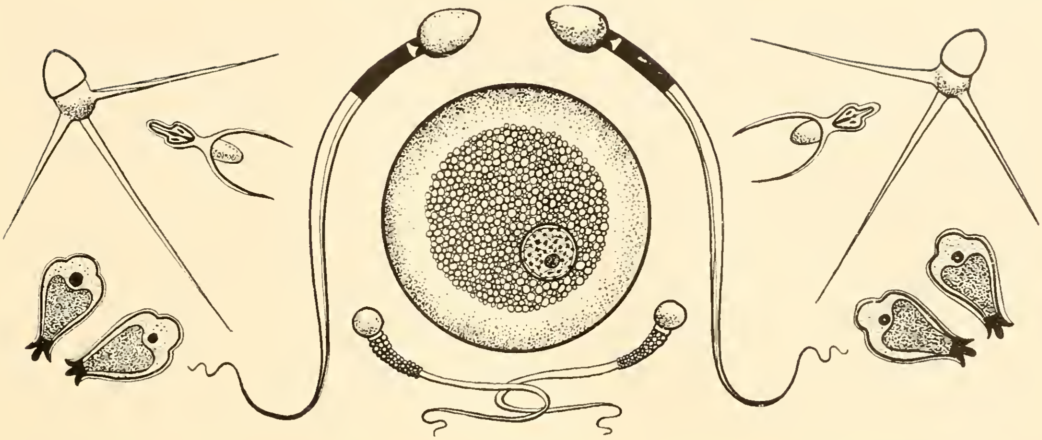


Fig. 22-3. A single egg and several different kinds of sperms are schematically shown here.

cytoplasm must be achieved before division can take place. When there is too much cytoplasm in relation to the surface area of the nucleus, exchange of vital materials cannot keep pace with the requirements essential to further growth. This may be an important factor in initiating cell division, for by nuclear division the nuclear surface area is doubled with no increase in cytoplasm, thus allowing growth to continue.

The significance of mitosis should be apparent when it is recalled that all the cells of our body have arisen by mitosis from the original fertilized egg and that every one of the quadrillions of cells contains the same numbers and kinds of chromosomes and genes that were present in that original cell!

A special kind of mitosis—meiosis

It has been implied that all cells divide in the manner outlined in the preceding section. We must hasten to discuss a very special kind of mitosis which does not follow this process in every detail. This occurs in the process by which **germ cells** (gametes or sex cells), namely, eggs and sperms, are produced (Fig. 22-3). The process is called **gametogenesis—spermatogenesis** for sperms and **oogenesis** for eggs. Obviously if, upon fertilization, the chromosome number is doubled, at some previous time the number must have been halved. If this were not true the number of chromosomes would double with each generation, which is not the case. Therefore, during gametogenesis the number of chromosomes is reduced from the **diploid number** (2N), which is the number found in the body cells, to the **haploid number** (N), just one-half the diploid number which is the number found in sex cells. As a matter of fact, all body or soma cells contain duplicate sets of chromosomes, one from the **paternal** parent and one from the **maternal** parent. Man, for example, has 24 **pairs** of chromosomes, 48 in all. His germ cells contain one full set or 24 chromosomes, in other words, only one complete complement of genes or chromosomes, not two as in the body cells. At fertilization the two sets are restored. How are these haploid cells produced?

Spermatogenesis

The formation of sperm cells takes place in the testis, of course, and varies only in detail among various animals. Let us consider the case of mammalian spermatogenesis.

Sperms have their beginning in the periphery of the **seminiferous tubules** (Fig 22-4), where the cells are very similar to those of any other body cells, namely,

Fig. 22-4. This is a section of the mammalian testis (rat), showing a seminiferous tubule in detail. Sperm cells begin their development at the outer edges of the tubule and as they mature they move into the cavity. The dark rod-shaped bodies nearest the cavity are mature sperms.

diploid with respect to chromosome number. They undergo successive mitoses to build up their population and move toward the **lumen** (cavity) of the tubule to become mature sperms. It is during this period that their number of chromosomes is reduced to the haploid condition. By following these cells it is possible to determine how this reduction occurs. This is done schematically in Fig. 22-5.

Because a great many sperms are produced, the **spermatogonia** undergo many divisions before launching into the final two divisions that bring about maturation and the production of mature sperm. At the end of these preliminary division stages, the spermatogonia increase in size and the **homologous** chromosomes pair up in a process called **synapsis**. The pairing occurs only between like (homologous) chromosomes, one from the paternal parent and one from the maternal parent. Then each chromosome, while in this paired condition, duplicates itself so there are as a result four united chromosomes. Duplication may have occurred at some earlier period but it is visible only at this time. These are called **tetrads**, and the cells containing them are called **primary spermatocytes**. These cells then divide, carrying paired chromosomes, now called **dyads**, to each daughter cell, or **secondary spermatocyte**. A second division occurs immediately in which the paired dyads separate into **monads**, so that each daughter cell, now known as a **spermatid**, contains one set of chromosomes only in-

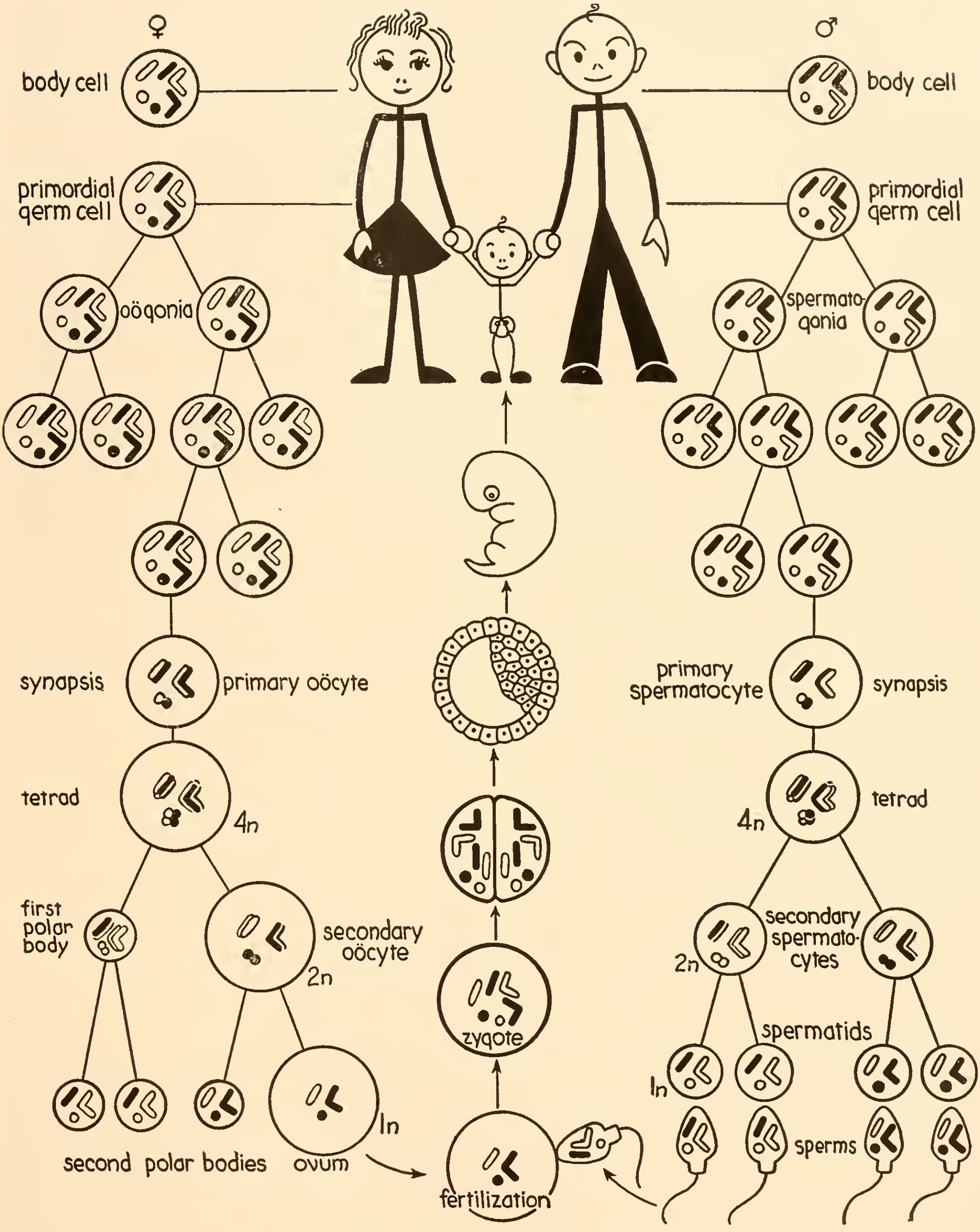


Fig. 22-5. A schematic representation of the germ cell cycle in animals.

stead of two that were present in the spermatogonium, in other words, the haploid number. The spermatid becomes reduced in size, develops a tail, and matures in other ways to become a full-fledged sperm capable of fertilizing an egg.

During this process it will be noted that the maternal and paternal chromosomes (indicated by black and white) may be distributed in several ways so that by the time they reach the spermatid there may be any combination present. There is, however, always a complete set. The mature sperm gets only one member of each homologous pair of paternal and maternal chromosomes, never both. This chance distribution of the members of each chromosome pair is very important in the understanding of the mechanics of heredity which we shall study presently.

Oogenesis

The process by which eggs are formed varies only slightly from the preceding account for sperms. The principal difference begins when the **primary oocyte** (comparable to the primary spermatocyte) divides. Instead of forming two equal-sized **secondary oocytes**, it produces one large one and one very small one, the latter being known as the **1st polar body**. This discrepancy in size is owing to the fact that virtually all of the cytoplasm goes to one daughter cell in the single secondary oocyte. The next division operates on the same principle and results in a single large **ovum** and a **2nd polar body**. Because of their scanty cytoplasm, the polar bodies are non-functional and soon disintegrate. The apparent value in this unequal division is to conserve the cytoplasmic contents in order to retain sufficient stored foods for energy during the early stages of embryonic development. This is not necessary for sperms, because once they have contributed their load of chromosomes to the egg in fertilization their job is done. Furthermore, millions of sperms are needed to insure fertilization whereas only comparatively few eggs are necessary to maintain the race.

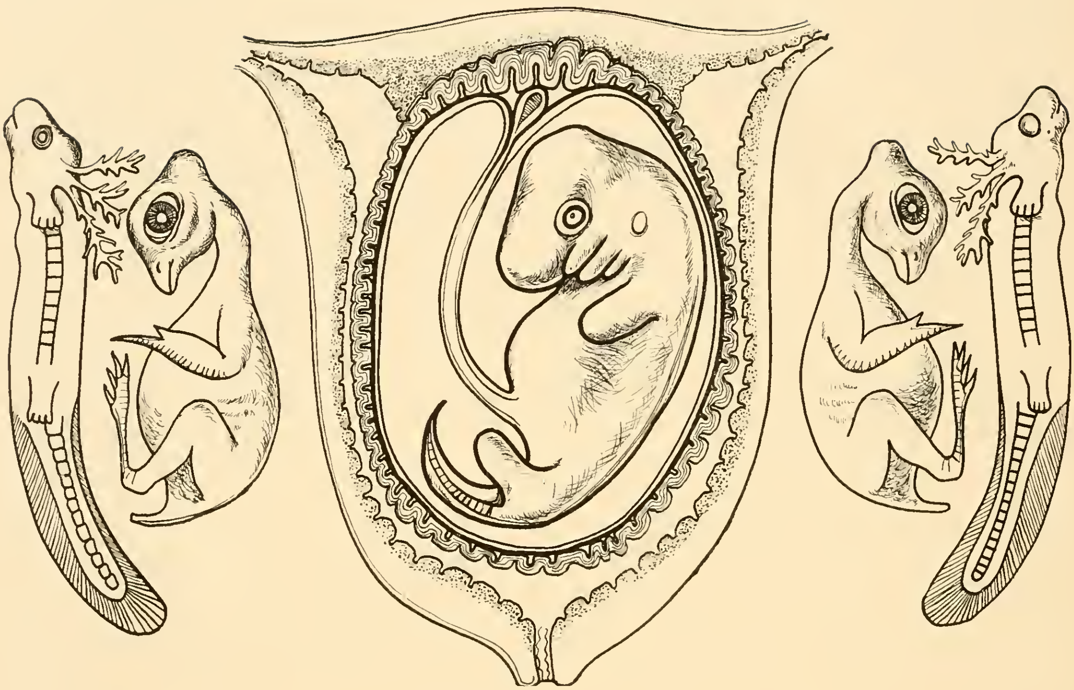
The zygote formed at fertilization thus possesses the full diploid number of chromosomes and all subsequent divisions are mitotic until the individual is formed. Then some of its cells are set aside to undergo meiosis in the production of gametes, which again unite with others, and so the process continues from generation to generation. We have seen that in the formation of gametes, the chromosomes may be distributed in a variety of ways. The greater the number of chromosomes (genes), the larger the variety. It is this perennial distribution which accounts for the great variation seen in all living things.

SIGNIFICANCE OF SEXUAL REPRODUCTION

The most obvious fact about sexual reproduction which has come from the discussion of gametogenesis is the great variety of germ cells that can be produced by one individual. From each tetrad each germ cell may receive either a maternal or a paternal chromosome but not both. This applies to all of the chromosomes, which makes the possible combinations in animals with numerous chromosomes almost infinite. This is further complicated by the fact that the chromosomes wind about each other during synapsis and often exchange genes, a phenomenon known as the **cross-over** (see p. 606). This exchange may occur in several places in each chromosome pair. When these produce tetrads and eventually germ cells, the chromosomes will not be like the original maternal or paternal chromosome but a combination of both. On the average, chromosomes will break and exchange genes in about three places, which means that the original mixing on the basis of chromosome is increased by 2^3, or 8 times. Let us consider, for a moment, the possibilities in man: there are 24 chromosome pairs in the body cells and, of course, 24 single chromosomes in the germ cells. The possible chromosome combinations then become 2 raised to the 24th power, or 16,777,216. If we multiply this figure by 8 we arrive at the number of kinds of germ cells it is possible for one person to produce. Providing it were possible, one couple could become the parents of all of the people in the world and no two of their offspring need be exactly alike.

Because of this wide variability among germ cells, the offspring resulting from their union are different from each other and from either parent. They are new and different individuals, each with its own respective parts assembled in a slightly different manner from any other members of the species. This makes for great variability among species, which is the fundamental reason why evolution has gone on the way it has. Without variation there would be no way for animals to become better suited to their environment because they would all be exactly alike, hence no one of them would be able to explore a new situation any better than another. This is what happens when asexual reproduction is the only means of reproduction. While it is generally confined to the lower animals, it is known to occur among some plants under man's cultivation. The seedless orange trees, for example, are all grown from grafts, so that actually all that is done is to increase the size of the original tree. Since all of the cells carry the same genes, they have no opportunity for variation and must therefore all be exactly alike, barring an occasional mutation. Most of the lower invertebrate animals reproduce asexually as well as sexually. In the former case they likewise have no opportunity for variation. Sexual reproduction evolved very early among animals and is probably largely responsible for subsequent evolution of more complex forms.

CHAPTER 23



DEVELOPMENT OF THE INDIVIDUAL

So far we have seen how cells duplicate themselves, those cells in the body tissues as well as those special cells, the germ cells. We shall now follow the course of events that takes place when the germ cells unite to form a zygote which then undergoes millions of mitoses directed specifically toward the formation of a new organism, different from any other on earth. This subject, **embryology**, is one of the most fascinating, and yet in its fundamental aspects one of the least understood, of any fields of biology. To realize the magnitude of the problem, consider how such a tiny object as a fertilized egg can carry within itself the potentialities of producing a living organism as complex as man.

The above question has stimulated speculation among thinking men for many centuries. Aristotle, for example, believed that the male element or semen was the seed that gave rise to the new individual. Indeed the word *semen* means seed. The female was thought of as the earth (Mother Earth) in which the seed was nourished so that it might grow. This was a natural deduction, since it was known that castrated animals were sterile; without semen there was no offspring. Furthermore, this was during the time when the male sex was considered all important, the female being passive in her social life as well as her biological life. The appearance of female characteristics in the offspring was apparently ignored. Moreover, the finding of the placenta attached to the embryo by the umbilical cord furthered the concept that the female functioned only in nourishing the fetus. The idea that both sexes contributed to the offspring apparently came much later.

With the actual discovery of the human sperm by Ludwig Hamm, who first saw it through a crude microscope in about 1677 and brought it to the attention of Leeuwenhoek, the importance of the male retained its place. This was further emphasized by the work of Hartsoeker, who not only claimed to have seen the human sperm first but who also went so far as to draw a miniature fetus within the head of the spermatozoan and thus advanced the idea of the **homunculus** (Fig. 23-1). This led to the establishment of the **preformation** school which included those who believed that the human embryo was completely formed within the sperm and had merely to unfold during its development. Impetus was given to this idea by Malpighi (1672), who concluded that the chick was fully formed, though in miniature, at the time the egg was laid. This was probably due to an error that could easily arise from a study of an egg that remained several hours (10-15) within the oviduct where development of the chick could proceed. However, because of the obvious existence of large eggs, such as those of birds and reptiles, there developed a school which believed that the egg was the center of development. This meant there were two schools of thought among performationists, the **spermists** and the **ovists**.

An interesting aspect of this controversy was the development of the **encasement** theory. One group of followers believed that the child was derived completely from the egg and that the egg contained a minute human being within it. If the egg in question contained a diminutive woman, within the eggs of her ovary were still more minute women and so on, each encased in the preceding. From this point of view the first woman contained all of the future generations wrapped one within the other. The absurdity of this theory became apparent

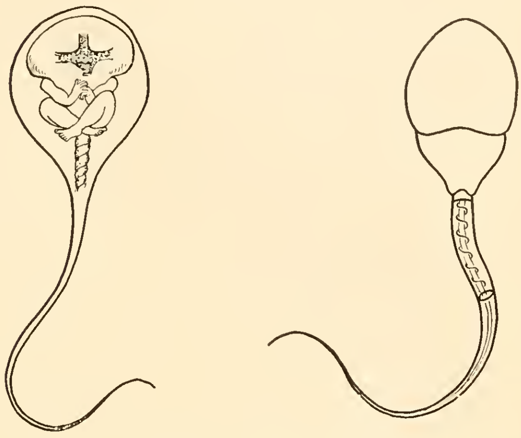


Fig. 23-1. One of the early schools of embryology was that of the spermists, who believed that the child was preformed in the sperm and merely unfolded within the confines of the female uterus. Among followers of this concept was Hartsoeker, who published a drawing in 1678 similar to the one shown here and advanced the idea of the homunculus. The human sperm as it appears under a modern microscope is shown for comparison.

with the discovery of the human egg by Von Baer in 1827 and by those who took the time to make a few mathematical calculations on the size that Eve must have been to house all future generations. All of these theories seem strange to us now, but when they were advanced they performed a necessary function in that they stimulated investigators to search more intensively for an answer which was to come only when instruments became sufficiently perfected to make accurate observations possible.

THE PATH OF DEVELOPMENT

By comparing the embryos of any species of animal at varying stages in their develop-

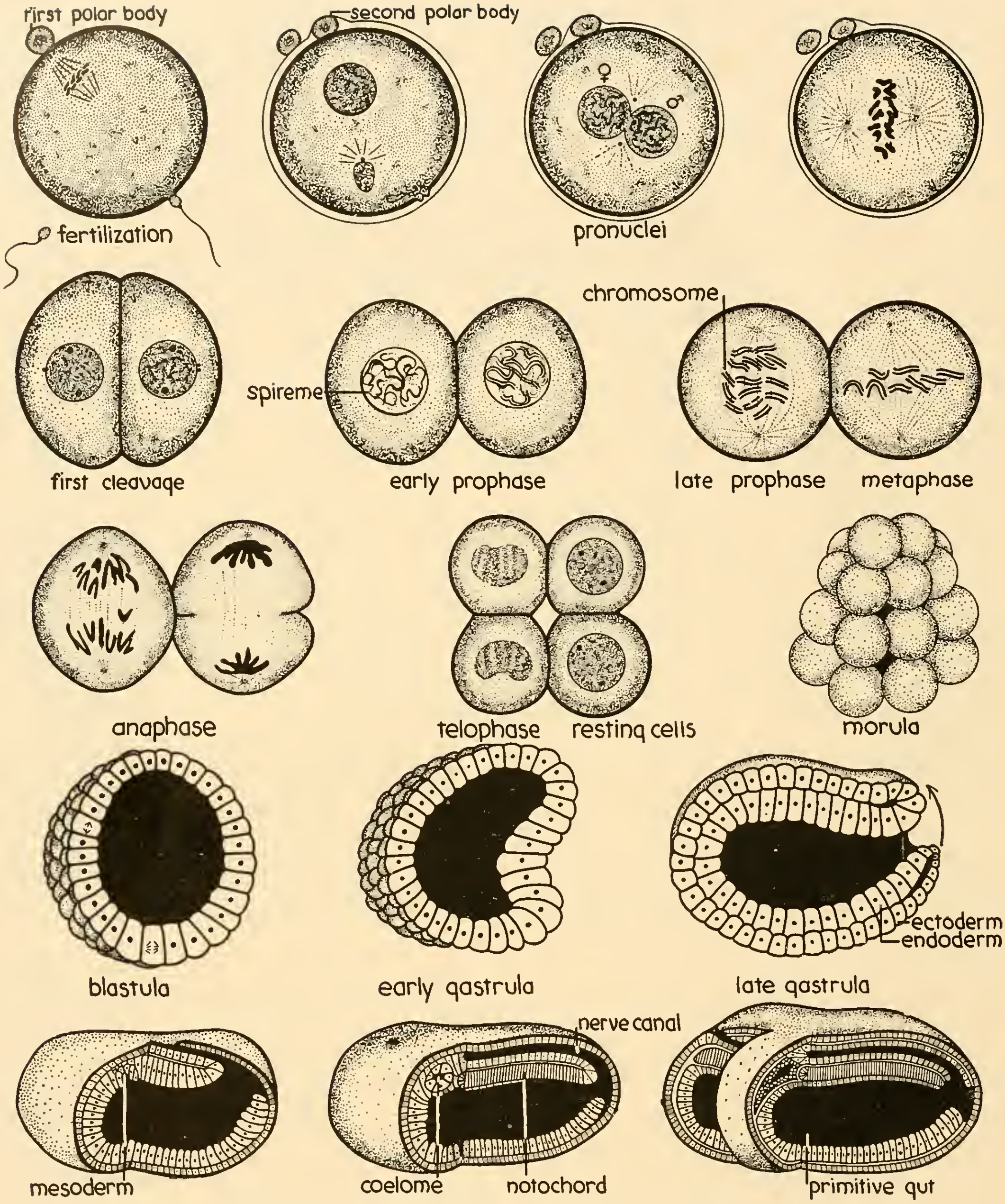


Fig. 23-2. Fertilization and early embryology of *Amphioxus* is shown in this series of figures.

ment, it is often difficult to recognize the adult characteristics. An adult frog, for example, only vaguely resembles the tadpole from which it was derived; similarly, the tadpole shows few of the anatomical features of earlier stages, and surely there is no resemblance between any of them and the fertilized egg. It is apparent that in development animals go through a long series of changes. At first they are very simple, with few parts, but as development proceeds complexity is added to complexity until finally the adult characters emerge. It is remarkable how all animals follow similar paths in their earlier stages, becoming more unlike as they approach maturity. It is difficult, for example, to distinguish between early embryos of a fish, bird, cat, or man (Fig. 25-9). We shall speak of this again in a later chapter on evolution.

Fig. 23-3. The early embryology of the starfish. In this photograph the fertilized egg, the two-celled stage, the four-celled stage, a blastula, and the young free-swimming larva are shown.

Let us examine briefly the stages in the early development of an animal. It might seem more meaningful to select human development for our study, but because of the obvious difficulties in obtaining suitable material we must resort to lower animals. Furthermore, human development is complicated by distinct specializations which are difficult for the beginner to understand. Obviously, much less is known about it, as well. Because the development is relatively simple and yet typical, we shall select the eggs of *Amphioxus,* a primitive chordate, for our study (Fig. 23-2). Eggs of starfish and sea urchins also provide excellent material and are frequently used for this study (Fig. 23-3).

Cleavage

In some animals the sperm enters the egg before the latter is completely mature, that is, before the formation of the second or even the first polar bodies. This is usually the case in vertebrates and is true of Amphioxus. The first sperm that strikes the membrane surrounding the egg enters head first, dropping its tail the moment it is inside. It enlarges to become the male pronucleus and then lies at rest in the cytoplasm while the egg nucleus completes its last division. When the egg nucleus is mature, the two pronuclei unite and the first division of the zygote follows shortly. In frogs this occurs in about one hour. The split divides the zygote into two equal parts. **Cleavage** divisions follow in rapid succession, resulting in a hollow ball of cells, the total being no larger than the original zygote. All that has happened is that the food-laden cytoplasm of the egg has been sacrificed to produce many cells, each containing a nucleus and cytoplasm. Growth, which is a different process, has not occurred. Each cell has the potentialities of producing other cells and eventually tissues and organs. Such a hollow ball of cells is called a **blastula** (Fig. 23-2).

Formation of germ layers

The ball of cells indents on one side until the two layers of cells almost touch, giving the appearance, somewhat, of a rubber ball which has been pushed in with the finger. This is the **gastrula,** and the single opening formed at one end is the **blastopore.** The newly formed cavity is called the **archenteron,** which will eventually become a part of the digestive tract of the adult animal. The two layers of cells that make up the gastrula are called **germ layers,** the one on the outside is the **ectoderm** and the inner one, the **endoderm.** Presently, tiny pouches push out from the archenteron and pinch off, forming a double layer of cells, the **mesoderm,** with a cavity, the **coelom,** between (Fig. 23-2). The coelom finally becomes the body cavity in the adult. In higher vertebrates such as mammals the coelom gives rise to the pericardial, pleurial, and abdominal cavities of the adult.

The three germ layers are formed in somewhat different ways in various animal groups, owing primarily to the presence of yolk in the egg. In the case of Amphioxus, where there is very little yolk, development proceeds in the manner described. However, when the egg contains a great deal of yolk, as in the case of the bird's egg, the formation of the three germ layers is modified, although the end result is essentially the same. In the chick, which is best known and most frequently studied (Fig. 23-4), the embryo forms on top of the yolk mass. The two-layered embryo or gastrula is produced by a splitting of the single-layered embryo, and the mesoderm subsequently appears between the ectoderm and endoderm, spreading laterally from a central axis called the **primitive streak.** Segmental blocks of mesoderm, the somites, appear first in the anterior trunk region of the embryo and continue posteriorly as growth occurs. The embryo becomes organized anterior to the primitive streak. By this time (33 hours) the cord and three divisions of the brain can be seen, and the heart is laid down. From these beginnings the embryo body is formed.

With the formation of these three germ layers, the basic raw materials are present

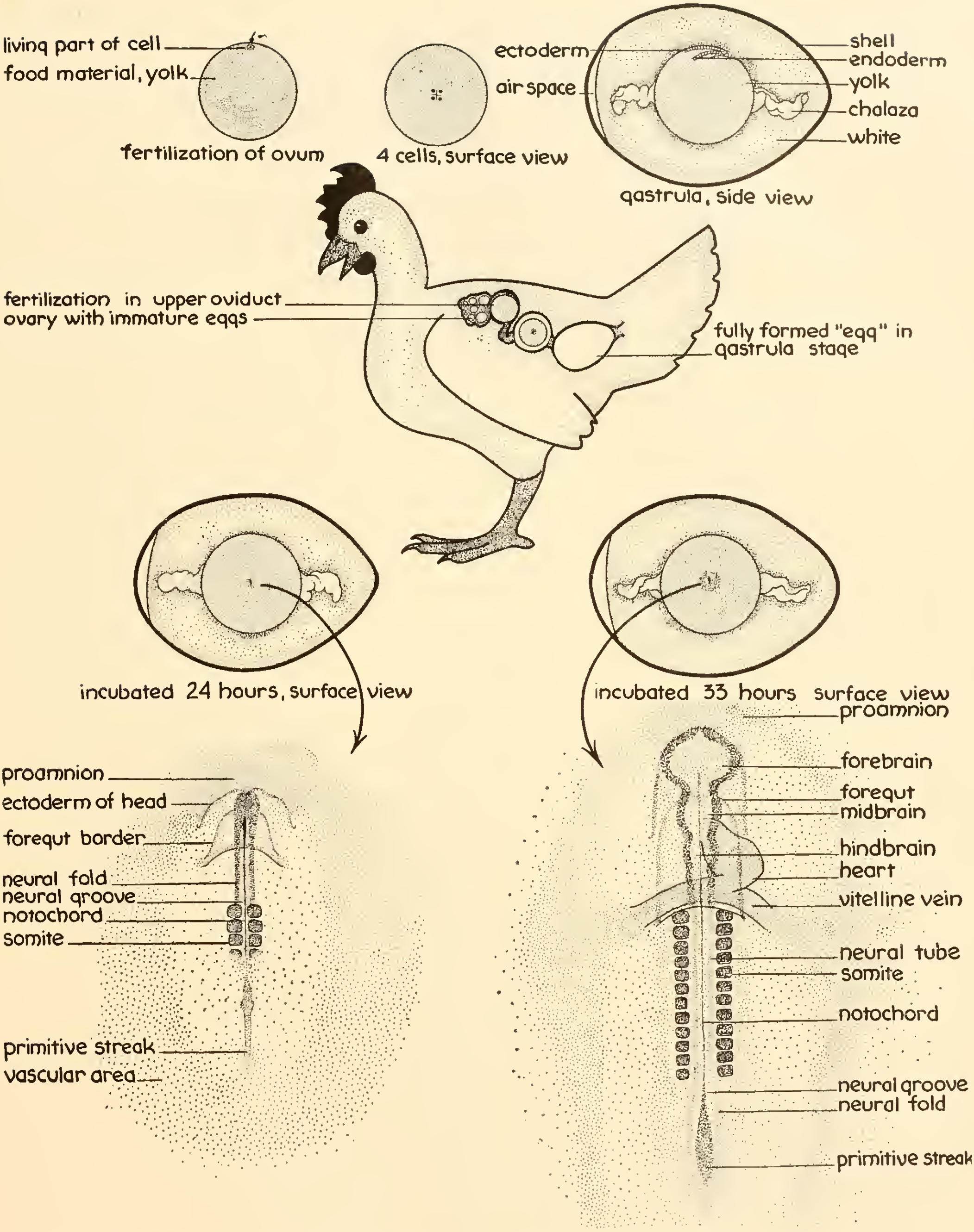


Fig. 23-4. Fertilization and early embryology of the chick. The egg is fertilized internally and by the time it is laid the embryo is in the gastrula stage. After 33 hours of incubation several regions that will become organ systems are laid out.

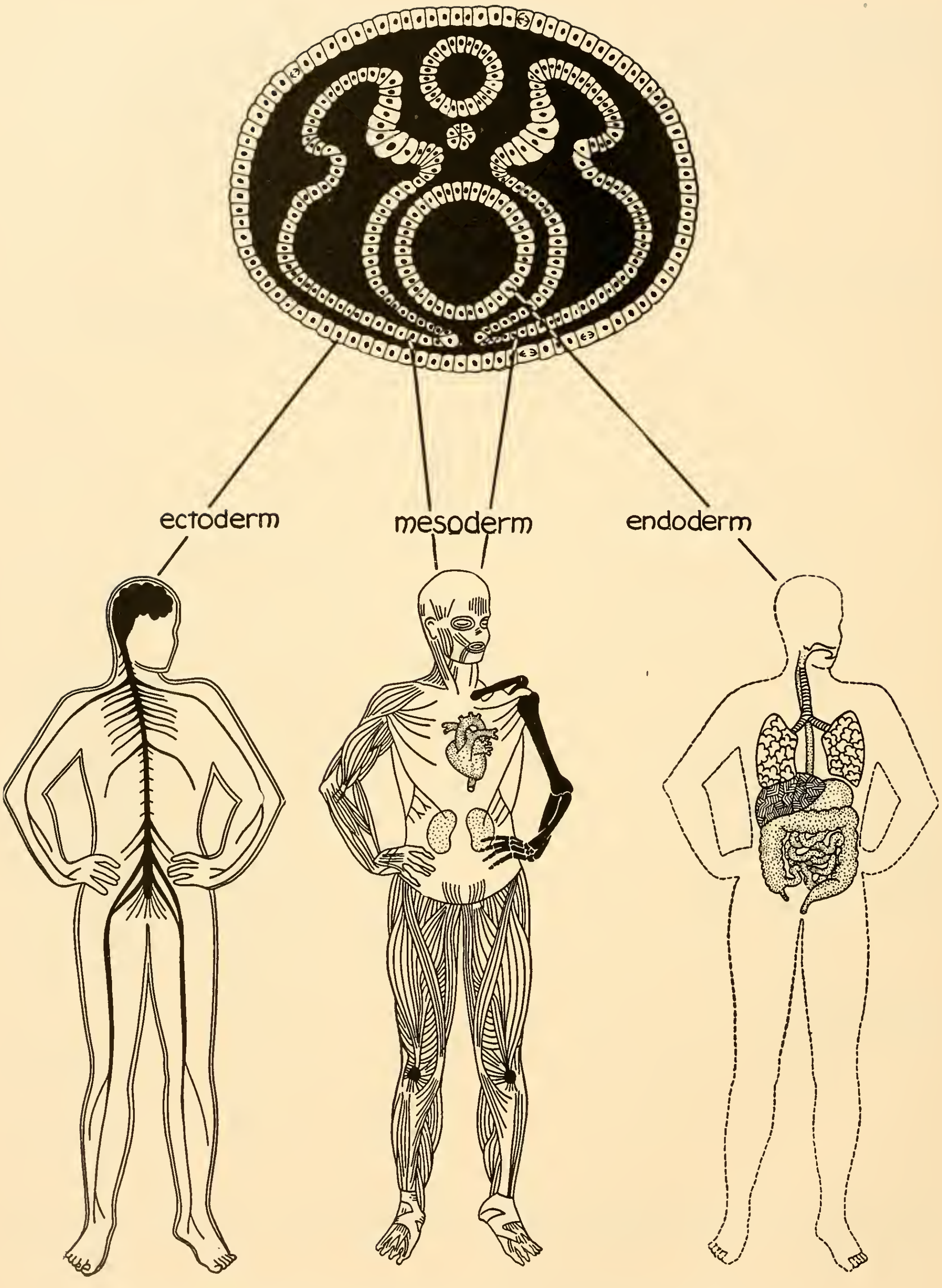


Fig. 23-5. Derivatives of the three germ layers are portrayed in a graphic manner.

from which a complex metazoan body can be built. The layers grow, fold, and differentiate into the adult structures. In the Metazoa in general, the endoderm becomes the epithelial lining of most of the digestive tract and its glands. The ectoderm gives rise to the outer layer of the skin, the nervous system, and the sensory cells of the adult. The two layers of the mesoderm form different parts: the inner portion becomes associated with the endoderm to form the gut wall, while the outer becomes associated with the ectoderm to give rise to the body wall, thus producing the familiar "tube-within-a-tube" body plan discussed in earlier chapters. Between the two tubes is the cavity of the mesoderm, the coelom. Derivatives of these layers in man are graphically portrayed in Fig. 23-5.

Organ formation

It is a long, complicated story from the simple germ layers to the full-fledged functional organs which, taken together, constitute the complete animal. This is accomplished by several methods. One of the most common is the folding of the layers, which is well illustrated in the formation of the nervous system of Amphioxus and of the chordates in general (Fig. 23-6). It starts by a pushing in of a groove along the dorsal side of the embryo about the time the mesoderm is established. The groove closes over on the dorsal side and sinks below the surface to form a tube which gives rise eventually to the entire nervous system and its associated parts. The retina of the eye forms by an evagination or outpocketing of ectoderm from the brain and the lens from an invagination of the overlying ectoderm of the head. Evaginations from the wall of the digestive tract give rise to most of the lungs, the liver, and the pancreas, as shown in the human embryo (Fig. 23-7).

Referring again to the chick embryo (Fig. 23-8), the orgin of the principal organs can be made out after 55 hours of incubation. The three primary brain vesi-

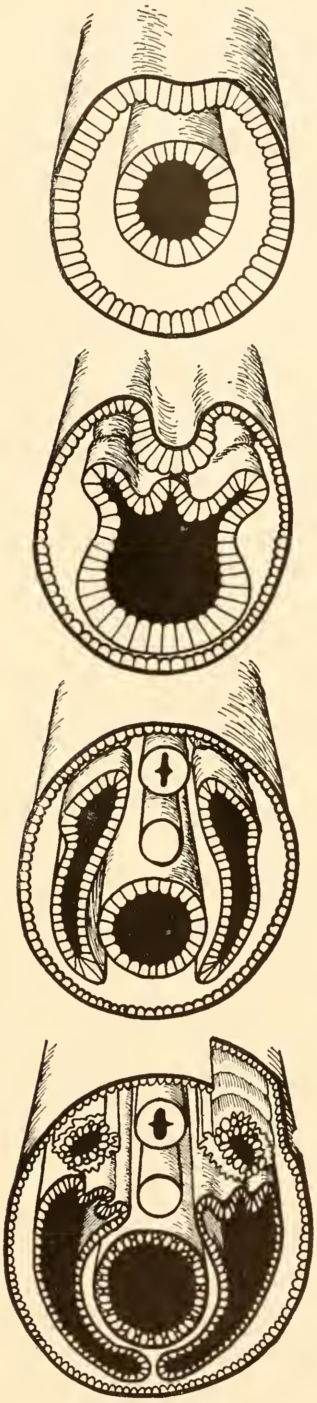


Fig. 23-6. The nervous system of Amphioxus and of all chordates is formed from a groove along the top side of the embryo, as illustrated by these figures from top to bottom. The mesoderm gives rise to the somites and lining of the coelom.

cles are clearly marked off, as is also the optic cup which will become the retina of the eye. The primitive ear is visible as a tiny vesicle (auditory vesicle). The most conspicuous organ is the heart, which is already functioning vigorously. Its early activity is essential so that the circulating blood can bring food from the yolk mass to nourish the growing embryo. Simple diffusion would be hopelessly inadequate to care for the needs of this rapidly developing

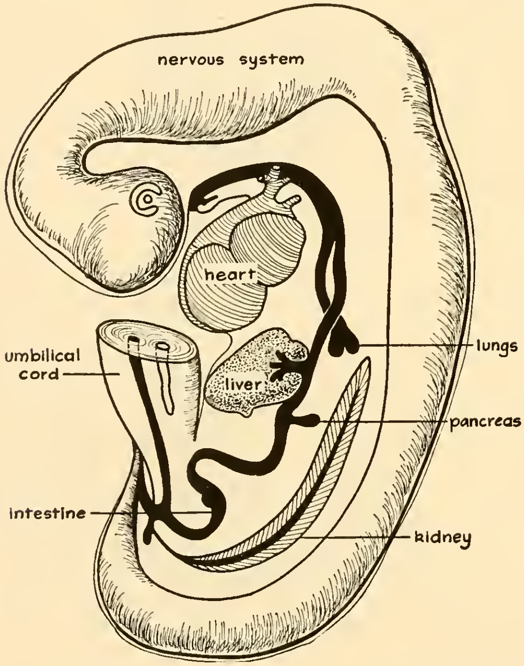


Fig. 23-7. The very young human embryo shows the beginnings of several organ systems. The digestive tract is shown here in black. Note how the lungs and pancreas are forming as outpocketings from the primitive gut. The nervous system and the kidney are very primitive at this stage of development (under five weeks).

embryo. Another important event is taking place at this time, that is, the formation of the extraembryonic membranes. The embryo is completely enveloped by the amnion (p. 533). This membrane is formed by a progressive folding over the embryo of the double-layered extraembryonic tissue from either side (Fig. 23-8). The allantois is formed later as an evagination from the hind gut.

Once the pockets and folds have formed, the growth rate of the various parts is highly variable; some cells grow much faster than others, so that some parts of the organ become greatly emphasized over other parts. For example, in the formation of the liver, the cells which form the bile duct grow relatively little, whereas those that give rise to the secreting portion multiply millions of times, resulting in a massive organ connected to the gut through a tiny tube. Similar unequal growth takes place in the nervous system. It is first a smooth tube, but very soon elaborate folds appear which result from the rapid growth of some cells and the retardation of others. Eventually a highly folded structure is formed that is capable of coördinating the parts of the entire body.

Another method of differentiation during development is cell migration. Cells once formed do not always remain in their original positions, and during early development individual cells as well as groups of cells migrate a great deal. The mesodermal cells especially, either as single cells or small groups, break loose and wander through the tissues to set up housekeeping in new locations where they differentiate into new structures, such as muscles, blood vessels, and all sorts of supporting tissue. This is not a fortuitous migration, for each goes directly to its future location and settles down immediately to the job of building the structure that is essential in the final organism. This is one of the many riddles in embryology. What forces are operative in directing these cells to the proper location and in causing them to differentiate there into the right kind of cells to do a specific job? For example, how do the tiny masses of nerve cells that migrate out from the primitive nerve tube find their way through "miles" of other cells to become associated with the muscle cells that have arrived at their location some minutes before? There is a question of time as well as space. If the nerve cells arrived before

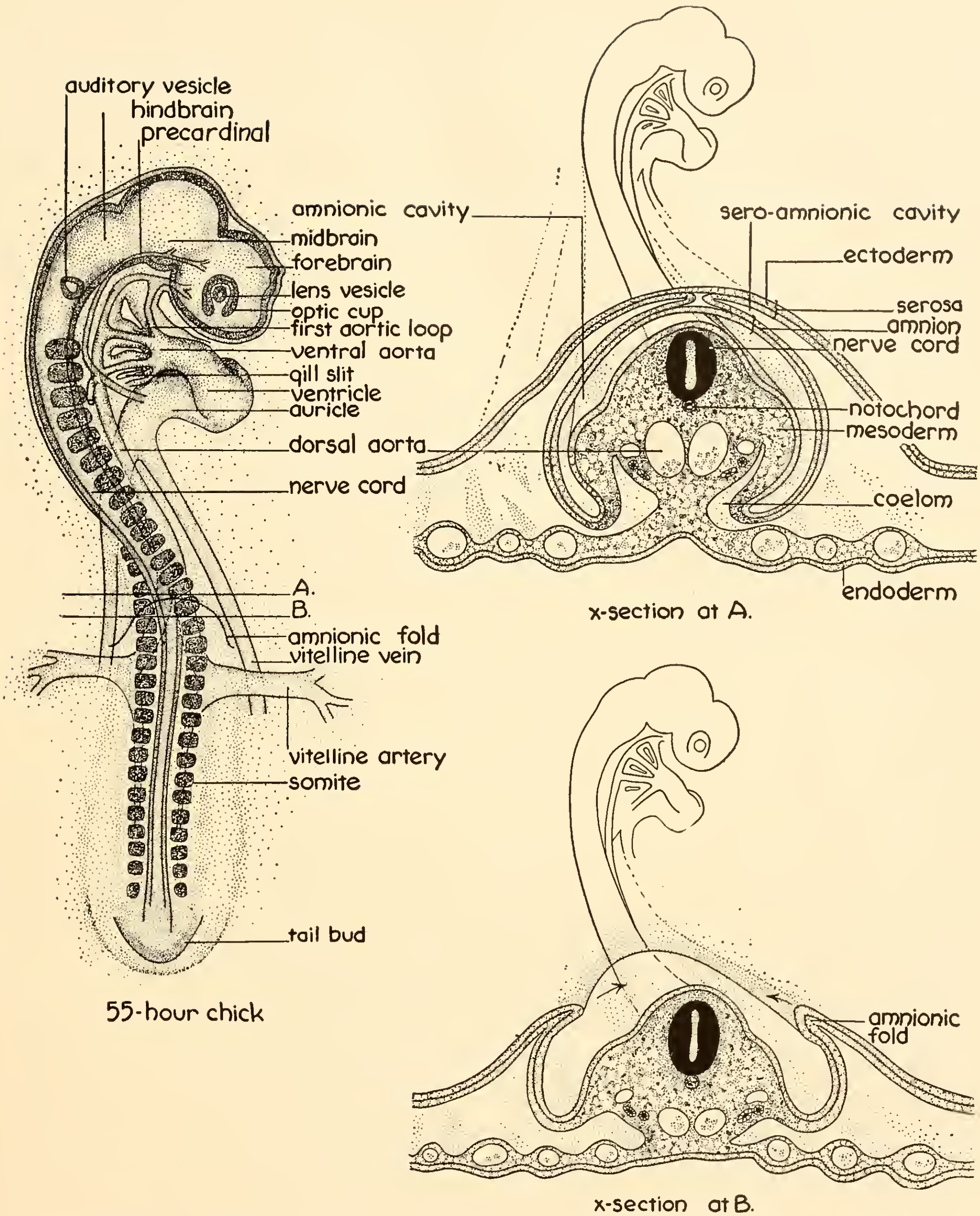


Fig. 23-8. The beginnings of the various organ systems are well marked off in the 55-hour chick. The figure to the left is of the dorsal view. Note that the head is turned to the right as it lies on top of the yolk mass. Two cross-sections are also shown: the upper figure is taken through the region marked *A;* and the lower, through the region marked *B.* Note how the extraembryonic membranes are formed.

the muscle cells, what would happen? This complex moving of cells must occur at precisely the right time and to the right location if the final organ is to form and function properly. Such an amazing series of events certainly challenges man's ingenuity to produce an explanation.

Still another essential phase of development must take place after these cells reach their destination. The cells must differentiate into specific kinds of cells in order to produce the definitive organ. In general, such differentiated cells can perform one function and no other, and once formed never revert to something else. There are some cells, however, that do retain the ability to become something else, for example, the connective tissue cells that can fill in the space resulting from a wound—the scar tissue cells. Most cells, however, once differentiated, perform no other function than the one destined for them.

One would expect the final differentiation of the cells to occur as the last thing in their long history. Consider, for example, the central masses of cells that push out into tiny **limb buds** which eventually form the appendages of vertebrates. These cells are all alike at first but they begin to differentiate into parts that soon become discernible. The cells at the tips become flattened and together rounded out into five tiny bumps, the ultimate digits. Up to this point the cells are all much alike, but they soon become variously transformed into cartilage in the center, with muscle and connective tissue of different kinds surrounding it, and blood vessels and nerves permeating the entire structure. Some cells become associated with the ectoderm to form the skin. When all of the cells have completely differentiated into their final structure the characteristic appendage comes into being.

Differentiation of the germ layers follows a similar pattern in all animals, and the final organs derived from them simulate rather well what might be expected from the story of evolution. That is to say, the layers that first formed ectoderm and endoderm might be expected to give rise to the covering and the lining of animals because those were their functions in the first Metazoa. The ectoderm, since it contacts the external world, might also be expected to give rise to the organ system that keeps it in touch with its external environment, namely, the nervous system and its associated organs. The endoderm lined the gut of the first Metazoa and it still performs that same function in higher animals, giving rise as well to such structures as the lungs, liver, pancreas, and so forth. The last layer to appear both in evolution and in embryology is the mesoderm, which might logically produce all of the remaining organs such as muscles, blood, vessels, skeleton, and so on. Although, in general, the three germ layers are destined to produce specific organs, there are rather interesting deviations from the set pattern, some of which lend themselves to experimentation.

FACTORS INFLUENCING DEVELOPMENT

Development does not always follow the age-old pathways in the production of embryos, as attested by the occasional appearance of malformed offspring among all groups of animals. This means that something has gone wrong along the way in the formation of the various systems. Perhaps some chemical or physical factor did not function quite as it usually does. The fact that such things happen opens the way for experimentation by purposely interrupting the normal course of events. This fertile field of investigation, called **experimental embryology,** has opened new vistas in our understanding of normal development. It is interesting to note that several Nobel Prizes in medicine have been awarded to experimental embryologists whose efforts have been concentrated primarily on the embryos of lower animals such as the frog, a fact that is often difficult for the layman to understand. It simply means that in order to understand the more important aspects of medicine we must reach into the fundamental workings of development and growth. This can only be done with lower animals and it is through the knowledge stemming from such work that the near-ultimate answers are going to come. Let us examine some of the more recent information concerning development.

Fertilization

The logical place to start in an experimental study of development is fertilization. Is it necessary that a sperm enter the egg? What factors influence its entrance? Aside from contributing a complete set of chromosomes, what other function does the sperm perform? These are some questions that have invited experimentation and for which we have some answers.

Even Aristotle knew that the drone bee was a result of an unfertilized egg. How does this fact fit into the general assumption that all eggs must be fertilized? The situation in bees as well as other animals led biologists very early to investigate the necessity of the sperm for development. **Parthenogenetic development**, as this is called, can be produced in a large number of animals by simply subjecting the eggs to an appropriate chemical or physical change, such as immersing them in certain chemicals or pricking them with a needle dipped in blood (Fig. 23-9). This would seem to indicate that the sperm serves two functions: one to contribute a haploid set of chromosomes, the other to initiate development of the egg. Apparently the potentialities of development are locked up in the egg, waiting to be released at the right time by the entrance of the sperm. If other suitable physical or chemical factors are applied, they too can perform this second function of the sperm very satisfactorily. The action is probably tied up with enzymes in some sort of trigger mechanism which can be set off by a variety of stimuli. What this mechanism is will be revealed only when we learn more about the fundamental nature of protoplasm itself.

Principle of potency

What are the factors that determine which parts of an embryo will produce what structures? In most animals the cells in early cleavage resemble one another very closely. At this time, say in the eight-cell stage, is each of these cells assigned a specific job to do? Will one become muscle, another nerve, and so on? This was one of the initial problems investigated by early embryologists. The cells of cleaving sea urchin eggs were separated in the two-, four-, eight- and 16-cell stage and their development followed. It was found that in each case the separated cell had the ability to give rise to a complete embryo though progressively smaller, the last one being one-sixteenth the size of a normal embryo. The separation of eggs beyond the 16-cell stage did not result in complete embryos. This indicates that each cell retains its **potency** to produce a complete embryo up to the 16-cell stage, beyond which point it becomes a part of the embryo. Such early cells are said to be **totipotent**, that is, they retain all of the potentialities of the original egg and,

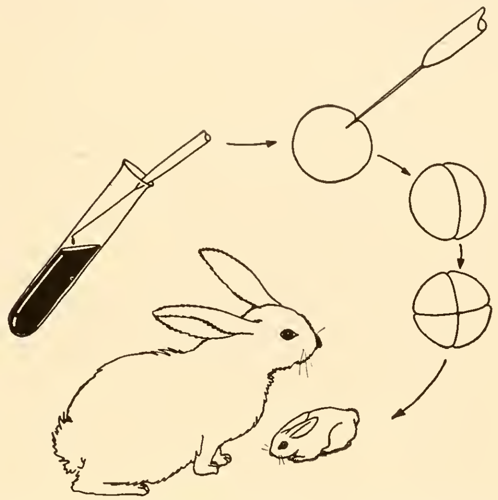


Fig. 23-9. Parthenogenetic development can be obtained in a rabbit's egg by pricking it with a needle dipped in blood.

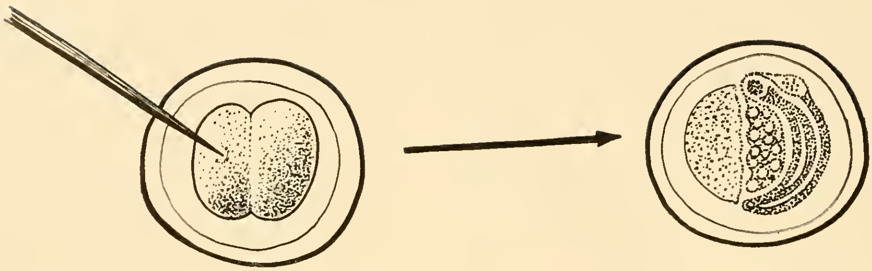


Fig. 23-10. If one cell of a frog's egg is killed when the embryo is in the two-cell stage, only a half embryo develops.

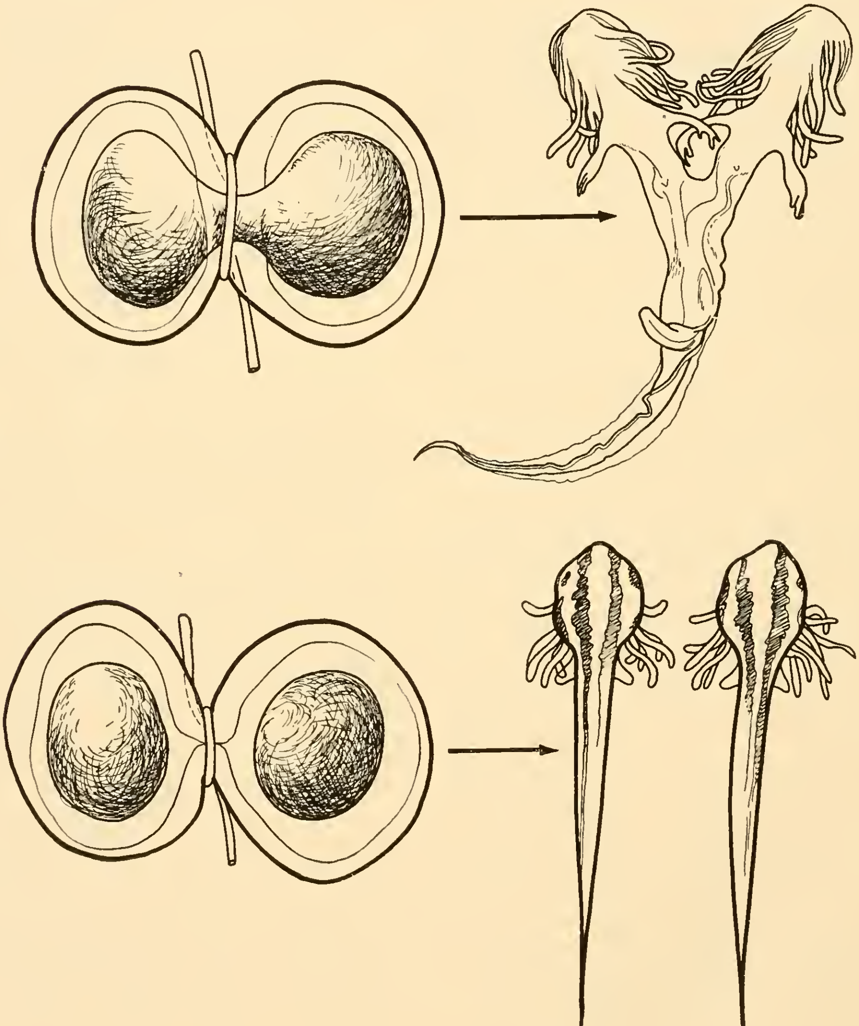


Fig. 23-11. If a hair loop is tied in such a way as to separate the cells partially in a two-cell amphibian embryo, a partially double ("Siamese twins") embryo will result. If the hair loop is pulled tightly enough to separate the two cells completely, two normal, half size embryos result.

therefore, can give rise to a complete embryo, though smaller than normal. It seems, then, that under normal circumstances only a portion of this potency is utilized. When the cell is retained along with its neighbors, even though it has the power to become a complete embryo, it merely becomes a part of the embryo. There is wide variation among the eggs of animals in respect to potency, some being totipotent only in the egg stage whereas others resemble the sea urchin in this respect.

Whether or not an egg is totipotent depends on such factors as the presence of other cells. For example, if one of the cells of a frog's egg in the two-cell stage is killed with a hot needle (Fig. 23-10) what will happen in later development? Will it produce a whole or only half an embryo? Because the latter is true, one might be inclined to say that the frog's egg is totipotent only in the single-cell stage. If the experiment is continued a little farther, as Hans Spemann (a famous German embryologist) did by tying a hair loop around the egg in the two-cell stage and completely separating them, each cell gives rise to a complete embryo (Fig. 23-11). Strangely enough, if the loop was not sufficiently tight so that some part of the two cells was allowed to remain in contact, a partially double embryo resulted, that is, a pair of "Siamese twins" was produced (Fig. 23-11). Undoubtedly, their counterparts in fish (Fig. 23-12) or humans are formed the same way. For some reason, cleavage between the two cells starts but is not completed, thus producing embryos attached to a greater or lesser degree. Occasionally one embryo grows normally and incorporates the abnormal one inside its body, forming a tumor. Some of these tumors contain skin and hair, indicating that they probably started as partial twins. They often give trouble in adult life and need to be removed.

These basic concepts concerning development can be carried to older embryos. How soon are the cells of the embryo definitely

Fig. 23-12. "Siamese twins" in fish. These are probably formed as a result of an incomplete separation of the early embryo, perhaps in the two-cell stage.

allocated a specific task to do, as that of producing the arm, for example? By removing various parts of early embryos and following their subsequent development, the answer to this question can be found. Whenever certain parts are removed the resulting embryo lacks those parts which that area normally would have formed. If the region which normally gives rise to the left arm in an amphibian is removed, the embryo will develop without a left arm. Furthermore, if the removed part is transplanted to the area of a second embryo which normally produces belly, an arm will develop in the new location. This means that at a specific time the task of producing an arm is assigned to a certain group of cells and they will produce that organ and no other if placed in a position where they can be properly nourished.

In the early embryo, then, every cell is totipotent and can produce a complete embryo. Later, however, potency is distributed to groups of cells which can form specific parts of the embryo and nothing else. This sorting does not end here but continues in the cell areas, becoming more and more specific. For example, the arm-producing region is totipotent for producing this appendage, but as development proceeds potency becomes more specific, that is, certain cells are detailed the task of producing the hand, the wrist, the fingers, and so on. Development proceeds from the general to the specific. It might be compared to what takes place when a college student begins his training to be a heart specialist. At first he receives a general education, learning as much as he can about the various fields of human endeavor. He then concentrates on the natural sciences, gaining a broad background in biology, physics, and chemistry. Entering medical school next, he learns about the entire body and its functions. Finally, he assigns himself the task of learning all he can about the heart and the way it works. He may even go farther and become specialized in certain diseases of the heart. Thus his education has gone from the general to the specific. Likewise in the developing embryo, the job of the first cleavage cells is a general one, and as development proceeds the tasks become more and more specific until finally by the time the animal is ready to take on the business of living on its own, the tasks have all been assigned and, with few exceptions, the cells can do little else but perform those functions.

The principle of induction

What is the guiding influence that directs these cells into a single course? That it must have something to do with the neighboring cells was seen in the preceding discussion. Certain ingenious experiments, again performed by Spemann 25 years ago, throws some light on the answer to this question.

It was demonstrated that by transplanting cells located just above the blastopore in amphibian embryos to an area in a second embryo that would normally form something else, belly, for example, a second embryonic axis was set up in the new site, even though the embryo had one of its own (Fig. 23-13). The transplanted cells sank below the surface and induced a nerve cord above the area, just as they would have done if left in the original embryo. Such cells were thought of as the organizing center of the embryo and hence were called the **organizers**.

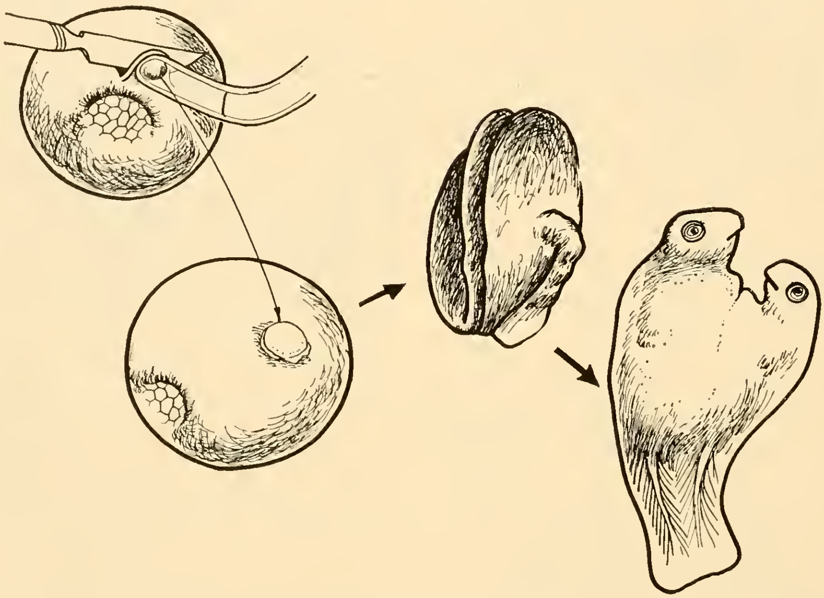


Fig. 23-13. If a few cells from the region above the blastopore of an amphibian embryo are removed and placed in some other region of a second embryo, they will produce a nerve cord just as they would have done had they remained in their original location. The operation is performed in the two left figures and the results are shown in the middle (early) and right (later) figures.

This was further illustrated in the formation of the vertebrate eye. As the bulb of tissue that pushes out from the brain to form the retina comes near the ectoderm it induces the latter to form a lens. This will happen even if foreign ectoderm is placed over the eye cup, in other words, whenever the eye cup approaches ectoderm, it induces a lens in that germ layer. In both of these cases it is apparent that something, most likely a chemical, issues from the organizer (dorsal lip cells and eye cup, respectively) and induces the formation of the second structure.

These observations pose an important question. Is embryonic development due to these organizers, which are produced, perhaps, one after the other by different tissues? Does one organ develop as a result of one organizer and does that organ, in turn, produce another organizer that stimulates the development of another organ and so on? This may be true, but until more is known about what an organizer is, the answer to this question will be slow in coming.

Regeneration

In earlier chapters we considered the phenomenon of regeneration among the invertebrates, especially in hydra and planaria where it is particularly striking. Can the observations made on these forms, and others as well, be explained in the light of the information available as a result of experimental embryology?

Polarity is one of the first features that appears in embryonic development. Can such polarity be demonstrated in a coelenterate and, if so, can it be controlled? If the stem of a hydroid is cut into two equal parts, each will give rise to a base and tentacles, retaining the polarity of the parent form (Fig. 23-14). This is reminiscent of polarity in early embryos. Now if these two parts are placed in a tube and the cut tips exposed to different concentrations of oxygen, the polarity can be reversed (Fig. 23-14). This means that organization of the tissue is labile, that is, it can be changed. This can be further shown to resemble the condition in the amphibian egg by bringing about a partial constriction in the mid-region of a section of the hydroid (Fig. 23-14). In this case, tentacles form at both ends. How can this be explained? According to Professor L. G. Barth, we might think that perhaps some organizing substance is distributed throughout the tissues of the hydroid which is tentacle-forming, and that tentacles form where the concentration of this substance is the highest. We would expect the concentration of such a substance to be greatest in the head or anterior region and least near the base. In a cut section there would still be a concentration gradient from anterior to posterior and the tentacles would still form at the end where the concentration was the highest, thus maintaining its polarity.

This same idea might explain why planaria, when cut into several pieces, gives rise to an equal number of whole animals, each with mouth, digestive tract, nervous system, and all (Fig. 9-7). In planaria the situation is much more complicated than in a coelenterate, because of the greater variety of structures, but the explanation may still hold.

Another aspect of this problem has come to light through metabolic studies of a number of lower animals including planaria. It has been shown, for example, that the metabolic rate, as demonstrated by oxygen consumption studies, is greatest at the anterior and least at the posterior end, and, indeed, that there is a definite **gradient** running in an anterior-posterior direction. This is confirmed by applying poisons of various sorts to the animals, in which case the anterior end is always injured first, the effect gradually diminishing in a posterior direction. This same gradient is observed in cut pieces of planaria, for the anterior part of each piece has a higher metabolic rate than the posterior part. The head always develops at the more active end and the tail at the other. Long ago, this principle was stated in the form of a theory, called the **axial gradient theory**, which has been helpful in explaining some abnormalities appearing in various kinds of embryos, including man. Supposing some toxic or foreign substance were introduced in the human egg, at the time of fertilization or shortly thereafter, which was able to stimulate the formation of two regions of high activity, that is to say, two axes of polarity. The resulting embryo would then be doubled in some sort of twinning, partial or complete. This would have the same effect as the ligaturing described above, and the end result would be the same. Other abnormalities in embryological development—of which there are many—may similarly be explained.

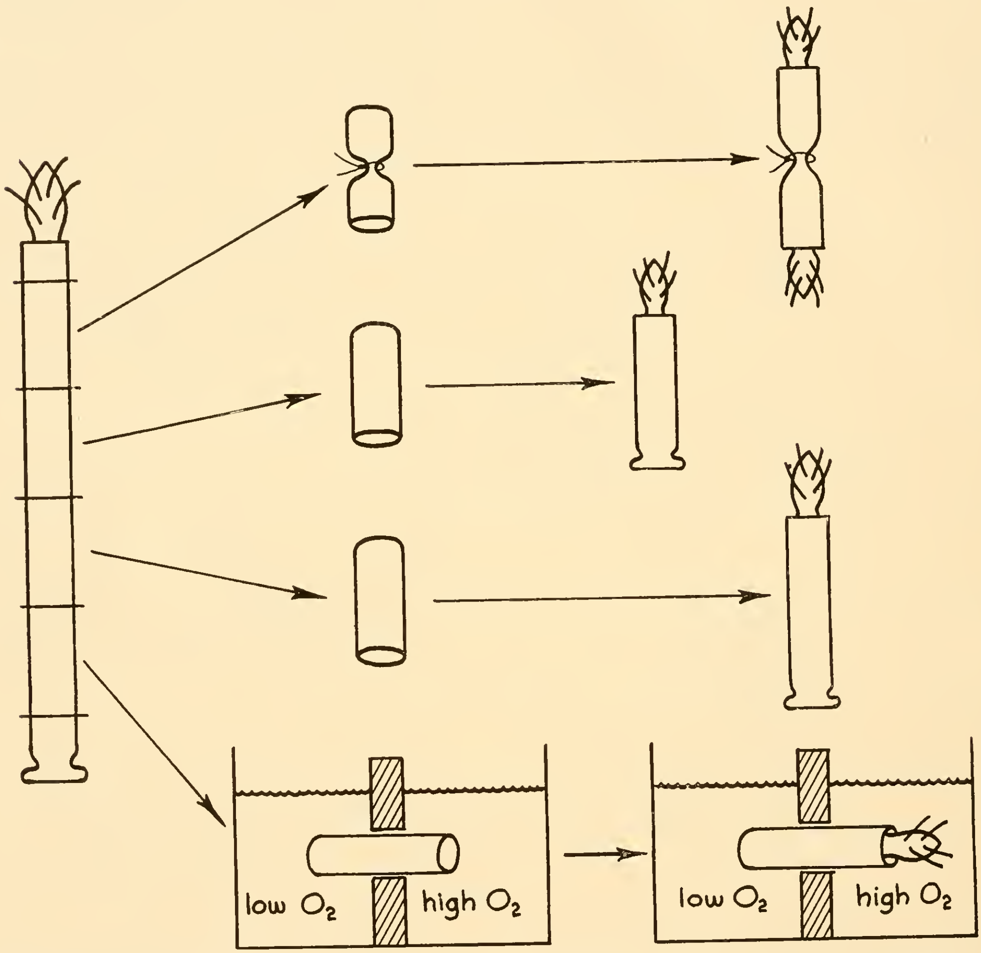


Fig. 23-14. The first character that appears in embryonic development is polarity and this can be demonstrated by performing same experiments on hydroids. Segments cut out of the stem will regenerate tentacles and bases oriented in the same manner as in the parent hydroid. If a constriction is made in the middle of a segment, tentacles form on both ends. If one end is placed in a region of high oxygen level, tentacles will form on that end regardless of its position in the parent hydroid.

Study of the regeneration of parts in adult animals is a natural outgrowth of work on embryos. Many interesting questions raise themselves in the field of regeneration. For instance, why do limbs of salamanders regenerate completely, whereas those of the closely related frogs do not? Further, why have the tissues of higher animals lost most of the power of regeneration,

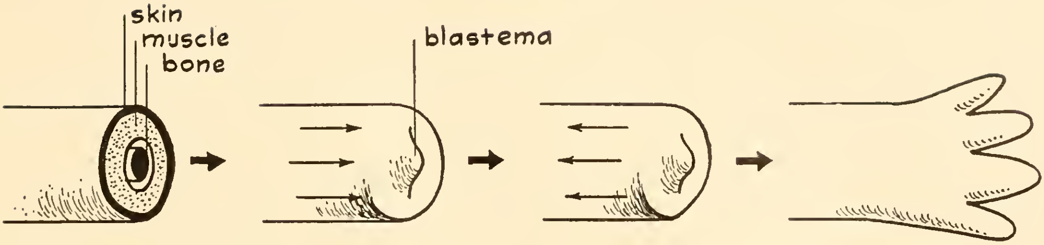


Fig. 23-15. An amputated limb of a larval salamander will regenerate completely. Why does a mammalian appendage fail to regenerate?

if indeed they have? Some interesting experiments have thrown light on these problems.

When a limb of a larval salamander is amputated, the epidermis quickly grows over the cut surface while a concomitant series of changes go on underneath resulting eventually in a new limb (Fig. 23-15). The cells of the cut muscle, dermis, and bone change in appearance. They **dedifferentiate,** that is, lose most of their specialization, and eventually form a small region of special cells called a **blastema.** Once the blastema is formed further dedifferentiation ceases. The cell mass then begins to **redifferentiate** into the various parts of the limb, that is, into bone, muscle, skin, vessels, and nerves. Thus the lost part is completely formed and becomes functional.

To go back to our earlier question, why does this fail to occur in the closely related frogs and other vertebrates, man for example? Further experimentation tells us something more about this. If the cut limb of a frog is placed in saline (salt solution) it will regenerate completely. Why? Apparently, the saline prevents the normal closing over of the wound and brings about the formation of a blastema which normally does not appear. Once the blastema is formed, regeneration proceeds just as it does in salamanders. It appears that the healing skin of the amputated frog limb blocks further regeneration, because if the skin of the salamander appendage is made to cover the cut end, regeneration also fails, whereas if just the epidermis, which normally covers the opening, appears, regeneration proceeds in a normal fashion. It seems, therefore, that the ability to regenerate appendages is not lost, but merely blocked. What, then, about the regeneration of appendages or other parts in mammals? That must await future research.

In all of these experiments we see the direct bearing of the environment on development. Animals possess certain genetic potentialities which will be realized in a specified environment. If this environment changes in any way, corresponding alterations occur in the developing embryo. The two factors of heredity and environment are both important in development. We shall have more to say about them in the next chapter.

So far we have discussed the basic problems involved in development. Intimately linked with development is growth, and, in fact, the two go hand in hand. The embryo grows continually while it is differentiating. In the light of what we know about development, let us look at this problem of growth.

GROWTH

By the end of the eighth week of human life the embryo has increased to 2 million times its original mass and during the next eight lunar months it will increase another 4,000 times. This represents a tremendous accumulation of protoplasm which we call **growth.** What are some of the facts concerning this important vital phenomenon?

We might start by considering how growth occurs in single cells, Protozoa for example. If one or only a few Protozoa are placed in a flask containing complete nutrients for this particular cell, in a short time there will be millions. Since they are single cells, we can count them at regular intervals during this period of increase and from this information construct a curve which will tell us something about how growth occurs (Fig. 23-16). Such a curve is said to be **sigmoid**, because it is S-shaped. At the beginning the cells fail to divide for a time, as indicated on the curve by the so-called **lag phase**; just why this occurs is not known. They then begin to divide at a rapid and uniform rate. This is called the **logarithmic phase** of growth because the cells increase in a geometric manner, that is, 2, 4, 8, 16, etc. Once they reach this phase they continue dividing at a uniform rate, so the line is straight. As the limits of food in the culture are reached or the accumulation of wastes inhibit further divisions, the population gradually falls off until it finally reaches a plateau. Either the organisms no longer divide, or if they do, they die as fast as they are produced, for the total number remains the same. This is called the **stationary phase**. This curve can be repeated again and again by simply taking some of the organisms in the stationary phase and placing them in a fresh medium. If the medium is continually changed, the culture can be kept in the logarithmic phase indefinitely. Apparently, these cells can continue to grow and divide indefinitely at a uniform rate with no sign of aging. Aging then may be only the exhaustion of food or the accumulation of wastes in any community of cells.

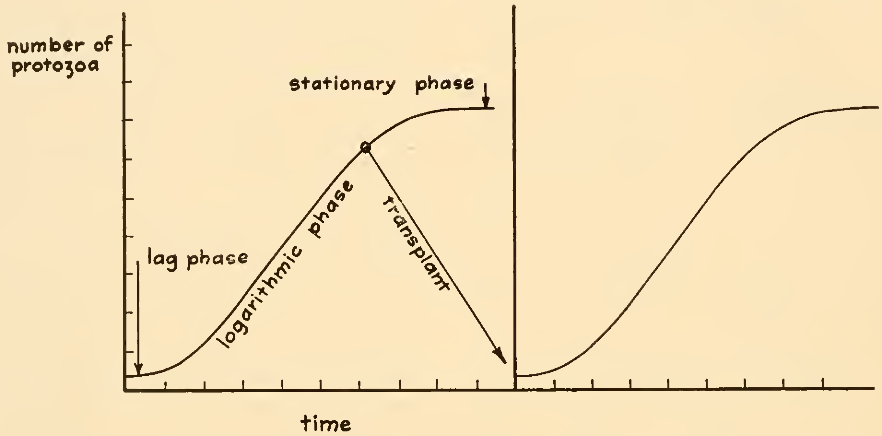


Fig. 23-16. Growth of cells, such as Protozoa in a flask of nutrients, follows very precise stages. During the initial stage there is little increase in numbers (lag phase). This is followed by a rapid uniform rate of increase (logarithmic phase) that continues until the food becomes exhausted or the accumulated wastes become toxic, or both factors operate simultaneously. Growth then remains at a plateau for a time (stationary phase). This cycle can be repeated any number of times by transplanting some of the cells to a fresh medium.

The Protozoa in this culture are all alike and are not complicated by differentiation, as would be the case in a growing embryo. Can this information be applied to embryonic cells? Tissue culture studies give us some information on this point. By removing a small bit of embryonic chick heart, for example, and placing it in a flask containing adequate nutrients, growth of the cells will occur following the same curve as that demonstrated for the Protozoa. At first the cells divide very slowly, then increase to a uniform rate, and finally fall off until no more divisions occur. If a small bit is transferred to a fresh flask of medium, the cycle will be

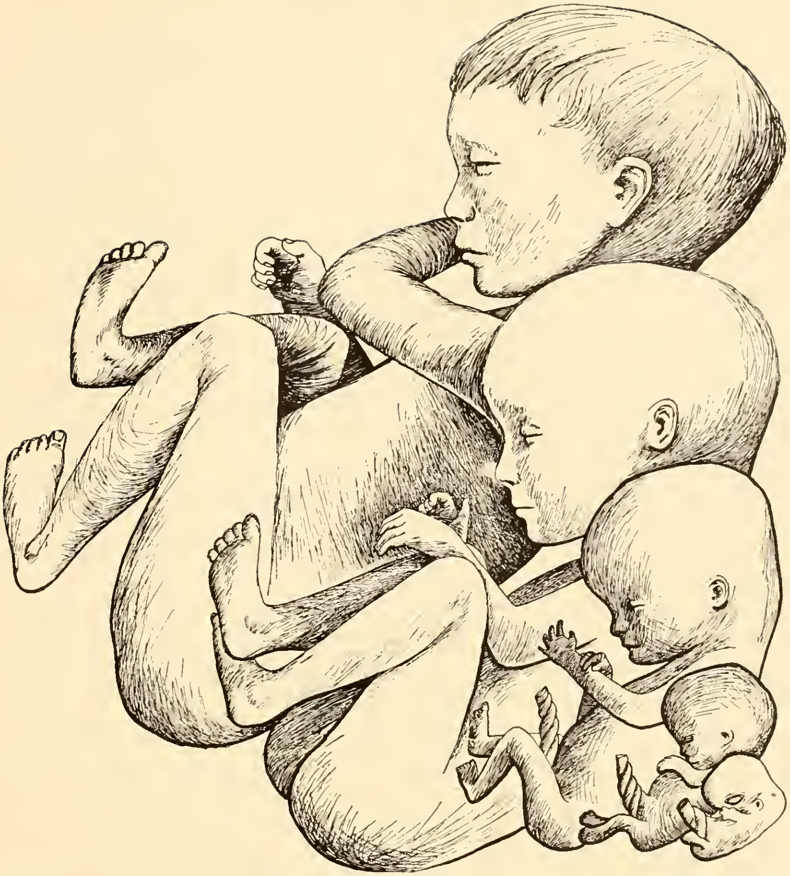


Fig. 23-17. A human fetus undergoes considerable change in body proportions during gestation. These five are compared as to relative size and body shape. Their approximate ages are 8 weeks, 12 weeks, 16 weeks, 6 months, and full term.

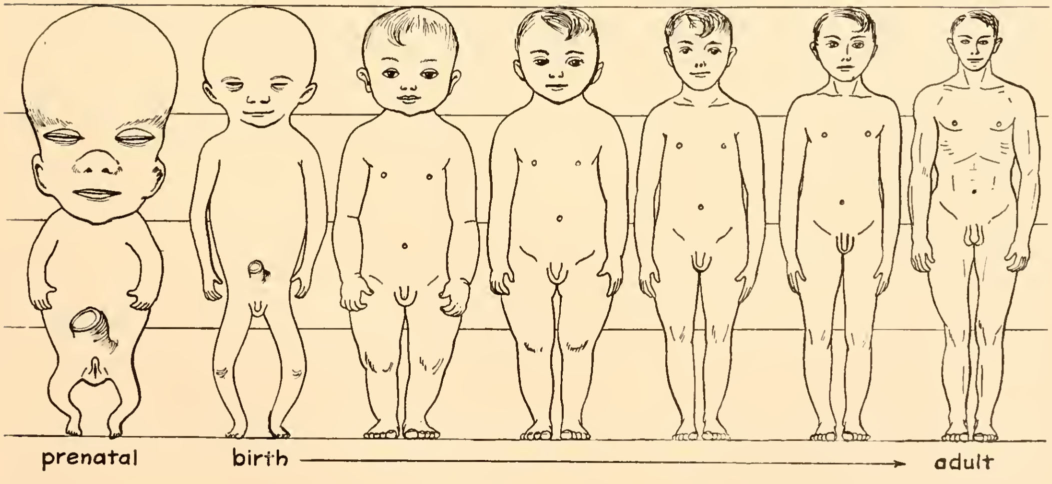


Fig. 23-18. Various parts of the body grow at different rates during the life of an animal. Here in the human being many changes occur from prenatal life at the left to the adult at the right. Note particularly the proportionate difference in the head and body size.

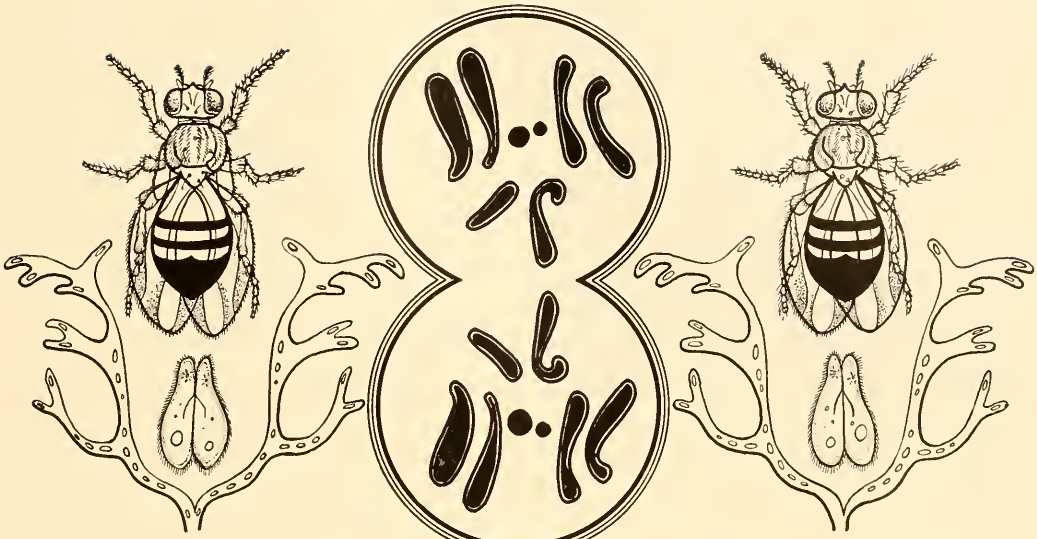
repeated, and this can be continued indefinitely, apparently forever, without change in the cells. Therefore, cells in isolated tissues grow like individual protozoan cells. But how do these cells grow when they are a part of the intact embryo? Do they follow these same phases as we have seen in Protozoa and tissues?

Just as we note limiting factors (nutrients and accumulation of wastes) in the studies of Protozoa, we also note limiting factors in the growth of the whole embryo. We know that animals grow to a certain size and stop; they do not grow forever. Something about the community of cells limits the number of divisions that occur. The individual organs also fail to grow after a certain number of cell divisions or after a certain time has elapsed. For example, if bits of tissue are removed from embryos at various ages it will be found that those from older embryos will not grow as well as tissues from younger ones; in fact, some, like nerve tissue, will not grow at all when removed from adult animals. Others like epithelium retain the capacity for growth throughout the life of the organism. Still others, like cancer tissue, grow readily no matter what their source or age. From these experiments we can conclude that cells, when confined to an organism, are subject to factors that limit growth, and these factors may be the same as the ones that limit growth in a culture medium. What all of these limiting factors are is a fertile field for research.

In the growth of an embryo, the sizes of the various organs increase at varying rates. The human heart, for example, approximates the growth of the body as a whole, whereas the brain grows tremendously during the first five years of life and thereafter grows very little. Because all of the organs grow at different rates the general over-all proportions of the human body gradually change. The change is radical during the gestation period (Fig. 23-17) but even after that it progresses slowly throughout life (Fig. 23-18).

In review, we have seen that the complex adult is a result of a long series of changes in which each change precipitates further change, and in which each change occurs as a result of a previous one. The egg is stimulated to divide by the impetus given it from the sperm. Subsequent cleavages are accompanied by the formation of an organizer that stimulates the formation of the embryonic axis which in turn orients the future embryo. Other stimuli arise, each producing one organ system after another, until the embryo comes into being as an integrated whole. Through growth, intimately tied up with development, the embryo finally becomes an adult organism. Future studies in embryology must be centered around the nature of the stimuli which bring about these changes. With an answer to this problem will come a method of control of development.

CHAPTER 24



CONTINUITY OF THE RACE

In the last two chapters we have followed the duplication of cells and the development of an individual. Now we come to the next great problem, namely, the linking of each generation to the next. From the beginning of life on the earth every generation of living things has been tied to the preceding through the tiny genes that are handed on with meticulous care. It is staggering to reflect that the next generation of human beings on this earth, over two billions of them, will come from nuclear material that will not quite fill a thimble. Just how this material is passed from one generation to the next is the subject of **genetics**, the science of heredity. It is an infant science, having gained recognition as a science only during the present century, although its beginnings extend back many thousands of years.

HISTORICAL BACKGROUND

The fact that "like begets like" has been known by man since early times. This observation probably came from his first efforts at domestication of plants and animals. Records indicate that one of the first animals to have its life interwoven with the lives of early men was the dog. Undoubtedly the first association was casual, but through selection the animal became more and more the kind of beast that best fitted man's personality and habits. It must have required thousands of years of selection, intentional or accidental, to produce an animal so beau-

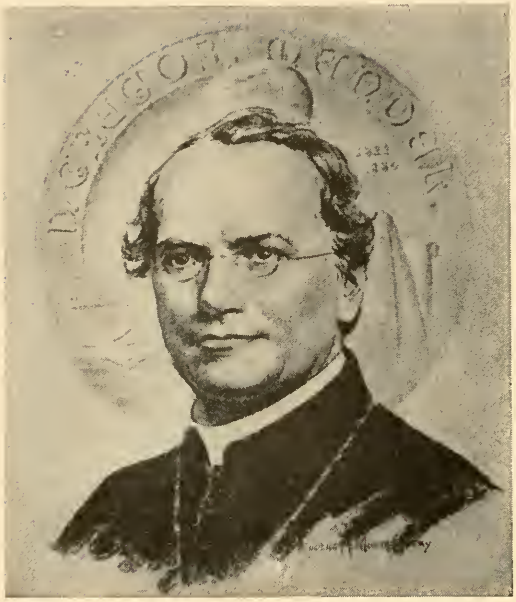


Fig. 24-1. Gregor Mendel (1822-1884), working with plants, laid the foundation for modern genetics, although his great work was not recognized by the scientific world until 1900.

tifully adapted by size, aggressiveness, and behavior to all of the whims of primitive man, to say nothing of the idealistic requirements of man today. The greatest changes were acquired through selection long before anything was known about the science of genetics. Selection is still going on today but with the aid of some understanding as to how it should be done.

Other animals, such as horses, cattle, and sheep, as well as many plants, were domesticated later, and in all of them intentional selection for improvement was practiced. This was done simply by applying the rule that "like begets like." Even though we know now that this "principle" does not always follow, the fact remains that after thousands of years of selection animals and plants were gradually changed toward the kind that could best be utilized by man. Therefore, the principles of genetics were beneficially employed by man for centuries without any knowledge whatever of how they operated.

Although information concerning selective breeding of domestic plants and animals was accumulating through the eighteenth century and the first half of the nineteenth, no one had been successful in formulating any definite theory or law as to how this all came about. Inspired by Darwin's *Origin of Species,* Sir Francis Galton began a series of studies on inheritance in about 1857 which resulted in significant conclusions concerning variation within a species. In regard to inheritance he, like many others, had studied certain complex characters such as height and intelligence and tried to follow them in succeeding generations. This resulted in an impossible situation because the problem became too complicated and no generalizations could be made from such a study.

It was left for Gregor Mendel, an obscure Austrian monk, to solve the problem (Fig. 24-1). In 1864, he presented his efforts in the form of a short paper read before a scientific society of his day. Mendel's paper could hardly be heard above the heated arguments that had been stimulated by Darwin's forceful presentation of evolution published seven years previously, yet in it one of the principal keys to evolution was handsomely portrayed by this modest clergyman. One can easily imagine the chagrin that swept over this truly great man when he realized that his findings, which to him must have seemed fundamental, were passed over by the scientific world. The significance of his monumental work was not appreciated for 36 years, 16 years after Mendel had died. About 1900, three scientists working in different parts of the world came upon essentially the same thing that Mendel had discovered many years before. They were: DeVries in Holland, Correns in Germany, and Tschermak in Austria. Mendel's paper, which had gathered dust through the years, was republished and only then did this humble man receive the credit due him. With this rediscovery of Mendel's Laws the science of genetics was born.

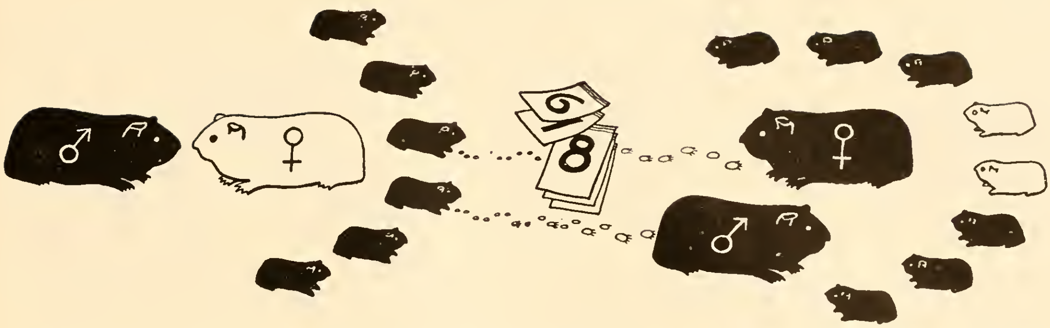


Fig. 24-2. Mendel's first law—segregation—can be shown by breeding guinea pigs as outlined here. Black and white animals (parents) give rise to only black pigs in the F_1 generation. When these are crossed the black and white hair color segregates out so that the ratio is three black pigs to one white one in the F_2 generation.

Mendel succeeded where others had failed for several reasons. First he chose to study single characters instead of the whole individual as others had done before him. He was unusually fortunate, also, in his selection of material for study. Had he worked with other plants or had he even selected other characters, he might have encountered difficulties that would have precluded his clear-cut ratios. Because of his training in mathematics and his rigorous attention to detail, he was well suited by training and aptitudes to pursue the exacting experiments that were essential for this kind of work. After eight years of experimentation in his monastery gardens, Mendel was able to give us his now famous conclusions.

It was a happy stroke of luck that Mendel selected plants such as the pea in which there is little difficulty in establishing pure-breeding strains, that is, strains that always produce a particular trait, such as flower color, in all their offspring. Once he obtained pure strains he could then cross them (hybridization) and follow the trait carefully in subsequent generations. This he did by keeping copious notes with actual counts, no matter how numerous, recorded in tabulated form. From these figures his ratios for each experiment stood out strikingly. The ratios appeared over and over again in numerous experiments in which he crossed a large variety of characters. This uniformity of specific ratios, regardless of the character, led him to formulate his final conclusions, which were later incorporated by others into what are now known as Mendel's Laws.

With the rediscovery of Mendel's Laws in 1900 the science of genetics took root. It grew very rapidly, and continues to grow today at an unprecedented rate. Research workers all over the world are contributing to our knowledge in this extremely productive field, productive not only because of its practical nature but also because of the part it plays in understanding the fundamental processes in nature.

MENDEL'S LAWS

First law—segregation

Mendel worked entirely with plants, but what he learned in plants has since been found to be equally true of animals. We will therefore employ familiar animals to describe his discoveries rather than the plants of Mendel's original experiments.

If guinea pigs of the same color (pure strains) are crossed with one another, as, for example, a pure-breeding black with a pure-breeding white, the offspring will all be black (Fig. 24-2). From this cross one outstanding fact is observed, namely, that black is **dominant**, white **recessive.** This means that when two such characters are brought together in the production of a

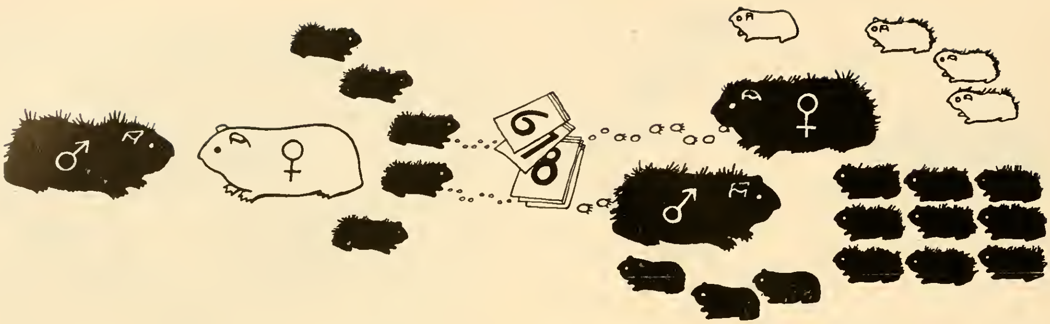


Fig. 24-3. Mendel's second law—independent assortment—can also be demonstrated with guinea pigs. By crossing a black rough pig with a white smooth one the F_1 generation consists of only black rough pigs. If any two of these pigs are crossed both characters (coat color and texture) reappear, but in different combinations. There will be 9 black rough, 3 black smooth, 3 white rough, and only one white smooth. This shows that the characters are independent units.

hybrid, one character will completely mask the other. In the above case, the factor for black hair completely dominates the factor for no color, or white. Consequently, all of the offspring are black.

The hybrid is known as the **first filial** or **F_1 generation.** In order to determine whether or not the white is completely lost in the F_1 pigs, they can be bred together, producing another generation, the **F_2** (**second filial**). When many crosses are made, so there are large numbers of offspring, about three-fourths will be black and one-fourth white. This is called the 3:1 ratio which Mendel was able to obtain so many times with his plants. From this experiment it is obvious that the character for white was not really lost in the F_1 generation. It was merely temporarily hidden or latent, because when the hybrids were crossed the character for white **reappeared unchanged** and in a definite ratio. This means that the character was a **unit** and remained as a unit, even though it was unable to express itself when in the presence of the dominant character. This is Mendel's **Law of Segregation.**

Second law—independent assortment

The above crosses involve only one character, namely, color of the skin coat. What would happen if two characters are followed through two generations? Will the characters again be lost, will new combinations be formed, or what will happen?

There are thousands of characters in any animal, but by selecting any two, preferably those that demonstrate a striking dominant and recessive condition, it should be possible to determine the fate of the characters as they pass from one generation to the next. Employing guinea pigs again we may select another pair of characters in addition to black and white color, such as **rough** and **smooth** coats (Fig. 24-3). Ordinarily the coats are smooth, with all of the hairs pointed in one direction. However, there is a breed in which the hair grows in whorls in various places on the body, giving the animal a roughened appearance. The character is easily seen and is dominant over smooth. When a **rough black** guinea pig is crossed with a **smooth white** one, all of the hybrids (F_1) are **rough black.** When these are inbred new combinations are seen. There are **nine** rough black, **three** rough white, **three** smooth black, and **one** smooth white. This is called the **9:3:3:1** ratio. The essential fact obtained from this experiment is that each of the two characters retains its identity absolutely **independent** of the other. They are all combined in the F_1, though only the dominant ones, namely, rough and black, were visible. In the F_2 each character went its own way independent of the other and showed up in the offspring in

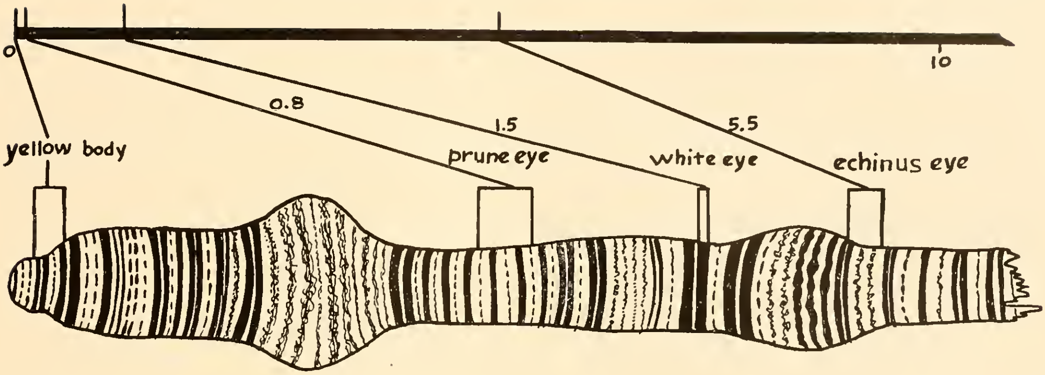


Fig. 24-4. The linear arrangement of the genes on the chromosomes has been worked out for a few animals, among them Drosophila. This has been accomplished in two ways, one by employing cross-over technics and the other by actual observation, the latter method being possible only because of the tremendous (1000 to 2000 times normal) size of the chromosomes in the salivary gland cells. A portion of the left end of the X-chromosome is shown here with a few genes indicated as to observable position on the chromosome and as computed by cross-over studies.

new combinations that were not present in either parents or grandparents, that is, rough white and smooth black. This is the **Law of Independent Assortment.**

The significance of Mendel's work is difficult to estimate because it was the starting point from which geneticists were able to delve into the more precise nature of the mechanism of inheritance. Let us now view these discoveries in the light of information that has come to us since Mendel's time, for we now understand what he did not know, namely, what goes on within the cell that is responsible for these ratios.

PHYSICAL BASIS OF INHERITANCE—THE GENE

From the very beginning of serious study of genetics, scientists concentrated on the nuclei of sex cells for an explanation of inheritance. In 1902, W. S. Sutton and C. E. McClung in this country, and Theodore Boveri in Germany, decided that **hereditary factors** within the chromosomes were responsible for heredity. In 1911, another American scientist, Thomas Hunt Morgan, conceived the idea of **genes**, lying in a linear fashion on the chromosomes. He was convinced of this because whenever he saw irregular behavior in the inheritance of certain traits in his *Drosophila* (fruit fly) cultures he also noted irregularities in their chromosomes and, conversely, any deviation in the chromosome pattern was reflected in abnormal flies. From this information Morgan and his associates were able to construct chromosome "maps" showing rather definitely where the genes lay with respect to one another on the four chromosomes in Drosophila. Today, maps have been constructed for several species of Drosophila (Fig. 24-4), for several plants, the most complete of which is corn, and for certain chromosomes of mice and poultry. Even the sex chromosomes of man have been mapped.

Even in very early studies many efforts were made to see the genes within the chromosomes. As early as 1881, Balbiani in Italy pointed out the giant chromosomes in the salivary glands of certain flies, although at that time he had no interest in the mechanics of inheritance. In recent years, however, these cells have been studied again in the light of present knowledge of genetics. The chromosomes in these cells appear under the light microscope as ribbons of alternately dark and light discs or bands (Fig. 24-5). Because of their great size in comparison to most chromosomes, it is possible to distinguish the characteris-

Fig. 24-5. The chromosomes from the salivary glands of Drosophila are extremely large and for that reason show their constitution. Note the black discs arranged on a non-staining strand. The genes are thought to lie within the strand in a linear fashion.

tics of each of the discs in their linear arrangement. The most striking observation is that they are remarkably similar to corresponding chromosomes of neighboring cells. There is considerable evidence now to show that each disc corresponds to a group of genes with respect to location on the chromosome. Whether or not these are actually genes is open to question, although pictures of genes have been published in recent current scientific journals.

In the early chapters of this book we discussed the gene in connection with the origin of life on the earth. It was stated then that the gene was a nucleoprotein and that it was able to duplicate itself in a remarkably precise manner. Modern biologists consider it the **basic unit of life,** and there is considerable evidence to support this view. Even though it is the basic unit of all life, how can these tiny genes in sex cells influence so profoundly the development of a billion-celled organism such as a higher animal? Obviously it must come about by some physico-chemical actions that go on first within the nucleus, then the cell, and ultimately the whole organism. Some light has been thrown on these problems in the last ten or fifteen years through the study of microörganisms.

Two American workers, Dr. G. W. Beadle and Dr. E. L. Tatum, while searching for an organism that would lend itself to this kind of work, came upon the common baker's mold, *Neurospora.* This mold normally thrives on sugar, salts, and one vitamin, biotin, since it is able to synthesize all other compounds that are essential in manufacturing its protoplasm. Beadle and Tatum found that by showering the spores of this mold with x-rays they could produce a large number of varieties of this mold that required much more than the minimal diet. Apparently the genes were changed in some way (mutations) so that they could no longer make possible the production of a certain nutrient, say an amino acid or a vitamin, and therefore required that substance in their diet. We know that synthesis of proteins and other constituents of protoplasm is accomplished through the work of enzymes; furthermore, we know that the steps in synthesis are many and usually complex. These men have been able to show, by using their large numbers of strains of Neurospora, that each one was deficient in its ability to synthesize one substance, that each step in the production of a nutrient is controlled by a single enzyme and that this enzyme is directly controlled by a single gene. Therefore, there is a one-to-one relationship between the gene, the enzyme, and the ultimate biochemical reaction.

On the basis of this information, let us then explain the observations on hair color in guinea pigs portrayed above. The black guinea pig has a gene which is responsible for his coat color. The black color is due to a pigment, **melanin,** which is formed by the oxidation of a complex chemical nicknamed "dopa" (dihydroxylphenylalanine), but this oxidation process will not proceed without the enzyme, **dopa oxidase.** In the white pig this enzyme is not produced because the gene responsible for its production is absent. Without it, the oxidation of dopa and the production of melanin cannot take place, hence the pig has no pigmentation and is white.

Once this theory was established, an effort was made, naturally, to find characteristics in man that could be explained the same way. Of several, the one concerned with the abnormality called **alcaptonuria** is the best known. In this anomaly the urine turns black upon standing, owing to the presence of homogentisic acid which is oxidized to carbon dioxide and water in the blood of normal people by an enzyme. Without the enzyme no oxidation takes place, and the acid appears in the urine where it eventually turns black. The enzyme is apparently produced by a gene and those people who have this anomaly do not possess the gene. Whether or not the action of all protoplasmic activities can be explained by this one-gene, one-enzyme, one-reaction principle awaits further research.

GENE COMBINATIONS

As was learned in an earlier chapter, each body cell contains a pair of genes for each trait, a **paternal** gene from the father and a **maternal** gene from the mother. The genes lie in the same position in homologous chromosomes and these points on the chromosomes are called **loci** (singular—*locus*). At the time of meiosis they separate and are distributed to the sex cells, but upon fertilization the pair is restored once more. Obviously, if the gene in each of the homologous chromosomes carries the potentialities for producing the identical trait in the offspring there is no evidence of their existence. It is only when the genes produce opposite effects that the mechanics of inheritance can be studied. Two such contrasting traits are called **allelomorphs** or **alleles** and they are always inherited in a way that the offspring can possess one but not both of them. For example, the gene that controls color in guinea pigs is located at one locus on the chromosome and it may possess the ability to produce black coat or brown coat in the offspring, but it cannot produce both because only the one gene can exist in one locus. There may be genes that alter the hair in other ways such as producing a rough coat, but these genes would occupy other loci on the same or other chromosomes and would therefore have no effect on those that produce color. Note that although the genes produce the effect, they are not colored themselves nor do they carry the actual trait in any way except that the production of the trait is bound up in the chemistry of the gene.

When the homologous genes are alike, the stock is said to be "pure" or, better, **homozygous**, that is, it always breeds true by showing only the one character. If, on the other hand, it carries a gene for one trait in one of its chromosomes and a gene for a contrasting trait in the homologous chromosome the individual is said to be **heterozygous** or **hybrid.** This is best illustrated by the use of letters as symbols for genes. For example, a homozygous black guinea pig may be represented thus, *WW;* likewise, a homozygous white pig may be represented thus, *ww*. By convention, the first letter of the trait that has appeared most recently in evolution is used. In guinea pigs, colored pigs probably preceded white ones, therefore the letter *w* is employed. Capital letters indicate the condition of one gene whereas lower case letters represent its allele or contrasting trait. An animal carrying both genes, that is, a heterozygote, would be represented by the letters *Ww*. With this scheme it is a simple matter to follow the genes from one generation to the next.

It is convenient to designate an individual both in respect to its appearance and its genetic constitution. The appearance of an individual with respect to a specific trait is known as its **phenotype**, and its genetic constitution as its **genotype.** The F_1 hybrid in the crosses mentioned above are phenotypically black but genotypically *Ww*. Pigs that are *Ww* or *WW* are phenotypically alike, that is, they are both black, but genotypically different because their genes are not the same. Likewise, brown-eyed human beings are phenotypically alike because the gene for brown eyes (*B*) is dominant over the gene for blue eyes (*b*), but they may or may not be genotypically alike. They may possess both genes for brown eyes (*BB*) or they may have one of each (*Bb*); blue-eyed people, of course, have only the one kind of gene (*bb*).

In observing the ratios in actual practice one might think that they are not very precise. For example, in one litter of guinea pigs as a result of a mating between the F_1 hybrids in the above experiment there may be nearly all combinations of the expected 3:1 ratio. If only four pigs were born they may all be black or they may all be white, although the latter possibility is very remote. It is more probable that there would be some combination of black and white, two of each color or even the expected 3:1 ratio. If, on the other hand, the litters of many such matings were used, say 1000 offspring, the 3:1 ratio would be approximated very closely. This simply means that all genetic ratios follow the laws of probability and in small samples these laws, while operative, are not very reliable. In the above cross there are always three chances out of every four that the pigs will be black and only one chance that they will be white. Likewise, in the matings of heterozygous brown-eyed people, each child has three chances of being brown-eyed and only one of being blue-eyed, and this holds true no matter how many children there are in the family. If there are three brown-eyed children in a family and a fourth one is expected, there is no more likelihood that he will be blue-eyed than there was for any of the other children. It must be remembered that at every union of the egg and sperm the chances are three to one for brown eyes no matter what previous unions have produced.

With this information, let us study various crosses in order to understand how they work out in actual practice.

A simple monohybrid cross

In tracing through the simple Mendelian ratios we shall use the same organism that Morgan first employed because much more is known about the genetics of *Drosophila melanogaster* than any other animal. This tiny fly possesses four different chromosomes, all of which have been partially mapped. By the use of x-rays hundreds of gene changes (mutations) have been produced, so that there are a great number of alleles, many of which have been investigated. Through the study of hundreds of thousands of generations of this tiny animal has come most of our knowledge of animal genetics.

In Drosophila cultures, occasionally a fly will appear with shrunken wings, called vestigial wings (Fig. 24-6). If this individual is crossed with a normal fly what might we expect in the offspring? First let us examine the nature of the germ cells of these two flies, assuming that the female is normal-winged and the male has vestigial wings. In this cross it makes no difference which sex has vestigial or normal wings. During meiosis in the male each sperm will receive a single gene, *v*, for vestigial wings because it is homozygous; likewise, each egg produced by the female will contain a gene, *V*, for normal wings. The flies resulting from the union of these eggs and sperms will be heterozygous (*Vv*) and normal-winged (Fig. 24-6), because normal wing is dominant. Without making this cross we have no way of knowing which of these two traits is dominant. If these F_1 hybrids are crossed with one another (in-

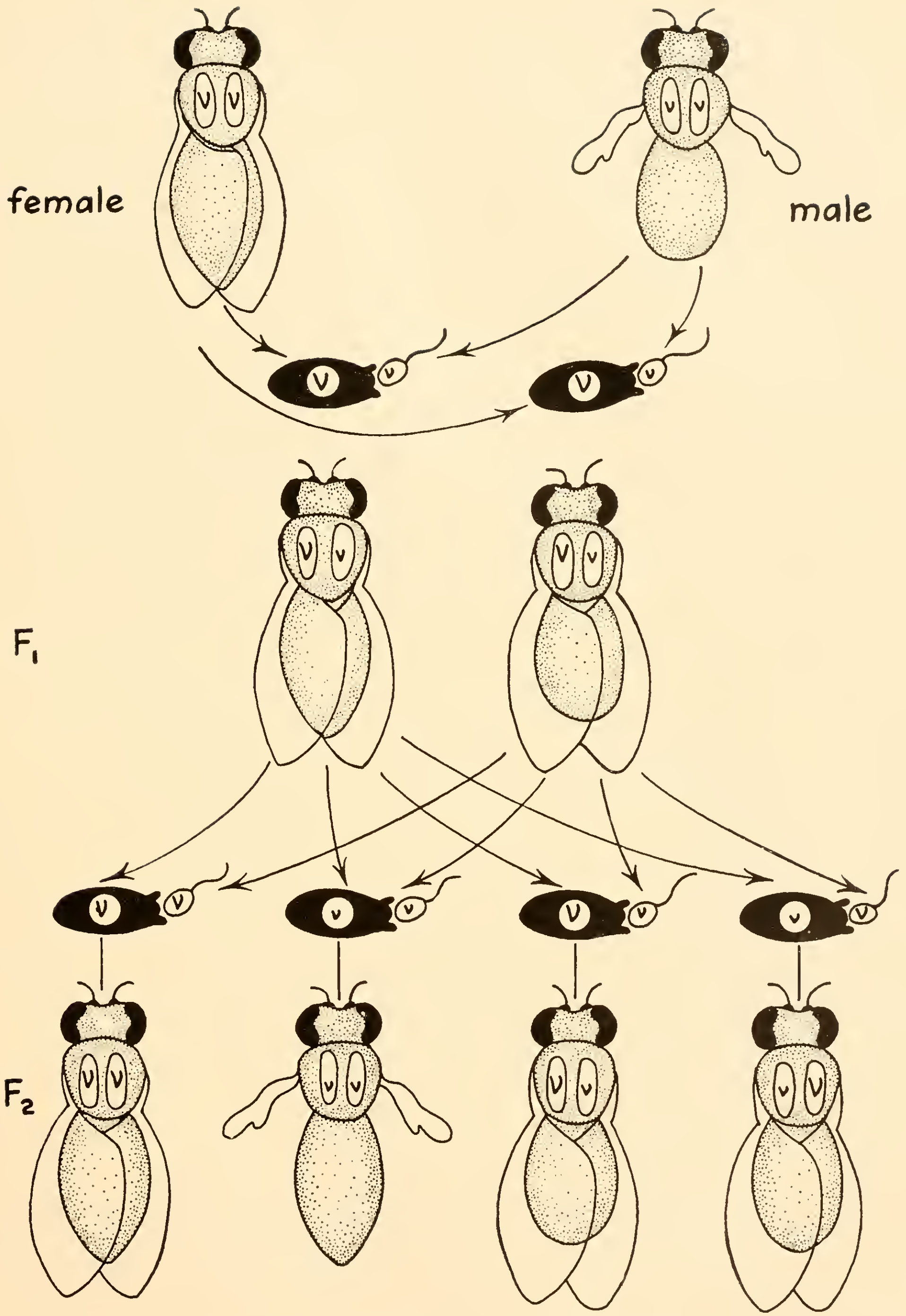


Fig. 24-6. A simple monohybrid cross in Drosophila, showing the behavior of the genes.

bred) we already know there will be 3 normal and 1 vestigial-winged flies. But why?

During meiosis of both male and female hybrids, the two alleles are distributed to the sperms and eggs in a random manner. Half of the germ cells of each will contain a gene for vestigial wing and half for normal wing. Upon fertilization these unite according to the laws of chance, and since there are four possibilities, we would expect them to occur in equal numbers for each combination. There is no special attraction between eggs and sperms of different or the same kind of gene. One-fourth of the offspring should be homozygous for normal wing (*VV*), one-fourth should be homozygous for vestigial wing (*vv*) and the remaining one-half should possess both genes, that is, they should be heterozygous (*Vv*), and since normal is dominant, they will all have normal wings just like the parents. It does not matter whether we designate the genes as one-fourth *Vv* and one-four *vV*, since the end result is one-half heterozygotes *Vv*, the order of the genes making no difference in the end result. See Table 1, below.

These germ cells unite at random. This can best be shown by employing the "checkerboard" or Punnett square, named after the British geneticist who first used it.

F_2 Generation:

		Sperms *V*	Sperms *v*
Eggs	*V*	*VV*	*Vv*
Eggs	*v*	*vV*	*vv*

Phenotypic ratio = 3 normal wings : 1 vestigial wing (3:1)

Genotypic ratio = 1 homozygous normal wing : 2 heterozygous normal wing : 1 vestigial wing (1:2:1)

Back crosses

It is sometimes important to know the genetic constitution of animals showing the dominant trait but suspected of being heterozygotes. This is particularly true in breeding of livestock. In the above F_2 flies, three-fourths of them are normal-winged, but the question arises as to which of these are heterozygous and which are homozygous. By mating each of them with the homozygous recessive grandparent this can be told. This kind of cross is known as a *back cross* or *test cross*. If the normal-winged fly is heterozygous the offspring will be half normal- and half vestigial-winged, but if it is homozygous the offspring will be normal-winged. This is made clear as follows:

If the fly is heterozygous for vestigial wings (*Vv*) the ratio will be:

	Vv	× *vv*	(recessive)
Two kinds of gametes	*V* & *v*	*v*	One kind of gamete
Possible offspring	*Vv*	*vv*	
Ratio	1	: 1	

In other words, one-half of the offspring would show the recessive trait.

If the fly is homozygous for the dominant trait (*VV*) the ratio will be:

	VV	× *vv*	(recessive)
One kind of gamete	*V*	*v*	One kind of gamete
Possible offspring	*Vv*		

All offspring would show the dominant trait.

TABLE 1

Male		Female
Parents:		
Normal wings	*VV* × *vv*	Vestigial wings
One kind of sperm	*V* *v*	One kind of egg
F_1 Generation:	*Vv*	Normal wings (Heterozygotes)
Crossing two hybrids	*Vv* × *Vv*	
Two kinds of sperms	*V* & *v* *V* & *v*	Two kinds of eggs

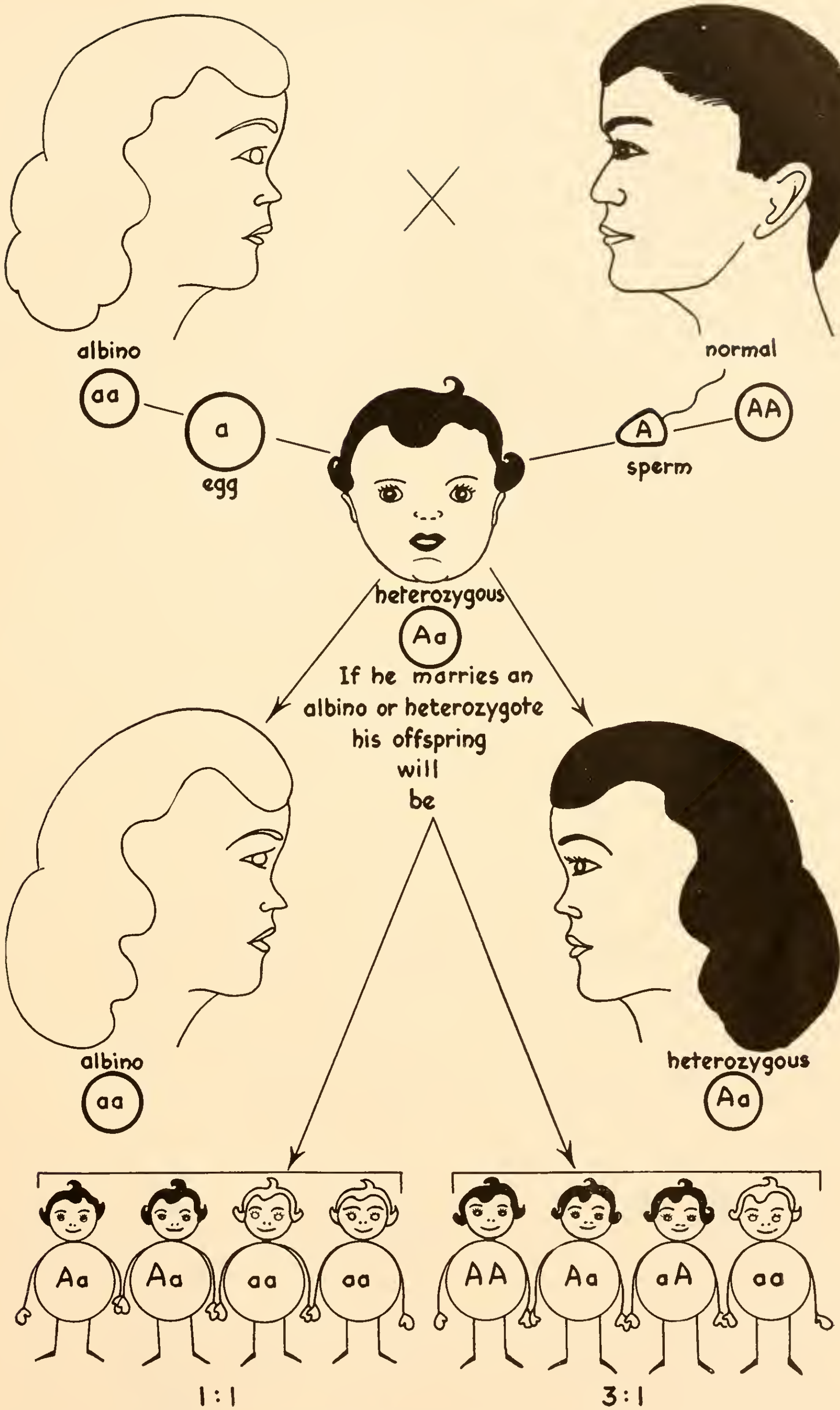


Fig. 24-7. Albinism in humans is recessive and appears only when homozygous. The manner in which it is inherited is indicated here.

A study of the inheritance of the abnormality, albinism, in man will also demonstrate this type of inheritance. An albino is lacking a gene to produce pigmentation in the skin, hair, and even in the eyes. This is inherited as a recessive, hence it must be homozygous (*aa*) to appear. If, then, a normal man (*AA*) marries an albino woman (*aa*), their offspring will be normal, although heterozygous for albinism (Fig. 24-7). If this offspring later marries an albino, his children will have a one-to-one chance of being albino, which is similar to a typical test cross and definitely establishes him as heterozygous. If, however, he marries another heterozygote like himself, their children will have one chance in four of being an albino. This is simply an F_2 generation of a monohybrid cross. If he marries a normal person, that is, a homozygote for normal pigmentation (*AA*), all of their offspring will be normal (not shown in Fig. 24-7).

Such test crosses have proven of great value in the establishment of "pure" breeds of domestic animals such as cattle for beef or milk production and chickens for egg laying. Rather than pick out the best phenotypes, as was the custom for centuries, breeders now make such test crosses until they establish the genotype for a particular trait. Animals possessing this trait are then used as breeding stock. This has been particularly profitable to farmers who wish to build up their herds in respect to milk production. It is possible through recent techniques in artificial insemination to fertilize thousands of cows with sperms from a single bull that is known to produce offspring with high milk-giving qualities. With the use of **progeny selection** the output of cows is increasing each year until today some record cattle have produced as much as 19,000 quarts of milk a year. This is a far cry from unselected cows of primitive people which give no more than 350 quarts in a year!

Dihybrid cross

So far, we have explained what happens when only one pair of contrasting genes are considered. Now let us attempt to explain what Mendel did not know when he crossed two pairs of contrasting characters. The F_1 generations of such crosses are called **dihybrids**. It sometimes is essential for geneticists to follow three and four or more characters simultaneously; this becomes increasingly complex with each added character. We shall confine our attention to the two-character cross and leave the others for advanced books in genetics.

Using normal and vestigial wings in Drosophila again, we can also follow body color. Ebony or dark-colored individuals occasionally occur in stocks of the normal gray-bodied wild type, and these dark individuals are recessive to the gray-bodied wild type (Fig. 24-8). By crossing a gray vestigial female with an ebony normal-winged male the F_1 offspring are all gray and normal-winged. Note that each of the parents were recessive and dominant for different traits. We could as well have crossed a gray normal-winged individual with an ebony vestigial fly and obtained the same normal-appearing heterozygous offspring. The sexes could also have been switched and it would have made no difference in the outcome. When these two hybrids are crossed, sixteen combinations are possible in the F_2 generation. To follow these possible combinations it is convenient to employ the Punnett square again (Fig. 24-8).

Each of the hybrids can produce four different kinds of gametes during meiosis, each bearing the two different genes. These genes must necessarily be located on different chromosomes, for if they were on the same chromosome the typical ratios would not occur, for reasons that we shall discuss a little later (linkage, see p. 606). By arranging the four different kinds of sperms

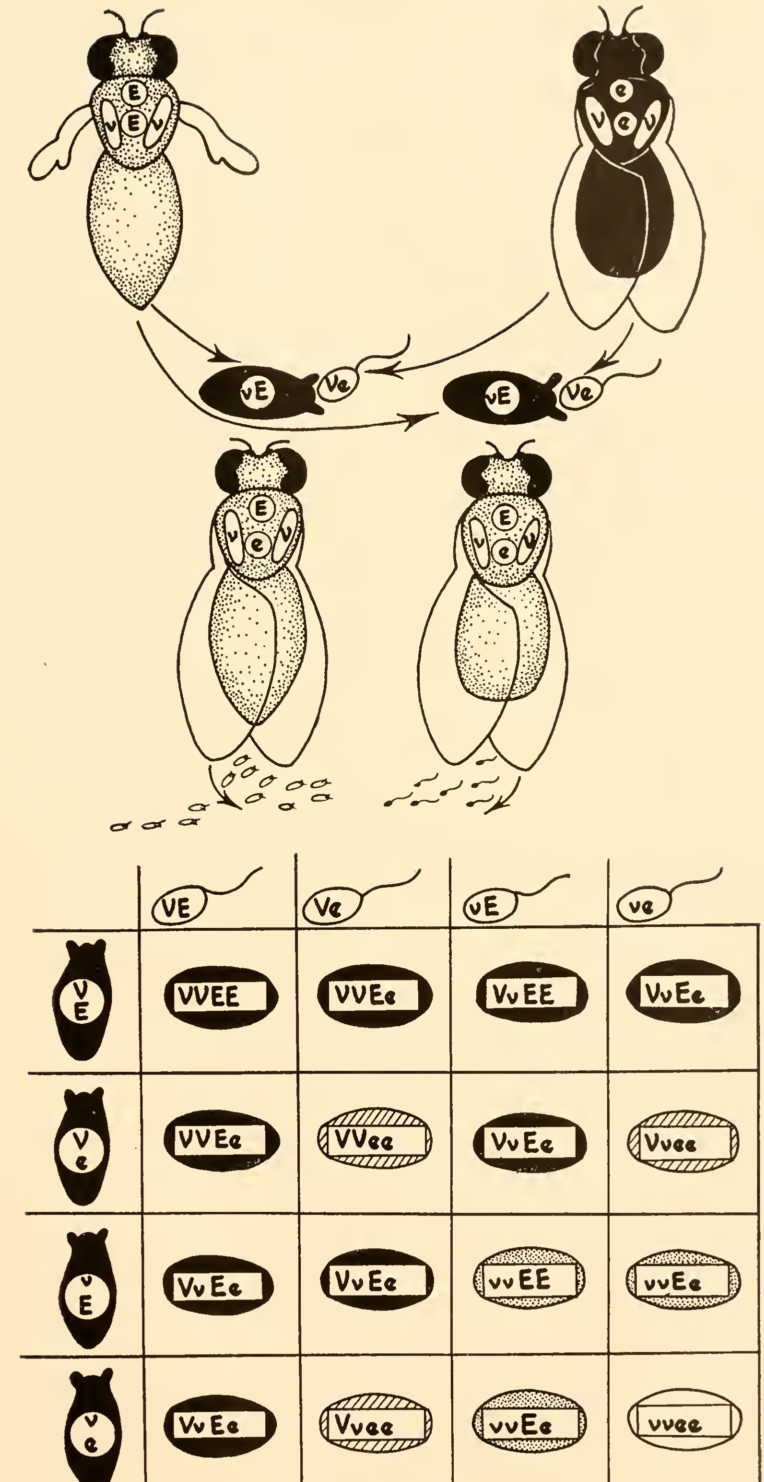


Fig. 24-8. A schematic representation of the gene behavior in a typical dihybrid cross using Drosophila.

along the top of the checkerboard and the eggs along the left side and placing in each square the gene combinations that result from the union of those particular eggs and sperms, the sixteen possible combinations become obvious. Remembering which are dominant and which recessive, it is clear that there will be 9 gray normal, 3 gray vestigial, 3 ebony normal and 1 ebony vestigial. This is the 9:3:3:1 ratio that Mendel verified many times with plants. We see here an explanation for both genotypes and phenotypes. The heterozygotes can be checked for their genes by employing test or back crosses just as was done for the single-pair genes. If, for example, a gray-bodied, long-winged heterozygote (*VvEe*) is crossed with a double recessive (*vvee*) the offspring will fall into four groups: ¼ long gray, ¼ vestigial gray, ¼ long ebony, and ¼ vestigial ebony. This is portrayed in Table 2, below.

A test cross to the dominant parent would yield all long gray offspring and would tell nothing about the genotypes.

HEREDITARY VARIATION DUE TO INTERACTION OF GENES

Up to this point we have attempted to explain Mendel's observations and the explanation has been essentially simple. With the passing of time a great many genetic variations have been noted that cannot be explained so simply. Several new principles have been discovered which are based on the interaction of alleles as well as genes occupying different loci on the same or other chromosomes. With the addition of these new principles, genetics has become an exceedingly complex science.

Blending or incomplete dominance

Occasionally a gene does not demonstrate complete dominance, so that the heterozygote shows a mixing or blending of the dominant and recessive traits. This may be due to a cumulative effect where the recessive allele is negative and the dominant allele manifests itself according to whether or not it is single or double. The heterozygote would then show half the effect that the dominant homozygote would. For example, in hair color in cattle, a red bull (*WW*) may be mated to a white cow (*ww*) and the hybrid (*Ww*) will be roan, which is a mixture of red and white (Fig. 24-9). Actually the hairs are still red or white, but they both appear, thus giving the coat its roan color. The appearance of one dominant red gene produces only half as many red hairs as the two genes will produce. When the hybrids are mated (*Ww* × *Ww*), the F_2 generation shows a ratio of 1 red, 2 roans, and 1 white. In other words, the genotypes and phenotypes are identical. In such matings it becomes impossible to "breed out" the original stock, because reds and whites will continue to show up in future progeny no matter what selecting procedures are employed.

Single gene effects

Not all genes control a single trait; in fact, most of them have multiple effects. One gene in early development may start a series of reactions that will ultimately alter or control several traits. A gene that we usually think of as controlling eye color in Drosophila, for example, may have had its share of influence along the way in the development of a host of other vital proc-

TABLE 2

	long gray *VvEe*		×	*vvee*	Vestigial ebony
Four kinds of eggs:	*VE, Ve, vE, ve*			*ve*	Only one kind of sperm
Test cross	¼ *VvEe*, (long, gray)	¼ *Vvee*, (long, ebony)	¼ *vvEe*, (vest. gray)	¼ *vvee* (vest. ebony)	
Ratio:	1 :	1 :	1 :	1	

esses, though we see its ultimate effect only in eye color. In experiments with Drosophila where the location of the gene in the giant chromosomes of the salivary gland cells can actually be seen through the microscope, it is observed that when a piece of the chromosome is missing which contains the gene for eye color, progeny from such homozygous individuals are either much weakened or do not survive at all. In other words, the gene that ultimately registers itself in eye color plays other rôles along the way that are vital to the adult organism.

An interesting example of this multiple effect of single genes in humans is illustrated by the rare anomaly known as **phenylketonuria.** In this defect, a simple

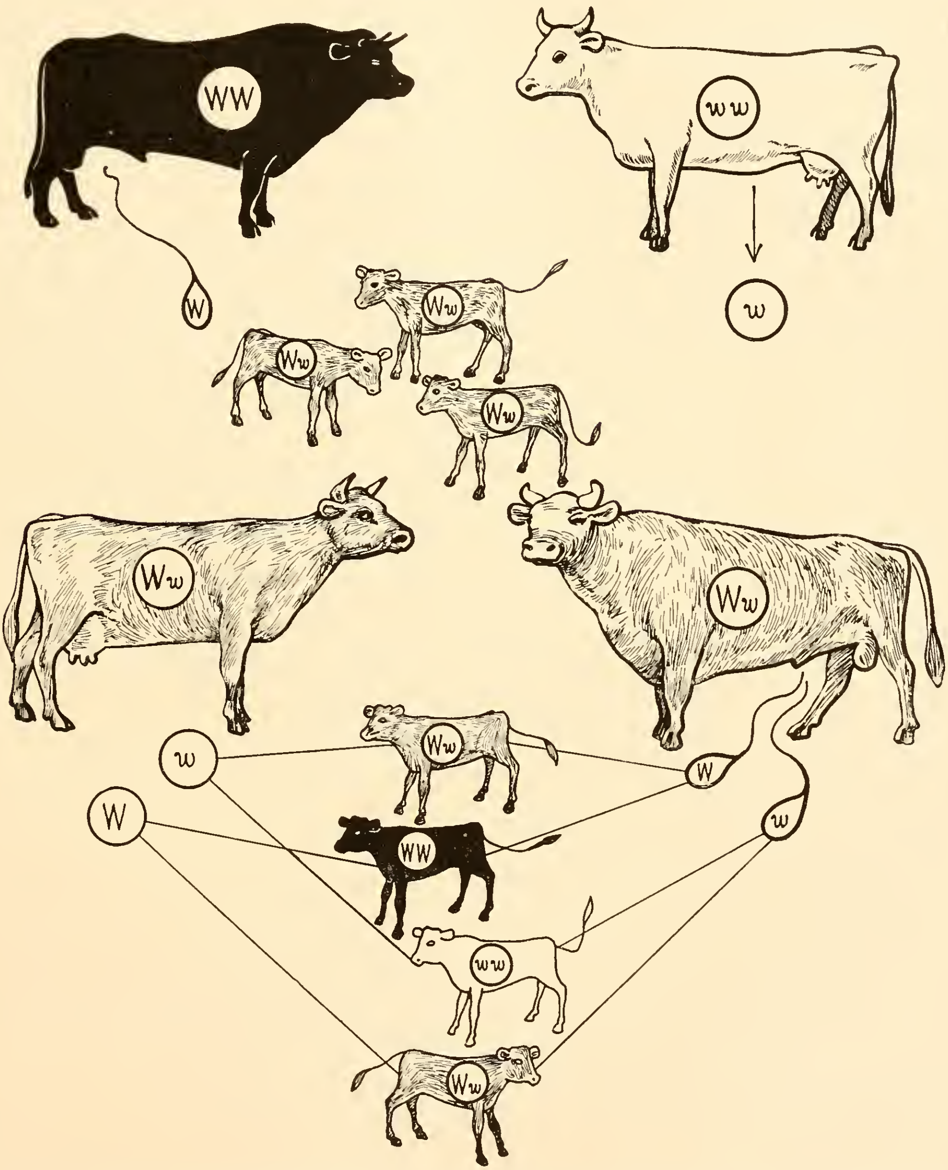


Fig. 24-9. Blending dominance can be illustrated with red and white cattle. Here the genotype can be distinguished by simply observing the coat color.

recessive, there apparently is no enzyme to oxidize phenylpyruvic acid in the blood, so that it appears in the urine. This simulates alcaptonuria mentioned earlier, except that people who have phenylpyruvic acid in their urine are also imbeciles or low-grade morons. It appears, then, that the gene which fails to produce the enzyme that oxidizes this acid has even more profound effects in some other parts of the body. Just what these are remain unknown at present.

Multiple gene effects

It was pointed out earlier that several unlike genes may occupy the same locus in a chromosome but not at one time. These are called **multiple alleles**. By the use of x-rays, hundreds of multiple genes have been produced in Drosophila, so that for one locus, eye color for example, there are fourteen known alleles, all different. Their influence on eye-color production ranges from dark red to white with all shades in between. Coat color in rabbits likewise is controlled by multiple alleles. There is a gene (C) which controls coat color, whereas the homozygous genes (cc) cause no color or albinism. Two alleles, (c^{ch}) and (c^h), when homozygous, produce "Chinchilla" and "Himalayan," respectively. The former is steel gray, while the latter is white all over except the tips of the ears, toes, tail, and nose. When arranged in a series, C, c^{ch}, c^h, c, each gene is dominant to those following it and recessive to all of those preceding it. For example, a rabbit with the genes $c^{ch}c$ is a "Chinchilla," one with c^hc^{ch} is also "Chinchilla," whereas one with genes c^hc is "Himalayan."

Another interesting fact has come from the coat-color studies in rabbits with respect to physical factors that control genic action. In the "Himalayan" rabbits the intense black color that occurs at the tips is controlled by temperature. If the hair is removed from a portion of the body that is white and this region kept cool, the hair grows in black, indicating that the gene for colored tips (which are cooler than other portions of the body) can produce its effect only at reduced temperatures. This observation probably is a general phenomenon which needs further attention by geneticists.

One of the best-known characteristics in man that is inherited by multiple alleles is the A, B, AB, and O blood groups which we discussed in Chapter 19 (see p. 513). Three alleles are responsible for the various groups: genes A, A^B and a, of which the first two are dominant to the last. Gene A controls the formation of anti-A (agglutinogen); gene A^B controls the formation of anti-B; and gene a is without effect in that it causes no antibody formation. Neither A nor A^B is dominant to the other, so when both are present in homologous chromosomes the blood group AB results. Since these genes are inherited in a definite fashion, the knowledge of blood types has some value in addition to that needed in transfusions. In cases of questionable paternity the knowledge of blood types can be used and may rule out certain males as possible fathers of a child. It cannot be employed to determine whether a certain man *is* the father but only that he *could be*. The manner in which this operates can be seen from a consideration of all of the genotypes:

Blood Group	*Genotype*
A	Aa or AA
B	A^Ba or A^BA^B
AB	AA^B
O	aa

A child with blood group A (Aa or AA), for example, and a mother with Group B (A^Ba or A^BA^B) must have a father with group A or AB. A male with group O or B could not possibly be the father of such a child. Do you see why?

Supplementary genes

Sometimes two pairs of genes interact, so that the expected 9:3:3:1 ratio in the F_2 is significantly altered; in fact, an en-

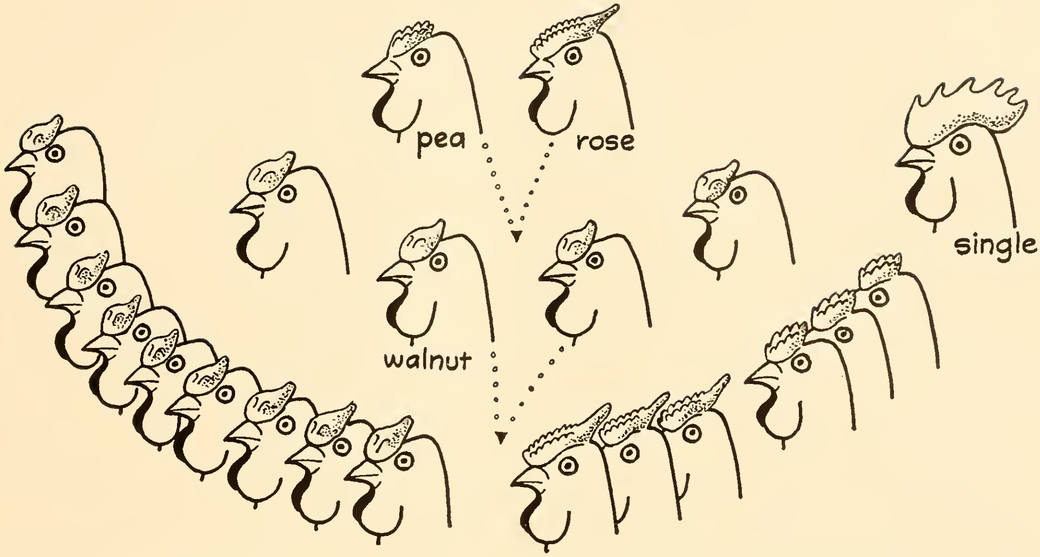


Fig. 24-10. The inheritance of combs in fowls is due to two dominant interacting or supplementary genes. In a cross between pea- and rose-combed animals a new type of comb, walnut, is produced. Crossing walnut-combed fowls gives the typical 9:3:3:1 two gene ratio, but the interaction of the genes show a distribution of comb types as shown here. The double recessive comes out to be a fourth kind, single comb.

tirely new phenotype may appear. When two dominant genes interact so as to produce a new phenotype, they are called **supplementary genes.** One of the simplest cases of this interaction occurs among combs in chickens. Three kinds of combs are well known: **single, pea,** and **rose** (Fig. 24-10). Both pea and rose are dominant to single. What happens when pea and rose, two dominants, are crossed? The result is a new kind of comb, called **walnut**! This demonstrates the combined action of two dominant genes, namely, that each supplements the other and the result is a comb different from that each would produce alone. The proof of this conclusion can be shown merely by crossing two walnut-combed animals. The offspring appear in the ratio of 9 walnut : 3 rose : 3 pea : 1 single, which means that wherever the genes for rose and pea come together their supplementary action produces a walnut comb. Supplementary gene action is different from blending because the genes are located on different chromosomes and are therefore not alleles. Moreover, it is possible to produce a pure breed of walnut-combed chickens simply by making test crosses with the double recessive single comb to establish homozygous genes. Once this is done, the mating of two homozygous birds will result in all walnut-combed offspring and the pure breed is established. You will remember that this procedure is impossible with those showing incomplete dominance.

Another slight variation in supplementary gene action can be demonstrated in guinea pigs. Black coat (*BB*) is dominant to brown coat (*bb*). In addition to these genes there is a third gene (*C*) which is essential in order that the color appear at all. A double recessive (*cc*) is an albino. If a brown guinea pig (*CCbb*) is mated with an albino (*ccBB*) the offspring will all be black (*CcBb*) which might seem surprising until the genes are examined. Whenever the gene for color (*C*) is in combination with the supplementary gene (*B*), the phenotype will be black, but if it occurs only with the recessive (*c*) no color appears. If two of these F_1 pigs are mated, the F_2 generation will have the ratio of 9 black, 3 brown, and

4 albino. Here we see two independent gene pairs interacting in such a way that one dominant will produce its effect with or without the other. The second dominant, however, can produce its effect only in the presence of the first.

Multiple factors

So far we have been considering characters that are clearly defined, where the phenotypes are sharply set off by color or some other trait. But there are a great many characters which, instead of demonstrating clear-cut differences, show continuous variation from the two extremes; this is particularly true of such human traits as skin color, height, weight, special abilities, and intelligence. In cross-matings between individuals possessing the two extremes of these traits, children do not resemble one parent or the other but are intermediate between the two. This is like **blending inheritance** in which more than one pair of genes is involved. This means that several genes, known as **multiple factors**, influence one trait and their ultimate effect depends on additive action. This can be illustrated by a consideration of skin color in humans, which is the best-known example of this type of inheritance.

In certain parts of the world where there is no "color line," marriages between Negroes and whites are common, and such practice has afforded geneticists sufficient information about the inheritance of skin pigmentation to understand it genetically. It is known that two pairs of genes on separate chromosomes are involved. These may be called *Aa* and *Bb* where *A* and *B* are responsible for pigmentation. In the F_1 generation resulting from a mating between a homozygous Negro (*AABB*) and a homozygous white (*aabb*) we would expect the hybrid (*AaBb*) to be either all black if the genes for pigmentation were completely dominant or half black, **mulatto**, if blending occurred. The latter proves to be the case. The genes for pigmentation show incomplete dominance and the offspring are dark-skinned, approximately intermediate between the white and black parents. This resembles exactly what one would expect in a single gene pair trait. The double gene-pair proof comes when two mulattos mate (*AaBb* × *AaBb*). If there were but a single gene pair, the typical 1 white : 2 mulatto : 1 black ratio would be expected, but instead an entirely new ratio appears, that is, 1 black : 4 dark brown : 6 mulatto : 4 light brown : 1 white. Since there are sixteen possibilities, there must have been four genetically different sperms and four genetically different eggs, or two pairs of genes, each located in different chromosomes. This is simply the F_2 generation of a dihybrid cross. Why, then, should this peculiar ratio result instead of the typical 9:3:3:1?

If we assume that the genes *A* and *B* influence the production of equal amounts of pigmentation even though located on different chromosomes, and that blending occurs between each with its recessive, *a* and *b*, then the 1:4:6:4:1 ratio is exactly as one would expect. Moreover, the intensity of the skin pigmentation, that is, the phenotype, would give a clue as to the genetic constitution or genotype of an individual. The darker the skin, the more capital letters would appear in the genic constitution. For example, a full Negro would have the genetic formula of *AABB*; a dark brown Negro would be *AABb* or *AaBB*; a mulatto would, of course, have one of each gene, *AaBb*. However, it would be impossible to tell whether the formula was *AAbb*, *AaBb* or *aaBB*, since each dominant gene has the same influence in producing pigmentation. The light brown would have but one dominant gene, *Aabb* or *aaBb*, whereas the white would be double recessive (*aabb*), naturally. Thus, in this F_2 generation there would be one person resembling each of the grandparents and all others would be graded in respect to pigmentation.

Can such information be of assistance in predicting what one might expect in offspring of matings where the skin pigmentation varied in the two parents? Obviously matings between the double recessive white and a person with any degree of pigmentation will produce offspring lighter than the dark parent. Matings between individuals carrying only one gene for pigmentation and appearing as light as many non-Negroes *may* produce children darker than either parent. On the other hand, they have an equal (1:4) chance of producing children with no genetic trace of pigmentation. Such white children are double recessives (*aabb*) and therefore can never transmit pigmentation to their offspring.

Normal frequency and multiple factors

The character of skin color involving two gene pairs in man is a relatively simple case of multiple factors. As a rule such characters involve many more gene pairs, as, for example, height in man, where ten or more are influential. With three gene pairs influencing one trait, the F_2 comes out in the ratio 1:6:15:20:15:6:1. With each added gene pair the shape of the distribution approximates more and more closely a normal bell-shaped frequency curve (Fig. 24-11). When ten gene pairs influence a single trait, the distribution coincides with the normal distribution curve. In other words, ten gene pairs are sufficient to produce a normal population in respect to one trait whether it be height, weight, length of neck, or degree of intelligence. If one measures the height of 10,000 adult white males in America, he would find a range from about 55 to 85 inches with an average falling around 68. There would be very few as short as 55 inches and very few as tall as 85 inches but a great many around the average of 68 inches. By plotting the number of people at each height against inches, a normal distribution curve results (Fig. 24-11). This is exactly what is obtained when the distribution is computed for height on the basis of ten gene pairs being involved.

Quantitative studies of populations

Long before Mendel's Laws were known, some effort was made to understand inheritance by a careful analysis of a single trait in large populations. The most outstanding investigator in this field was Sir Francis Galton of England, referred to earlier, who studied the inheritance of many traits of British people, including such intangible ones as intelligence. He discovered that high intelligence seems to "run in families," as shown by the frequency that names of members of famous families appeared in the British "Who's Who." Such traits as

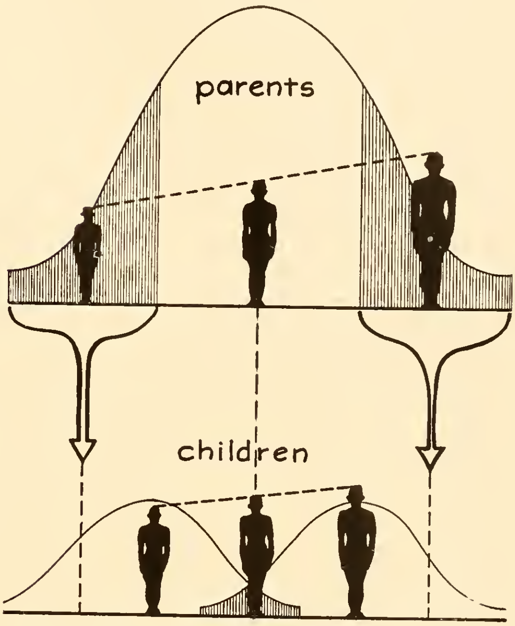


Fig. 24-11. Height in a population of humans shows a normal bell-shaped frequency curve as shown in the upper figure. There are a few about 55 inches tall and a few about 85 inches tall; most people are between these extremes, the average being about 68 inches. When these heights are plotted against numbers, a bell-shaped curve results, which is what is expected when ten gene pairs are involved.

The lower portion of the figure shows how Galton's law of filial regression operates. Children of short and tall parents are never as short or as tall as their parents. They tend toward the average height of the population.

height, which, as we have seen, is inherited through multiple factors, led him to formulate his **filial regression law.** This law merely states that offspring of tall or short parents, while taller or shorter, respectively, than the average British subject, are still not as tall or as short as their parents. This means that at the extremes of height offspring tend to regress toward the average (Fig. 24-11).

Although Galton's studies contributed virtually nothing to the mechanics of inheritance, they did give later workers, not only in biology but also in sociology, economics, and other fields, a tool by which a quantitative description of a naturally or artificially occurring series of variables could be stated. It has been used extensively in biology in determining a normal population in respect to one or more traits. This is important to animal breeders who are trying to improve their stock with respect to a particular character, such as egg laying in chickens. By carefully selecting for breeding stock, those birds that produce the greatest number of eggs the whole population can gradually be improved along that line. This means a selection toward all dominant or all recessive genes. When the stock becomes homozygous for a particular trait there is nothing more to be gained by further selection. One needs only to inbreed and keep the desired qualities which have thus been attained.

Hybrid vigor or heterosis

One of the strange and unexplained outcomes of multiple factor inheritance is that the hybrid resulting from two parents with contrasting traits is frequently more vigorous, bigger, and apparently better in every way than either parent. This condition is known as **heterosis** or **hybrid vigor.** This observation has been made on a great many animals. The mule, which is a result of a mating between a jack and a mare, is notorious for its strength and endurance as well as its stubborness. Every farmer is familiar with the value of hybrid corn, which demonstrates heterosis very markedly. Some striking cases of heterosis among human beings have occurred where two distinctly different races have crossed. The most celebrated instance is that of Captain Christian and his fellow mutineers of the "Bounty" who took native Polynesian women from Tahiti and settled on tiny Pitcairn Island. The first generation of children were more vigorous, taller, and more fertile than either the white or the Polynesian stock from which the parents came. Incidentally, this is also one of the few cases in human history where a nearly perfect inbreeding experiment was carried on. Studies of half-breed Indians, as well as hybrids from Hottentot and Boer crosses, have likewise revealed heterosis to a marked degree, although the condition does not seem to be evident on certain black-white crosses.

The second generation following the original crosses usually results in a gradual loss of the early hybrid vigor and the offspring in succeeding generations slowly return to an intermediate type. This might be explained by considering that each member of the first cross possesses certain dominant genes for desirable traits which were lacking in the mate. When crossed, a now full complement of dominants would produce their desirable effects, thus producing the vigorous offspring. In subsequent hybrid matings the dominant genes would segregate out, as one might expect, and eventually the recessives would once more reduce most of the race to the condition of the original parental stock.

Inheritance of sex

The obvious fact that sexes appear in the ratio of 1:1 meant nothing until geneticists noted that the cross of a hybrid (*Ww*) and its double recessive (*ww*) was also a 1:1 ratio, which fact suggested the possibility that sex might likewise be determined genetically. Cytological evidence before 1900

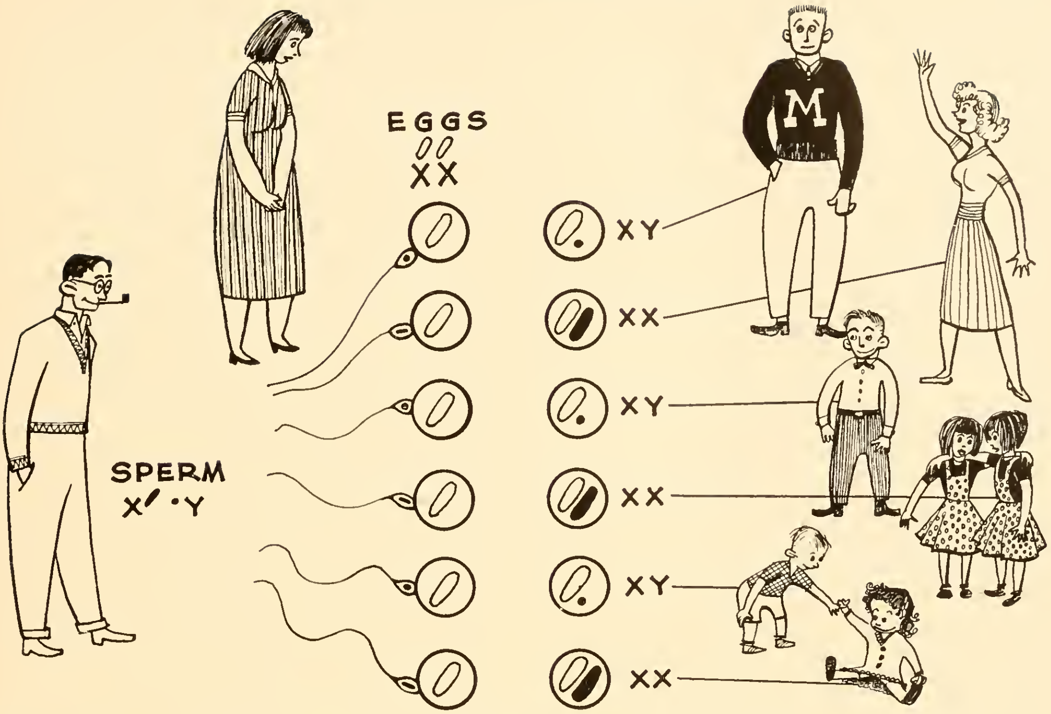


Fig. 24-12. Sex is determined in animals at fertilization, depending on the genetic composition of the sperm which enters the egg. If it contains an X chromosome the offspring will be female; if it contains a Y chromosome the offspring will be male.

had shown that some of the sperm cells of certain insects such as the firefly had a very tiny chromosome, whereas the other sperm cells had a large one in place of the small one. As early as 1902, McClung in this country suggested that this difference might control sex and for the next 20 years the problem was avidly pursued until his conjecture was generally accepted as true. This meant, then, that there are two kinds of chromosomes in every cell: the **sex chromosomes** which determine the sex, and the **autosomes** which include all of the remaining chromosomes. The female is distinguished by having two sex chromosomes, called **X chromosomes,** while the male has only one of these plus a second very much smaller chromosome, the **Y chromosome.** Therefore, a human female has 23 pairs of autosomes and one pair of *X* chromosomes in every body cell, and the male has 23 pairs of autosomes plus one *X* chromosome and one *Y* chromosome. With a few exceptions (some fish, butterflies, and birds where the situation is reversed) microscopic examination has shown this to be true of animals in general.

At meiosis two kinds of sperms are produced, both containing the autosomes plus either an *X* or a *Y* chromosome (Fig. 24-12). Upon fertilization the egg, which contains only a single *X*, may receive either a sperm containing an *X* or one with a *Y*. In the former case the offspring will be female (*XX*) and in the latter, male (*XY*). Since fertilization occurs at random, there is a 50-50 chance of either kind of sperm fertilizing the egg, hence the equal numbers of both sexes. In other words, the male is heterozygous for sex, the female homozygous. It would seem that sex determination is a very simple matter, but experimental work over a long period of time has brought to light certain conditions which indicate that the process is, unfortunately, not as simple as was once thought.

Genic balance and sex determination

One of the first experiments that upset the theory of sex determination by the *X* and *Y* chromosomes was the appearance in about 1922 of a fly in Dr. Calvin Bridges' cultures at Columbia University which possessed three sets of autosomes (9 chromosomes instead of only 6) and 2 *X* chromosomes. According to the theory, this fly should have been a female but actually it was an intermediate between male and female, or an *intersex.* Apparently the presence of an extra set of autosomes upset the "genic balance" in such a way that the two *X* chromosomes could not completely control the situation in order to produce a female. This and subsequent experiments made it clear that other genes scattered throughout the autosomes were also influential in determining the sex. The distribution of the genes in the autosomes and *X* chromosome seemed to be the deciding factor, as indicated in Table 3, below.

From these experiments it is evident that the *X* chromosomes carry a preponderance of genes for femaleness while the autosomes contain a preponderance of genes for maleness; how much "maleness" or how much "femaleness" the offspring exhibits is determined by how great a dose of either one or the other it receives. If the dose is intermediate, the offspring displays the external characteristics about evenly divided.

This revised view of sex determination does not explain all of the observed facts. Earlier (p. 438) we saw that the sex of a hen chicken could be reversed when the ovary was destroyed because it received male hormone from an activated residual testis. Certainly the genetic balance was not changed. What actually did happen is another unsolved riddle in biology.

Sex linkage

In addition to carrying genes for sex the *X* chromosomes also contain other genes that have nothing to do with sex, such as those that control eye color in Drosophila. The *Y* chromosome is virtually without genes, that is, it seems to be a genetic blank, and at least some insects (*Anasa*—the squash bug) do not have it at all and apparently get along satisfactorily. Since the *X* chromosome carries certain genes that control traits besides sex, it follows that those genes will be tied in some peculiar fashion to the sex, in other words, they will be **sex-linked.** In man the genes responsible for **red-green color blindness** and the blood abnormality, **hemophilia,** are carried on the *X* chromosome so that one might expect these anomalies to be associated with sex. This is definitely true and has been recognized for centuries, particularly with respect to hemophilia. Because this condition has occurred in royal families whose histories are well known, it was learned very early that the dread disease passed from mothers to sons but never from father to sons. For example, Queen Victoria of England apparently carried the defective gene because she herself did not have the disease but transmitted it to one of her sons and through two of her daughters to succeeding generations so that it has occurred again and again in her male descendants, particularly in the Russian and Spanish royal families.

This great enigma in man's inheritance remained a mystery until a mutation producing white eye color occurred in some of T. H. Morgan's fly cultures. When the inheritance of this trait was worked out it

TABLE 3

2 *A* (autosomes)	plus 1 *X*	= Normal male characters
2 *A*	" 2 *X*	= Normal female characters
3 *A*	" 1 *X*	= Over-developed male characters
2 *A*	" 3 *X*	= Over-developed female characters
3 *A*	" 2 *X*	= Intersex

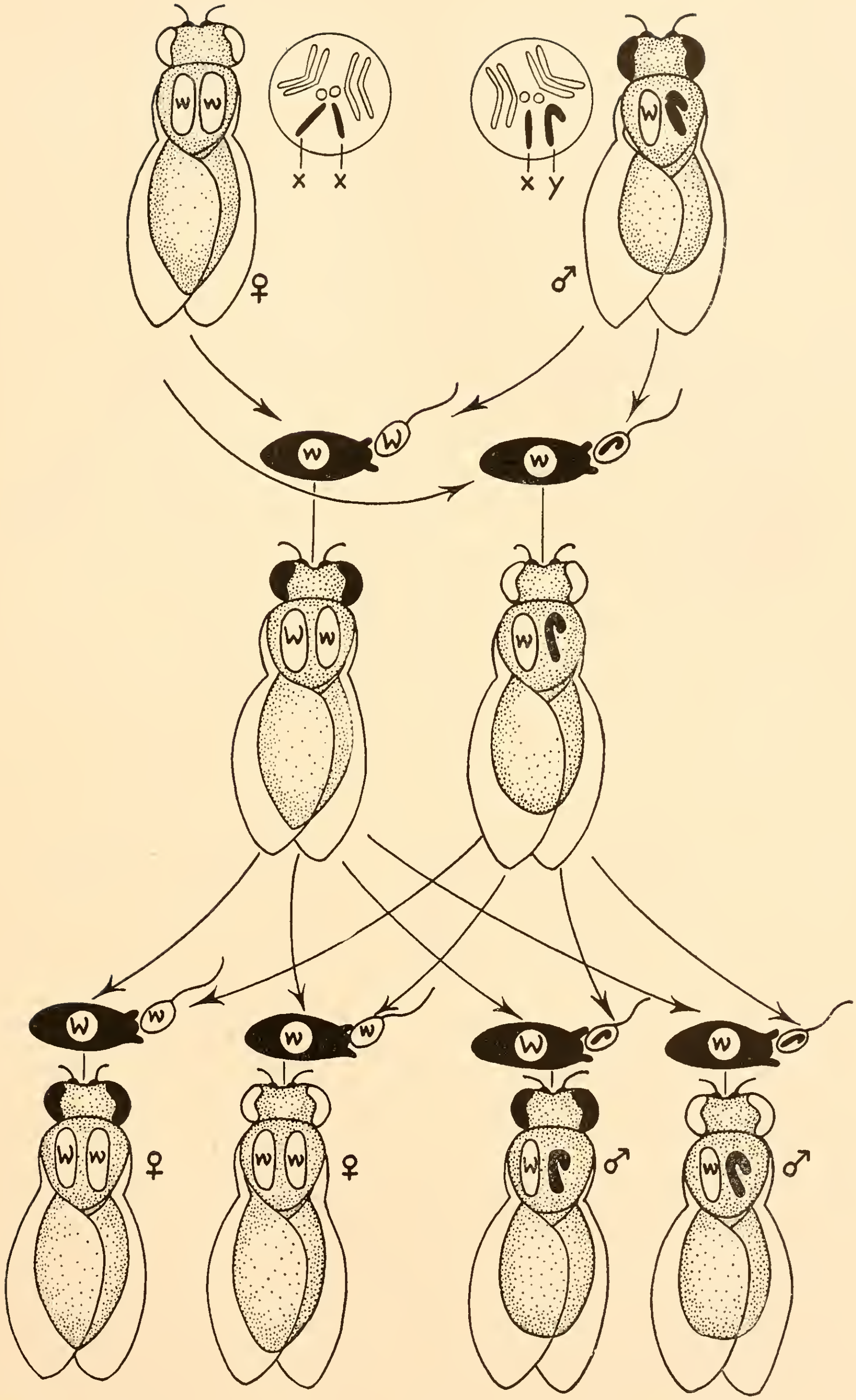


Fig. 24-13. Genes that are located on the sex chromosome (*X*) are associated with the sex of the animal, as indicated here in Drosophila. The gene for eye color (white) is located on the *X* chromosome and behaves in the manner shown here.

paralleled the transmission of hemophilia in man. From this white-eyed stock of Drosophila, Morgan was able to show that the gene for eye color was located on the X chromosome and that its inheritance was definitely linked with this chromosome and consequently with sex. As a result of many experiments, it has been found that the inheritance of this sex-linked trait follows though they will be heterozygous, and all of the males will be white-eyed because their one X chromosome carries the defective gene (Fig. 24-13). When these F_1 flies are allowed to interbreed, the effect of the linked condition is further demonstrated. The female can produce two kinds of eggs, one-half containing an X chromosome with a normal gene and one-half bearing a de-

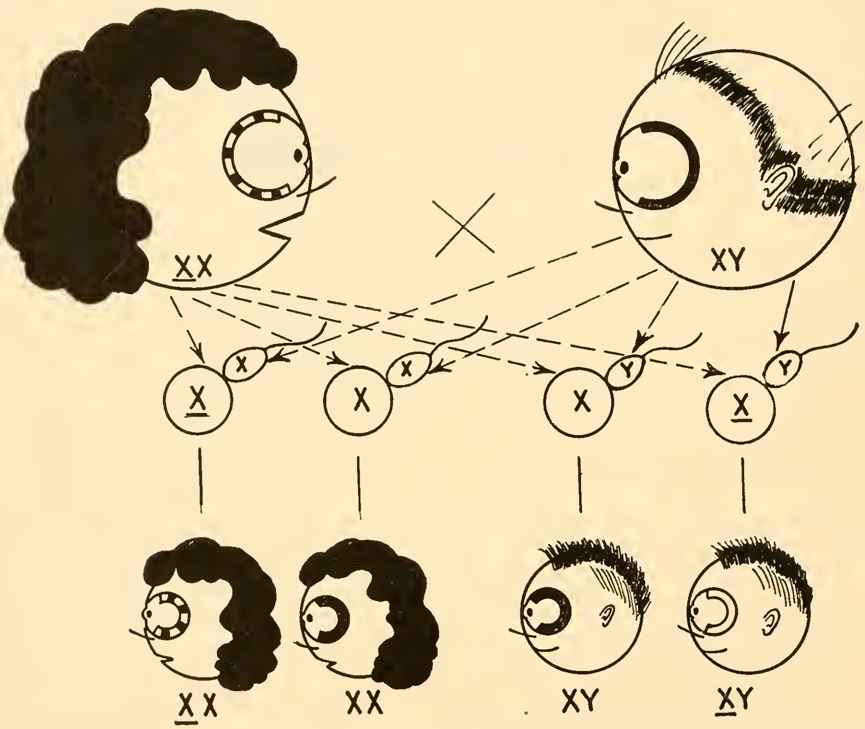


Fig. 24-14. Color blindness is sex-linked in man and is inherited the same as white eye color in Drosophila. In these figures the solid black retina indicates normal vision, the broken retina represents the heterozygous condition in the female, and the white retina indicates red-green color blindness.

a specific pattern (Fig. 24-13). The gene for white eye color is recessive and is therefore obvious only when homozygous. Since the male has but one X chromosome, white eyes will appear whenever a single X chromosome carrying a defective gene is a part of the genetic make-up of the male fly.

In a cross between a white-eyed female, whose X chromosomes must each carry the defect, and a normal red-eyed male, all of the female offspring will be red-eyed, al- fective gene. The male produces two kinds of sperms as usual, that is, half containing an X and half a Y chromosome. The sperm containing the X chromosome, however, carries the defective gene (w). Random fertilization will result in half of the female offspring being homozygous and therefore white-eyed; the other half will be red-eyed but heterozygous. Half of the males will be white-eyed and half red-eyed because the eggs from which they came contained

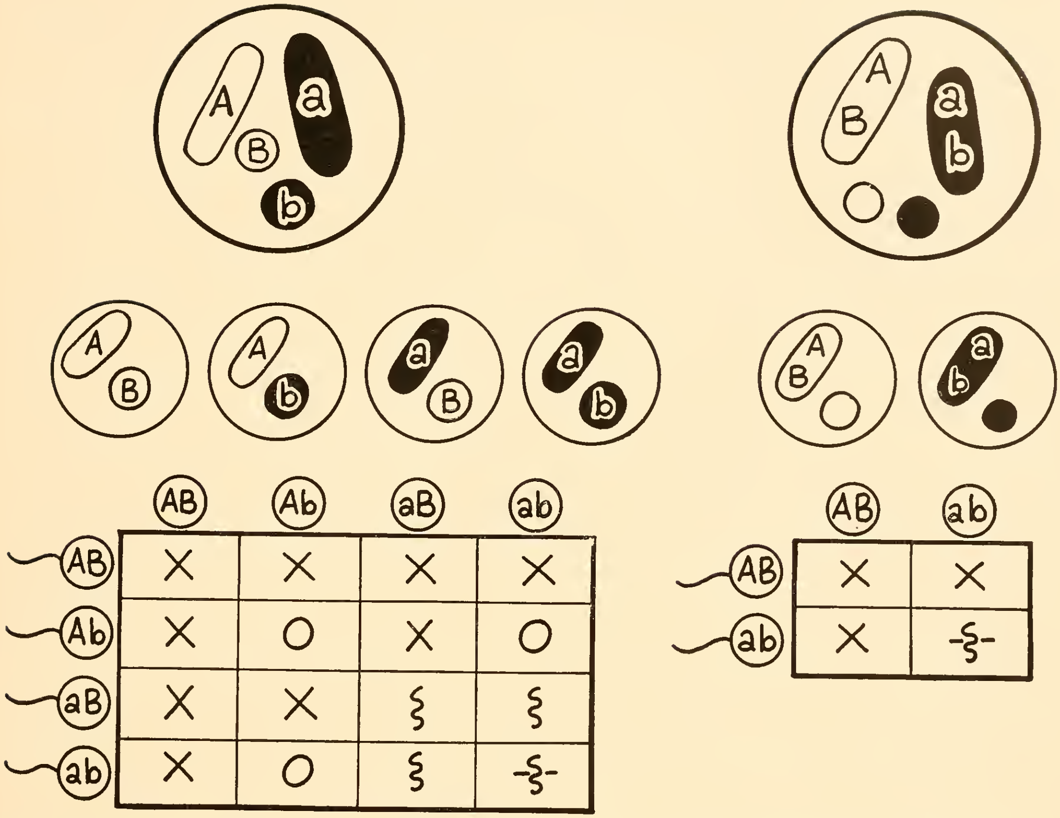


Fig. 24-15. Genes that are located on separate chromosomes give the typical Mendelian ratios, as in the case of four genes located on four different chromosomes in the left above. The typical 9:3:3:1 ratio results in the F_2. If the dominant genes are located on one chromosome and the recessives on another, they will behave as single genes as shown in the figures to the right.

one-half defective and one-half normal genes for eye color. The *Y* chromosome, of course, plays no part except in determining the sex. Therefore, the ratio is 1:1 for each of the sexes and also for the entire F_2 generation.

The explanation of sex-linked genes in Drosophila suffices for hemophilia and red-green color blindness in man. For example, in the latter instance, if a woman heterozygous for color blindness marries a normal-visioned man, all of the daughters of this combination will have normal vision but half of the sons will be color blind (Fig. 24-14). One-half of the daughters, however, will be heterozygous for the defect, whereas the normal sons will show no trace of the anomaly and therefore will never transmit it to their children. The heterozygous daughters can have color-blind sons while the homozygous daughters will never pass the trait on to either sons or daughters. Obviously, this type of **criss-cross** inheritance explains the early observation concerning hemophilia in royal families. Many other organisms, both plants and animals, exhibit this type of inheritance.

Characters other than the sex organs are controlled by genes on the autosomes but, even so, they are definitely associated with the sex. Their effect is probably on the production of hormones which in turn control the appearance or absence of the trait. Such traits are said to be **sex-limited** because they do not follow the pattern of sex-linked genes. The presence of horns in one sex

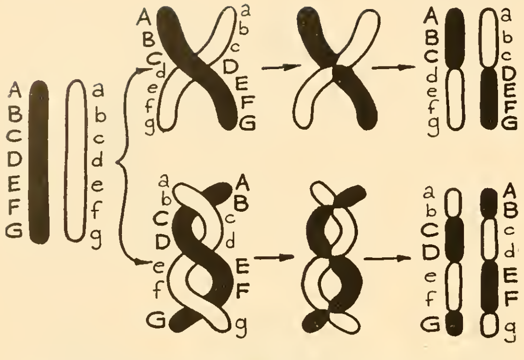


Fig. 24-16. Homologous genes have a tendency to exchange places during synapsis in some such manner as shown here.

of certain animals and not in the other is controlled by such autosomal genes.

Linkage and crossing-over

During the early studies of Mendelian inheritance it was soon discovered that there were more traits than chromosomes and this fact led workers to conclude that more than one gene existed on each chromosome. If this were true, then what happens during meiosis? As long as the genes are on separate chromosomes the ideal ratios of Mendel come out beautifully, but if they are located on the same chromosome, the ratios are different, though quite exact. Morgan and his students showed that traits entering a cross often stayed together in subsequent generations, which proved that they were linked together on the same chromosome. This condition is called **autosomal linkage** to distinguish it from sex linkage.

There should be as many linkage groups as there are chromosomes, which proves to be the case in those plants and animals where sufficient information is available. Drosophila, for example, has four pairs of chromosomes and four linkage groups. Moreover, the linkage groups even approximate the chromosomes in size. There is a small pair of chromosomes and a small linkage group, a middle-sized pair and a middle-sized linkage group, and there are two pairs of large chromosomes and likewise two large linkage groups. These facts, together with information that is to follow, certainly identify genes with chromosomes.

Linked genes respond in a manner similar to single gene inheritance. For example, if genes *A* and *B* are linked in one chromosome (Fig. 24-15) and their homologous recessives, *a* and *b*, are linked on the homologous chromosome, they segregate out in the formation of germ cells as if they were single genes and the subsequent typical one-gene ratio will result. Whereas if the genes were located on separate chromosomes, the typical 9:3:3:1 ratio would follow. Such linkages obviously decrease the possible number of combinations and thus definitely limit variation.

Strangely enough, genes once linked do not always remain so. During synapsis in meiosis, you will recall, the homologous chromosomes come together and wind about one another just before the tetrads are formed. You will also recall that the homologous genes lie opposite each other, that is, those for the same trait are drawn together by some mutual attraction. When the chromosomes separate during the subsequent meiotic divisions they are pulled apart with such force that the chromosomes often fragment where they are entwined about each other. In this way, gene groups from one chromosome become a part of the other chromosome in some such manner as indicated in Fig. 24-16. The resulting chromosomes, containing a mixture of genes, seem to heal perfectly because for the most part they contain their full complement of genes. This process of **crossing-over**, as it is called, operates purely fortuitously, so that in it we see another opportunity for a further juggling of the genes, compensating in part for the limitations placed upon variation through linkage.

The troublesome ratios that resulted from crossing-over were a blessing in disguise because they made possible the ultimate construction of chromosome maps. Sturtevant, in 1913, reasoned that crossing-over should occur more frequently between genes that lie farther apart in the chromosomes than between those lying close to one another. For example, in Fig. 24-16 there would be a greater chance for crossing-over to occur between genes *A* and *F* than between *A* and *B*, because of the distance between them. The frequency of crossing-over can be taken, then, as a criterion of the distance between genes. Thousands of experiments with Drosophila, maize, and others have resulted in the chromosome maps (Fig. 24-4) which indicate rather precisely the loci for several hundred genes.

Crossing-over, together with the other methods of mixing genes during meiosis, accounts for the vast array of combinations that are possible in offspring, particularly in organisms where the chromosomes are numerous. Consider the case of man, with 24 pairs of chromosomes. If each of the maternal set could be designated *A, B, C,* and so on, up to 24 and likewise each of the paternal set labeled *A′, B′, C′* up to 24, following meiosis some sperms may have a majority of their genes from one parent or the other, but most of them will contain a well-mixed set. The number of possible combinations that every couple is capable of producing is tremendous (see p. 558).

MUTATIONS: ALTERATION OF GENE STRUCTURE

We already have learned that genes are considered to be nucleoproteins and therefore subject to change, as are all molecules. This may occur spontaneously or be produced artificially as a result of physical forces from the outside. When the molecule changes, its properties change correspondingly. If genes are synonymous with these molecules, some change must take place in the genes from time to time; such gene changes are called **mutations**, a term we have used from time to time without explanation.

Gene mutations can be detected only when they produce visible changes in the organism, and since most mutations are recessive, they only become effective when homozygous. A great many mutations may occur but because they are recessive they remain hidden in heterozygotes, perhaps for many hundreds of generations. Eventually, by pure chance, they will show up, which probably accounts for the apparent spontaneous occurrence of anomalies in many plants and animals, including man. Strange as it may seem, most mutations are harmful to the species and soon after they appear are eliminated, because the animals possessing them are not as well fitted to cope with their environment as the unchanged wild type. Through centuries of selection the wild type probably already possesses the best possible combinations of genes to fit it for its particular environment, so that any change that might be made is more likely to result in an organism less suited for survival.

Undoubtedly gene mutations occur in the soma cells, but when they do, there is no effect on subsequent generations because the mutation is not passed on to the offspring unless the change occurs in the sex cells. Aside from the results in the individual possessing them, somatic mutations are of no importance in evolution.

Occasionally a mutation may reverse itself, that is, mutate back to its original condition. Such **back mutations**, as they are called, rarely occur, but when they do the resulting organism is apparently in no way different from the original stock. Such reverse actions might well be expected in the light of similar actions in protein molecules. Similarly, certain mutations seem to occur again and again in a stock of animals. This might mean that under certain environmental conditions genes are receptive to change, and such changes are more likely to occur when these conditions are met. Moreover, similar mutations have been known to occur in closely related species of organisms under similar conditions. Such mutations are referred to as **parallel mutations.**

Mutation rate

Obviously, genes must be very stable molecules, because if they were not it would be difficult to understand how a species could maintain itself for any great length of time. If changes occurred readily in response to minor alterations in the environment, the race would be very unstable. Under normal conditions, mutations occur in Drosophila cultures about once in every million individuals. Even then, some genes mutate more frequently than others; indeed, some have never been known to mutate. Since mutations are the tools with which the geneticist works, it is understandable that in the early days of modern genetics a continued effort was made to find some means of bringing about these gene changes artificially. For a long time the work was fruitless until Muller, a Nobel prize winner in 1946, found that by exposing fruit flies to a blast of x-rays just short of the lethal dose he was able to increase the normal mutation rate 150 times. Apparently the particles were able to penetrate to the genes in the sex cells and bring about a change in the structure of their molecules. Many of the mutations that appeared in Muller's cultures were no different from those appearing spontaneously. They were also recessive and usually harmful or lethal. Here, then, was a technique of bringing about gene changes artificially, which was a boon to genetic research. Other radiations such as ultra violet and radium have since been successfully employed. Even high temperatures may be effective if used at particular times in the life cycle of the animal.

CHROMOSOME ALTERATIONS

Mutation refers to changes within the gene itself, that is, chemical changes of the nucleoprotein that makes up (or is) the gene. Not all changes in hereditary pattern are due to such changes—some are caused by a physical change in the chromosome itself. For example, during meiosis a small segment of a chromosome may break off and become lost, thus rendering that chromosome short in those genes that were contained in the missing fragment. This kind of alteration is called **deletion.** Such gametes, deficient in certain genes, often cannot function at all or if they do the resulting offspring may be deficient in certain visible traits. Occasionally a broken fragment becomes attached to another chromosome where it does not belong, thus duplicating certain genes in such a gamete. This condition is referred to as **duplication.** The duplicate set of genes may have the effect of exaggerating that particular trait in the offspring. It has been possible in some instances actually to verify these breaks by examining the chromosomes under a microscope. When this has been successful, gene locations on chromosome maps have been definitely ascertained.

Another peculiar aberration that sometimes occurs among chromosomes is **inversion,** a condition that results when one portion fragments and then reattaches itself but in reverse order, that is, end for end. Inverted chromosomes seem to have no effect on the offspring because all of the genes are present and they can perform their function even though in reverse order. However, in gamete formation, trouble is encountered during synapsis when the homologous genes must lie opposite one another, and since they are arranged in a linear fashion on the chromosome, this becomes a physical impossibility.

Variations in chromosome number

One might expect that occasionally during meiosis the number of chromosomes going to the gametes might vary in number. This happens when a pair of homologous chromosomes fails to separate at reduction division. One gamete will then have one extra chromosome (n plus 1) while another will be short one (n minus 1). If fertilization occurs with normal gametes, one offspring will possess an extra chromosome in each cell while another will be short one. The latter probably will not develop whereas the former may show variations in the resulting trait because the genes are doubled. There have been many cases of **heteroploidy,** as this condition is called.

This phenomenon of extra chromosomes includes the addition of complete sets, so that gametes possess a diploid instead of the usual haploid number, and in some cases (particularly in plants where the phenomenon is better known) even 3, 4, and 5 extra sets. Organisms possessing more than the diploid number are called **polyploids.** They are usually larger and more vigorous than the usual diploid, hence polyploids have found a definite market in the plant world. Polyploid flowers are much larger and more beautiful than the normal ones. Leaves of polyploid tobacco plants are much larger. Efforts to induce polyploidy artificially have been successful. The drugs **colchicine** or **camphor** prevent division of the cells but do not interfere with the dividing of chromosomes; hence, the gametes possess the diploid number of chromosomes instead of the normal haploid number. Upon fertilization, the resulting offspring then have a double set of chromosomes, that is, they are **tetraploid. Triploids** will result from the union of a diploid gamete with a haploid gamete. Experimental breeding of these various polyploids has resulted in the introduction of new strains of plants that have proven very valuable in increasing our food output. Very little is known about the occurrence of polyploidy in animals. Evidence is accumulating that it occurs in at least one protozoan, namely, paramecium.

HEREDITY AND ENVIRONMENT

The age-old question of which is more important, heredity or environment, stimulates the most passionate arguments among people in various walks of life, from educator to the man on the street. The problem has recently become so important a political issue in Russia that it threatens the professional life of geneticists living behind the iron curtain. What are the best unbiased answers to the questions rising from such discussions that have come to light so far?

One should first be concerned with the problem of what is really inherited. Is a child unmusical because his parents have no musical skills or is he unintelligent because his parents possess a low order of intelligence? Is a starved child short and underdeveloped because his parents are likewise starved and poorly developed? A careful examination of some data should give us an inkling of the answer to these questions. A child placed in an environment in which every opportunity is afforded him to study music as well as other cultural subjects may show unusual artistic talents and intellectual achievement even though he might not appear to have inherited such ability. Likewise, well-fed children of starved, stunted parents often exceed them in height and physical vigor by a considerable margin, as has been demonstrated so many times when children of immigrants are larger and more robust than their parents, who matured on inadequate diets. In these instances was it the environment or was it heredity that played the more important part?

It is clear that the children inherited a set of genes which provided the capacity to reach these goals. The environment was merely the factor which determined whether or not the genes would be given a full opportunity to express themselves. Without the substantial set of genes in the first place, no amount of encouragement from a satisfactory environment would have brought them to heights beyond the basic design established by the genes. Of course, the desired goal in any society is

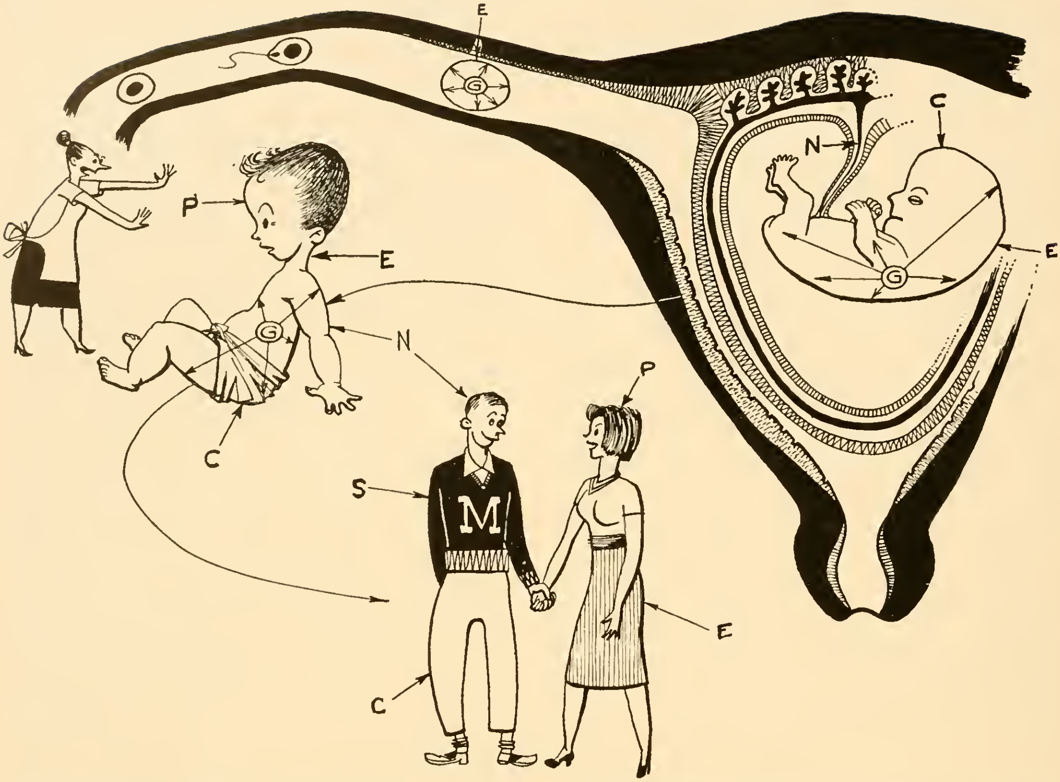


Fig. 24-17. The individual is a result of two forces, one due to the inherited genes and the other to the surrounding environment which begins with the zygote and continues throughout the life of the individual. These various steps as sketched here are explained in the text.

to give the genes in each person ample opportunity to express themselves to their greatest capacity. Therefore, while good genes are essential for good stock, they are not enough. Good genes in a good environment is the ideal goal.

There is experimental evidence to demonstrate further the intricate relationship between environment and heredity. In studying the life span in fruit flies, Raymond Pearl found that the vestigial-winged forms lived only half as long as the wild type in a closed milk bottle. If he increased the number of flies of the wild type he cut their lifetime to that of the vestigial-winged flies. If both types were starved they lived about the same length of time. Certainly the environment limited the capacity of the genes. Similarly in the Himalayan rabbits previously discussed (p. 596), the chilled regions of the body grew black fur while all other parts grew white. If the rabbit is chilled in a refrigerator, for example, it will develop black hair all over; conversely, if it is warmed up to relatively high temperatures it will develop white, tips and all. In this case, body temperature limits the expression of the genes. It is obvious in all these instances that the genes lay the pattern for capacity whereas the environment determines whether or not that full capacity will be realized.

The close interaction of these two forces, environment and heredity, can be still further emphasized by following through the development of an organism, say a human being, from fertilized egg to young adult (Fig. 24-17). Begining with the fertilized ovum, we have a cell consisting of cytoplasm, controlled by the genes (G) and surrounded by an environment. Very soon, as cleavage starts, the surrounding environment (E) contributes to the cytoplasm, thereby changing it slightly. Moreover, the immediate community of cells has its effect upon the cytoplasm of each of the other cells. The cytoplasm is therefore influenced from within by the genes (G) and from without by the environment (E), even at this early stage. As development proceeds, the cytoplasm of the many different cells continues to be influenced by surrounding cells (C), yet the genic constitution remains essentially the same in all of them. All of this brings about the development of organ systems, and ultimately the full-fledged fetus, but in each step the genes control the cytoplasm which, in turn, is influenced by surrounding cells (organizers) so that the cells are channelled into a pattern directed toward the final organized individual. Another environmental factor that is influential is the nourishment (N) received by the fetus from the uterine wall. If food, as well as oxygen and hormones, that come to it from the placenta are deficient in any respect, the fetus is directly affected, perhaps to a point where normal development is impossible. This is a very important environmental aspect of development. The genes strive toward the production of a normal offpsring but they can accomplish this end only if the environment is adequate.

When the child is born, another factor, the psychological factor (P), enters the picture. All of the other factors still operate, and the addition of this new factor definitely controls further mental development and probably physical development as well. Lastly, as the child matures, the social factors (S) become more and more a dominant part of his environment. The genes are still at work and will continue to be throughout life but the environment has a marked molding effect on their action. Thus, we see that it is impossible to have heredity without environment and vice versa. The two forces work hand in hand to produce a normal, well-adjusted individual.

The occasional appearance of two offspring as a result of one fertilized egg (identical or monozygotic twins) has provided almost perfect material for the study of the relative effects of environment and

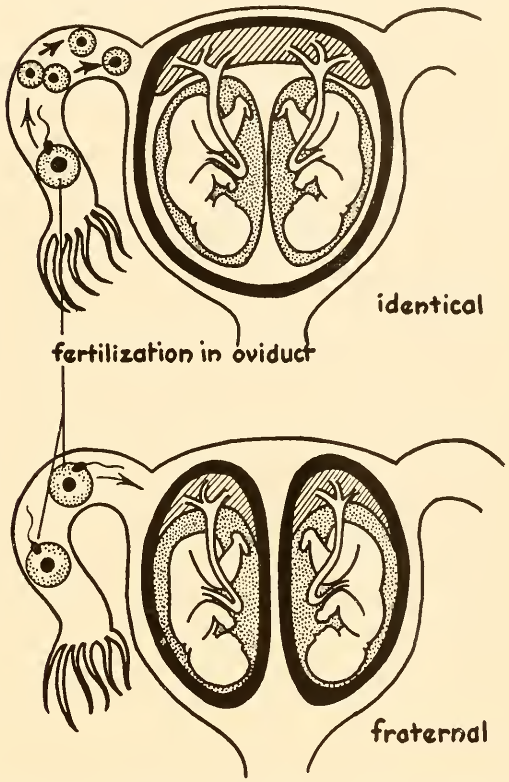


Fig. 24-18. Identical or monozygotic twins are a result of a single fertilized egg, therefore they are genetically alike as shown in the upper figure. Fraternal twins are a result of two zygotes and may be as genetically different as any other members of the family. Furthermore, each developing fetus has its own placenta, whereas this is usually not the case with monozygotic twins.

heredity (Fig. 24-18). Monozygotic twins have the same sets of genes, so that if heredity were solely responsible for all of their characters they should be exactly alike. A study of a large number of identical twins by Newman and others has shown that they are indeed remarkably, almost unbelievably, alike (Fig. 24-19). Such traits as height, weight, general appearance, fingerprints, and tooth formation show very

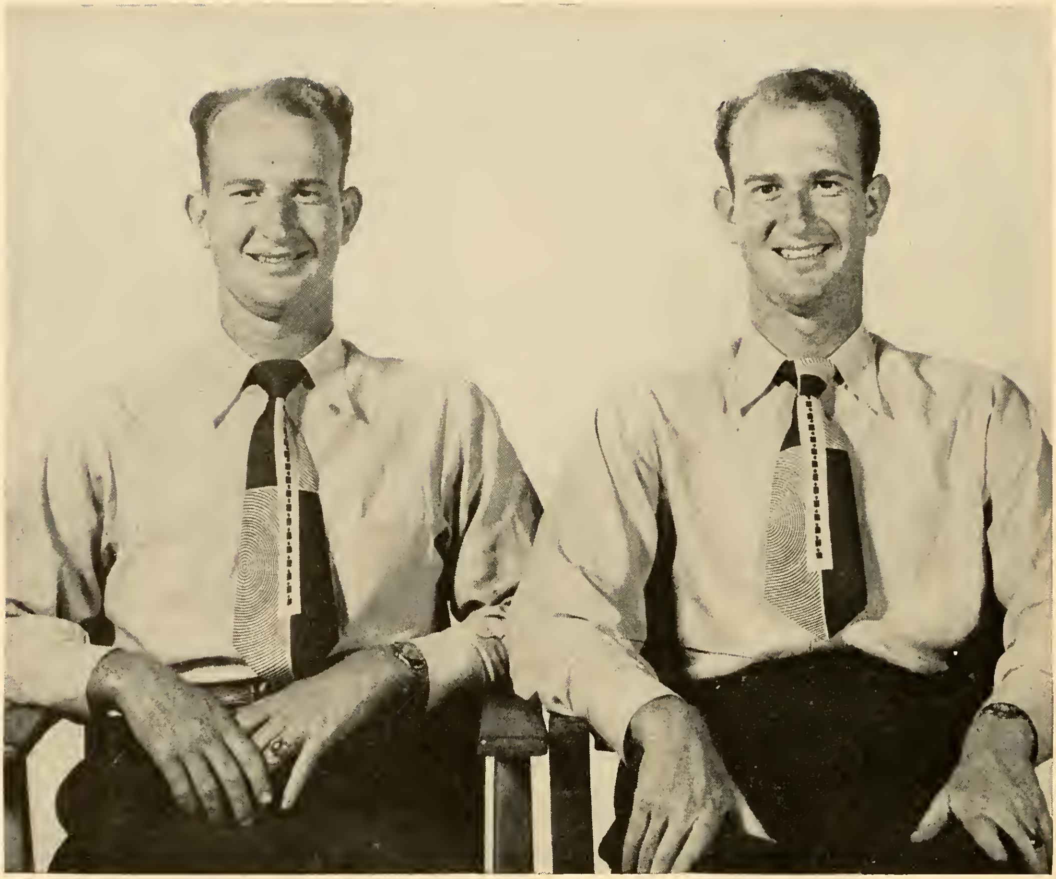


Fig. 24-19. A pair of identical or monozygotic twins. These two men are a result of a single zygote, hence their likeness. They are alike physically, mentally, and even emotionally. Studies of such genetically identical individuals has added much to our knowledge concerning the relative importance of heredity and environment.

close similarity as might be expected, but when such intangible traits as susceptibility to disease (both organic and infectious), food preferences, and even attitudes of mind show marked correlations it seems quite incredible. Intelligence tests usually show that they vary no more than either individual might on two different tests. With such material as this, it should be possible to learn some interesting facts about the effects of environment.

Newman found in his studies that identical twins reared apart were over 90 per cent alike in height, nearly 90 per cent alike in weight, but only about 70 per cent alike in intelligence as measured by standard I.Q. (intelligence quotient) tests. Identical twins reared together had about the same scores for height and weight but were also nearly 90 per cent alike in regard to intelligence. Two-egg twins (Fig. 24-18) of the same sex were only about 65 per cent alike in all of these traits. When one monozygotic twin is bright, the other is also, but when their educations vary considerably their I.Q.s also vary correspondingly. Better schooling definitely raises the I.Q. rating. However, under similar cultural environments identical twins, although reared apart, differed only 5 points in their I.Q. ratings. This is within the normal variation that might be expected from day to day with the same person. From these studies, environment seems to have a considerable influence on intelligence as it is measured with I.Q. tests, although this may not be a valid measure of true intelligence. On the other hand, in regard to such physical traits as height and weight, the inherited genes are strikingly more important.

Fortunately, because of the stability of genes, the environment has little or no effect upon them. Excellent genes may be carried along for many generations in starved, poorly developed bodies, but as soon as the environment becomes completely adequate they express their full capacity by producing a vigorous, healthy body. In a world that has always suffered periods of famine intermingled with times of abundance only stable genes could have made possible a race that has been able to survive up to the present.

HUMAN HEREDITY

Human beings, like all species of animals, show wide variations in height, weight, eye color, hair color, skin color, facial configuration, mental ability, and many other traits. Within limits, these variations are highly desirable because they allow evolution to take place. However, at the extremes of each one there are usually either mildly or highly undesirable conditions which do not permit the individual possessing them an equal chance with others to become a self-sustaining member of his own social group. Some defects such as albinism render the individual only slightly more handicapped than his normal fellows. Most of us are pretty apt to agree, however, that a combination of genes that produces idiots, blindness, or deafness is undesirable. Although we are concerned with the inheritance of defects in order to breed them out of our people, we should be even more concerned with the positive approach, that is, retaining the quality of our present stock and improving it where possible. Let us now consider what is known about some of the common human defects and later some of the problems involved in improving the human race.

Some congenital defects

We have previously discussed the slight defects of color blindness (p. 604) and albinism (p. 592), as well as the more serious anomaly, hemophilia (p. 602). Some others are listed in Table 4 (see also Fig. 24-20).

Ichthyosis, sometimes called fish-skin disease, is a congenital disease. Those suffering from this malady have dark skin, ¾-inch thick, which is cracked in such a way that it resembles scales, hence the name, fish skin. It occurs over the entire body except the palms of the hands and the soles of the feet. It is fatal, the child dying shortly after birth. The disease was seen for the first time in England in 1731 where it appeared in the

TABLE 4

Disease	*Condition*	*Type of Gene*
Ichthyosis (one type)	Thick skin	Sex-linked
Congenital cataract	Opaque growths in eye	Dominant
High-grade myopia	Extreme nearsightedness	Recessive
Astigmatism	Irregularity of cornea	Dominant
Brachydactylism	Short digits	Dominant
Polydactylism	Extra digits	Dominant
Lobster-claw	Split hand and foot	Dominant
Achondroplasia	Short appendages	Dominant
Diabetes mellitus	Improper sugar balance	Dominant
Ataxia	Paralysis	Recessive
Microcephaly	Idiots with small heads	Recessive
Amaurotic idiocy	Degeneration of nervous system	Recessive
Deafness	Atrophy of auditory nerve	Dominant

son of a laborer. Another type of ichthyosis (non-lethal) has been traced through five generations and has successively appeared in the sons but never in the daughters. Furthermore, the daughters never transmit it to their offspring, which definitely places the defective gene in the *Y* chromosome. This is one of very few cases where a gene has been definitely located in the *Y* chromosome in man.

A type of blindness caused by the clouding, or fogging, of part of the transparent portions of the eye is called **cataract.** Pedigrees of families in which this disease occurs bear out the contention that the trait is carried by a dominant gene, although it usually appears in the heterozygous condition. That is to say, a parent may have the disease but usually only certain of his children, regardless of sex, will show it, indicating that the parent must have been heterozygous. Had he been homozygous for the trait, all of his children would have the defect. Cataract is also acquired by excessive exposure to heat, radiations, and contusions, but in these cases heredity, of course, is not involved.

Vastly more important than obvious physical defects are hereditary traits that affect the nervous system, altering the be-

Fig. 24-20. There are a great many human anomalies that have been traced to a genetic origin. Certain types of hare-lip are inherited. One of the common types is shown here (upper left). Modern surgery has worked wonders in repairing these unfortunate abnormalities (upper right).

Many deformities of the hands and feet are inherited. Here are two cases of "split-hand" (lower). This trait is usually dominant and occurs once in about 90,000 births. More often than not the gene responsible for this abnormality is also responsible for others. Both of these cases were abnormal in other respects.

havior of the individual so radically that he must be institutionalized. Because of the expense involved, most states are far behind in buildings and other facilities to take care of all those needing such attention. The situation seems to be growing worse from year to year. Competent authorities who have studied the problem carefully feel that it will eventually reach a hopeless situation unless something is done to curb the ever increasing number of mentally defective people. There is no doubt that many of these mental illnesses, like physical defects, are gene-controlled, so that a careful study of them should yield some valuable information to aid in guiding our future actions.

One kind of nervous disorder, called **microcephalic idiocy,** is inherited as a recessive, meaning that an afflicted individual must have two genes for the defect. It usually springs up in families of normal parents, as one might expect. However, a large proportion of the children resulting from the marriage of an idiot to a normal person would be idiots. Fortunately such marriages are rare and the line usually dies with the defective person.

Another very serious congenital disease is **Huntington's Chorea,** in which there is a marked degeneration of brain tissue, resulting in poor muscular coördination, twitching, and jerking movement. In addition, there are other associated defects which contribute to produce socially and mentally deranged individuals. The most unfortunate part is that the disability does not become apparent until middle life (25-55 years of age) after most, if not all, of the children have been born. Thus the trait is passed on to the next generation before it is recognized in the parent. Cases of the disease in this country have been traced back to three brothers who arrived here from England in 1630. The malady has shown up hundreds of times in the several thousand descendants of these men, and studies have revealed that about one-half of the children of afflicted persons develop the disease some time after they are 25 years old. A person who knows that he might develop it or pass it on to others is under terrific mental strain, which in itself is often sufficient to bring on nervous disorders.

A host of other mental disorders encompassed in the term **schizophrenia** are known to be gene-controlled. Schizophrenics suffer from delusions of persecution or grandeur or they may become completely apathetic, oblivious to the world around them. Such response to the outside world is naturally incompatible with success in society as we know it. A large proportion of mental patients in our hospitals are schizophrenics and the number seems to be increasing annually. During times of stress, such as in periods of war or depression, the number seems to increase. Apparently such people are on the verge of mental collapse, and any undue stress is sufficient to affect the breakdown. It seems that this type of insanity itself is not inherited but is due rather to a genic constitution that cannot remain normal under stress. This is owing to recessives, because schizophrenics are usually found in families of normal parents, a fact that makes it next to impossible to breed out.

MEDICAL GENETICS

From such studies as those indicated above, the medical profession seems to have found some information of real clinical value. Data accumulated by the pure geneticists for the past fifty years is just now reaching a point in its development where some practical use can be made of it by physicians. This has resulted in the young flourishing science of **medical genetics,** which is not to be confused with **eugenics** (see later), a subject that has enlisted the active participation of people outside the field of medicine.

Professor L. H. Snyder has cited many illustrations of the use of genetics in the diagnosis, prognosis, and even prevention of a wide variety of diseases. For example, in attempting to diagnose what was causing a patient to vomit blood, the doctors decided it must be one of two things, ulcers or liver disease. Elaborate laboratory tests revealed that neither of these seemed to be the cause. One of the physicians recalled that the father of the patient had shown a tendency to bleed due to the fragility of his capillaries in local lesions. Because this condition is controlled by a dominant gene, the likelihood of a similar condition appearing in the son was good. By an exploratory examination of the stomach the suspected diagnosis was verified, the region of capillaries giving the trouble was removed and the case was cured. Here a knowledge of genetics was very helpful in solving a problem which probably would have continued to be a mystery to the physician and a source of discomfort to the patient.

Of equal and perhaps greater importance is the use of genetics in the realm of prognosis. Young married people or those about to be married often wish to know what the probabilities are for them to have normal children. This is particularly important to those who have some so-called "taint" or "skeletons in the closet" in their family. Sometimes advice is sought for on the positive side, that is, they wish to know what the chances are for them to transmit certain talents to their offspring. One case will illustrate the importance of such information. In a family of five children, two boys were severely crippled by serious muscular disease; the others, two girls and a boy, were normal. The problem that concerned the parent was the chance of this disease appearing in the next generation. After careful analysis of the situation it was evident that the gene causing the difficulty was sex-linked. Therefore the father must have had a normal *X* chromosome (*AY*) while the mother must have carried the defect in one of her *X* chromosomes (*Aa*). The boys showing the affliction must accordingly have been *aY*, whereas the normal son was like his father (*AY*) and the daughters might or might not have had the defective gene (*Aa* or *AA*). The normal son would, of course, be unable to transmit the defect to his children. The daughters, on the other hand, had an even chance of picking up the defective gene from their mother. Such information is highly valuable to intelligent people because they can make their decisions in the full light of scientific fact rather than blind faith. The field of medical genetics is just beginning and cannot fail to become eventually a most fruitful part of medical science.

EUGENICS

Eugenics is the study of race improvement or the "science of being well born." Certainly, man who has done so much in improving his domestic plants and animals should be able to do something about improving his own combination of genes. It would seem that all he has accomplished in a material way is useless if he stands idly by and allows his own protoplasm to deteriorate with each succeeding generation, yet some human genticists tell us that is actually what is happening today. Some authorities estimate (Fig. 24-21) that by the year 2000 the 12 per cent of people we have today with an I.Q. of 115 or better will have been reduced to 7 per cent, and the present 2 per cent below 70 (moron, etc., group) will have doubled their numbers. The situation might not be quite as grave as these figures would indicate because we know that some of the progeny of the more intelligent will have lower I.Q.s than their parents and some of the children from the less able group will be brighter than their parents. Even though there is only a slight loss in our intellectual heritage, we should make every effort to combat this downward trend. Is there any way that this can be done? Perhaps so, but many difficult problems present obstacles.

Suppose we could breed the ideal race of men, what would we breed toward? What kind of man do we want? What are the desirable traits and who is to be the judge? These are difficult questions for which no scientist and only a highly conceited layman would have an immediate answer. Every sane person, however, would have an immediate positive response to the question of preventing the continual production of defectives such as microcephalic idiots. At this end, common agreement can be attained, because such defectives bring misery to everyone who is in any way associated with them. Fortunately, very few of the hopelessly defective individuals reproduce.

Present dysgenic practices

Instead of improving our people genetically it would appear that the operating forces in our modern civilization are doing just the opposite. Our way of life has vastly improved in the past two hundred years, but paralleled with it is this insidious decline in our genetic heritage. The features that have made our lives more safe and pleasant and have been responsible for our tremendous increase in numbers have simultaneously introduced factors that interfere with the agencies of natural selection, which through the ages have tended toward the building of a sturdy body and mind in a very demanding environment. When that point is reached, it seems that decline has followed. Modern man has interfered with natural selection in several very important ways which are only now showing their effects.

Birth rates compared to death rates readily reveal whether a population is increasing or decreasing. Whether the number of people in a population such as we have in America is increasing or decreasing is not as important as the more serious problem of what groups are reproducing the population. Are the qualities we agree are desirable being perpetuated or are they

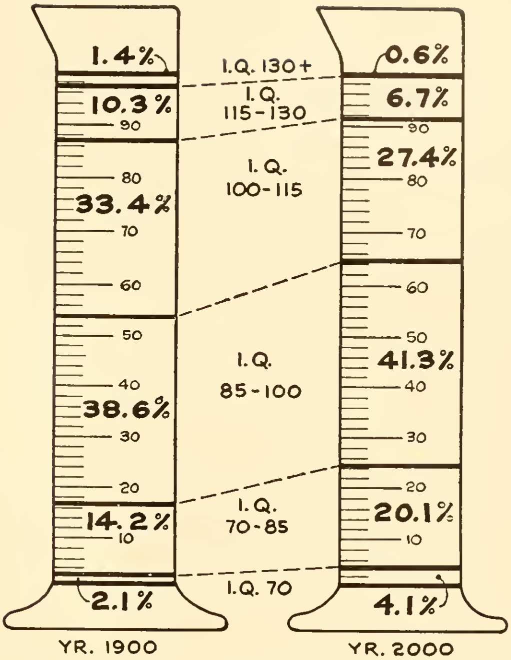


Fig. 24-21. There is substantial evidence that our intelligence, as measured by I.Q. tests, is steadily dropping with each generatian. When these figures are projected to the year 2000 the shift in intelligence may reach the levels indicated in the above figures.

gradually being sacrificed for less desirable qualities? The picture is not as comforting as we wish it were.

One of the potent forces bringing a shift in the quality of people is the difference in the rates at which children are born to groups of various abilities. If different groups reproduce at different rates, as we know they do, the over-all reproductive rate of a country is a composite of all of these groups. For example, if one group reproduces at a rate 20 per cent higher than the native stock, there will be a gradual replacement of the native stock by the faster multiplying groups. This is important only if there is a concomitant dropping in the quality of the people as a whole.

During colonial days in America, the families of the more prosperous citizens were larger than those of the less able. Statistics taken from an early study of New England showed that the upper quarter of the more successful families had on the average one more child than the lower two-thirds (that is, 7.2 to 6.2). The years since this period have seen a gradual decline in the more able group. Thus today persons belonging to the professions and business class are not replacing themselves by 15 to 25 per cent. The largest families occur in people in the lowest occupational levels. In other words, there is an inverse relationship between occupational level and size of families. The birth rate among unskilled laborers is almost double that of men in business or professions. Likewise, there is an inverse relationship between intelligence and the size of family. A study made by Lentz over 20 years ago demonstrates a trend that is no different today. He found that children with an I.Q. of 150 or over came from families with 2.2 children, whereas those with I.Q.s of 70 to 79 averaged 5.3 children per family. The family sizes increased with each succeeding declining I.Q. In such a situation, the families with high intelligence were not replacing themselves while those in the lower brackets were more than doing the job. If the present trends continue, within three generations a great proportion of the population will come from the less intelligent class, resulting in a continued drop in general intelligence of the population as a whole. It has been estimated that the I.Q. is dropping in the United States at the rate of one point each generation and in England at the alarming rate of 3 points each generation. Bertrand Russell predicted that for the next few hundred years each generation will become more stupid than its predecessor. It is questionable whether or not a nation depending on an intelligent population can survive such inroads on the prime factor responsible for its existence.

Modern medicine, while certainly alleviating the miseries of mankind during the past two hundred years, has also prolonged the lives of many and saved the lives of a multitude of others who in the normal course of events, would never have survived. The genes responsible for these weaknesses would have been kept to a low frequency under natural selection, but with the intervention of modern medicine they have been saved to be perpetuated and thus increased in subsequent generations. Let us hasten to point out that saving these lives from a humanitarian point of view can only be praised, but in the eyes of the geneticist it simply means that one of the most potent factors in building a strong race is prevented from functioning. The results could lead to inferior stock.

Another dysgenic factor in our present civilization is modern warfare. In centuries past the strongest, cleverest, and most intelligent men went into battle and the best of these survived to come home and become the fathers of the next generation. This was natural selection at work. Since the advent of gunpowder and subsequent deadly weapons, the strong and able are cut down equally with the less well endowed. Indeed, it is said that taller men are more apt to be hit first because they constitute a larger target. In the past it is believed this has had a tendency to reduce the stature of large groups of people. Furthermore, in all wars the best equipped both physically and mentally are selected for duty first, thus eliminating many of them from the opportunities of becoming parents. To be sure, there is always a sudden burst in the numbers of babies sired during and following wars, but it is unlikely that this alters the over-all genetic constitution of the race. Too much of this increase is accounted for by the physically and mentally unfit that are left at home. The military can hardly be blamed for wanting the best men they can get to man the complicated instruments of modern warfare, but these same men are also the best stock we have and their chances of becoming the parents of the next generation are much reduced when in service as compared to life at home. For the past several hundred years, then, we have been following a policy that is definitely contrary to natural selection and undoubtedly has had its influence in reducing the quality, not the quantity, of our stock.

From the foregoing discussion it would seem that while our present civilization has brought us a higher standard of living, at least in America, it has likewise introduced several factors that tend to drag the body and mind of man to ever lower levels. Is there no way out of this dilemma? Can we have a high standard of living without losing our genic heritage? It would certainly seem that we should have sufficient intelligence to apply some of our knowledge of human genetics to our own situation and curb the disastrous decline that seems to be upon us.

Possible solutions

Many thinking people have faced this problem and there is some concerted effort, feeble though it is at present, to halt this tide of ever increasing defectives and the dilution of our precious germ plasm that has taken millions of years to produce. A few years ago, some over-zealous people equipped with more enthusiasm than facts wrote about the possibilities of building a super-race of mankind. Fortunately, this type of nonsense has given way to a sane approach to the problem of race improvement, based on what we know about human genetics together with what is within the realm of social possibility. The problem is extremely difficult because of our incomplete knowledge of human inheritance. Even more difficult is the problem of convincing people that something should be done about it. Thinking in terms of world population, how, for example, can the people of India be convinced that they should throttle their terrific reproductive rate? In a country where the average diet contains 960 calories (a minimum American diet consists of 1600 calories) and where 3 million people die each year of starvation, how can they be made to understand that this is wrong? In spite of this terrific waste in life, the population as a whole has increased at the alarming rate of 83 millions in the past 20 years. Perhaps natural selection is still operating in this and other unfortunate nations in the world today, producing a race that can survive on minimal diets. If so, they must be reckoned with in any world planning for the future. Once more focusing our attention on the problems as we see them in America and perhaps some of the European countries where eugenics has been and is being practiced, what progress has been made?

To stem the tide of defectives, sterilization is being practiced in 27 states in the United States and many countries in Europe. By February, 1935, Germany had sterilized about 200,000 hereditary defectives, perhaps the most ambitious program in the world. It would be interesting to know what effect, if any, this has had on the relative numbers of such people in the general population of Germany today. Such figures are not available, if they have been prepared. Our first sterilization law was passed in 1907 (Indiana), and by the end of 1948, 49,207, of which 19,042 were in California, have been sterilized. These are primarily feeble-minded and insane patients who have been committed to institutions. Just what effect does sterilization have in reducing the number of defectives in future generations? It has very little, unfortunately. It is estimated that most defects which are carried as recessives would probably require 2,000 years to reduce their numbers by 50 per cent, employing the most rigid sterilization laws.

Segregation and sterilization will have little influence on the ominous drop in general intelligence brought on by differential birth rates that exist today in our population. Birth-control measures have been gaining a foothold in recent years and seem to be providing a partial answer to the problem. Such organizations as the Planned Parenthood Leagues emphasize both the negative and positive side of the problem, that is, they are as much, if not more, interested in encouraging larger families among certain groups as they are in lending a hand in helping the less fortunately endowed to reduce the number of births. Workers in birth-control clinics are well aware that people in all walks of life are very much interested in spacing their children so that they bring into the world only the number they can adequately care for. People in the lower income groups, for example, have shown over and over again that their large families are due more to ignorance than desire on the part of the parents. Birth-control information is eagerly received by these groups and practiced to a point where beneficial effects are already clearly observable. On the positive side, the dissemination of birth-control information has had little effect, mainly because those people who should have more children also have the information and have been practicing contraception anyway. A thinking couple of moderate means, even though they may desire to do so, will hesitate to bring a large family into the world when they know that to rear each child will cost between $15,000 and $25,000 if they want to give them the best possible opportunities. No amount of persuasion emphasizing patriotism will offset this barrier.

The drop in birth rates in some nations has stimulated them to attempt several different plans designed to prevent further decline. None of them has succeeded in altering the trend of the birth rate in any fundamental way. These devices have included marriage bonuses, family allowances for each additional child, and salary increments based on family size. Even public acclaim has gone out to women with the greatest number of children. Think of all the women who tried but were only runners-up in such marathons; what about the quality of such children? The kind of people who would go in for such breeding experiments probably would not be the kind to contribute substantially to the intellectual level of the population as a whole. Any plan designed to make children a financial asset is bound to fail from the genetic point of view because it will never be attractive to the people who should be reproducing themselves. Is there any way, then, to reverse the present dysgenic trends that are threatening the civilized nations of the world?

The most comprehensive studies of this problem have been made by the Scandanavian countries where they have settled on a solution which seems to have more merit than any others. They argue that since the nation's people is its prime asset, the burden of providing a continuing stream of high-grade protoplasm is the responsibility of everyone. Therefore, all should share in the care and education of all children. Consequently, the burden of educating and feeding during the maturing years falls upon the state. This has encouraged the rearing of larger families in the upper and middle classes and has been no stimulus to the lower classes. The present movement in the United States toward federal supported scholarships to young people who can profit by a higher education should also have gratifying results in the years to come. This has been an outgrowth of the G.I. Bill of Rights, which was one of the finest things that came out of the last war. It made possible the continued education of those who could profit by it even though they were in many cases beyond the normal college age level. An even more encouraging side of this picture is the fact that many or most of them were able to have families while they were gaining a higher education. This meant that a large proportion of our population were rearing their families at the time when they should be and not postponing it, as is so often the case, and thus cutting down the reproductive years. Support of this kind undoubtedly will have substantial eugenic effects in future generations and should be heartily endorsed by everyone.

PART VII

Organic Evolution

CHAPTER 25

EVOLUTION—PAST AND PRESENT

Throughout this book constant reference has been made to the gradually increasing complexity of life from Protozoa to mammals; in fact, the underlying theme is this basic concept of change from simple to complex. The word *evolution,* in its broad sense, means unrolling or unfolding and, used in terms of the living world, simply implies that all plants and animals alive today have descended by slight modifications from simpler preëxisting forms. Our discussion of the various animal groups has been based on this idea and, even though we have accepted it as a basis for our thinking, let us now return to the story of the rise of animal life to examine the theory of organic evolution as a logical explanation of what has taken place.

EVIDENCE FROM ANCIENT ANIMAL LIFE

Geologic time

In tracing life from the beginning, the course of events has afforded us a convenient way of reckoning time. The earth's thin crust has provided "clocks" that tell time in millions of years. Geologists are becoming more and more adept at reading these clocks, although a reading with an error of a few millions of years one way or the other is still considered satisfactory. Even though the exact times may not be accurate, the sequence of events and the orders of magnitude of each event are correct. By reading these geologic time clocks it is possible to approximate dates of the origin of various forms of animal and plant life.

One of the most accurate methods of reading time which has recently come into prominence employs radioactivity. Radioactive elements disintegrate at a remarkably uniform rate, extending over millions of years in some elements. Uranium, for example, decays or disintegrates at an extremely slow rate into a special kind of lead (atomic weight 206 as compared to 207.2, the atomic weight of ordinary lead) and helium gas. It requires 2 billion years for one-quarter of a sample of uranium to decompose into these constituents. In determining time by this method, a rock containing a mineral impregnated with uranium is analyzed for its lead content. Since the mineral was incorporated into the rock when it was formed, the relative proportions of lead and uranium would be an indication of the age of the rock. If one-fourth of the uranium had been converted to lead, the rock would be 2 billion years old. It is from such data as these and others that the earth is thought to be at least 2 billion years old.

In the study of animals that have lived in past ages it is more convenient to use terms which denote sequence of animal life rather than numbers of years. The entire history of the earth's crust is divided into **eras, periods,** and **epochs,** each succeeding one being a subdivision of a previous one, as shown in Fig. 25-1. Although the dates are only approximate and may vary one to several million years either way, the sequence of events is rather well established. For example, it is quite certain that the Permian Period precedes the Triassic and follows the Pennsylvanian. Moreover, the relative lengths of the periods are rather well known. Such information is helpful in understanding the relative success of animals as well as the rates at which evolution occurred.

How fossils are formed and preserved

Under very special conditions parts or even whole animals have been preserved in many different ways. From these remains we can learn not only something about their anatomical features but also how they lived. It must be remembered that fossilization occurs only under ideal conditions and that only a very small fraction of the animals existing at any one time died under these conditions. Most of them, of course, disintegrated completely, just as they do today, leaving no clue to anyone in the fu-

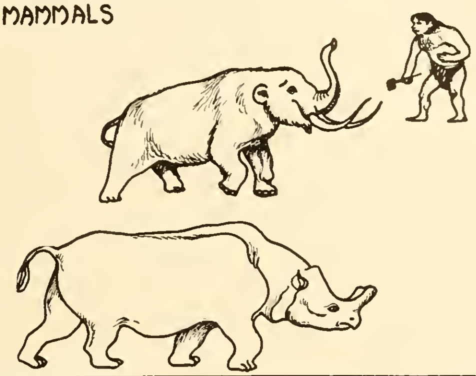
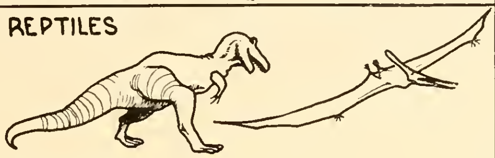
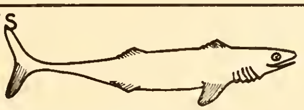
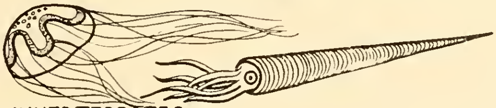
DOMINANT ANIMAL LIFE	MILLIONS OF YEARS	EPOCHS	PERIODS	ERAS
MAMMALS 	.025	recent	QUATERNARY	CENOZOIC
	1	pleistocene		
	11	pliocene	TERTIARY	
	16	miocene		
	11	oligocene		
	19	eocene		
	17	paleocene		
REPTILES 	130		CRETACEOUS	MESOZOIC
			JURASSIC	
			TRIASSIC	
AMPHIBIANS 	75		PERMIAN	PALEOZOIC
			PENNSYLVANIAN	
			MISSISSIPPIAN	
FISHES 	80		DEVONIAN	
			SILURIAN	
 INVERTEBRATES	145		ORDOVICIAN	
			CAMBRIAN	
FIRST LIFE	1500		PRECAMBRIAN	PROTEROZOIC
FORMATION OF EARTH'S CRUST	?			ARCHEOZOIC

Fig. 25-1. Geologic time is represented here both in approximate numbers of years and in terms that denote sequence of animal life. Representative animal types are also shown in the approximate periods they lived.

Fig. 25-2. This is a restoration of a herd of American mammoths that lived in Michigan as recently as 15,000 years ago. To the right of the large boulder in the right foreground can be seen a giant beaver that was abundant also during this period. Both species are now extinct.

ture that they had ever lived. There are many ways in which fossils are formed, some of which we shall consider.

The ideal fossil is the whole animal preserved intact so that its entire anatomy can be studied in detail. This has occurred in the case of insects of the Oligocene, when they became embedded in the sticky pitch of the coniferous trees of that period. These animals show bodily structures in the finest detail. Even scales on the wings of butterflies are as perfectly preserved as if they had lived only yesterday. In certain cold regions such as Siberia the woolly mammoths (Fig. 25-2) often fell into crevasses in the ice where they were quickly frozen

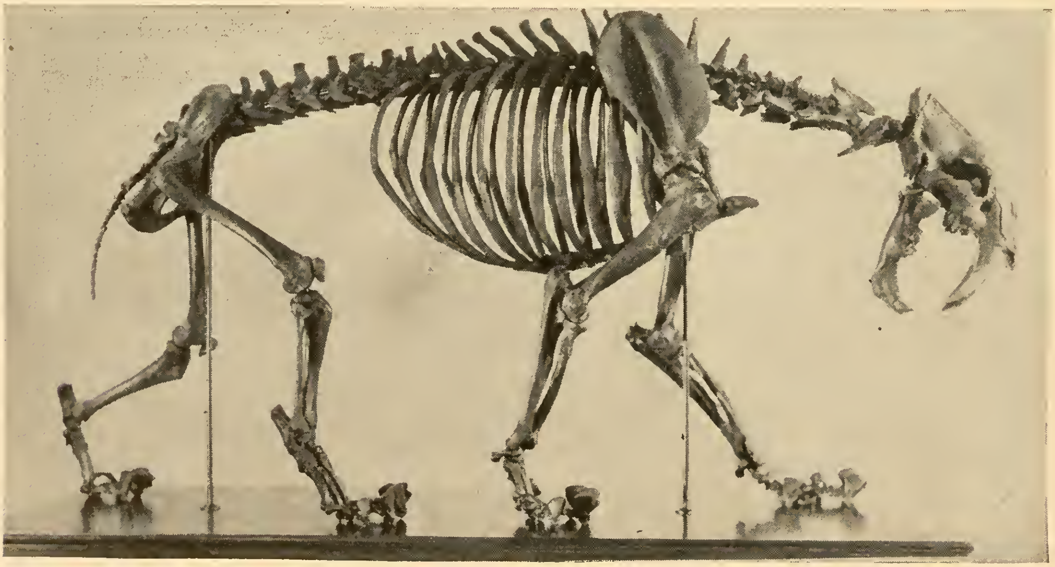


Fig. 25-3. A reconstructed skeleton of a saber-tooth tiger taken from the La Brea tar pits in Los Angeles. These are the actual bones which have been preserved by the action of tar. Note the large canine teeth which undoubtedly made this big cat one of the more formidable animals of its day.

and thus preserved—flesh, skin, and all—for at least 20,000 years.

Animals that have fallen into petroleum surface deposits have been preserved in their entirety, although more frequently the flesh disintegrates, leaving only the bones in perfect condition. The most famous case is that of the La Brea tar pits in Los Angeles where elephants, antelopes, bears, lions, horses, and the famous saber-tooth tigers (Fig. 25-3) have been found in great abundance. Apparently the animals became bogged down in the viscous tar and were attacked by predators which also met the same fate; hence, the rich fossil find in this one locality. The efforts of man to preserve his own kind by various means has been reasonably successful in that mummies have been found dating back 6,000 years.

The hard parts of animals become fossilized very readily, as attested by the large numbers found in various parts of the world. Such parts as shells and other exoskeletons of invertebrates (Fig. 25-4) and the endoskeletons of vertebrates are most commonly preserved. Here again ideal conditions must prevail if the fossil is to form. The animal must be buried shortly after death, usually by the sinking of its body into the soft mud bottom of a stream or other body of water, and then be quickly covered by silt which subsequently becomes rock by the cementing action of minerals in the water. Thus the original shape of the animal is maintained even though the organic parts completely disappear at some later time. Ground water containing carbonic acid dissolves away the shell, leaving a **mold** which is later filled with minerals that precipitate out as the ground water seeps through. The **cast** that is formed is an almost perfect replica of the original shell or other hard part. More commonly the replacement is accomplished a little at a time: the most soluble parts are filled in first, the least soluble portions last. This type of replacement often reveals the minute detailed internal anatomy and is referred to as **petrifaction.**

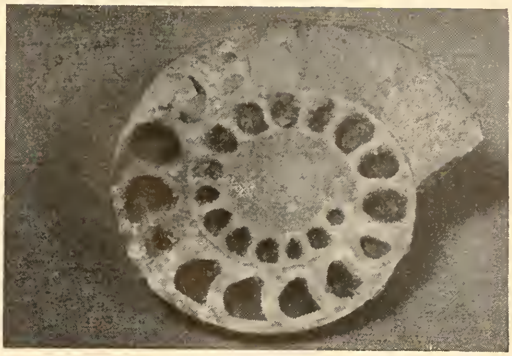


Fig. 25-4. Invertebrates with shells were fossilized in great profusion in ancient times. The shell was usually completely replaced by minerals and the detailed anatomy of the shell was frequently preserved as shown in this relative of the chambered nautilus. This specimen has been sectioned to show how even the details of the chambers have been retained.

Animal products such as eggs and excrement have been fossilized, and even tracks have been preserved in great abundance in certain localities, including the southwest part of this country (Fig. 13-42). Such impressions as tracks were made in soft mud which later dried sufficiently hard to withstand subsequent rains, and were finally filled with new material. Both the old and new deposits became rock and thus the tracks were preserved. Today when these strata are split open, the tracks are as distinct as when they were first made. Raindrops have also been preserved in this way. Such findings have been invaluable in determining the habits of these ancient animals. Tracks, for example, reveal whether the animal walked on all fours or hopped on its two hind legs. This information, together with the fossil remains of the animal itself, gives a rather full picture of animal life in the past.

Ancient animal life

We have concrete evidence that life took hold in earnest only during the last quarter of the 2 billion years of earth history. As was pointed out at the beginning of this

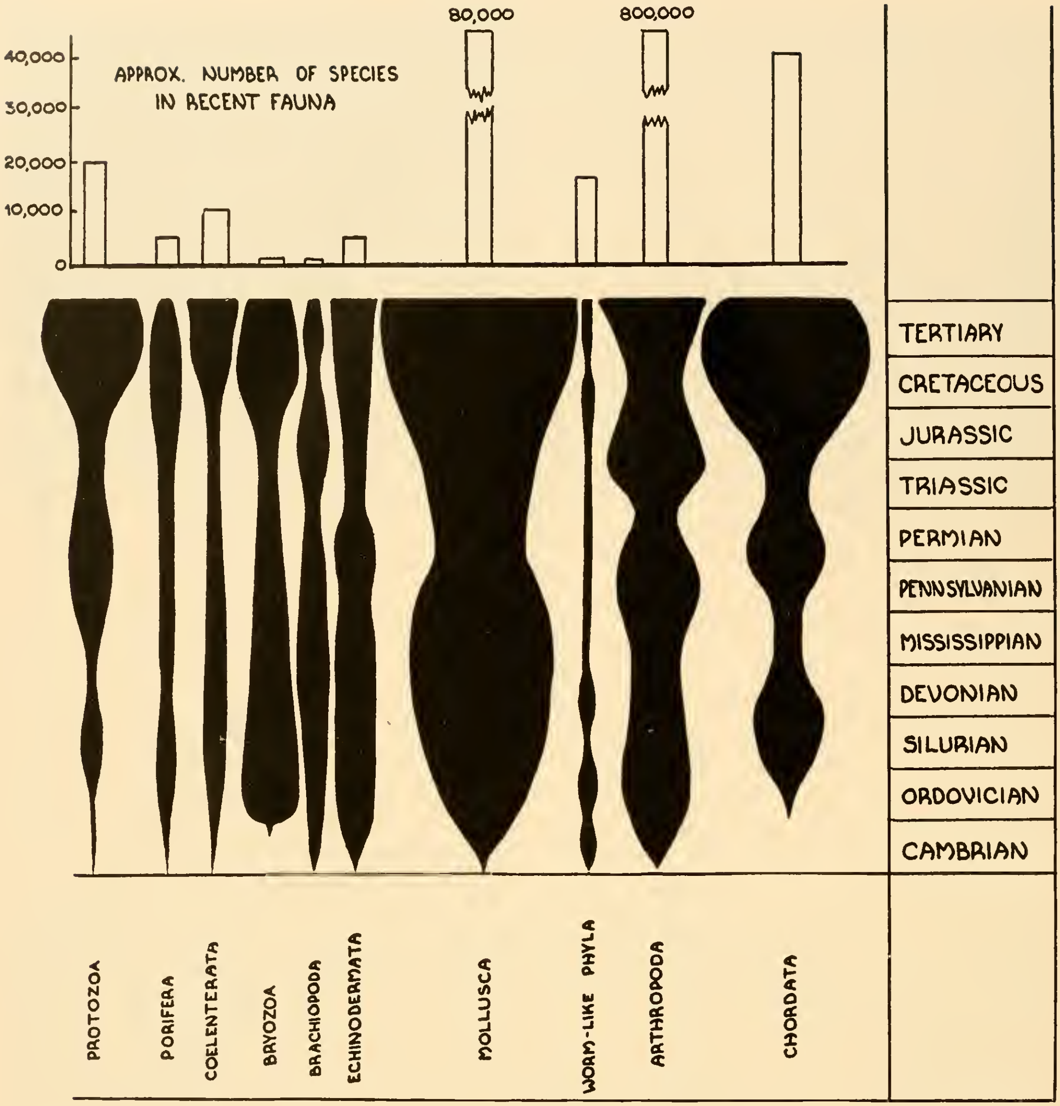


Fig. 25-5. The historical record of life is here shown in graphic form. The various phyla extend from the Cambrian or Ordovician up to the present, and the width of the black pathway indicates the relative numbers of genera in each phylum over this period of time. The upper figure represents the variety of species in each phylum in fauna of the present time.

book, millions of years were required to produce the first living thing, but once it was formed evolution went forward at a rapid pace. It probably took longer to produce the first simple cell than it has taken to evolve man from that first cell. Evidence of living things appears for the first time in the Cambrian rocks and, strange as it may seem, occurs here in great abundance. This must mean that once evolution started it went forth with a burst of speed from the very beginning, because fossils are found in all periods following the Cambrian. There is very little proof that animals lived in pre-Cambrian times, although had they possessed soft body parts which do not fossilize they could have lived and died without leaving recognizable imprints in the rocks. It seems incredible, however, that hard parts would appear almost sponta-

Fig. 25-6. This is a reconstruction of a Devonian coral reef that existed in the region of Rochester, New York. Note the great variety of form and structure of these ancient coelenterates. In the foreground on the right is a huge trilobite, a distant relative of the crustacea. In the middle foreground are two cephalopod mollusks, one in a straight cone-like shell and the other in a segmented coiled shell. All of these species are extinct today.

neously and simultaneously in a large variety of forms. Assuming that they did, all groups would very shortly acquire the character or perish, in accordance with the law of selection. This might conceivably account for the sudden appearance of the ancestors of all modern phyla in this very early period of geologic history.

Most, if not all, of the major phyla have left fossil remains in the Cambrian, which lasted 60 million to 90 million years, certainly a sufficiently long period of time to allow for the evolution of such a large variety of forms. Each of the principal phyla represents a distinct level of anatomical organization which had its beginnings then. Apparently by happy coincidence, specific anatomical and physiological characteristics appeared that possessed great evolutionary potentialities. These became evident in the diversification of species within each phylum that followed. The course that each has taken from the Cambrian up to the present is portrayed in Fig. 25-5 in graphic form. It will be seen that each of the principal phyla today started in the Cambrian and through the subsequent periods has had its "ups and downs." Moreover, in the past geologic periods the relative proportions of the various groups differ from those of today (Figs. 25-6, 25-7). The most striking fact that emerges from this observation is that all of the original phyla have living representatives today and that all of them are more numerous than in Cambrian times. Not only are there more individuals, but there is also a much greater variety of species. This is one of the remarkable outcomes of organic evolution—more and more animals with greater and greater diversity of form and structure. To say it another way, there is a never ending trend toward producing more and more protoplasm organized in more and more different ways.

With the phyla well established in the Cambrian, let us follow the history of one,

Fig. 25-7. This is a reconstruction of the ocean floor during the Cretaceous Period in the region of Tennessee (U. S.), showing the abundance of invertebrate life. Although none of these species is alive today, it is not difficult to recognize them as mollusks. The two squid-like forms in the upper right certainly are very similar to our present-day forms. The large coiled ammonite in the lower right is very much like the chambered nautilus of today. The numerous cephalopods with shells resembling cones are all extinct in any form. Our present-day clams and snails seem to be well represented on the floor of this ancient ocean.

the Chordata, during the ensuing periods and note some of its ramifications in establishing subgroups. In this brief survey we should gain some understanding of how evolution has gone on in the past, which will prepare us for the next chapter where we shall consider how it is going on today.

The story of vertebrates

The vertebrates, both past and present, constitute the most important animals in the phylum Chordata. Since the prochordates have left no fossil remains, we are forced to ignore them and study the history of the vertebrates alone.

The Chordates undoubtedly had their beginnings in the late Cambrian because they are well established as vertebrates in the Ordovician, well on their way toward becoming the most important of all groups of animals (Fig. 25-8). There are eight classes represented, of which four are swimmers and four possess legs adapted to movement over solid surfaces. Of the classes of swimmers, all but the placoderms have living representatives today. The jawless fishes (cyclostomes) had rather modest beginnings and all but died out in the late Devonian. In recent times they have shown signs of increasing in numbers and varieties as indicated by considerable numbers in the oceans. Some have also invaded fresh water. The placoderms had the first true jaws which were hinged to the skull,

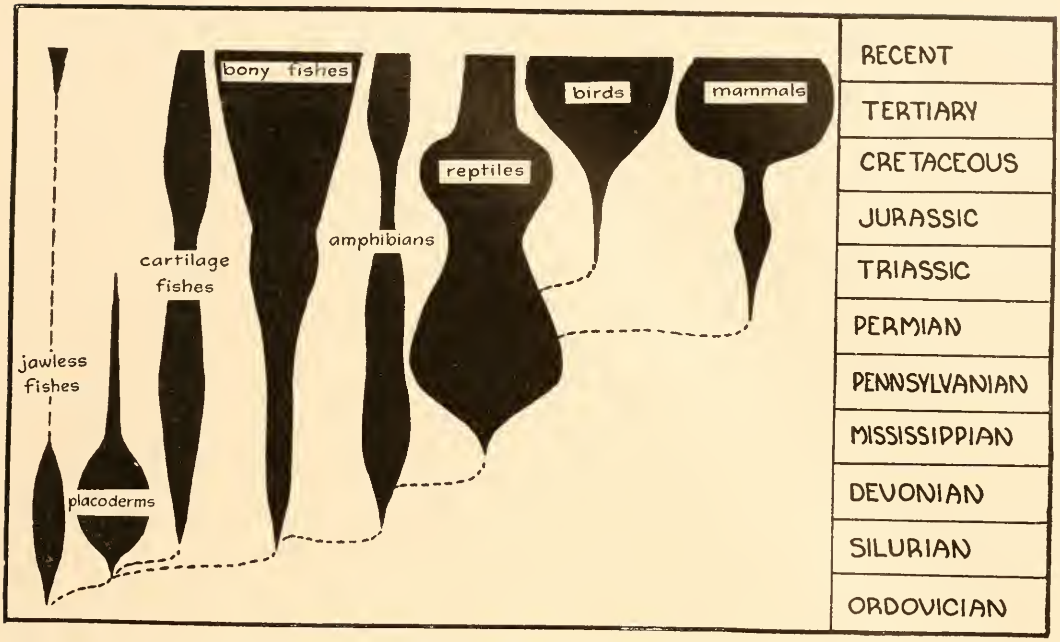


Fig. 25-8. The historical record of the vertebrates is shown, where the width of the black pathways indicates the relative variety of known forms in the various vertebrate classes.

a feature that was retained in all subsequent forms. They also possessed heavy bony skeletons. Both the cartilaginous and bony fishes were offshoots from the placoderms, the former sacrificing bone for cartilage and the latter retaining the bone. Today we have both represented: the cartilaginous fishes in the sharks and rays, and the more successful bony fishes which abound in all waters of the globe. The cartilaginous fishes have held their own rather well through this long geologic time while the bony fishes have increased at a tremendous rate, particularly since the Permian.

The most primitive land-dwellers, the amphibians, arose from the bony fishes some time during the Devonian, reaching a peak which they maintained through the Pennsylvanian and Permian, but then suddenly lost ground probably because their chief competitors, the great reptiles, became the dominant land life. With the passing of the great dinosaurs, the amphibians made a slight comeback which they have maintained up to the present. The reptiles came from the amphibians in the Pennsylvanian and very soon reached a peak which they continued to hold, with a setback during the Triassic, until the end of the Mesozoic (beginning of the Tertiary), when all of the large dinosaurs suddenly disappeared leaving only remnants which have continued on to the present. The reptiles have been the most successful of all animals living in the past and it is problematical whether any group in the future will reach such peaks as they did.

Both the mammals and birds were derived from the reptiles some time during the Triassic but good records are available only in the early Tertiary. Both started out very slowly, seeming to "bide their time" while the great reptiles ruled the earth. With the decline of these beasts, both the birds and mammals came into their own, increasing in numbers and variety at a tremendous rate. One can imagine that through the Triassic and Jurassic small birds and mammals occupied the secluded niches in the environment, keeping well out of the way of the numerous reptiles. All the while their bodies were evolving to a stage where, when the opportunity for survival improved, they were ready to set forth on the road that led them to the dominant position among present-day animals. Certainly the mammals have become the most diversified of all animals, whereas the birds have clung pretty much to a common pattern that seems to serve them well for life involving flight. Mammals reached their peaks in the Tertiary and have since shown a steady decline in numbers of species even though man, a member of this group, is considered to be the dominant form of life on earth today.

All of the evidence from studies of ancient life confirms and elaborates the theory that living things today descended from similar but different forms living in past ages. In other words, paleontological studies confirm and extend the theory of evolution as accepted by all scientists and most others today. Let us continue our search for facts supporting this or any other theory by examining evidence that appears in our living world of today.

EVIDENCE FROM RECORDS OF LIVING ANIMALS

We have seen that paleontology lends substantial support to the theory of evolution, but what about the living world of today? Can we find additional evidence among the animals around us to add to the bulwark already substantiated? Zoologists have been busy for the past 150 years adding vast stores of information to this end, and today we find supporting evidence from many branches of the biological sciences. Indeed, so much has been accumulated that it is questionable whether evolution should be referred to any longer as a **theory**. It is rather a clearly established **fact**. Some of the evidence which has afforded proof we shall consider briefly.

From embryology

The German biologist, Ernest Hendrich Haeckel, many years ago, formulated the Biogenetic Law based on the fact that all early vertebrate embryos show remarkable similarity in their early stages of development. He claimed that animals recapitulate in their early embryological stages the phylogenetic history of the race, which we have already seen in various animals. Haeckel's all-inclusive statement has since been attacked from many sources and today stands only in its skeleton form. Although there is definite resemblance between the embryos of related species (Fig. 25-9), they are not as clear-cut and absolute as was once thought, and this is as one might expect. Since evolution has come about by a series of many small changes (micromutations) in the genic constitution of a species, it might be expected that gene changes would occur affecting all stages of the individual, that is, gene changes might affect the embryo itself so that "short cuts" could be taken in producing a certain organ system, for example. Similarly, structures which no longer serve a purpose in the adult animal might be retained simply because they were not "in the way" during the course of development and because no specific gene change occurred that ruled them out. Therefore, one might expect numerous remnants lingering on in the bodies of some animals but not in others, even closely related species. This is exactly what we observe.

In spite of some important omissions, the parallelism between the developing individual (ontogeny) and the phylogenetic sequence of animals (phylogeny) is remarkable and certainly lends support to the theory of evolution. Both the fertilized egg and single-celled Protozoa exist as individual cells, the former destined to become something more complex, whereas the latter never rises above the one-celled condition (Fig. 25-10). Colonial Protozoa (for

Fig. 25-9. The early embryos of all vertebrates are very similar during some stage of their development.

example, *Volvox*) resemble the blastula, and the gastrula parallels the two-layered coelenterates (for example, *Hydra*). Subsequent stages of higher embryos become worm-like tubes reminiscent of the annelids (for example, *Neanthes*). Organ systems are formed in a primitive stage and function as such in primitive forms, while in higher forms they are laid down only in basic design, to become something far more complex at a later time. From this point on, the embryo undergoes further changes which take it farther and farther up the line of animal development. Early embryos from

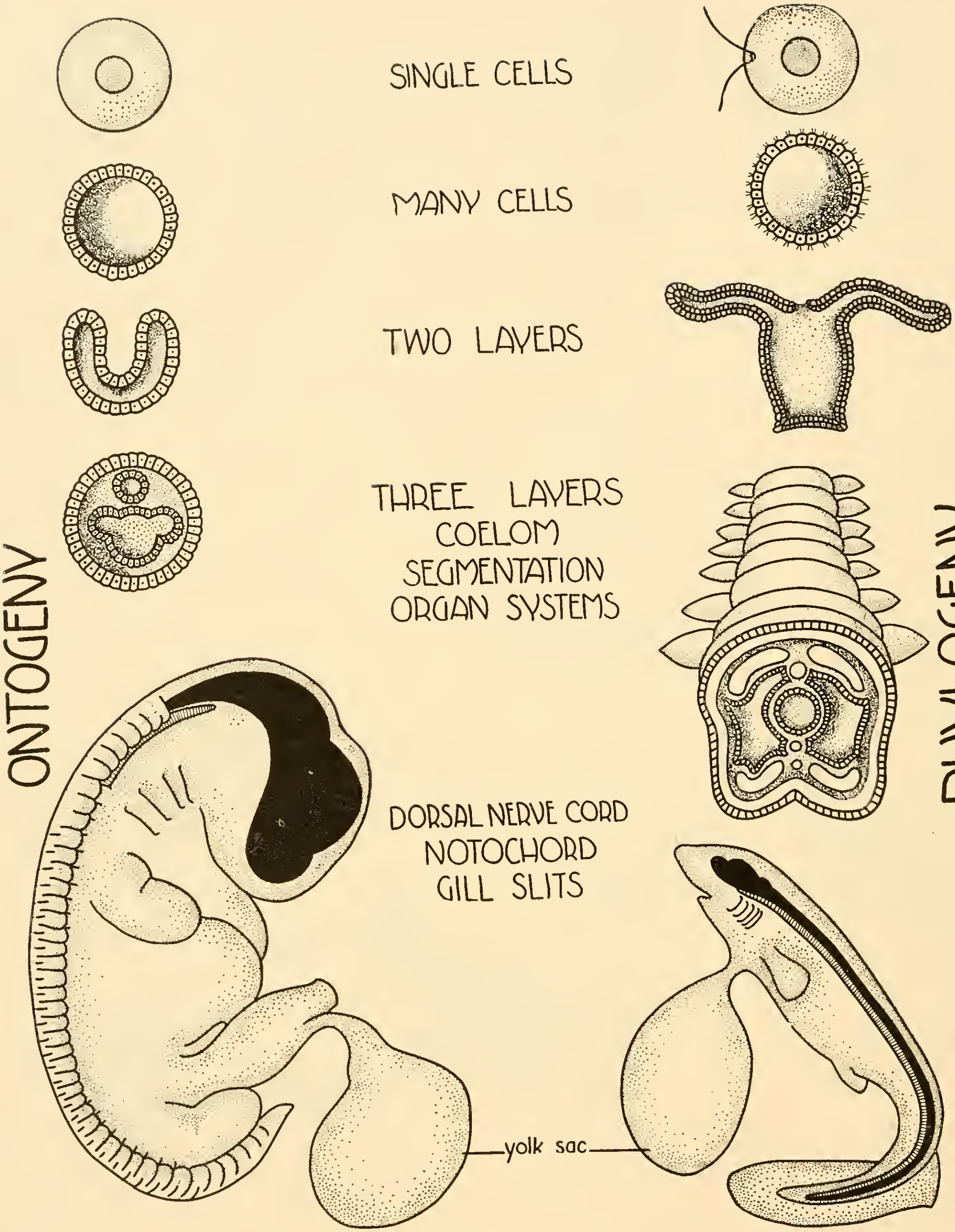


Fig. 25-10. The Biogenetic Law can be demonstrated by comparing the embryological stages in the development of a complex animal, such as a vertebrate, and adult representatives of certain of the phyla. Each higher form reënacts the long history of the race in its own embryology.

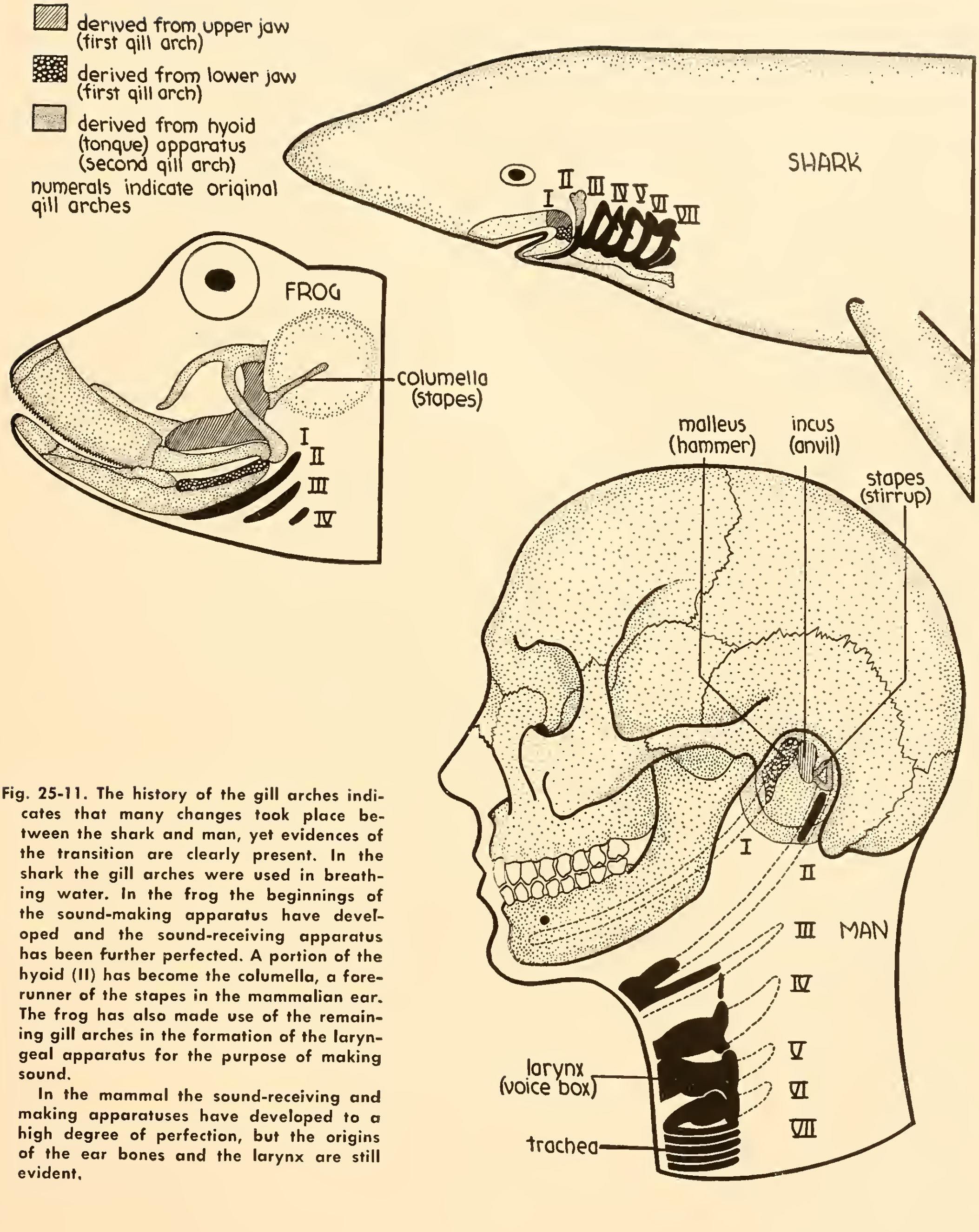


Fig. 25-11. The history of the gill arches indicates that many changes took place between the shark and man, yet evidences of the transition are clearly present. In the shark the gill arches were used in breathing water. In the frog the beginnings of the sound-making apparatus have developed and the sound-receiving apparatus has been further perfected. A portion of the hyoid (II) has become the columella, a forerunner of the stapes in the mammalian ear. The frog has also made use of the remaining gill arches in the formation of the laryngeal apparatus for the purpose of making sound.

In the mammal the sound-receiving and making apparatuses have developed to a high degree of perfection, but the origins of the ear bones and the larynx are still evident.

fish to man follow similar pathways, each dropping out in its appropriate place along the line—the fish first, man last.

Obviously, from what we have already said, the higher embryos will possess features that are functional in the adults of the lower forms. For example, the human embryo has a set of folds in the neck region in the fourth and fifth week of life. The fish embryo in a comparable stage of development possesses a similar set of folds; and, in fact, the embryos resemble one another so closely at this early stage that it is difficult to distinguish one from the other (Fig. 25-9). In the fish the folds become functional gills in the adult, whereas in the human they undergo a whole series of modifications, ultimately becoming a part of the hearing and sound-making apparatus as well as a part of the upper respiratory tract (Fig. 25-11). We are reminded once again of the fact that, in the long evolutionary history of animals, structures which no longer find a use in the body often become assigned new tasks and by slight or great modifications become beautifully adapted to the new function.

There are many other features that appear in the developing human embryo that are tell-tale evidence of our lowly origin. For instance, a well-developed tail (Fig. 25-16) makes its appearance in the first few weeks of life but soon vanishes without performing any function other than to indicate to us that man came from stock which once possessed a tail. We have already noted the presence of a yolk-sac which could hardly have a function since it is devoid of yolk (food) and is not needed because nourishment is provided by the placenta. Here again it tells us that some time far back in evolutionary history our ancestors were egg-laying animals in which the embryos did receive their nourishment from a yolk-sac. The later human embryo, along in the fifth month, develops a coat of hair called the **lanugo**, which is shed before birth, usually in the eighth month of gestation. Such hair could not possibly perform any conceivable function but does lead us to believe that at one point in our evolution we possessed a coat of hair as adults, extending back, probably, to some common ancestor of both man and apes. The entire study of both invertebrate and vertebrate embryos supports the theory of evolution; no other explanation serves as well.

From comparative anatomy

One of the most striking observations that impresses anyone who studies a large variety of vertebrates is the fundamental likeness of the body architecture. The similarities are evident no matter what system is examined—appendages, muscles, digestive systems, circulatory systems, or any other. By comparing the appendicular skeletons of the horse, man and the frog (Fig. 25-12) it is obvious that the bones are similar, varying only in emphasis of specific parts of certain bones. In the horse, the forelegs are extended by elongating the equivalents of the wrist and hand bones of the frog and man. This provides the horse with an appendage well adapted for traveling at high speeds over soft turf. The same bones modified in different ways have given man a maneuverable appendage which is handsomely adapted to the kind of life he leads. Consider how much of our surroundings are designed for manipulation with the hand! An appendage not greatly different from that of man serves the frog satisfactorily in its way of life. Similarly, the hind appendages have been modified to perform specific jobs. The important point to note here is that the fundamental plan is the same; that is, the appendages are **homologous**, which means that they must have had a common origin. It would be difficult to explain their likenesses on any other basis.

A study of the muscles in any two vertebrates, man and cat for example (Fig. 25-13), will reveal the same sort of homologies noted in the skeletons. The large, major

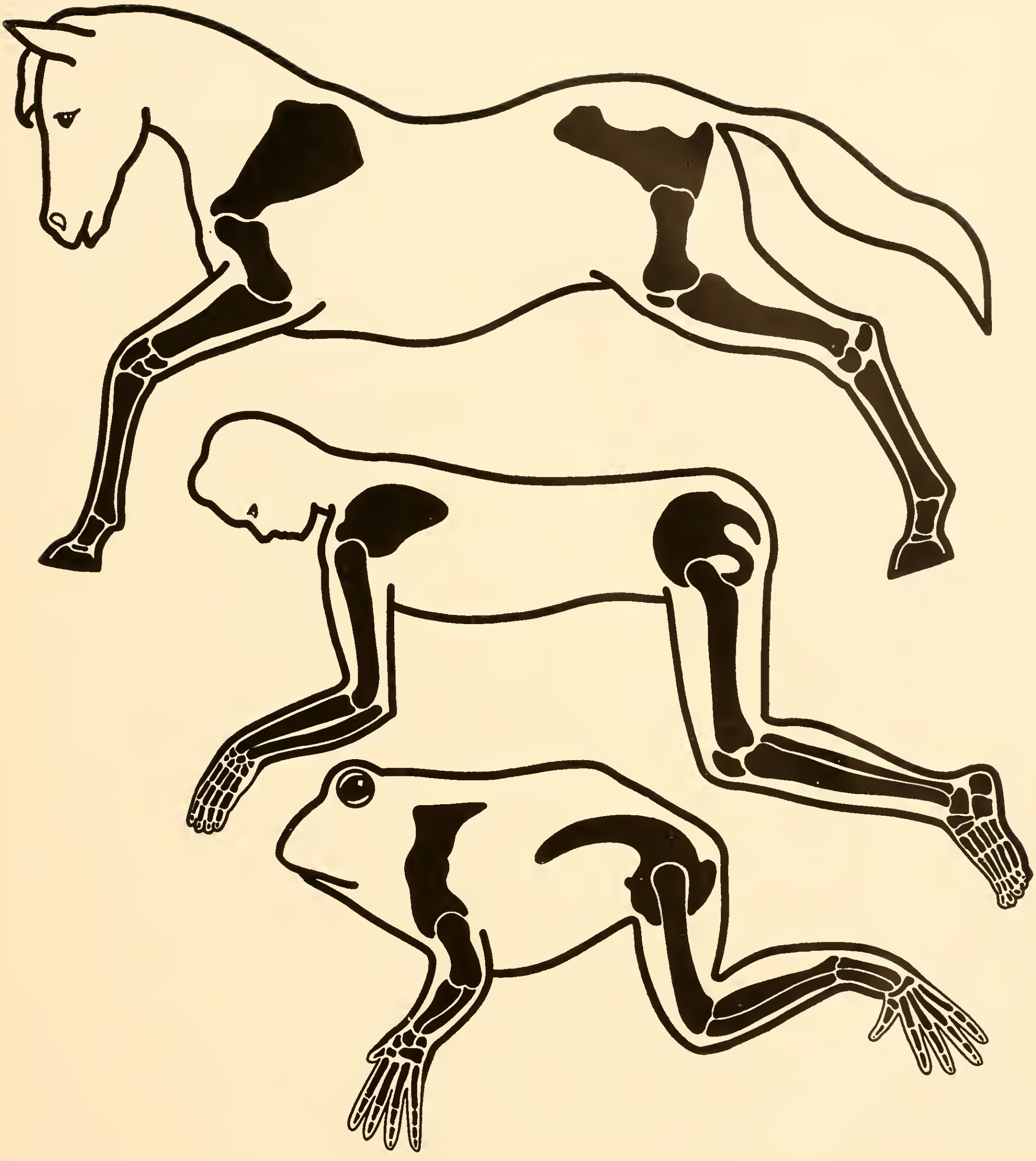


Fig. 25-12. The appendages of the vertebrates are homologous, as shown by comparing the skeletons of these three. It would be difficult to explain these similarities on any other basis than organic evolution.

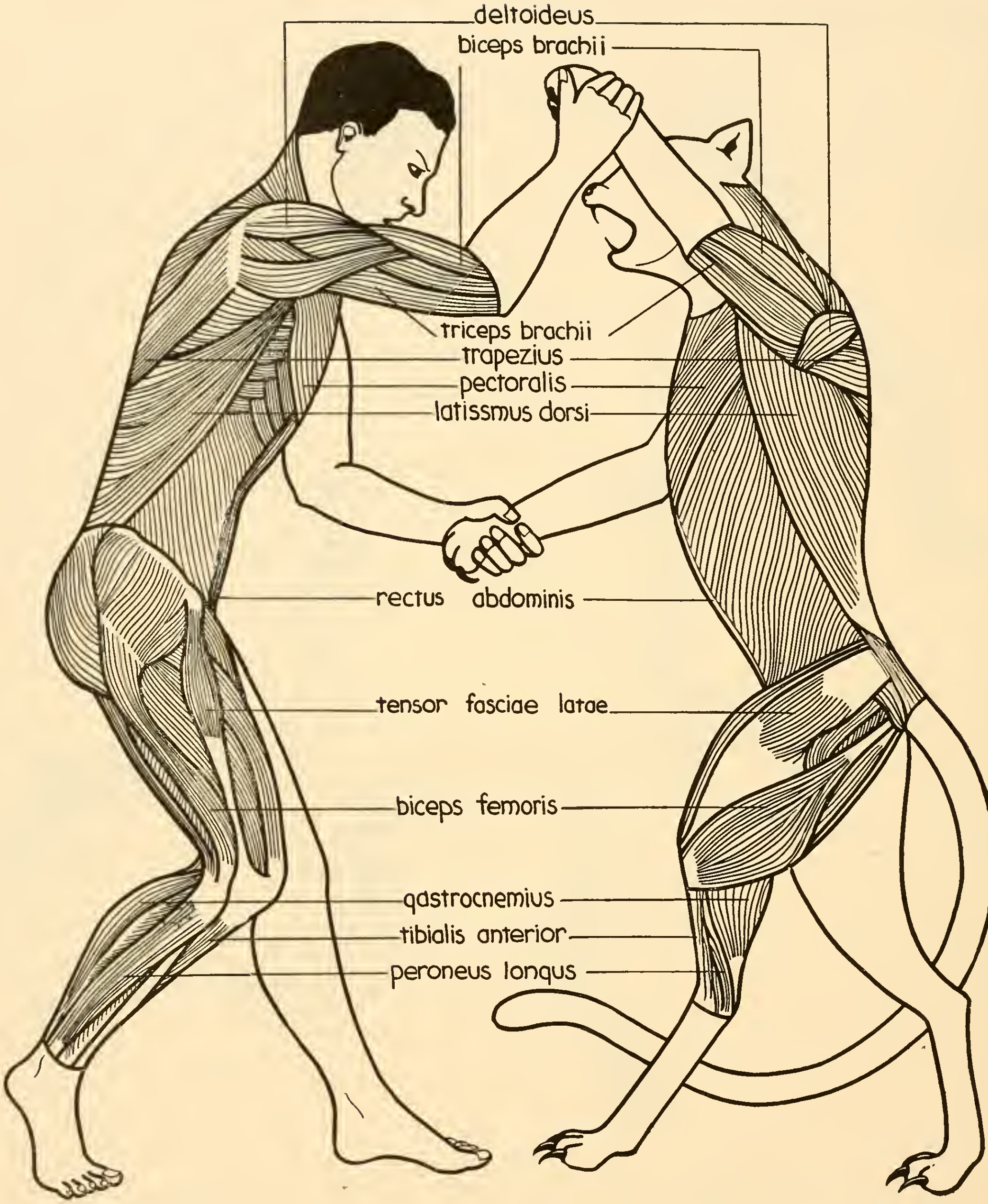


Fig. 25-13. The muscles of man and cat compare favorably, indicating comman origins.

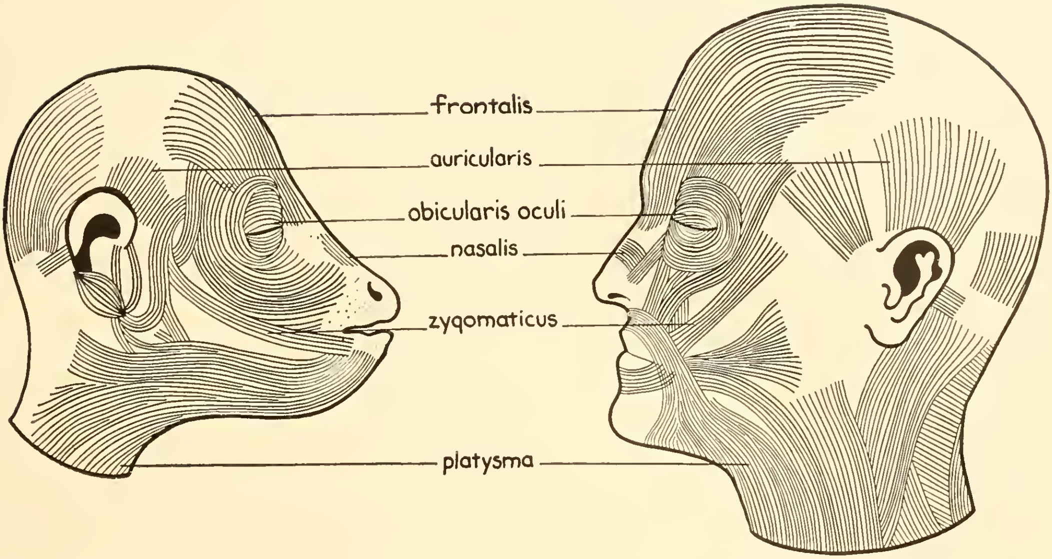


Fig. 25-14. Vestigial structures such as ear muscles in man (auricularis) are similar to those in the monkey. In the latter they have some function in moving the ears which perhaps aids in directing the sound into the ear; in man they are vestigial and serve no purpose, yet they persist.

muscles in both animals are similar, most of them performing the same function in both. They vary only in size due to use, which is reflected in the activity of the animal. The cat walks on all fours and therefore uses its front appendages primarily for locomotion, whereas man puts his homologous appendages to quite a different use. Facial muscles of both man and monkey are likewise similar, although we have more of them and consequently can register more emotions in our faces (Fig. 25-14). The digital tips of a bird, a man, and a horse, referred to earlier (Fig. 14-2), can be compared in the same way. Other examples were mentioned earlier in the discussion of the origin of scales, teeth, and feathers (see p. 369). All of these comparable structures and many more support the thesis of common origin, with modifications in various species in response to function. Common origin implies evolution.

From vestigial structures

Many animals possess structures which are vestiges of some past functional organ. The appendix in man is such a structure. It apparently performed some function when man's diet was not quite what it is today. Perhaps at one time he was more of an herbivore. In any case, it is no longer needed, as is attested by continued health after its removal. Indeed, failure to remove an infected appendix may mean death in man. It seems strange that this potential danger has not been removed by selection!

Another human vestigial structure is the ear muscle. Man possesses a complete set of muscles, similar to those in other primates, for moving the ears in all directions (Fig. 25-14). However, it is only with extreme difficulty that he can move his auditory appendages and even then the movement is ineffective in improving his hearing. Man also possesses a rudimentary tail together with a complete set of muscles for wagging it in all directions. These are even more useless than the ear muscles yet this structure has persisted for thousands of generations. Since there is wide variation in the number of segments in the tail (coccyx) one might believe that it is disappearing, and this is probably true. A similar situation exists with the last set of molars (wisdom teeth). Perhaps a few thousand generations hence people may be born without wisdom teeth, an appendix, or a tail.

Vestigial structures in other animals often tell us something about their life history. The porpoise, for example, has a tiny pelvic girdle (Fig. 25-15) buried deep in its hip region where it could not possibly perform any function whatever, yet it is faithfully produced in the body of every porpoise. This vestige supports other evidence that this animal was a four-footed land animal at one time in the far distant past. Similarly, the python possesses a rudimentary pelvic girdle (Fig. 25-15), whereas all other snakes are without appendages of any sort. This vestige indicates that snakes had four-footed ancestors in the dim, distant past.

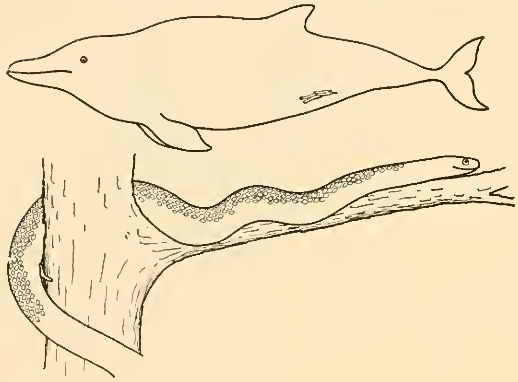


Fig. 25-15. Structures that performed a function at one time in an animal's history often continue to appear although today they are useless structures. Two good examples are the posterior appendage bones in porpoises (whales as well) and the remnants of similar appendages remaining in the python. Porpoises have no use for the bones, yet they always appear in every animal. The observable external remnant of posterior appendages in snakes occurs only in a few snakes but indicates that the ancestors of present-day snakes had legs.

Anomalies in development occasionally occur which give some hint as to the history of certain structures. They are caused by the retention of embryonic structures in the adult and are called **atavisms** or **reversions.** For example, it is not uncommon for a child to be born with a well-developed external tail, reminiscent of a similar structure in the embryo (Fig. 25-16). Sometimes, additional nipples occur along lateral lines that coincide with the milk ridge in the embryo. In animals with multiple births this arrangement of the mammary glands is customary. Such "mistakes" in development throw light on the history of the body.

From comparative physiology and biochemistry

The very fact that all animals posses essentially the same elements and chemical compounds would indicate a common origin. Even protoplasm is very similar among all animals. The various enzymes that are found in the digestive tract of man can be identified in other animals, even down to the Protozoa. Other intracellular and extracellular enzymes can likewise be identified in all animals which have so far been studied. It appears reasonable to assume, then, that the chemical constitution of two closely related species is more nearly alike than that of two distantly related species. Appropriate immunological and biochemical tests of the various fluids and tissues of a large variety of animals have shown this to be the case. Blood is most commonly studied because it is most readily obtained and most easily handled in the laboratory. By utilizing the antigen-antibody technique described earlier (p. 510), it has been possible to verify the relationships between many animals. It is gratifying to note that the relationships established by these blood tests corroborate those erected by our system of classification based on homologous structures. For example, it is possible to show that among invertebrates *Limulus* is more closely related to the scorpions than any other invertebrates, and among vertebrates that seals and sea lions are more closely related to one another than to other mammals. Man's nearest kin among the primates has been shown to be the great apes and his most distant the lemur. The uniformity of birds has been verified by blood tests because they all give strong reactions with sera containing antibodies for the domestic fowl. Paleontologists have long contended that birds evolved from the line that gave rise to turtles and crocodiles rather than the snake-lizard line and blood tests have confirmed their findings.

Another interesting evidence for evolution comes from a study of the salt content of the ancient and modern seas as compared with that of body fluids of ancient and modern animals (Fig. 25-17). It is known that the salt content of the seas has steadily increased through the ages. Freezing-point depression studies are a convenient method of determining indirectly the number of particles of solute in a fluid, for the greater the number of particles, the greater the freezing point is depressed. Such studies show that the fluids (blood) of modern animals are about as saline as those of the ancient seas (0.55), which would be expected if animals migrated onto land at the time when the salt content was considerably less than it is today (1.85). The blood of a fish, such as the shark, which has never left the ocean possesses about the same salt content as modern seas. This is likewise true of invertebrates such as crabs. Certain fish such as the salmon, which survives in both fresh and salt water, show freezing-point depressions of 0.74, which is intermediate between salt and fresh-water animals. The whale shows a figure of 0.58, again indicating its mammalian affiliations, even though today it lives in the ocean. This striking physiological evidence corroborates the course followed by animals from

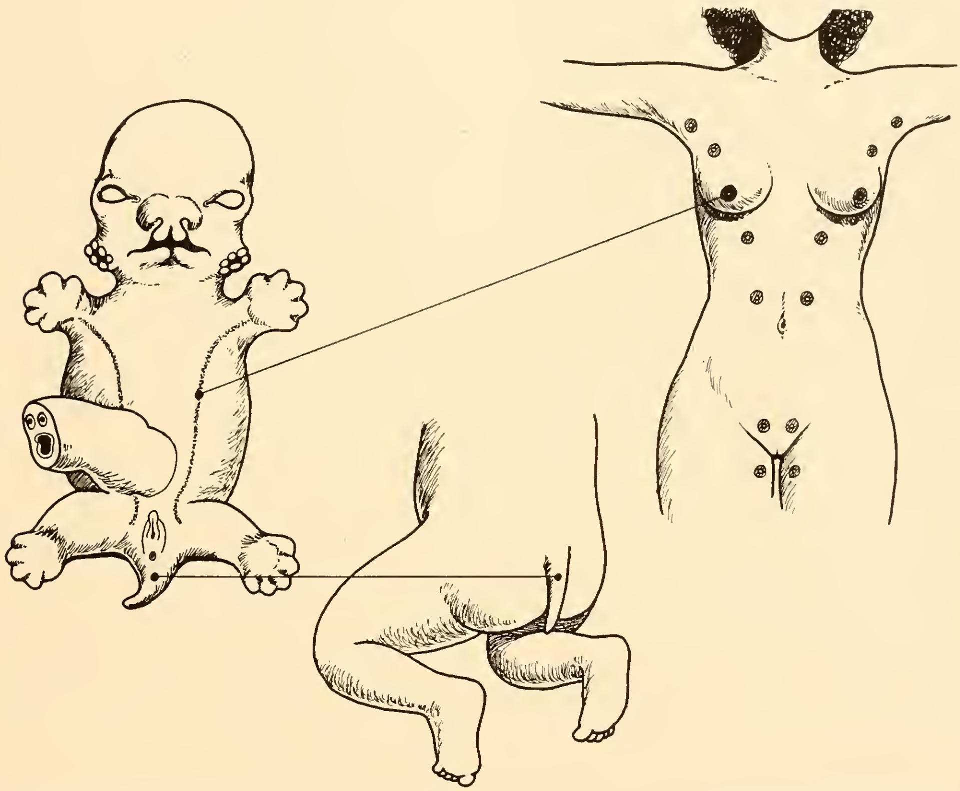


Fig. 25-16. Occasionally an embryonic structure persists in the adult, such as a well-developed tail or numerous nipples in humans. These structures are found in relatives of man and may have existed in his ancestors. The only feasible explanation is that of common origins.

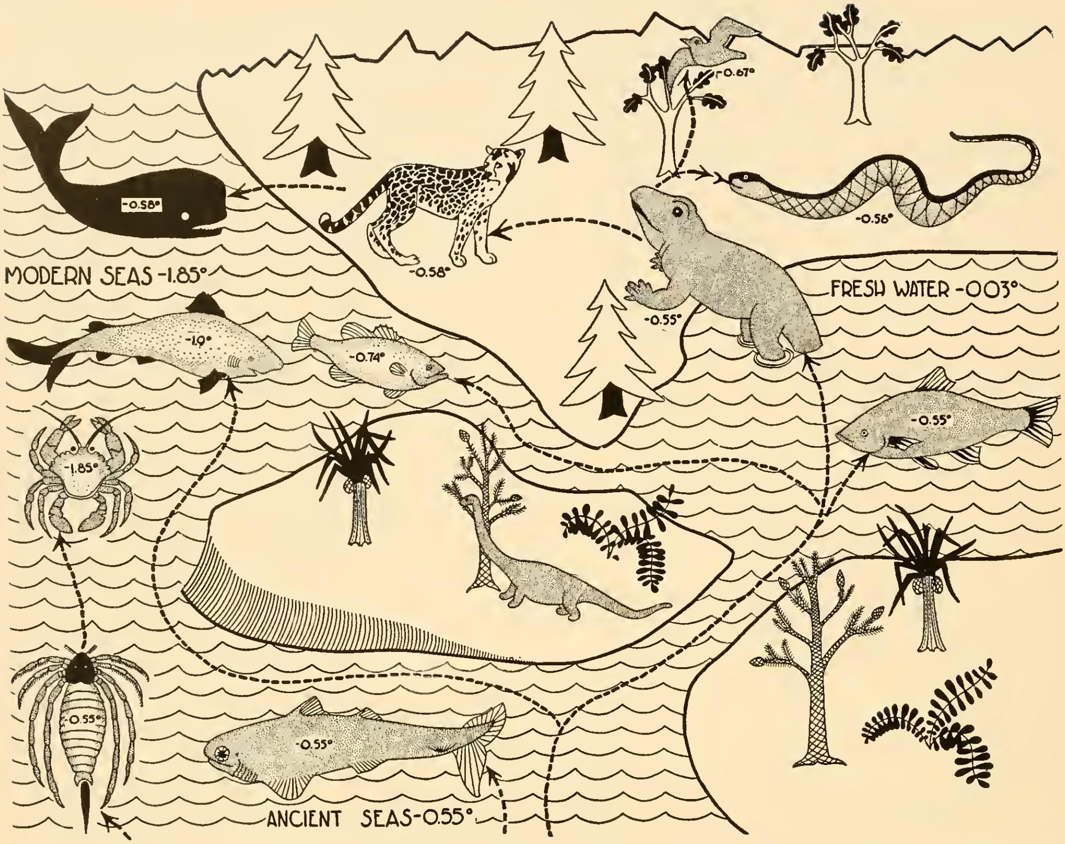


Fig. 25-17. By studying freezing-point depressions (indicated here by the numbers) of modern seas and the blood of modern animals and comparing these with indirect evidence for similar data on ancient seas and primitive animals, it has been possible to trace animals from the sea onto land. For an explanation see text.

water to land as determined by other studies. All physiological and biochemical data that have been carefully examined supplement those gathered from other disciplines supporting the theory of evolution. Many other substances present in the bodies of higher animals can be traced to their origins in lower forms, which certainly lends support to the thesis that they have a common origin. It would be difficult to explain them any other way.

From animal distribution

There are many places on the earth's surface that are idyllic spots for a large variety of animals, yet none occupies these regions. If animals were created simultaneously, why are not all of the favorable places in the world occupied by those that are fitted for such environments? Only in the light of evolution, both physical and organic, can a satisfactory answer be found for this situation.

Interplay of two evolutions, one of the earth itself, the other of the animals and plants upon it, has taken place. The young earth changed violently at first, gradually quieting down as it grew older and finally becoming inhabited with living things. Once life originated and new species began to appear, any subsequent alterations of the earth's surface or climate drastically affected the life then existing. Such changes as the rise and fall of large areas of the earth's surface and sharp climatic shifts were most important in determining not only the animals that survived but also the direction evolution took in any given locality.

Although there seems to be some question about the movement of entire continents (continental drift), there is no doubt about the fact that there have been many "ups and downs" within the various continents themselves. The presence of fossil remains of sea animals on the top of mountains is unequivocal evidence that these regions were at the bottom of some ancient ocean. Great sections located in mid-continental North America abound in marine fossils, though these areas are over a thousand miles from the sea today. The rising and falling of these areas has occurred again and again in certain regions, and geologists can tell us how many times and approximately when this has happened. There is no doubt but that such striking dislocations of great areas had a profound effect on animal life, and we know the history of some of these.

Coincident with these shifts in the surface of the earth, the climate changed dramatically from one extreme to another and back again. The great coal deposits in the northern sections of the globe are a result of luxuriant plant growth in some ancient period, which is substantial proof that such regions were tropical during these times. Areas that once received a tremendous rainfall later became dry plains. This transition can be observed today by flying over large regions of the North Central United States. It is possible to see the outlines of ancient lakes that are now forest lands and old forest lands that have become grasslands. All of these changes have come about because of the gradual trend toward a more arid climate. The sudden appearance of a mountain range must have had a profound effect on the amount of precipitation that fell in surrounding regions, which in turn would alter both plant and animal life. Undoubtedly the success of a species depends a great deal upon the coincidence of gene mutations with changes in the climate and topography of the region. The proper timing of genetic changes in the animal with climatic and environmental changes might mean the success or failure of a species. These constant shifts in climate and topography have influenced the evolution of animals to a marked degree.

Closely related species of animals are usually found in adjacent ranges (region occupied by a species), just as one might expect. If they had split off from one another only recently, they would not be separated by very great distances, and more than likely some barrier would exist between them such as a mountain, canyon, or body of water, which may have been responsible for the new species in the first place. The more recent the separation of two species the more closely related they are, and the more ancient the separation the greater the differences between them. The greater differences constitute genera, families, orders, classes, and phyla. When great land masses are separated for millions of years one would expect the entire fauna to be quite different on each of them. Such is found to be the case when, for example, the animals in Australia and in the continent of Asia are compared. The explanation of the occurrence of primitive animals in Australia has direct bearing on the history of this large land mass.

Most of the earth's land is located in the northern hemisphere. It was all connected at one time when there was a land bridge across Bering Strait. Therefore, animals originating in any part of this great land mass could have migrated to any other part during this period. It is thought that mammals originated in these northern continents and spread in all directions. The frigid barrier to the north encouraged southward migrations of primitive mammals during the Mesozoic when the three great land masses to the south (Africa, South America, and Australia) were connected at various times to the continents

Fig. 25-18. The opossum is the oldest living mammal, having originated in the Cretaceous and maintained itself unchanged up to the present time.

of the northern hemisphere. Australia was bridged through the Malay Archipelago and the two Americas were connected through Central America, just as they are today, although during early Tertiary times there was no land bridge at this point and the two continents were separated. Evidence for this is substantiated by the fact that marine life in the Atlantic and Pacific oceans in this region is very similar yet sufficiently different to be accounted for only by the formation of a relatively recent land barrier which separated the two oceans.

The primitive mammals, which probably resembled our present-day monotremes and marsupials, spread over these land bridges into Africa, South America, and Australia. Later the placental mammals evolved in the northern continents and, because of their superior ability to cope with the environment, were able to drive out or destroy all of the primitive mammals in these northern areas. However, before the placental mammals made their way too far south, the sinking of the land connection between North and South America below the surface of the oceans prevented them from getting into the southern continent. Likewise, the land connections between Asia and Australia and to a lesser extent between Europe and Africa gave way, thus cutting off the possibilities of further migrations southward. The primitive mammals were thus isolated from their more aggressive relatives and were able to survive up to the present. For that reason we see not only primitive mammals but also other primitive groups of animals ranging from insects to birds in the southern continents.

The fact that primitive mammals could not withstand the onslaught of their more recent placental relatives has been demonstrated within historical times. Rabbits introduced into Australia all but took over the continent, outstripping the local marsupials at a tremendous pace. Only recently it was estimated that they consumed one-quarter of the country's pasturage in spite of every effort of man to exterminate them. This seems to be true of other northern animals as well when introduced into southern continents. One interesting exception to this apparent superiority of northern fauna is the case of the opossum (Fig. 25-18). This marsupial made its way back north over the recent land bridge between the two Americas and it has competed rather successfully there with its aggressive descendants.

Another interesting case of animal distribution which can be explained in no other logical way than by evolution is the occurrence in widely separated parts of the world of animals that are morphologically similar yet geographically far apart. For example, the camel family is represented by the true camels in Asia and Africa and by the llama and its relatives in South America. How can one explain the existence of these closely related animals in

Fig. 25-19. The chambered nautilus is one of the "living fossils." The group to which it belongs was dominant during Paleozoic times when forms such as the one represented here (upper) lived. Note the elaborate configurations of the partitions that separate the chambers. The shell of the chambered nautilus (lower) closely resembles that of its ancient ancestor.

areas so far distant today? To account for this one can consult the fossil records. It has been found that the ancestor of these two species roamed over not only their present habitats but also Europe and North America, which lie between them. Apparently, relatives of the present living members of the camel family died out in the intervening regions. Similarly, the only alligators in the world exist in southeastern United States and the Yangtse River in China. Fossil alligators have been found in North America and Europe, which accounts, then, for the present location of living alligators. Just why they died out over the large intermediate areas is conjectural.

The theory of evolution is the most logical explanation for the distribution of animals over the earth. We may rest assured that if and when a better explanation presents itself scientists will be the first to recognize and accept it.

RATES OF EVOLUTION

From the foregoing discussion it is obvious that evolution has gone on at different rates at different times, bringing about radical changes in some groups whereas in others little or no change at all has occurred over millions of years. For example, the chambered nautilus (Fig. 25-19) evolved rapidly to a certain point after which, for the past 75 million years, it has not changed. During the same period of time the horse has come all the way from a many-toed, shy little animal to the huge beast we see today. The nautilus evolved very rapidly from Silurian times, reaching a peak in the Jurassic and then coming to a standstill in the Tertiary with no change from that point up to the present. All of its relatives died out in this early period and it was only by some peculiar circumstance that this "living fossil" has survived to the present time. The horse, on the other hand, has shown a progressive change up to the present and is still changing (Fig. 26-4).

Even if the whole animal seems to have evolved steadily, a careful examination of its various structural aspects shows that it has undergone change at varying rates. For instance, among the early Pliocene horses some show marked changes in both teeth and feet over the ancestral Miocene horse, others show changes in teeth but not feet, and still others show no change in feet or teeth. This indicates that the teeth and feet have changed at different rates and at different times in the various groups of horses. Similar instances can be found in other groups of animals. It is apparent that structural evolution has gone ahead erratically with bursts of speed and sudden pauses for reasons which we do not know at present and may never know.

Another way of studying the rates of evolution is to determine the number of different kinds of animals produced, that is, the number of new species, new genera, and even larger categories that came into existence in a specified period of time. Using as factors the number of genera of animals in a family and the length of time known, it is possible to compute how many years are required to produce a new genus. This has been done for the familiar horse lineage and it has been estimated that a new genus appeared about every 7,500,000 years. Estimates for other hoofed mammals seem to be about the same during that period, although this generalization does not hold for all animals, even mammals. The opossum, for example, has changed very little if any since the Cretaceous, over 80 million years ago, and at that time it was the most advanced of all animals. This is certainly substantial evidence that some animals have evolved much more rapidly than others, and also that the rate may vary greatly at different times within a small group of animals.

Considerable data, brought together by G. G. Simpson, show the rate at which

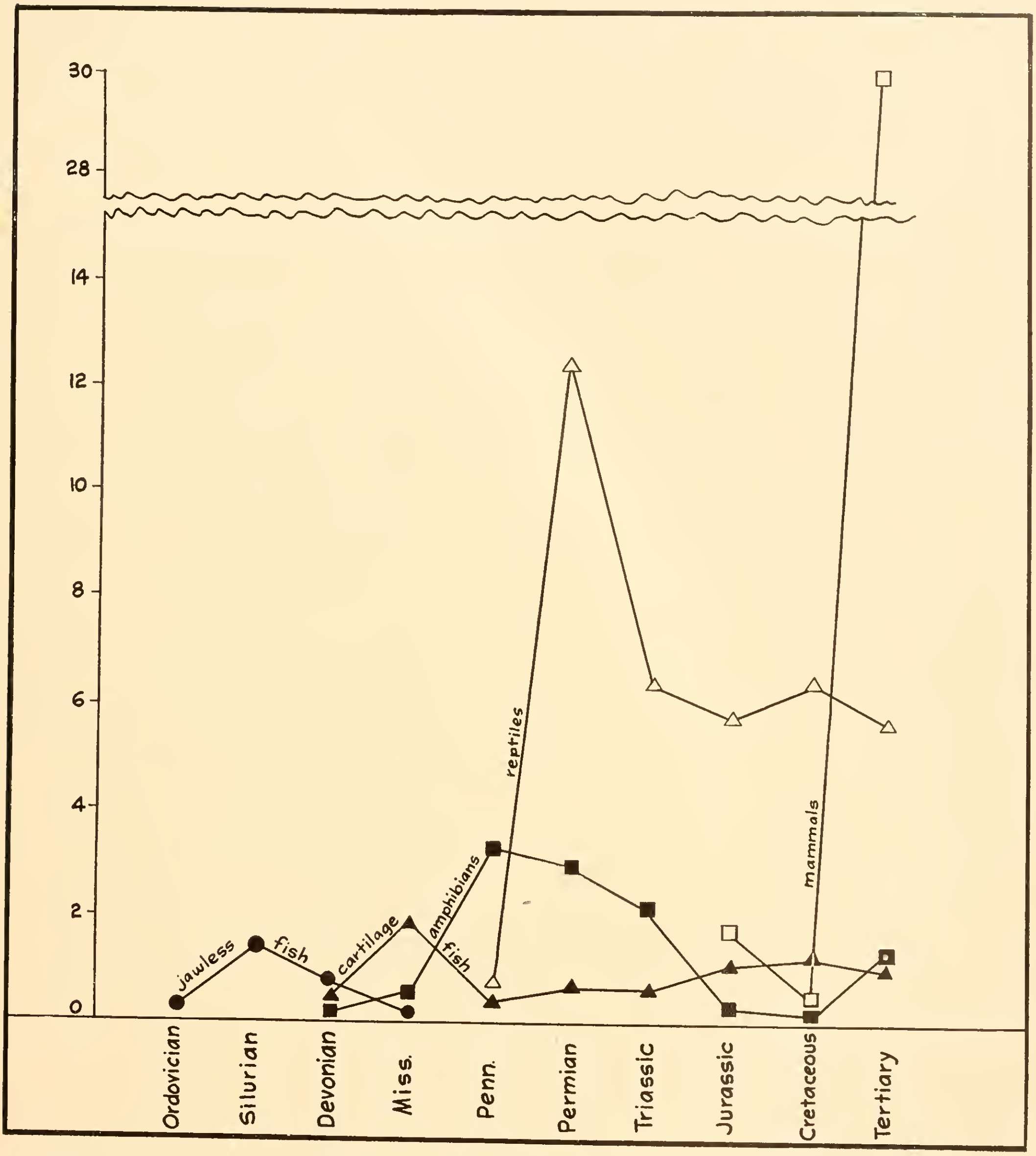


Fig. 25-20. Rates of evolution in several classes of vertebrates are shown from Ordovician to Tertiary. The curves indicate the number of new genera that appeared in each one million year period. The numbers to the left represent the number of new genera.

genera have originated in several groups of animals from the Cambrian to the Tertiary (Fig. 25-20). The amphibians start producing new genera at a slow rate during Devonian times and then build up to a peak in the Pennsylvanian. The rate drops off until it reaches its lowest numbers in the Jurassic and Cretaceous, gradually coming back in the Tertiary. The reptiles produce new genera at a tremendous rate from their very beginnings in the Pennsylvanian reaching a sharp peak in the Permian, followed by a sharp decline in the Triassic and levelling off from that point on to the present. Mammals, starting in the Jurassic, show first a decline and then a sudden and continuing burst of speed in the production of new genera that has been maintained up to recent times. Only within the past 10 million years have there been any signs that indicate the peak has been reached and passed.

An interesting feature of the rates at which new genera are produced in vertebrate groups is that each has a peak followed by a decline. Starting with the jawless fishes, which are the lowest in numbers of new genera and the first to appear in geologic time, each succeeding peak is higher than the preceding, that of the amphibians being higher than the jawless and cartilaginous fishes, that of the reptiles being higher than the amphibians, and that of the last, the mammals, being the highest of all. If the mammals have passed their peak in the production of new genera, perhaps they are on their way out. In that event, if historical evolution repeats itself, there must be some other group of animals coming up. Careful studies may make it possible to predict which group will succeed us as the dominant animals on the earth. We may even be able to do something about it!

CHAPTER 26

THEORIES AND MECHANISM OF EVOLUTION

The question as to *how* the present colossal array of living things came about has puzzled man from the dawn of human intelligence. Civilizations of all kinds have pondered the problem and have come up with some sort of answer which usually has been incorporated into their philosophy and religion. The most gratifying answer was a simple one, and to the western mind special creation as portrayed in the Book of Genesis was also the most satisfactory. The idea that all living things were created for a purpose which they now fulfill left little room for argument and was satisfactory for large segments of the populations of the civilized world until about 100 years ago. The belief that the earth was much older than the allotted 6,000 years ascribed by Christians did not obtain a secure foothold until geologists began to unearth very convincing evidence confirming the antiquity of the earth. Once the earth was shown to be very old, the history of life on it became an immediate and a very important problem. The constant discoveries of fossil remains of plants and animals led to the concept that life on the earth was likewise very ancient, much older than anyone had imagined. With this start, the whole matter of the origin of living things, both past and present, became a problem demanding careful scientific analysis. Several theories have been advanced, the more important of which we shall consider after a brief historical background.

HISTORICAL BACKGROUND

Rudiments of the theory of organic evolution can be found in writings of the early Greeks, especially Anaximander (588-524 B.C.), Empedocles (495-435 B.C.), and Aristotle (384-322 B.C.). Of these, Aristotle overshadowed all others because of his command of natural history of the world of his day. He, like others of his time, believed that living things progressed from simple to more complex forms, reaching the pinnacle in man. In this sense his writings had the germ of the evolution idea, but beyond that they showed little advance over primitive mysticism. Unfortunately, Aristotle's ideas were proclaimed as dogma and hence the possibility of scientific reasoning was impeded for many centuries. His tenet was idealistic in that each animal was specially created in its present form. Since that fitted perfectly into the doctrines of the churches there was no quarrel at this early period. Historical geology had not yet been born, so there could be no conflict from that quarter. It was only when fossils were unearthed and needed explaining that serious clashes occurred between those adhering to special-creation dogma and those willing to accept historical facts of organic descent.

Certainly during the long period between Aristotle and the Renaissance there must have been some brave souls who entertained *sub rosa* ideas concerning the historical hypothesis, but because of the dominance of the special-creation doctrine they are unknown to us. By the seventeenth century social sanctions relaxed somewhat, and it was then that historical descent gradually became a topic for open discussion. Some of the men who were bold enough to speak and write their thoughts were Hooke (1635-1703) and Ray (1627-1705) of England, de Maillet (1645-1738) and Buffon (1707-1788) of France, and finally Erasmus Darwin (1731-1802) again of England, the grandfather of Charles Darwin, of whom we shall hear much more later. While all of these men considered evolution as the most likely explanation of animal life on earth, they did not succeed in establishing this principle to any appreciable extent because of the scanty facts they were able to muster in support of their thesis. Furthermore, opposition from theologians carried such staggering weight that the world gave scant attention to the struggling historical hypothesis. But the seed had been sown, and it could not help but gather support as more and more knowledge of the natural world accumulated. Moreover, as those who proclaimed evolution began adding theories as to how evolution occurred, more attention and often more support were given to the budding principle.

Among the outstanding men of this period who pushed the doctrine of evolution farther than most was Lamarck (1744-1829), a French biologist, who not only accepted the theory of evolution as an explanation of the existence of all living things but also proposed a theory which seemed to explain evolution very well. Lamarck was a vitalist, as were the majority of eighteenth-century biologists. He believed that all living things are endowed with a vital force, distinguished from a physical force, that controls the function of all their parts and ultimately makes it possible for them to inhabit the environment where they now reside. Furthermore, he believed that any traits acquired in the lifetime of an organism were transmitted to succeeding generations. Any such acquired traits could be enhanced or depressed by "use and disuse," that is, the more an organ or part was used the better suited it became to do the job. Such acquired advantages would then be passed on to the offspring. He used the now classical example of the giraffe's neck, in which he assumed that the ancestor of this animal possessed a short neck but because it began browsing on tree leaves and twigs a long neck was particularly advantageous in survival. Hence the continuous stretching of the neck brought about a longer neck, which trait was then passed on to the offspring whose necks would thus be longer. This is a captivating idea and was readily acclaimed by many as the ideal answer to the question as to how evolution occurred.

Lamarck's theory was the outcome of much thought about the problems that must be solved, namely, random and oriented evolution. He knew that a general theory, if it were tenable, must explain both. In addition, the great problem of adaptation must occupy the center of the stage in any explanation, because it was at that time and for many years later the most difficult to interpret. His theory encompasses these features in a manner that would be completely satisfactory if his major premise could be borne out by fact. It has been thoroughly established that acquired characters cannot be transmitted because they do not influence the genes which are the only means of reaching from one generation to the next. Any traits acquired in the lifetime of an individual influence only his soma cells and have no effect on the germ cells. Thus the very heart of Lamarck's theory is faulty. Since genetics has firmly established this fact, his theory has no following among modern biologists. In spite of Lamarck's failure, his ideas were important during this early period in stimulating others to propose other theories from which the correct one finally emerged.

Although interested in natural history as a child, Charles Darwin's (Fig. 26-1) college training was in medicine and theology. Neither of these professions suited his taste, so when the famous naturalist, Professor Henslow, suggested that he might accompany and assist him on the ship *Beagle* for a five-year cruise around the world, Darwin grasped the opportunity to continue his earlier studies of geology and biology. The British Navy needed maps and charts of Great Britain's oceanic island possessions, as well as some knowledge of their geology and natural history. The trip took him to the east and west coasts of South America, to Ecuador and west to the Galapagos Islands. It was while he was making a comparison of the flora and fauna of these islands, together with their geology, with that of South America that he became convinced that living things were not static nor specially created as he had thought up to this time, but rather that they were undergoing constant change and that this change was intricately linked with the movements of the earth's surface. This extensive cruise gave him a rare opportunity to study animals and plants in different parts of the world where he could see those relationships. It is interesting to note that Darwin left England a devout special creationist and returned, after five years of direct field study of natural history, with very little reference to the works of others, a confirmed evolutionist.

During the trip he gathered voluminous notes which, when assembled back in England in the course of the next twenty years, so thoroughly convinced the world of the validity of evolution that it has never been seriously questioned since. This one effort alone placed Darwin head and shoulders above his contemporaries or predecessors. Not satisfied with this accomplishment, he sought an explanation for evolution which eventually was resolved in his theory of natural selection. This second achievement, added to the first, projected Darwin to a position in man's intellectual progress that had never before been attained and may never be again.

Fig. 26-1. Charles Darwin in his later years. He was born February 12, 1809, the same date a famous American was born, and died in the year 1882.

A quirk of fate brought forth the character of Darwin when his good friend, Alfred Russell Wallace, working over the flora and fauna of the Malay Peninsula and the East Indies, hit upon an explanation of evolution which was in essence identical with his own natural selection. He conveyed his ideas to Darwin in the form of a letter. This occurred in the year 1858 after Darwin had completed his data and was about to consider publishing his findings. Rather than rushing into print to obtain priority as a lesser man might have done, Darwin presented a short draft of his work simultaneously with that of Wallace before the Linnean Society in London. The following year, 1859, he published his classical work, *On the Origin of Species by Means of Natural Selection,* in which he formulated his theory backed up by abundant evidence. Even though both men had arrived at similar explanations of evolution, the credit has gone to Darwin, as it justly should.

Darwin's book convinced the scientific world of the soundness of evolution and his theory of natural selection provided food for thought for those interested in how it came about. Because the book was written in a manner comprehensible to laymen and because it was staunchly defended by such eminent biologists as T. H. Huxley, the theory of evolution came to be generally accepted by the intelligent world. Natural selection as an explanation as to how evolution came about was immediately attacked by scientists and has continued under fire up to the present, although today it is generally accepted, with modifications, as the most tenable of the explanations advanced thus far.

THE THEORY OF NATURAL SELECTION

Both Darwin and Wallace had been stimulated by Robert Malthus (1766-1834) for the central theme which culminated in the theory of natural selection. Malthus had written his "Essay on Population" in 1798 in which he argued that since human beings reproduce at a rate far outstripping the food supply, there must be positive checks such as wars, disease, and famines to keep them from overrunning the world. This by its very nature involves a "struggle for existence." Darwin seized upon this phrase as a possible explanation for the origin of new species which is the heart of evolution. He reasoned that favorable traits would be preserved and unfavorable ones would be destroyed, thus paving the way for the origin of new species. With this kernel as a start, Darwin, as well as Wallace, developed the theory of natural selection.

In essence, Darwin's theory of evolution or origin of species through natural selection involves the following steps in reasoning which are borne out by fact.

First, he considered variation an innate property of protoplasm because he encountered it in all groups of plants and animals (Fig. 26-2). Any species of living thing varies widely, a fact that he could not account for but for which we have since found an explanation, to be considered presently. This variation within a species provides raw material with which evolution can proceed. Without it there could be no evolution.

Second, since each organism produces many more offspring than can possibly survive and yet populations remain fairly constant, there must be a continual "struggle for existence" within and between groups as well as with the environment. Out of this would come those best suited to survive under the existing conditions. This could be a passive struggle, such as plants and animals resisting the desiccation of desert regions; or it could be extremely active, as in predation, that is, one feeding on the other. In any case, only the most fit would survive, and for this Darwin coined the phrase, "survival of the fittest." Thus the struggle for existence has a selective effect in removing the unfit and preserving the fit. Moreover, since only the most fit survive, they alone can perpetuate the traits that made them best suited and hence pass them on to their offspring. This, continuing under changing circumstances of environment, would result in wider and wider differences between organisms, ultimately resulting in new species originating.

It is possible that the changing environmental conditions at the extremes of a large area occupied by a single species might be such as to bring about variations around

Fig. 26-2. A series of pelts of the striped skunk (*Mephitis*). These are all of the same species, yet they show wide variation in regard to the white-stripe pattern.

these widely different conditions. Thus more than one species might originate simultaneously or at different times from one ancestral form. As ages pass, the differences between these may become great enough to classify them as separate genera. This continues through families, orders, classes, and finally phyla, thus accounting for the entire animal kingdom. Obviously, all that is necessary to establish evolution is to explain how a species originates and Darwin felt, as we do today, that natural selection was the answer.

Modern interpretation

Although the theory of natural selection has withstood the attacks of several generations of scientists, it must be interpreted in the light of information that has come to us since Darwin's time. The science of genetics has made it possible to interpret one very important aspect of natural selection for which Darwin had no information, namely, variations. Remember that variations provide the raw materials on which natural selection operates. Darwin was well aware that variations were essential to evolution but he could not explain how they occurred. We know now that they result from gene changes or **mutations**. Any variations due to environmental changes during the life of the individual, in the embryo or later, have no effect on the genes, hence are of no significance in evolution. Mutations may involve only a single gene (micromutations), which is the most usual, or they may include a group of genes (macromutations), which account for sudden large changes such as short legs in sheep or extra toes in cats. Most biologists believe that

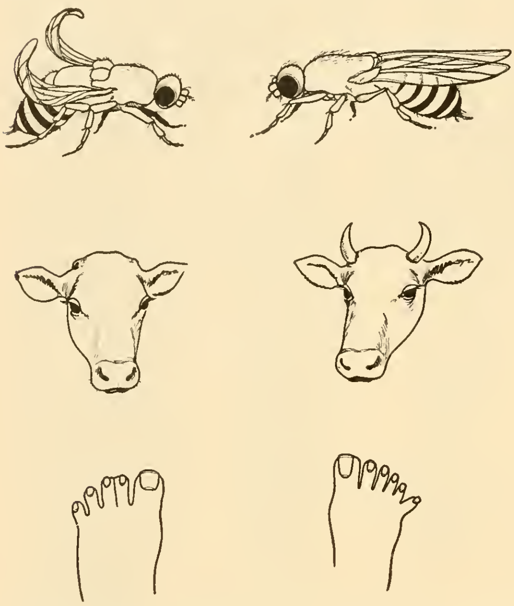


Fig. 26-3. Three mutations that commonly occur in animals. Curled wings in Drosophila is recessive to normal wings. Hornless (polled) condition in cattle is dominant to horned. Fused or webbed toes (syndactyly) and extra toes (polydactyly) in man are dominant to normal toes.

species have originated from the accumulation of a great many micromutations rather than by one or more macromutations. Accordingly, it is doubtful that a full-blown species ever appears in one generation, it is more likely that many tiny, almost imperceptible, mutations occur and by the process of natural selection accumulate until a new species appears.

The first careful records made of mutations were those of the Dutch botanist, Hugo DeVries, who described them in the evening primrose. In fact, DeVries named these sudden and spontaneously occurring changes mutations, a term which today applies to any alteration in the genic composition of an organism. DeVries thought that evolution occurred as a result of mutations and not by natural selection. Now we know that mutations provide the basis for the operation of natural selection. In other words, both mutations and natural selection are essential for evolution.

Mutations have been noted in a large number of plants and animals under experimental conditions and they are undoubtedly occurring continuously among organisms in their natural habitats (Fig. 26-3). Over a thousand mutations have been recorded for Drosophila alone. A great many gene changes probably go unnoticed which, in nature, might have considerable survival value. For example, a mutation might occur in an animal living in a region where some element in the diet was becoming deficient, which would so affect the enzyme systems of the animal that it could get along on a minimum amount of the element. Such a mutation might show no visible difference in the animal itself and yet be most important in survival. Animals with the favorable gene would be more apt to live to produce progeny than those without it, hence selection would be toward the favorable gene. While we have a great deal of information concerning anatomical mutations we know almost nothing about biochemical mutations (see p. 586). Nevertheless, such physiological changes must have been and must continue to be very important in their evolution.

Isolation

Darwin realized, as have most biologists since, that isolation played a very important part in the origin of new species, but it was not until inheritance was thoroughly understood that the full meaning of isolation became apparent. It is known now that in addition to **geographic isolation, genetic isolation** is also essential for the origin of new varieties and eventually new species. Genetic isolation may even be the more important. Let us consider each of these briefly.

Geographic. Darwin and many other naturalists noted very early that animals living on an island were frequently quite different from those on the neighboring mainland. Other barriers, such as a mountain range, a deep canyon, a wide body of water, or a desert, have been known to separate members of a species long enough for differences to be detected between the two groups. For example, there are two closely related species of squirrels on the two opposite rims of the Grand Canyon, different only in color markings. Undoubtedly, at one time they migrated freely from one rim to the other but eventually, because of the great depth of the canyon and the turbulence of the Colorado River, they were unable to mingle as they had in the past. Today they are gradually changing, though slightly, in spite of the fact that the environment is almost identical.

It is understandable that when a barrier occurs in the range of a given species so that groups of individuals of that species are completely separated, the continual occurrence of mutations and the slightly different environments acting selectively upon them will eventually bring about divergence of the two groups. If the barrier continues for a sufficiently long period of time, the differences may become sufficient to constitute two species. If the barrier is then removed so that the two groups once again intermingle they will probably maintain their identity as different species. However, if the barrier is removed at a time when they have not changed enough, that is, while they are still varieties, it is possible that the differences may be lost through interbreeding. The latter instance is illustrated by the human species, *Homo sapiens.* Although he has occupied nearly all portions of the earth's surface and does show some marked physical variations, the various races have not lost their ability to interbreed. The barriers that have been set up between races have not been effective sufficiently long to bring about infertility. With the intervention of modern means of transportation those original geographic barriers are now all but erased, so theoretically man should lose what changes have been produced by his isolation, providing there is a free mingling again of all races. But such, as we all know, is not the case. Society places barriers that can be as effective as infertility or vast geographical obstacles. However, while it is possible it seems highly improbable that such practices will lead to a new species of mankind. Indeed, the social barriers seem likely to continue to grow less as time passes, with the resultant merging of existing races.

It is interesting to note that under natural conditions hybridization is only rarely observed among closely related species of animals. To be sure, it has been possible to effect it under laboratory conditions—the biscow, for example, as a result of the mating of a bison and a cow—but such cases are unusual and do not normally occur in nature. Since the animals occupy the same environment and are therefore subject to the same conditions, why do they not mate freely and thus reverse the differences established earlier through isolation, inducing reverse evolution in this way? This can best be answered from a study of genetics.

Genetic. When animals are separated for long periods of time so that they become slightly different physically, the difference extends to their genes. Then, when two such species or even varieties mate the genes are not as perfectly compatible as they were in the common ancestor. This results in low fertility or in most cases complete sterility. Thus such crosses under natural conditions would be unfruitful if they did occur and the hybrid would have little chance of establishing itself. Also, the hybrid itself is often sterile, as is true of the mule previously referred to (p. 600). Furthermore, slight differences in the mating season might act as a barrier even though the animals were fertile. These and many other slight differences act as barriers to keep the two species distinct and separate.

Many kinds of gene changes occur, from slight modifications in the gene itself to an alteration in the arrangement of the genes on the chromosomes, any of which may make fertility impossible. Under laboratory conditions these changes sometimes occur spontaneously in a species that in all other respects is like the parent form. Such genetic changes are as effective in isolating animals as any physical barrier could be. Many biologists agree that interfertility is the acid test of a species. No matter what other characteristics two species may have in common, they are distinct species if they lack interfertility. The problem of establishing species on such a basis is almost hopeless at the present time because of our lack of information concerning the genetic constitution of all but a few species of animals. These are the animals extensively used in the laboratory, such as Drosophila, mice, rats, and paramecium.

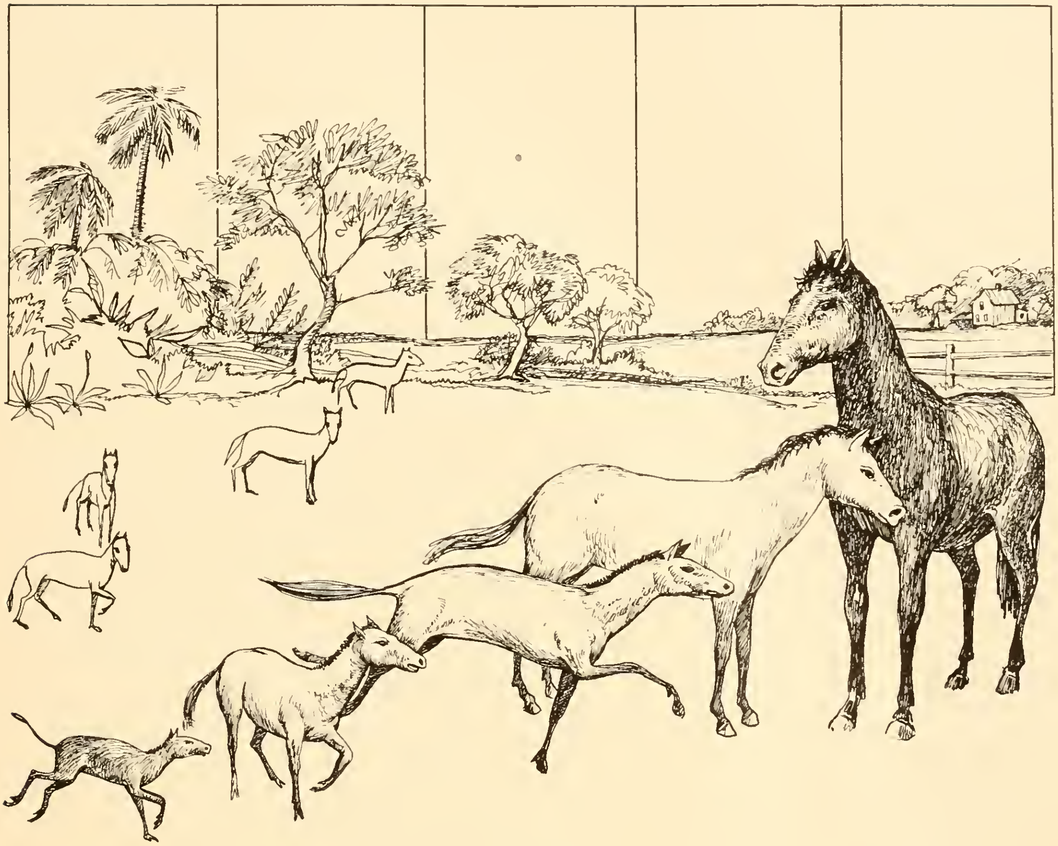
DIRECTION OF EVOLUTION

At the beginning of life there must have first existed only one species. After a time this must have varied as a result of mutations, thus giving natural selection an opportunity to initiate evolution. It is conceivable that evolution might have proceeded in any or all directions, and perhaps it did at first, but after a time it seems to have headed in a certain rather general but definite direction, which has continued more or less uninterrupted ever since. This is as one would expect, because genes, being chemical entities, would be apt to change in fairly similar ways. Because of their structural nature it would seem impossible for them to change in any or all directions. Similar mutations do appear repeatedly, as a matter of fact, indicating that the same gene changes again and again. Since mutations can occur only within certain limits, the resulting organisms will then be able to change only in certain ways. This would have the effect of guiding any possible mutations in a general direction so that evolution could proceed in that direction and no other. While evolution may have been random at first, it has since become oriented or directed so that today it is occurring along specific lines. This idea is often referred to as **orthogenesis** or **straight-line evolution.** While, in general, it does occur and evolution is not totally random, it is not as directional as was once thought. One of the classic evidences for straight-line evolution is that of the horse.

Horse evolution

The modern horse has had an interesting evolution and one that can be followed better than most because of the abundance of fossils left from the Eocene to the present and because most of them occur in North America where much digging has been going on during the past 200 years.

Eohippus, the earliest known ancestor of the horse, and perhaps the tapirs and rhinoceroses as well, occurred in early Eocene times and was anatomically quite remote from *Equus*, our modern horse (Fig. 26-4). It was about the size of a jackrabbit and possessed functional toes on each appendage, four in front and three behind. There were rudiments of others which, when accounted for, demonstrated that the animal had descended from an ancestor with five digits, the usual number among vertebrates. In the forefeet only the inside or "thumb" was rudimentary while in the hind feet both the thumb and the "little finger" were missing but could be seen as functionless splints along the next foot bone. The teeth of *Eohippus* were also quite different from those of the modern horse. They had short crowns and long roots nicely adapted for browsing in and around the edges of forests. The face was short, the eyes placed well over the teeth. These tiny mammals apparently lived in seclusion, feeding on



Eohippus Miohippus Merychippus Pliohippus Equus (modern)

Fig. 26-4. The evolution of the horse illustrates orthogenesis. Probably these animals did not progress along a direct path from the tiny *Eohippus* to *Equus* but rather there were many deviations along the way. Progress was in a general way toward the present-day horse, but there were many paths that led to extinction.

succulent leaves and avoiding contact with the huge mammals of this period.

In the Oligocene we find a somewhat larger animal, *Miohippus,* with only three toes on the forefeet, although a rudiment of a fourth remains. The middle toe on each foot apparently bore the brunt of the weight of the animal because it was much larger than those on either side. Otherwise, there were few changes from *Eohippus.*

During the Miocene *Merychippus* came into prominence, still with three toes but with added emphasis on the middle one which bore all of the body weight. The other two toes, while externally visible, appear to have been of little or no use to the animal. The molar teeth possessed rather high crowns and the flat nature of the upper surfaces indicates that these animals were grazers rather than browsers, that is, they fed on grasses in the open prairie lands rather than on leaves in the forests. The face was longer, thus displacing the orbit posteriorly. *Merychippus* was larger than any of the horses up to that time, standing about 3 or 4 feet in height.

This gradual tendency toward greater size and reduction of the number of toes continued into the Pliocene, where *Pliohippus* was without external lateral toes, although retaining splints indicating the historic loss. Thus, in *Pliohippus* we see only a single toe or hoof, a character which has remained unchanged up to the present.

This animal also possessed teeth better adapted for chewing grass and its general anatomy resembled the modern horse.

Horses that appeared in the Pleistocene had acquired essentially the same proportions as the modern horse. There is a single hoof on each foot, although paired lateral splints give evidence of the ancient toes of its forebears. On rare occasions a colt is born with the two lateral toes visible externally, thus reminiscent of its ancestors. The tendency toward a longer face has continued with the result that the eye is located at the edge of the most posterior molars. The teeth are beautifully adapted for grinding grasses, which form the principal diet of these animals. The size is larger than any of the earlier horses, and by selective breeding man has produced the kinds of horses he desires, from Shetland ponies to draft horses.

Through a period of 60 million years, the horse has evolved from a tiny animal living in the forest for protection and feeding on succulent leaves to a huge grass-eating beast roaming the prairies where fleet-footedness is essential for survival. This seems to be a case of straight-line evolution, almost as if the horse "wanted" to change its way of life from a shy, seclusive forest dweller to a swift-running prairie animal. Without going into a lengthy discussion of the reasons, it is now becoming clear that the evolution of the horse has not been as straight-line as might appear. Simpson, for example, believes that horses as well as other animals have never gone straight toward a goal but, instead, have pushed out in many directions at succeeding stages in their evolution, with one part of the anatomy such as the teeth going forward more rapidly at times than other parts. In other words, there have been many lines of horse evolution all along the way, each evolving in different directions but in the general direction of the modern horse. Some of these survived to give rise to the next great step whereas others became extinct. Indeed, he believes that the most direct line from *Eohippus* was not to the modern horse but to an extinct horse called *Hypohippus*. Apparently, then, the direction from *Eohippus* to *Equus* has not been a straight one but rather one with many deviations, jogs left and right, some paths leading to extinction, others carrying on to the next, perhaps only then to become extinct.

What, then, keeps this whole trend delimited to one general progressive course? There must be forces operating continuously to bring about this over-all trend, forces that seem forever to "nudge" the line in a general direction. Environment alone cannot be the answer because we know from genetics that mutations occur regardless of environmental changes, although it undoubtedly does play a part. When neither of two factors is the whole answer, both must operate simultaneously; both the environment and the functional capacities of the organism interact, resulting in the ultimate fitting of the latter to the former. This we call **adaptation**, the most significant outcome of evolution, about which we shall have more to say later.

Opportunity in evolution

Another feature that is probably important in oriented evolution, which also involves the relation of organisms and environment, is the relative time or coincidence with which these impinge upon one another. When the environment is just right for an animal to evolve in a certain direction, the animal must not only be present but must also be sufficiently adaptable (have sufficient mutations available) to take advantage of the opportunity. Simpson called this "Opportunism of Evolution." Because of these environmental opportunities, animals follow within certain restricted limits, progressing toward an apparent goal, as in the case of the horse. As the environment changes, the organisms change with it. Living things themselves constitute more opportunities by providing a new environment; the body of a vertebrate as a home for a blood parasite is an illustration. Thus new environments are constantly being created (and others destroyed) which open up more and more opportunities for a greater variety of living things. This has produced an untold number of kinds of animals, of which probably something over a million are alive today.

Evolution constantly operates with materials available and does the best it can with them to satisfy a need, frequently producing a structure that may not be perfect but serves the purpose more or less satisfactorily. Perhaps there is no structure in the body of any animal that performs its "intended" function to a perfect degree. Most of them do a tolerable job, some better than others, but nowhere do they function perfectly. Certainly there must be some design that is perfect. Why, then, are not all of the organs of animals perfect, or more broadly, why is the animal itself more or less imperfect in every detail? There is constant selection toward perfection, but complete and absolute fitness to the environment is never quite attained, as can be seen by a careful examination of any animal, including man himself.

To illustrate this point, any one of hundreds of examples in any animal or group of animals might be chosen. The matter of photoreception, which was reviewed previously in the various animal groups, is a good illustration of how all groups of animals have devised some method of receiving light rays. This is an important adjunct to orientation in the environment and, accordingly, every animal can make good use of such an organ. Among all of the photoreceptors there is none that we might call a perfect photoreceptor. The primate eye is the best and we are all aware of is imperfections. We have been able to build a better one in the laboratory—one that will do things the human eye cannot approach. Furthermore, our eyes seem to do a rather good job during adolescence and early maturity but fail in the later years, an imperfection that might be due to the fact that in their evolution they were not "intended" to last into old age, or perhaps the body itself was not "intended" to survive past its period of optimal activity. That is, evolution has tended toward the production of a satisfactory animal body until after the young are reared, after which it becomes more imperfect, eventually causing the death of the entire organism due to the failure of its separate parts.

Animals have experimented with photoreceptors and seem to have tried about every possible way of receiving light, from very simple stigmas in the Protozoa to the complex molluscan and vertebrate eyes. All gradations are found from those that merely record light and darkness to those that form crude images and finally to those that produce clear, distinct images. We need only recall the crude patches of pigmented cells in planaria (Fig. 9-6) to see a photoreceptor that is very primitive yet sufficient for the species to survive. A better eye would be of no value because the animal does not possess a nervous system adequate to record such impressions if they were received. Hence, the eye has paralleled the development of other organs of the body, and has usually been as good as needed to maintain the species. We might argue that man could conveniently use an eye with the speed of perception that is possessed by a photoelectric cell, but our brains could not receive and interpret the impressions that would come through such eyes.

From the planarian eye we see steady improvement concomitant with the development of organ systems until finally among the mollusks, arthropods, and vertebrates we see the best eyes of all. It is interesting to note that each of these types has faced the same problem but has solved it differently. The arthropod eye consists of many tiny units aggregated into a compound structure which forms many images, giving a composite picture (Fig. 11-16). Thus, the problem of receiving light has been satisfactorily solved but in an entirely different manner from that of the mollusk or vertebrate. On the other hand, the likeness of the vertebrate and squid or cuttlefish eye (Fig. 26-5) is amazing. The fact that two such distantly related groups of animals could solve photoreception in almost identical ways seems incredible. Each animal had different materials at hand to build a photoreceptor and each built it differently, but both came out with essentially the same organ, varying only in the placement of the sensory cells of the retina (the rods and cones in the vertebrate are directed away from the light source, whereas in the molluscan eye they are reversed). The pathways by which these eyes were formed is entirely different in the two groups, which merely proves the earlier contention that animals solve similar problems in different ways.

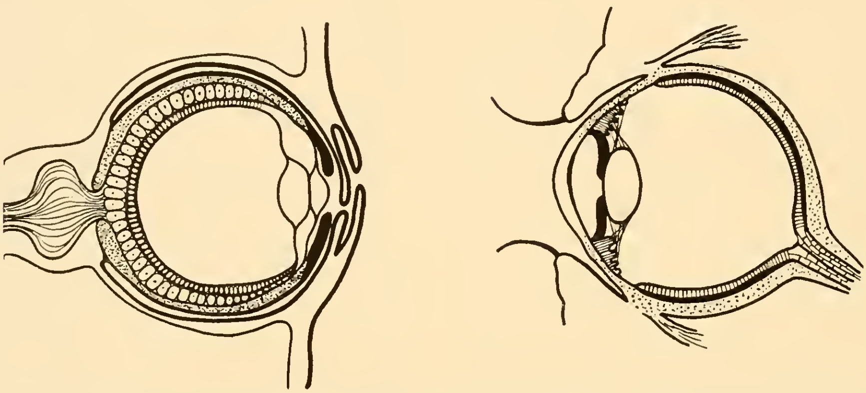


Fig. 26-5. There is a remarkable similarity between the molluscan (cuttlefish) and vertebrate (human) eyes, yet they have evolved along two quite different pathways. This type of evolution is called convergent evolution and is abundantly illustrated among animals.

Divergence and convergence in evolution

As opportunities have presented themselves, animals have evolved in many directions with respect to certain organs in order to take advantage of all possible environments. This is called **divergent evolution** or **adaptive radiation.** At some later time some members of various groups have evolved toward life in a particular environment; this is called **convergent evolution.** The manner in which these two types of evolution operate can best be understood by following a specific structure or organ through its evolution in several groups of animals. A good example is the forefoot of land vertebrates.

The ancestral land vertebrate appendage was a five-toed structure designed for surface locomotion. As new environments became available the forefoot underwent **divergent evolution,** becoming highly modified for locomotion in many ways. For example, it became a single-toed leg in horses, a five-toed clawed leg in cats, a flipper in whales, an arm in man, and a bird's wing (Fig. 26-6). This fundamental five-digited structure has become an effective instrument for locomotion in water, on land, and in the air. This is the situation in which we find vertebrates today. But long before vertebrates reached their present state, ancestral forms, even after they became adapted to land life, had the opportunity of taking to the air which has some obvious advantages over locomotion on land. Members of three groups took advantage of this opportunity and underwent **convergent evolution** toward locomotion in the air. These were: first, the reptiles (pterodactyls), then the birds, and finally the mammals (bats)

(Fig. 26-7). They all produced wings which were essentially the same, although varying slightly in minor details. None of them are perfect instruments of flight, yet they are sufficiently good to permit both the birds and the bats very real success, the former more than the latter. The pterodactyls became extinct for unknown reasons, but it seems unlikely that the ability to fly was a contributing factor.

Another case of convergent evolution is illustrated by still other members of these same three groups (reptiles, birds, and mammals) which returned to the water and became modified in many ways for an aquatic life (Fig. 26-7). The primitive reptile *Ichthyosaurus* took on the shape of a modern fish and its appendages became fin-like. The whale, a mammal, developed fish-like appendages and body form. The penguin, a bird, lost its ability to fly but became a proficient swimmer, using its wings as flippers.

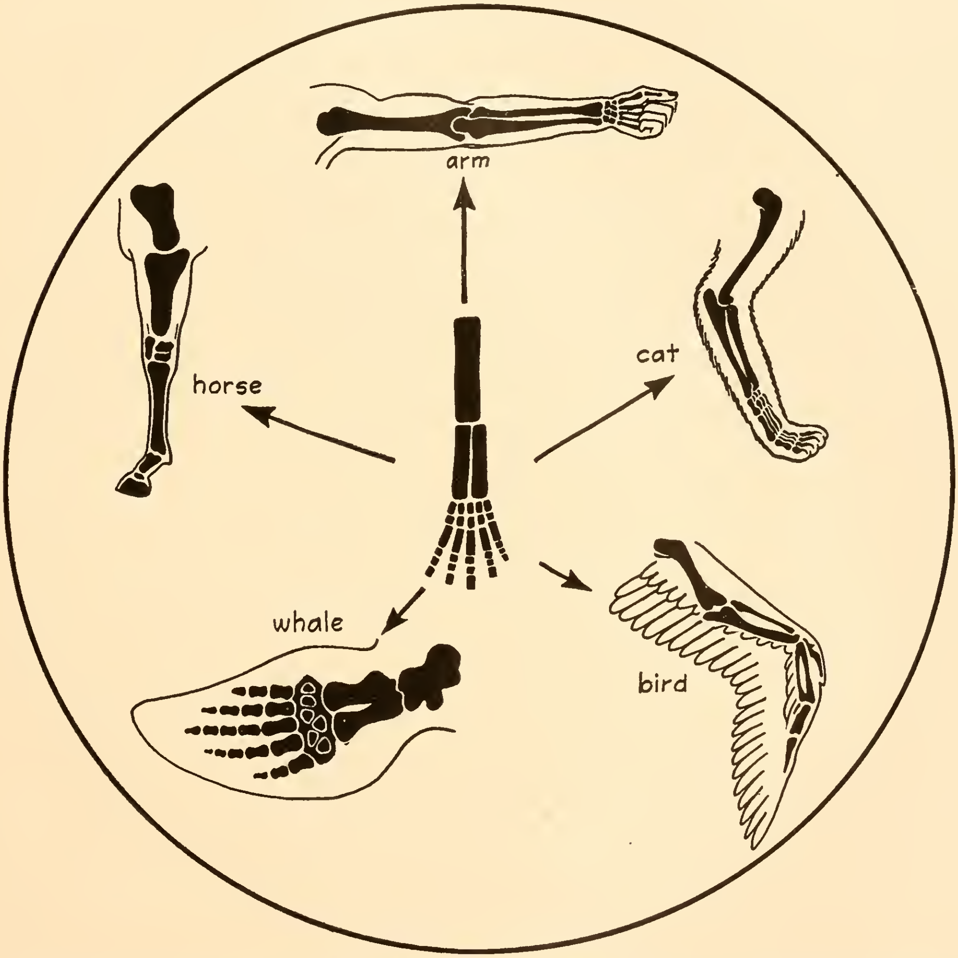


Fig. 26-6. The front appendage of vertebrates illustrates divergent evolution. The hypothetical vertebrate appendage was a five-toed structure which has been modified in many ways as represented by the arm of man, the front leg of the cat, the wing of the bird, the flipper of the whale, and the front leg of the horse. Each modification satisfies the needs of the particular animal living in an environment that requires such an appendage for survival.

Finally divergent evolution is nicely il-

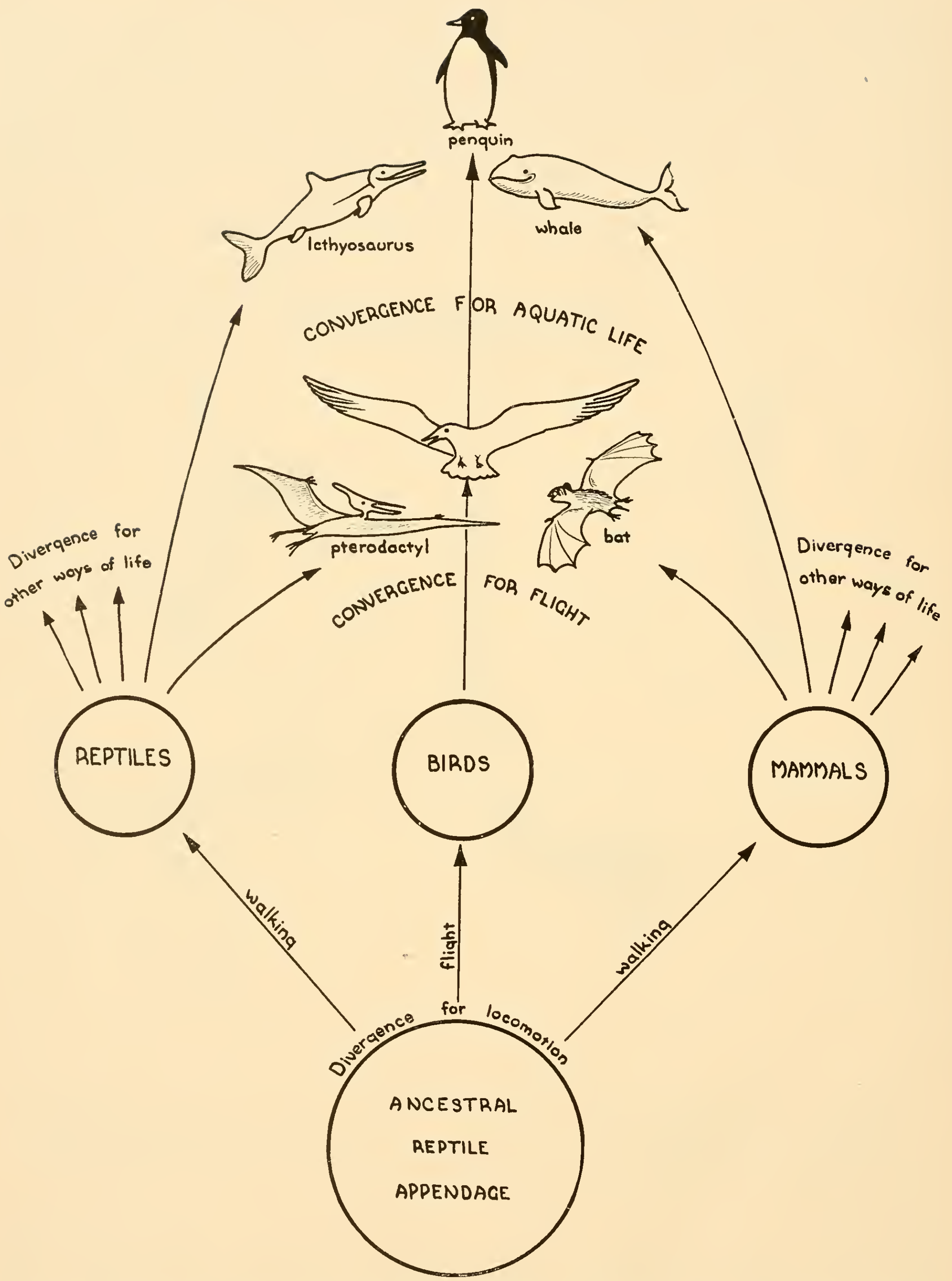


Fig. 26-7. Divergent and convergent evolution can be illustrated by a study of the anterior appendages of three different groups of vertebrates. The ancestral reptile appendages diverged for locomotion (walking and flying) at a very early time. Some members of each class (reptiles, birds, mammals) subsequently underwent convergence toward flight and life in the water by modifying their anterior appendages to function more effecively in these environments.

lustrated in Australia where the ancient marsupial stock gave rise to a variety of animals that closely parallel the placental mammals on other continents. For example, there are shrew-like marsupials, squirrel-like marsupials, dog-like marsupials and many others. It appears that, given only marsupials to begin with and no carnivores to destroy them, divergence has been commensurate with the possible niches, paralleling similar situations where placental mammals were the starting point. There are many similar cases of divergent and convergent evolution among animals that could be cited. They confirm one of the fundamental features of evolution, namely, that all opportunities are exploited with the materials at hand. How far the diversification goes depends on the animal and its supply of mutations, as well as the number of environments in which the animal can survive.

EVOLUTION THROUGH EXPERIMENTATION

Under natural conditions, animal hybridization probably is of little significance in evolution, although there are cases in which new species of plants have apparently arisen as a result of such natural crossing. Domestication among animals was carefully studied by Darwin and he used the results of these studies as a potent argument in favor of natural selection. He observed, as we all have, that under the influence of selective breeding a wide variety of animals can be produced which, if such forms appeared in nature, certainly would be assigned different species names. Darwin substituted environment for man as the selective agent and argued that new species could thus come into being. Since the environment was not endowed with reasoning powers, the tendency would be to select in many different directions with the ultimate goal always the adaptation to the particular environment in which the animal found itself.

Under the guiding hand of man a prodigious variety of animals have been produced to satisfy his whims, whether it be for food, as in the case of chickens and cattle, or for entertainment, as in the case of canaries and racing horses. He has done a notable job in the chicken, for example, which, with variants from the cocky Bantam to the tremendous Brahmin, is a far cry from the Oriental jungle fowl from which present-day chickens are largely or wholly descended. This ancestor laid perhaps two dozen eggs per year, whereas some present-day breeds equal that number in a month. The possibility of selection toward an egg factory such as this seems to be limited only by the number of feeding hours in a day and the ability of enzymes to transform the food into egg protein and carbohydrates. Certainly this is comparable to selection in nature which in the distant past produced such huge animals as the dinosaurs. As these great beasts disappeared because evolution proceeded in one direction for greater and greater size, so the domestic chicken would soon become extinct if suddenly removed from the protection of domestication and set free in a natural environment. It seems that progressing on such a one-way path spells doom for any species, for this has been demonstrated frequently in the past. An animal that retains a sort of "middle-of-the-road" type of development is more apt to weather the adversities of change and maintain itself as a species. Man is a good illustration in point.

Domesticated animals seem to preserve their interfertility, quite contrary to conditions found in nature. The reason why they do is that man so plans it. Sterile animals are of no use to him, so he has selected for high fertility along with other traits that he wishes to accentuate. Even with some of his domestic animals the beginnings of infertility have been evident. For example, some crosses between dogs are all but impossible, as between a very large one and a very small one. Furthermore, some crosses often

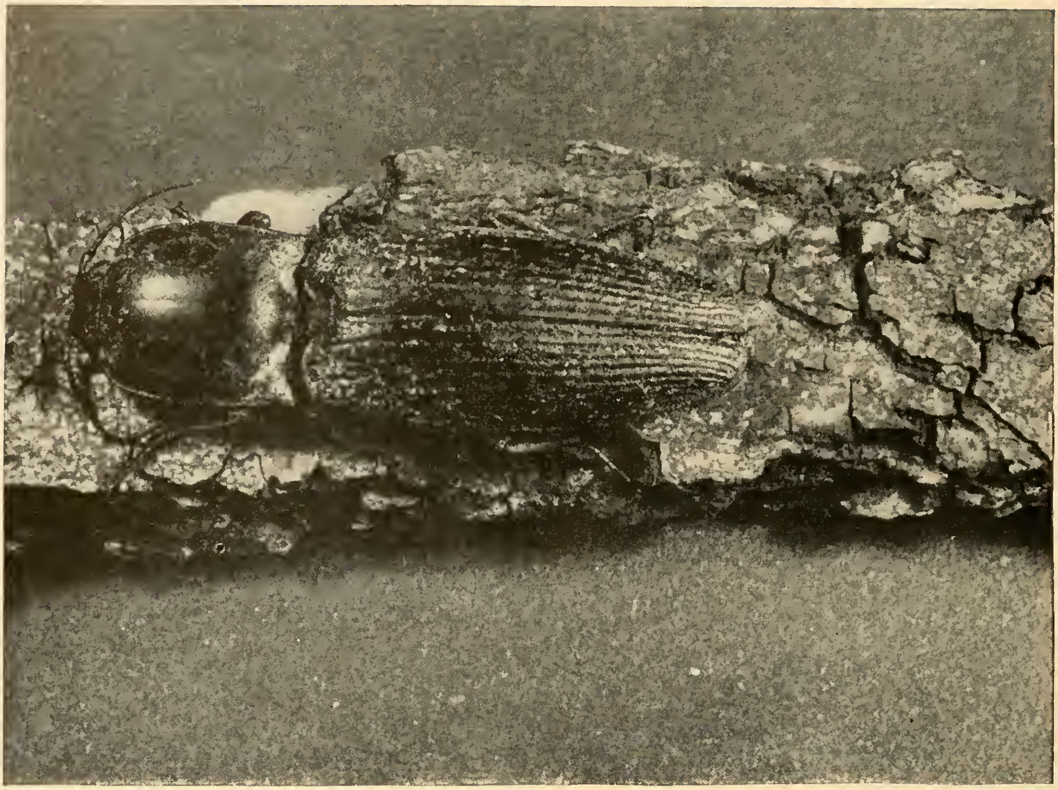


Fig. 26-8. A case of protective coloration. Notice how this beetle blends with the bit of bark on which it is resting.

produce malformed animals that soon die, or again the number of offspring may be small. These incompatibilities noted now, after several hundred more generations, may perhaps become so great as to place a strict genetic barrier between certain varieties of dogs alive today, thus inaugurating a new species. If that happens, man will have created a new species and thus controlled evolution under his own guidance. We must conclude, therefore, that in the domestication process, man has within his grasp the very mechanism by which evolution proceeds.

THE END RESULT OF EVOLUTION: ADAPTATION

Out of all this should come animals remarkably adapted to their environment but, as we have already seen, this is not completely so. In spite of the rather careless way in which most animals are keyed to their environments, certain examples of adaptation forever intrigue the naturalist and the layman. Among these, color adaptations are particularly interesting.

The matter of camouflage is an important factor in survival and is used almost universally by animals. Such concealing or **protective** coloration has been selected for, until the outer coverings of some animals match their background astoundingly well (Fig. 26-8). Most animals, particularly those that fly or swim, are dark on the dorsal side and white or lighter in color on the ventral side. Thus potential predators from beneath looking up will be less apt to see them because they blend with the sky and those from above would experience the same difficulty because of blending with the darker earth or stream bottom. Other

Fig. 26-9. Animals frequently resemble some aspects of their environment for protective purposes. Certoin insects, such as the ones shown here, resemble leaves upon which they rest, thus obscuring them from their enemies.

animals, such as fish, frogs, and lizards, can change their skin color to match the background upon which they happen to find themselves. Such concealing coloration is also advantageous to the predator because it can go unobserved until the prey moves into striking range. The positive survival value of such colorations has been shown by experimentation in which the prey with colors most in contrast to the background is always picked up first by the predators.

Some animals have found survival value in **mimicking** another species that carries a potent defensive or offensive weapon, such as a venomous snake or a honeybee, for example. Such well-equipped animals are frequently highly colored, which advertises their danger and warns unsuspecting predators that might take them by mistake. Hence a much lesser creature that might be a choice morsel finds distinct value in resembling the more formidable one. Some animals mimic living or dead leaves, and certain butterflies are so faithful in such resemblance that they may go unobserved even by a careful naturalist (Fig. 26-9). Even the veins of the leaves are portrayed by similar markings in the wings of the insect. These adaptations and many others undoubtedly have a marked effect on survival, but every such case is open to question and should be interpreted in the light of actual observations.

Things of much greater importance than color, body shape, horns, claws, and similar characters are such physiological qualities as ability to resist disease, high or low temperatures, desiccation, and so on. Fitness for a specific environment involves many qualities, and it is the product of all of them that makes for survival. It follows that most of them must be favorable, although an animal may survive and be rather successful while carrying along some unfavorable traits. When the weight of the adverse qualities exceeds that of the favorable ones the animal becomes extinct. This has happened to millions of races in the distant past and has happened in recent times, as in the case of the passenger pigeon.

Adaptations tend toward better and better fitness for the environment which results in specialization. When this has been carried to the extreme, the animal is said to be "overspecialized," a fact which biologists have long considered important in the extinction of certain species and even large groups of animals. Specialization is inevitable, and all animals are specialized, some much more than others (Fig. 26-10). Land animals, for instance, are adapted for obtaining oxygen from air, and if the earth were suddenly covered with water they would all be eliminated. This is specialization in a broad sense. As adaptation proceeds, animals become adapted to narrower and narrower limits of their environments and some, such as ruminants, have become adapted to eating grass and probably could not survive if all grasses of the earth were destroyed. Thus survival is intricately linked with consistency of specific environments.

The more an animal becomes specialized, the more closely it is forced to live in the environment for which it is fitted. Therefore, the more generalized types are less apt to become extinct. For example, omnivores are more apt to survive under conditions where the food is likely to change than strict herbivores or carnivores. If food becomes scarce and the omnivorous animal can no longer exist as a predator it can subsist on vegetable matter, or it may devour some of each as the situation demands. This is one of the reasons why the crow is so successful, since it feeds on carrion, grain, leaves, or almost any other form of food. Obviously, then, as animals become more specialized they are endangering their possibility of survival.

The Irish elk is often used to illustrate this point. While its overspecialized antlers were undoubtedly an important factor in its extinction, they probably were not the whole story. It seems that with each suc-

Fig. 26-10. A case of "overspecialization." This is the skull of a wild boar. The upper canine teeth have grown upward through the top of the snout and curved so that they could have little function as defensive weapons. The lower canines might have a little more value in this regard.

ceeding generation of this animal the antlers became larger and more complex until they became so fantastic that it is difficult to understand how the animal could manage them at all. It must have required much of the elk's metabolic output to supply materials for their construction, to say nothing of the burden of supporting them. Here is a case of progressive adaptation for a structure which had decided survival value when it first appeared, but which eventually became a factor, itself, in eliminating the species. However, our information is not complete and one must be cautious in drawing conclusions because other factors in its environment may have been equally important. For example, a sudden increase in wolves or a virulent disease, in addition to its cumbersome antlers, could have hastened the departure of this beautiful animal.

EVOLUTION AND THE FUTURE

Some believe that evolution has run its course and that all of the niches of the world have been filled so that no further change is possible. Furthermore, others contend that the ultimate goal of evolution, namely, man, has been attained and there is now no "place to go." One might be inclined to agree with these contentions if there were no evidence of evolution going on around us and if man had become perfect in every respect, leaving no room for improvement. Most of us would not subscribe to either of these statements. From what we know of the past it seems likely that as long as there is life on earth there will be continuing change or evolution. The directions it will take are unpredictable to us now, but that it will continue seems assured.

To be sure, the abundance of life in existence now might suggest that all of the possible environments capable of supporting life have been taken, leaving no room for any more forms. A similar situation might have seemed to be true even in the Cambrian, where all of the present phyla had their representatives. There were fewer niches then but all of them were probably filled, and as ages passed new niches appeared and new species filled them. There is no reason to believe that a similar process is not going on at the present time. New environments are constantly being created and those animals with an ample supply of mutations move into them, with the aid of natural selection. Obviously there will come a time, perhaps a billion or so years in the future, when all life will cease, but up to the bitter end living things will undoubtedly attempt to adapt.

It is highly probable that the evolution of certain groups could be repeated if the ones living today were wiped out. Many of the "immortals" such as *Sphenodon* and the opossum are still with us and perhaps they could radiate once again, giving rise to new groups of reptiles and mammals. Undoubtedly the new forms would not be exactly like the ones we see today, but they might be as diversified. One might ask why the opossum has not done this very thing today, why it is still essentially the same creature that lived in the Cretaceous. The most obvious reason is that placental mammals have occupied nearly all of the environments that are available to it and the competition gives it little opportunity to crowd in. Hence it has been able only to maintain itself up to the present. But if the placental mammals were suddenly removed the descendants of the opossum would soon fill the spaces left and there would be rapid evolution among the various forms, just as there was in Australia.

Likewise, if the human species came to an abrupt end, the spaces left would be filled by other forms, perhaps not exact duplicates but certainly some possessing the unique qualities of man. For example, high intelligence has high survival value and would undoubtedly be selected for again. The entire trend in evolution has been toward a more intricate coördinating system, and there is no reason to believe that such a trend would cease if there were no animals possessing those qualities on the earth. To be sure, no other groups are likely to usurp that position among animals so long as man maintains his present place. Unless he retrogresses, it is highly improbable that any other group could match or excel him in reasoning power.

What does future evolution hold for man? Can he profit by what he knows about this grand drama of evolution, can he control its future trends with respect to the animals around him, and most important, can he control it with respect to his own destiny? These are the really important problems that scientists and laymen alike wish to understand and, of course, they are the most difficult to answer. We might speculate briefly about them in the closing sentences of this book.

The evolution of man has placed him in a unique position among animals in that he is the first and only animal who can control his environment to a greater or lesser extent. He builds shelters, clothes his body, plans his food needs and provides for them, and in general improves his physical environment wherever his own ingenuity and available materials will permit. He knows enough about evolution to take advantage of it in controlling animal and plant life around him, which enhances his own chances for survival. In other words, he can give evolution direction with a goal. He is rapidly gaining greater and greater control over his environment in all respects, so that his continued existence is more assured from that point than it ever has been. However, there is a sinister aspect to all of this because, while he has acquired sufficient knowledge to direct evolution to a certain extent in the organic world about him, he has done almost nothing in directing his own evolution, either physical or social. Further confusing the issue, he has at his disposal means by which he can annihilate himself, in which respect he is unique among animals. Because his social evolution has not kept pace with his ability to control his physical world, he may destroy himself before he has time to evolve socially. Therefore, the two important aspects of evolution that need man's most earnest attention are those concerned with improving his own germ plasm and those directed toward his social enhancement.

We already know a great deal about the status of our protoplasm and how to improve it, as has been set forth in an earlier chapter. There is little doubt but that within a few hundred or thousand generations we could breed toward a much better adapted man than we have today. What to breed toward is a difficult question, but there are some obvious results that could be strived for. A few ideals that might be sought are, for example, resistance to disease, fewer congenital defects, and, most important, a higher grade of intelligence. If the last of these were realized, a solution to the others would follow, because high intelligence is the most important single quality that has been responsible for placing man where he is now. Continued stress on this trait should lead him to still higher levels. Our problems today stem primarily from the fact that we do not know enough about the world around us or the people in it. To take one illustration, and this applies to all fields as well, in the world of science it is impossible for one individual to accumulate sufficient information to be as proficient in his field as he would like to be. It is certainly true that as the intelligence of a people, as measured by their education, improves, they become better fitted to their environment, or rather they so control their environment that they are better off as a race. Improved intelligence would be a great asset to future man.

Although feeble efforts have been and are being made toward social evolution, we are even less ready for such changes than we are for measures of race improvement. Here again one is inclined to become apprehensive about the matter of time. Will we act soon enough to prevent catastrophe? If we do, *Homo sapiens* is destined for a glorious future; if we do not, we shall relinquish our position to some lesser animal that even now may be waiting to take our place.

CLASSIFICATION OF THE ANIMAL KINGDOM

Phylum Protozoa (One-celled animals)

Class Sarcodina	Form pseudopods (Amoeba)
Class Mastigophora	Flagella (Euglena)
Class Sporozoa	Parasitic (Malaria)
Class Ciliata	Cilia (Paramecium)

Phylum Porifera (Sponges)

Class Calcispongiae	Calcareous spicules (limy sponges)
Class Hyalospongiae	Siliceous spicules (glass sponges)
Class Demospongiae	Highly complex (bath sponges)

Phylum Coelenterata (Two-layered animals)

Class Hydrozoa	Hydroid polyps and medusae (Obelia)
Class Scyphozoa	True medusae (large jellyfishes)
Class Anthozoa	Polyps only (corals, sea anemones)

Phylum Ctenophora (Sea walnuts) Comb-bearers (Mnemiopsis)

Phylum Platyhelminthes (Flatworms)

Class Turbellaria	Mostly free-living (Planaria)
Class Trematoda	Parasitic (flukes)
Class Cestoida	Parasitic (tapeworms)

Phylum Nemathelminthes (Roundworms)

Class Nematoda	Complete digestive tract; no coelom (Ascaris)

Phylum Annelida (Segmented worms)

Class Polychaeta	Marine; parapodia well developed; setae well developed (Neanthes)
Class Archiannelida	Degenerate; without parapodia; mainly marine (Polygordius)
Class Oligochaeta	Terrestrial or fresh-water; without parapodia; few setae (earthworm)
Class Hirudinea	Mostly parasitic; without parapodia or setae; suckers for attachment; fresh-water or terrestrial (Hirudo)

Phylum Arthropoda (Jointed-legged animals)

Class Onychophora	Possess both annelid and arthropod characteristics; paired nephridia, cilia in reproductive organs (annelid char-

	acteristics); jaws, hemocoel, trachea, jointed appendages (arthropod characteristics) (Peripatus)
Class Crustacea	Water dwellers; breathe by means of gills; numerous modified appendages; possess head, thorax, and abdomen or fused head and thorax (cephalothorax) (lobster)
Class Chilopoda	Flattened dorso-ventrally with 1 pair of legs on each segment (centipedes)
Class Diplopoda	Segments possess 2 pairs of legs (millipedes)
Class Insecta	Air-breathers (trachea); body divided into head, thorax, and abdomen (grasshopper)
Class Arachnoidea	No antennae; cephalothorax and abdomen only; 4 pairs of legs (spiders and ticks)
Phylum MOLLUSCA (Shelled animals)	
Class Amphineura	Shell, when present, with 8 plates; no tentacles; bilaterally symmetrical (chitons)
Class Pelecypoda	Bivalve mollusks; tentacles; wedge-shaped foot; usually 2 gills (clams)
Class Gastropoda	Flat foot; tentacles (snails, slugs)
Class Scaphopoda	No gills; delicate tentacles (tooth shells)
Class Cephalopoda	Head and eyes large; foot modified into tentacles (squids, cuttlefish)
Phylum ECHINODERMATA (Spiny-skinned animals)	
Class Crinoidea	Five branched rays; tube feet without suckers; temporarily or permanently attached; mostly fossils (sea lilies)
Class Asteroidea	Five rays indistinct from disk; dermal branchiae (starfishes)
Class Ophiuroidea	Five flexible rays distinct from disk (brittle stars)
Class Echinoidea	Hemispherical or disk-shaped; no free rays; movable spines (sea urchins, sand dollars)
Class Holothurioidea	Long, ovoid, soft body; no rays; cloaca with respiratory tree (sea cucumber)
Phylum CHORDATA	
Class Cyclostomata	Without scales, jaws, or lateral fins; fishlike (lampreys and hags)
Class Chondrichthyes	With jaws; 5-7 pairs of gills in separate clefts; cartilaginous skeletons; placoid scales; paired fins (sharks, rays)
Class Osteichthyes	Bony skeletons; 4 pairs of gills in single cavity covered by operculum; cycloid or ctenoid scales (common fishes)
Class Amphibia	No scales; moist skin; pentadactyl; young aquatic (gills); adults terrestrial (lungs) (frogs, salamanders)
Class Reptilia	Dry, scaly skin; air-breathers (lungs) (turtles, lizards, snakes)
Class Aves	Warm-blooded; wings; feathers (birds)

Class Mammalia	Warm-blooded; hair; mammary glands (horses, whales, bats, man)
Animals of Uncertain Position:	
Phylum NEMERTINEA (Ribbon worms)	Circulatory system; proboscis; complete digestive tract (Lineus)
Phylum TROCHELMINTHES (Wheel animals)	Smallest of the Metazoa; mostly fresh-water (rotifers)
Phylum BRACHIOPODA (Lamp shells)	Marine; live within a calcareous, bivalve shell
Phylum BRYOZOA (Moss animals)	Mostly marine; resemble hydroids in form, but more advanced internally
Phylum CHAETOGNATHA (Arrow worms)	Marine; bilaterally symmetrical; consists of head, trunk, and tail
Phylum GASTROTRICHA	Fresh and salt water; body elongate and flexible with forked tail.

ANNOTATED REFERENCES

The student who has a keen interest in zoology may wish to extend his reading in the field. The following list of books, together with a brief appraisal, is included for that purpose. The list is intentionally short. However, each reference contains extended bibliographies which will suffice to serve the most avid student.

Part I. Zoology as a Science

Cannon, W. B., *Way of An Investigator: A Scientist's Experiences in Medical Research* (New York, W. W. Norton & Co., 1945). Though applied rather strictly to medicine, this is a very readable discussion of the scientific method.

Hall, T. S., *A Source Book in Animal Biology* (New York, McGraw-Hill Book Co., Inc., 1951). This is a compilation of the works, in the original form, of men who initiated and were instrumental in developing the important fields of biology.

Locy, W. A., *Biology and Its Makers*, 1915, and *The Growth of Biology*, 1925 (New York, Henry Holt & Co., Inc.). Both of these books are well illustrated and are written in a manner attractive to the beginner. Highly recommended.

Nordenskiold, E., *The History of Biology* (New York, Alfred A. Knopf, Inc., 1933). A lengthy treatment of the subject. Recommended for those who seek a complete coverage of the history of biology.

Singer, Chas., *A History of Biology* (New York, Schuman, 1950). Very readable account of biological history from Hippocrates to the modern theory of the gene. Well worth while for the student contemplating a future in the sciences.

Part II. Life: Its Beginning and Nature

Carlson, A. J., and Johnson, V., *The Machinery of the Body* (Chicago, University of Chicago Press, 1948). A most readable book and highly recommended for supplementary reading.

Gerard, R. W., *Unresting Cells* (New York, Harper & Brothers, 1940). A delightful book written in a style that is graphic and understandable for the beginning student yet stimulating for the advanced worker.

Heilbruun, L. V., *An Outline of General Physiology* (Philadelphia, W. B. Saunders Co., 1945). A highly detailed treatment of the physiology of cells. Recommended only for students well trained in the physical sciences.

Oparin, A. I., *The Origin of Life* (New York, The Macmillan Co., 1938). A readable little book that is very stimulating for the student who is looking for an answer to this complex problem.

Part III. The Organized Animal

Borradaile, L. A., *The Animal and Its Environment* (New York, Oxford University Press, 1923). A first-rate book for general reading.

Elton, C., *Animal Ecology* (New York, The Macmillan Co., 1939). The basic principles of animal ecology are set forth in a clear, interesting style. The beginning student can handle it with profit.

Pearse, A. S., *Animal Ecology* (New York, McGraw-Hill Book Co., Inc., 1939). A technical book and recommended only for the student especially interested in this field.

Sears, P. B., *Life and Environment* (New York, Teachers College, Columbia University, 1939). An attractive discourse on the practical application of ecological methods to man's problems.

Part IV. The Rise of Animal Life

Brown, F., *Selected Invertebrate Types* (New York, John Wiley and Sons, 1950). A good account in some detail of carefully selected representative invertebrate animals, principally those used in the course at the Marine Biological Laboratory at Woods Hole, Mass.

Buchsbaum, R., *Animals Without Backbones* (Chicago, University of Chicago Press, 1948). A popular, well-illustrated account of the invertebrate animals.

Chandler, A. C., *Introduction to Parasitology* (New York, John Wiley and Sons, 1950). An excellent and very readable account, even for the beginner, of the animal parasites.

Comstock, J. H., *Introduction to Entomology* (Ithaca, N. Y., Comstock Pub. Co., 1940). A technical book but useful to the beginner in identifying insects.

Hegner, R. W., and Stiles, K. A., *College Zoology* (New York, The Macmillan Co., 1951). A good reference for the groups of animals where more detail is desired.

Hyman, L. H., *The Invertebrates,* Vol I: *Protozoa through Ctenophora;* Vol. 2: *Platyhelminthes and Rhynchocoela*—The acoelomate Bilateria; Vol. 3: *Acanthocephala, Aschelminthes and Entoprocta* (New York, McGraw-Hill Book Co., Inc., 1940, 1951). These are authoritative, up-to-date treatises with all the animal groups included.

Johnson, M. E., and Snook, H. J., *Seashore Animals of the Pacific Coast* (New York, The Macmillan Co., 1927). A well illustrated, semi-popular treatment intended for those interested in natural history.

Kudo, R. R., *Protozoology* (Springfield, Ill., Thomas, 1946). A valuable account of the Protozoa, particularly in identifying them.

Romer, A. S., *Man and the Vertebrates* (Chicago, University of Chicago Press, 1948). A thoroughly readable book, with an evolutionary approach. It can be read by the beginning student and is recommended.

Snodgrass, R. E., *Anatomy and Physiology of the Honeybee* (New York, McGraw-Hill Book Co., Inc., 1925). An excellent account of the detailed anatomy and functioning of this insect.

Storer, T. I., *General Zoology* (New York, McGraw-Hill Book Co., Inc., 1951). A comprehensive coverage of the animal groups.

von Frisch, K., *Bees—Their Vision, Chemical Senses, and Language* (Ithaca, N. Y., Cornell University Press, 1950). This brief popular account is not only fascinating but actually has opened new fields in insect behavior. Well worth reading, even for the beginner.

Ward, H. B., and Whipple, G. C., *Fresh-Water Biology* (New York, John Wiley and Sons, 1918). An excellent reference for looking up the name of an aquatic animal.

Wheeler, W. M. *The Social Insects: Their Origin and Evolution* (New York, Harcourt, Brace, and Co., 1928). A readable and thoroughly fascinating account of these amazing insects.

Part V. Organ Systems of Man

Amberson, W. R., and Smith, D. C., *Outline of Physiology* (New York, Appleton-Century-Crofts, 1948). An excellent, beautifully illustrated book. Recommended for students interested in more physiological detail.

Best, C. H., and Taylor, N. B., *The Physiological Basis of Medical Practice* (Baltimore, The Williams and Wilkins Co., 1945). A highly technical book that should be consulted only for detailed physiological data.

Carlson, A. J. and Johnson, V., referred to earlier.

Neal, H. V., and Rand, H. W., *Comparative Anatomy* (Philadelphia, P. Blakistons' Son and Co., 1936). A detailed account of the chordate organ systems.

Turner, C. D., *General Endocrinology* (Philadelphia, W. B. Saunders Co., 1948). A well-written coverage of endocrine glands in general.

Zoethout, W. D., and Tuttle, W. W., *Textbook of Physiology* (St. Louis, C. V. Mosby Co., 1946). A good general text.

Part VI. Continuity of Life

Barth, L. G., *Embryology* (New York, The Dryden Press, 1949). A clearly written account of the more recent advances in experimental embryology.

Muller, H. J., Little, C. C., and Snyder, L. H., *Genetics, Medicine, and Man* (Ithaca, N. Y., Cornell University Press, 1947). An interesting discussion of the most recent advances in human heredity.

Patten, B. M., *Human Embryology* (Philadelphia, The Blakiston Co., 1946). A highly technical work but one which may be profitably consulted for more detailed information on the subject.

SHULL, A. F., *Heredity* (New York, McGraw-Hill Book Co., Inc., 1948). A scientific discussion of inheritance.

SINNOTT, E. W., DUNN, L. C., and DOBZHANSKY, T., *Principles of Genetics* (New York, McGraw-Hill Book Co., Inc., 1950). A scientific treatment of the field.

SNYDER, L. H., *The Principles of Heredity* (Boston, D. C. Heath & Co., 1935). A thorough treatment of the subject. Excellent for further knowledge of genetics.

SPEMANN, H., *Embryonic Development and Induction* (New Haven, Yale University Press, 1938). A technical though readable book by one of the pioneers in experimental embryology.

STERN, C., *Principles of Human Genetics* (San Francisco, W. H. Freeman & Co., 1949). An excellent reference if more knowledge is sought concerning inheritance in man.

PART VII. ORGANIC EVOLUTION

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GLOSSARY

The glossary is included as an aid in not only defining biological terms, but also in helping the student pronounce them. Their origin is indicated as follows: Gr., Greek; L., Latin; M.E., Middle English; A.S., Anglo-Saxon; Fr., French. Words that do not appear here may be found by referring to the index.

Long words with two accented syllables contain both the primary accent (″) and the secondary accent (′).

Ab-do′men (L. *abdere,* to hide). The belly region of animals, specifically in mammals that part which extends from the diaphragm to the pelvis.

Ab′i-o-gen″e-sis (L. *a,* not; *bio,* life; *genesis,* birth). The doctrine whereby life originates from the non-living world.

Ab-o′ral (L. *ab,* from; *oris,* mouth). The side opposite the mouth.

Ab-sorp′tion (L. *ab,* away; *sorbere,* to suck in). The taking up of fluids or other substances by living systems.

Ac-cre′tion (L. *accrescere,* to increase). The addition of material to an inert mass of the same material.

Ac′e-tyl-cho″line. A chemical substance produced at or near para-sympathetic nerve endings which is thought to be involved in conduction of nerve impulses across synapses.

A-coe′lo-mate (Gr. *a,* not; *koilos,* hollow). Animals without a coelom.

Ac′ro-meg″a-ly (Gr. *akron,* point, peak; *megas,* big). An organic disease caused by the hypersecretion of the anterior pituitary after the long bones have reached maturity.

Ad-ap-ta′tion (L. *ad,* to; *aptare,* to fit). A process by which an organism becomes better suited to its environment.

Ad-he′sion (L. *adhaerere*). A molecular force at surfaces causing unlike molecules to cling together.

Ad′i-pose (L. *adipo,* fat). Pertaining to fat.

Ad-re′nal gland (L. *ad,* to; *renes,* kidneys; *glans,* acorn). A double endocrine gland located on or near the kidney. The two parts consist of the cortex and the medulla, each secreting different hormones.

Ad-re′nal-in. A hormone produced by the medullary portion of the adrenal glands.

Ad-sorp′tion (L. *ad,* to; *sorbere,* to suck in). The attachment of molecules of one substance to the surface of other substances.

Af′fer-ent (L. *affere,* to bring). Carrying toward. An afferent artery carries blood to the lungs.

Ag-glu′ti-nin (L. *ad,* to; *glutinare,* to glue). A substance in the blood which causes cells or microörganisms to clump.

Al′bi-nism (L. *albus,* white). A condition in which the normal pigment of the skin, hair, and eyes is lacking.

Al-i-men′tary (L. *alimentum,* from; *alere,* to nourish). Pertaining to the digestive tract.

Al-lan′to-is (Gr. *allas,* sausage; *eidos,* form). An extra embryonic membrane arising as an outgrowth of the cloaca in reptiles, birds, and mammals.

Al-lele′ (**allelomorph**) (Gr. *allelon,* of one another). The alternative forms of a gene having the same locus in homologous chromosomes which influence "alternative" characters.

Al′ler-gy (Gr. *all, ergy, ergon,* work). A condition in which substances that are normally harmless cause a marked hypersensitivity or reaction.

Al-ve′o-lus (L. *alveus,* pit). A small cavity, such as the alveoli of the lungs or the socket of a tooth.

A-moe′boid (Gr. *amoebe,* change). Cell movements resembling those of the amoeba.

A-mi′no ac′id (from amine NH_2). An organic compound resulting from protein breakdown; it must contain at least one amino group (NH_2) and one acid group (COOH).

Am′i-to″sis (Gr. *a,* without; *mitos,* thread). Direct nuclear division without formation of condensed chromosomes or spindle fibers.

Am′ni-on (Gr. *amnos,* lamb). A transparent membrane surrounding the embryos of reptiles, birds, and mammals.

Am′ni-o″ta (L. *amniotes*). A group of vertebrates possessing an amnion and an allantois—reptiles, birds, and mammals.

Am′phi-as″ter (Gr. *amphi,* both sides of; *aster,* star). A figure formed by the spindle fibers and the two asters in the dividing cell.

Am-phib′i-a (Gr. *amphi,* of both kinds; *bios,* life). Class of vertebrates including frogs, toads, and salamanders which usually spend their larval life in water (water breathers) and their adult life on land (air breathers).

Am′y-lop″sin (amylase) (L. *amyl,* starch; Gr. *trysin,* to wear down). A carbohydrate-splitting enzyme produced by the pancreas.

An-ab′o-lism (Gr. *ana,* up; *bole,* stroke). Constructive metabolism.

Anal′o-gous (Gr. *ana,* up; *logos,* ratio, proportion). Body parts with similar functions but usually genetically dissimilar.

An-am′ni-o″ta (Gr. *a,* not; *amnion,* inner membrane around the fetus). A group of vertebrates without an amnion—cyclostomes, fishes, and amphibia.

An′a-phase (Gr. *ana,* up; *phasis,* appearance, aspect). A stage in mitosis following metaphase when chromosomes migrate from the equatorial plate to the poles of the cell.

A-nas′to-mo″sis (Gr. *ana,* up; *stoma,* mouth). The union of two or more blood vessels, nerves, or other structures.

A-nat′o-my (Gr. *ana,* up; *temnien,* to cut). The study of the structure of animals and plants.

An-nel′i-da (L. *annulus,* ring; Gr. *eidos,* resemblance). A phylum of animals.

An-ten′na (L. a sailyard). Tactile sense organs on the heads of arthropods.

An-ten′nules (L. diminutive of antenna). Tactile sense organs located near the antenna of many arthropods.

An-te′ri-or (L. foremost). Toward the head end of an animal.

An″ti-bod′y (Gr. *anti,* against; M.E. *bodi,* body). A substance produced in the body as a result of the presence of a foreign body (antigen).

An′ti-gen (Gr. *anti,* against; *genes,* born). A substance which, when introduced into the body, stimulates the production of antibodies.

An′ti-tox″in (Gr. *anti,* against; L. *toxicum,* poison). A substance in the body fluids naturally occurring or induced which neutralizes specific poisons or toxins.

A′nus (L. ring). The exit of the alimentary canal opposite the mouth.

A-or′ta (Gr. *aorte,* the great artery). The large artery carrying blood away from the heart.

Ap′er-ture (L. *aperire,* to uncover). An opening.

Ap′i-cal (L. *apex,* summit). The top or apex.

Ap-pend′age (L. *ad,* to; *pendere,* to hang). A part of the body that extends some distance, such as an arm or leg.

A-quat′ic (L. *aqua,* water). Living in water.

Ar-bo′re-al (L. *arbor,* tree). Tree-living.

Ar-chen′ter-on (Gr. *arche,* beginning; *enteron,* gut). The primitive gut of an embryo produced by gastrulation.

Ar′ter-y (L. *ateria,* windpipe, artery). A blood vessel carrying blood away from the heart.

Ar′thro-pod-a (Gr. *arthron,* joint; *pous,* foot). A phylum of animals.

Ar-tic′u-la-tion (L. *articulus,* joint). A joint.

A-sex′u-al re-pro-duc′tion (L. *a,* not; *sexus,* sex; L. *re,* again; *productio,* production). Reproduction without involving sex cells.

As-sim′i-la″tion (L. *ad,* to; *similis,* like). The conversion of the end products of digestion into protoplasm.

A-sym′me-try (Gr. *a,* without; *syn,* with; *metron,* measure). Without symmetry.

At′a-vism (L. *atavus,* ancestor). Resemblance to a remote ancestor.

At′ro-phy (Gr. *a,* not; *trephein,* to nourish). The gradual regression of the whole body or of its parts.

Au′di-to-ry (L. *audire,* to hear). Pertaining to hearing or ears.

Au-to-nom′ic (Gr. *autos,* self; *nomos,* law). Self-operating.

Au′top-sy (Gr. *autos,* self; *optos,* seen). The dissection of a body (post-mortem) to determine the cause of death.

Au′to-some (Gr. *autos,* self; *soma,* body). The chromosomes other than the sex chromosomes.

Au-tot′o-my (Gr. *autos,* self; *tome,* cutting). The automatic breaking off of a part of the body, such as in arthropods.

Ax′on (Gr. *axon,* axle). The nerve fiber that conducts the impulse away from the cell body.

Bi-lat′er-al sym′me-try (L. *bis,* twice; *latus,* side; Gr. *syn,* with; *metron,* measure). The arrangement of body parts so that the right and left halves are mirror images of each other.

Bile pig′ments (L. *bilis,* bile; *pingere,* to paint). The colored pigments of bile (Bili Rubin, Bili Verdin) resulting from hemoglobin breakdown.

Bi′na-ry fis′sion (L. *bi,* two; *fissus,* cleft). The type of reproduction (asexual) in which division into two parts is approximately equal.

Bi-no′mi-al no′men-cla-ture (L. *bis,* twice; *nomen,* name). The international system of naming animals whereby two names are used. The first is generic, the second specific.

Bi-o-gen′e-sis (Gr. *bios,* life; *genesis,* birth). The doctrine that life comes only from preëxisting life.

Bi-ol′o-gy (Gr. *bios,* mode of life; *logos,* discourse). The science of plant and animal life.

Blas′to-coel (Gr. *blastos,* bud; *koilus,* hollow). Cavity of the blastula.

Blas′to-pore (Gr. *blastos,* bud; *poros,* passage). The opening into the archenteron of the gastrula.

Blas′tu-la (Gr. *blastos,* bud). The early embryo in which the cells form a hollow ball.

Bow′man's cap′sule (named after Sir Wm. Bowman, English physician. L. *capsula,* a little box). The cup-like structure at the end of the kidney tubule which surrounds the glomerulus.

Bra′chi-al (L. *brachium,* arm). Pertaining to the arm of a vertebrate.

Bra′chi-ate (L. *brachium,* arm). A manner of swinging from limb to limb in trees with the hands, such as apes employ.

Bron′chi-ole (Gr. *bronchos,* windpipe). A tiny air tube in the lung.

Bron′chus (Gr. *bronchos,* windpipe). One of the two main air passages of the trachea.

Buc′cal (L. *bucca,* cheek or mouth cavity). The mouth cavity.

Bud′ding (Gr. *beutie,* bag). Reproduction by the splitting off and subsequent development of a small portion of the original animal.

Cae′cum (L. *caecus,* blind gut). A blind sac.

Cal-ca′re-ous (L. *calcarius,* limestone, limy). Containing lime or calcium carbonate.

Can′cer (L. crab, ulcer, sign of the zodiac). One of a variety of malignant tumors.

Cap′il-la-ry (L. *capillus,* hair). Tiny blood vessel with walls of one cell layer which connects arterioles to venules.

Car′bo-hy″drate (L. *carbo,* coal; Gr. *hydor,* water). An organic compound (starch, sugar) containing carbon, hydrogen, and oxygen in which the last two atoms are in the same proportions as in water (H_2O).

Car′di-ac (Gr. *kardia,* the heart). Pertaining to the heart.

Car-niv′o-re (L. *caro,* flesh; *vorare,* to devour). Flesh-eaters.

Cas-tra′tion (L. *castratio*). The act of removing the sex glands, usually from males.

Ca-tab′o-lism (Gr. *kata,* down; *ballein,* to throw). Destructive metabolism.

Ca-tal′y-st (Gr. *kata,* down; *lysis,* a loosing). A substance that alters the rate of a chemical reaction, which would go very slowly or not at all without it.

Cau′dal (L. *cauda,* tail). Pertaining to the tail.

Cen′tro-some (Gr. *kentron,* a center; *soma,* body). A tiny differentiated area of a cell near the nucleus containing the centriole.

Cen′tri-ole (Gr. *kentron,* a center). A small body in the centrosome around which the asters form during mitosis.

Ce-phal′ic (Gr. *kephale,* the head). Pertaining to or near the head.

Cer′e-bel″lum (L. diminutive of *cerebrum,* brain). The part of the brain in higher vertebrates which controls muscular coördination.

Cer′e-brum (L. *cerebrum,* brain). The anterior part of the brain, which is conspicuous in man, and is the seat of thought, memory, and reasoning.

Cer′vi-cal (L. *cervix,* neck). Pertaining to the neck.

Char′ac-ter (Gr. *charassein,* to engrave). Used specifically in biology to designate any trait, function, or structure of an organism.

Chi′tin (Gr. *chiton,* a kind of garment, tunic). A horny substance forming the skeleton of arthropods and other animals.

Chlo′ro-phyl (Gr. *chloros,* green; *phyelon,* a leaf). A green pigment in plants essential for photosynthesis.

Cho′a-no-cyte (Gr. *choane,* funnel; *kytos,* hollow). Flagellated cells with collars, typical of porifera.

Chor′date (Gr. *chord,* string). An animal possessing a notochord which subsequently may be replaced by backbone (tunicates, vertebrates, etc.).

Chro′ma-tin (Gr. *chroma,* color). The dark, staining material of the chromosomes.

Chro′ma-to-phore (Gr. *chroma,* color; *pherein,* to bear). Pigment-containing cells or bodies in the skin of certain animals, such as the frog and some reptiles which are able to change their skin color.

Chro′mo-mere (Gr. *chroma,* color; *meros,* part). One of the many linearly arranged bead-like structures found on a chromosome.

Chro-mo-nem′a (Gr. *chroma,* color; *nema,* thread). Thread-like strands of chromatin visible in the nucleus during mitosis and in some cells during interphase.

Chro′mo-somes (Gr. *chroma,* color; *soma,* body). Deeply staining rod-shaped bodies within the nucleus and conspicuously visible during cell division. They contain the genes.

Cil′i-a (L. *cilium,* eyelid). Microscopic, hair-like projections from certain cells which vibrate, causing fluid movement.

Class (L. *classis,* collection). Principal subdivision of a phylum.

Cleav′age (A.S. *cleofan,* to cut). Divisions of the fertilized egg.

Clo-a′ca (L. *cloaca,* sewer). A common receptacle for digestive and excretory wastes and the reproductive cells of lower vertebrates.

Clone (Gr. *klon,* twig). A group of animals produced by asexual reproduction from a single individual.

Co-ag′u-la″tion (L. *cogere,* to drive together). A process of changing a sol into a gel.

Co-coon′ (Fr. *cocon,* shell). A protective covering for eggs, larvae, pupae, or adult animals.

Coe′lom (Gr. *koilus,* hollow). The body cavity lined with tissue of mesodermal origin in which the digestive and other organs lie.

Col′loid (Gr. *kolla,* glue; *eidos,* form). A system in which particles larger than molecules of one substance are suspended throughout a second substance.

Co′lon (Gr. *kolon,* the colon). The part of the large intestine which extends from the caecum to the rectum.

Com-men′sal-ism (L. *cum,* together; *mensa,* table). The intimate association of two species in which one is benefited and the other is neither helped nor harmed.

Con′ju-ga″tion (L. *cum,* together; *jugare,* to join, marry). A sexual process in unicellular organisms where two individuals unite temporarily and exchange their nuclear material, later dividing.

Con-trac′tile vac′u-ole (L. *cum,* together; *trahere,* to draw; *vacuus,* empty). A space in the cytoplasm of certain species of Protozoa where fluids collect before being periodically discharged to the outside.

Cop′u-la″tion (L. *copulare,* to couple). The union of two individuals in which spermatozoa are transferred from the male to female.

Cor′ne-a (L. *cornu,* horn). The transparent outer covering of the anterior part of the eye.

Cor′pus (L. *corpus,* body). A body.

Cor′tex (L. *cortex,* bark). The outer layer.

Cra′ni-um (Gr. *kranion,* the head). The portion of the skull which envelops the brain.

Cross′ing o′ver. The process in which homologous chromosomes break and exchange corresponding parts.

Cu-ta′ne-ous (L. *cutis,* the skin). Pertaining to the skin.

Cyst (Gr. *kystis,* a bladder). The stage of an organism, where it is encased in a resistant wall.

Cy-tol′o-gy (Gr. *kytos,* hollow; *logos,* discourse). The science that deals with cell structure.

Cy′to-plasm (Gr. *kytos,* hollow; *plasma,* something molded). The protoplasm of a cell, exclusive of the nucleus.

Dac′tyl (Gr. *daktylos,* finger). Pertaining to the finger.

De-am′i-na″tion (L. *de,* from; *amino,* amino group). The process by which the amino group is removed from the amino acid.

Def-e-ca′tion (L. *de,* from; *faecis,* dregs). The evacuation of the bowels.

De′glu-ti″tion (L. *de,* down; *glutire,* to swallow). The act of swallowing.

Den′drite (Gr. *dendron,* tree). The branching protoplasmic outgrowth of a nerve cell.

Der′mal (Gr. *derma,* skin). Pertaining to the skin, especially the deeper layers.

Der′mis (Gr. *derma,* skin). The inner layer of the skin.

Di-al′y-sis (L. *dialysis,* separation). The process by which crystalloids and colloids are separated in solution. This involves a natural or artificial membrane through which unequal diffusion takes place.

Di′a-phragm (Gr. *diaphragma,* midriff). The internal muscular layer found between the mammalian thoracic and abdominal cavities.

Di-as'to-le (Gr. *dia,* through; *stellein,* to set, place). The relaxation phase of the cardiac cycle.

Di-en-ceph'a-lon (Gr. *dia,* between; *engkephalon,* brain). An area of the vertebrate brain immediately posterior to the cerebrum.

Dif'fer-en'ti-a''tion (L. *differre,* to carry apart). Specialization of cells and tissues as a result of growth and development.

Dif-fu'sion (L. *diffundere,* to pour). The movement of molecules as a consequence of their kinetic energy.

Di-ges'tion (L. *digestio,* digestion). The conversion of food into materials that can be absorbed and assimilated.

Dig'it (L. *digitus,* finger). A finger or a toe.

Di-hy'brid (Gr. *dis,* twice; L. *hibrida,* mixed offspring). The offspring of parents differing in two characters.

Di-mor'phism (Gr. *dis,* twice; *morphe,* shape). Having two forms.

Di-oe'cious (diecious) (Gr. *dis,* twice; *oikos,* house). Having the sexes in separate individuals.

Dip'lo-blas''tic (Gr. *diploos,* double; *blastos,* bud). Having two germ layers.

Dip'loid (Gr. *diploos,* double). The number of chromosomes in somatic cells.

Dis'tal (L. *dis,* apart; *stare,* to stand). Most distant from the point of attachment.

Di-ur'nal (L. *dies,* day). Associated with daylight.

Di'ver-tic''u-lum (L. *de,* away; *vertere,* to turn). A pouch or pocket leading out from a tube.

Dor'sal (L. *dorsum,* back). The upper surface of any animal.

Duct (L. *ducere,* to lead). A tube for the passage of metabolic products.

Duct'less gland. A gland which pours its secretion directly into the blood stream.

Du'o-de''num (L. *duodeni,* 12 each). The first part of the small intestine posterior to the stomach (about as long as the width of 12 fingers).

Du'ra ma'ter (L. *dura,* hard; *mater,* mother). The tough outer covering of the brain and nerve cord.

Dys-gen'ic (Gr. *dys,* hard, ill; *gignesthai,* to be born). Tending to bring about genetic degradation of a species.

Ec-cen'tric (L. *ex,* without; *centrum,* center). Away from center.

Ec'dy-sis (Gr. *ek,* out; *dyein,* to enter). To shed the exoskeleton, as in arthropods.

E-col'o-gy (Gr. *oikos,* house; *logos,* discourse). The division of biology dealing with the relation of plants and animals to their environment.

Ec'to-derm (Gr. *ektos,* outside; *derma,* skin). The outermost germ layer of the gastrula which gives rise to the nervous system.

Ec'to-par''a-site (Gr. *ektos,* outside; *para,* beside; *sitos,* food). A parasite which lives on the outermost surface of its host.

Ec'to-plasm (Gr. *ektos,* outside; *plasma,* something molded). The outer layer of cytoplasm in a cell.

Ec'to-sarc (Gr. *ektos,* outside; *sarx,* flesh). The outer layer of certain Protozoa.

Ef-fect'or (L. *effectus,* to effect). A nerve end organ which serves to distribute impulses which activate muscle contraction and gland secretion.

Ef-fer'ent (L. *efferre,* to bear out). Conveying away from, as motor nerves that conduct impulses away from the cord.

Egg (L. *ovum,* egg). The animal gamete or ovum formed by the female.

E-lec'tro-lyte (Gr. *electron,* amber; *lytos,* dissolved, dissoluble). A substance which, when in solution, dissociates into ions and thus conducts an electric current.

El-ec'tron. The part of an atom having a negative charge.

El′e-ment (L. *elementum,* of obscure origin). A simple substance which cannot be decomposed by ordinary chemical means and consisting of one kind of atom.

Em′bry-o (Gr. *embryon,* embryo). The organism in an early stage of development.

Em′bry-ol″o-gy (Gr. *embryon,* embryo; *logos,* discourse). The science of the development of the organism.

E-mul′si-fi-ca″tion (L. *e,* out; *mulgere,* to milk). The process of dividing fat into particles of very small size.

En-cyst′ (Gr. *en,* in; *kystis,* bladder). To become enclosed in a cyst.

En′do-crine (Gr. *endon,* within; *krinein,* to separate). Pertaining to a ductless gland.

En′do-derm (Gr. *endon,* within; *derma,* skin). The innermost germ layer of the gastrula which gives rise to the lining of the digestive tract and its derivatives.

En′do-mix″is (Gr. *endon,* within; *mixis,* a mingling). The non-sexual reorganization of nuclear material in some Protozoa.

En′do-par″a-site (Gr. *endon,* within; *para,* beside; *sitos,* food). A parasite living within the body of its host.

En′do-plasm (Gr. *endon,* within; *plasma,* something molded). Inner cytoplasm surrounded by ectoplasm.

En′do-sarc (Gr. *endon,* within; *sarx,* flesh). Inner mass of protoplasm in a protozoan.

En′do-skel″e-ton (Gr. *endon,* within; *skeletos,* hard). Internal bony and cartilaginous structure of animals.

En′do-the″li-um (Gr. *endon,* within; *thele,* nipple). Epithelial lining of the circulatory organs.

En′er-gy (Gr. *energein,* to be active). The capacity to do work.

En-ter-o-ki′nase (Gr. *enteron,* gut; *kinein,* to move). Intestinal enzyme which activates pancreatic trypsinogen.

En′ter-on (Gr. *enteron,* gut). That part of the digestive tract derived from endoderm.

En′to-derm. See Endoderm.

En′to-mol″o-gy (Gr. *entomon,* insect; *logos,* discourse). The study of insects.

En-vi′ron-ment (Fr. *environ,* about, thereabouts). External or internal surroundings.

En′zyme (Gr. *en,* in; *zyme,* leaven). Organic catalyst.

Ep-i-der′mis (Gr. *epi,* upon; *derma,* skin). The outermost layer of the skin.

Ep′i-gen″e-sis (Gr. *epi,* upon; *gignesthai,* to be born). The concept that development begins with an undifferentiated cell.

Ep-iph′y-sis (Gr. *epi,* upon; *phyein,* to grow). The tip of a bone separated in early development by cartilage but later becoming a part of the bone.

Ep′i-the″li-um (Gr. *epi,* upon; *thele,* nipple). A sheet of cells covering either external or internal parts of body surfaces.

E′qua-to″ri-al plate (L. *aequator,* one who equalizes). The plate-like arrangement of chromosomes formed at the equator during cell division.

E-rep′sin (L. *eripere,* to set free). A mixture of peptone and proteose-splitting enzymes produced by the intestinal mucosa.

E-soph′a-gus (Gr. *oisophagos,* gullet). The tube extending from the pharynx to the stomach.

Es′ti-va″tion (L. *aestivus,* pertaining to summer). Inactivity brought about by extreme dryness and heat.

Es′tro-gen (L. *aestus,* fire, glow). A hormone produced by the ovarian follicle which, together with one of the pituitary hormones, influences estrus.

Es′trus (L. *aestus,* fire, glow). The mating period in female mammals marked by intensified sexual urge.

Eu-gen′ics (Gr. *eu,* well; *genos,* birth). The science of applying genetic knowledge for the improvement of the human species.

Eu-sta′chi-an tube (named after *Eustachi,* Italian physician. L. *tuba,* pipe). A tube leading from the pharynx to the middle ear.

Eu-then′ics (Gr. *euthenein,* to thrive). The science of improving the human race by improving the environment.

E-vag′i-na″tion (L. *e,* out; *vagina,* sheath). An out-pocketing of some part or organ.

E-vis′cer-ate (L. *ex,* out; *viscera,* entrails). To remove the internal organs.

Ev′o-lu″tion, organic (L. *evolvere,* to unroll; Gr. *organon,* instrument, tool). Descent with modification.

Ex-cre′tion (L. *ex,* out; *cernere,* to sift). Discharge of wastes of metabolism.

Ex′o-skel″e-ton (Gr. *exo,* outside; *skeletos,* hard). The hardened external structure of animals.

Ex′pi-ra″tion (L. *ex,* out; *spirare,* to breathe). To breathe out.

Ex-ter′nal res′pi-ra″tion. The exchange of gases between the alveoli of the lungs and the blood.

Fac′et (L. *facies,* face). A sub-division of the compound eye in arthropods.

Fam′i-ly (L. *familia,* from *famulus,* servant). The main sub-division of an order.

Fas′ci-a (L. a band). A sheet of connective tissue which covers and binds parts together.

Fau′na (L. *faunus,* a god of the woods). The animal life characteristic of a region.

Fe′ces or **fae′ces** (L. *faeces,* dregs). Undigested, unabsorbed food residue.

Fer′ti-li-za″tion (L. *fertilis,* from *ferre,* to bear). The fusion of the sperm with the egg to produce a zygote.

Fe′tus (L. a bringing forth). The unborn young of any viviparous animal.

Fi′brin (L. *fibra,* band). The essential insoluble protein found in the blood clot.

Fi-brin′o-gen (L. *fibra,* band, Gr. *gignesthai,* to produce). The soluble protein material which is converted to fibrin during clotting.

Fis′sion (L. *fissus,* cleft). Asexual reproduction in which the cell divides into two parts.

Fis′sure (L. *fissus,* cleft). Any groove, furrow, cleft, or slit.

Fla-gel′lum (L. *flagellum,* whip). A mobile, whip-like process.

Fol′li-cle (L. *folliculus,* small sac). A small excretory or secretory sac or gland.

Fo-ra′men (L. *foramen,* an opening). A hole in a bone or membrane.

Fos′sa (L. *fossa,* ditch). A pit or depression found in bone.

Fos′sil (L. *fossilis,* from *fodere,* to dig). Any naturally preserved record of prehistoric life.

Func′tion (L. *fungi,* to perform). Plant or animal action.

Gam′ete (Gr. *gametes,* spouse). A mature germ cell.

Gam′e-to-gen″e-sis (Gr. *gametes,* spouse; *genesis,* birth). The development of gametes.

Gan′gli-on (Gr. *ganglion,* enlargement). A mass of nerve cell bodies.

Gas′tric (Gr. *gaster,* belly). Pertaining to the stomach.

Gas′tro-vas″cu-lar (Gr. *gaster,* belly; L. *vasculum,* vessel). A cavity used both for digestion and circulation.

Gas′tru-la (Gr. *gaster,* belly). The early embryonic stage following the blastula in which the embryo consists of two germ layers.

Gas′tru-la″tion (Gr. *gaster,* belly). The process of invagination of the blastula to form the gastrula.

Gene. Hereditary units located on the chromosomes.

Ge-net′ics (Gr. *gignesthai,* to be born). The science of heredity.

Gen′i-tal (L. *gignere,* to beget). Pertaining to the reproductive organs.

Gen′o-type (Gr. *genesthai,* to be produced; *typos,* impression). Genic constitution.

Ge′nus (L. *genere,* to beget). Taxonomic sub-division of a family.

Ge-ot′ro-pism (Gr. *ge,* earth; *repein,* to turn). Response to gravity.

Germ lay′er (L. *germen,* germ). An embryonic primary cell layer.

Germ plasm (Gr. *plasma,* something molded). Reproductive and hereditary substance of individuals which is transmitted in direct continuity to the germ cells of succeeding generations.

Gest-a′tion (L. *gerere,* to carry). The period of pregnancy.

Gill (Gr. *cheilos,* lip). An aquatic respiratory organ.

Gill arches (Gr. *cheilos,* lip; *arcus,* bow). The walls bearing the gills.

Gill slit (pharyngeal cleft) (A.S. *slitan*). Paired openings in the wall of the pharynx of chordates which permits the water that entered through the mouth to escape externally during breathing.

Giz′zard (Fr. *giser,* gizzard). An enlarged muscular part of the digestive tract.

Gland (L. *glans,* acorn). A cell or collection of cells which produces a specific product.

Glo-mer′u-lus (L. *glomare,* to make a ball). A tuft or cluster of blood vessels projecting into the capsule of each uriniferous tubule.

Glot′tis (Gr. *glotta,* tongue). Opening from the pharynx into the larynx.

Gly′co-gen (Gr. *glykus,* sweet; *gen,* producing). A carbohydrate stored in many parts of the body; also known as "animal starch."

Go′nad (Gr. *gonos,* reproduction). A gamete-producing reproductive organ.

Go-nan′gi-um (Gr. *gone,* seed; *angeion,* vessel). The reproductive individual of a hydroid colony.

Gre-gar′i-ous (L. *gregarius,* from *grex,* a herd). The property of animals of flocking together.

Gul′let (L. *gula,* gullet). Esophagus.

Hab′i-tat (L. *habitare,* to dwell). Environment of an organism.

He′mo-coel (Gr. *haima,* blood; *koilus,* hollow). A body cavity functioning as a part of the circulatory system.

He′mo-cy″a-nin (Gr. *haima,* blood; *kyanos,* a dark-blue substance). An oxygen-carrying pigment, copper-bearing and blue in color, found in the blood of mollusks and arthropods.

He′mo-glo″bin (Gr. *haima,* blood; L. *globus,* globe). Oxygen-carrying red pigment of blood.

He′mo-phil″i-a (Gr. *haima,* blood; *phil,* to love). A hereditary condition in man in which blood clotting is abnormally slow.

Hap′loid (Gr. *haploos,* single; *eidos,* form). The reduced number of chromosomes found in the gametes; half the diploid number.

He-pat′ic (Gr. *hepar,* liver). Pertaining to the liver.

Her-biv′o-rous (L. *herba,* herb; *vorare,* to devour). Subsisting on plants.

Her-ed′i-ty (L. *hereditas,* heirship). Organic resemblance based on descent.

Her-maph′ro-dite (Gr. *Hermes, Aphrodite*). The possession of both male and female reproductive organs.

Het′er-o-zy″gote (Gr. *heteros,* different; *zeugon,* yolk). A hybrid formed from gametes having different genes for the same trait.

Hi′ber-na″tion (L. *hiems,* winter). The dormant state in which some animals spend the winter.

His′ta-mine. An organic compound which is a powerful dilator of the capillaries and a stimulator of gastric secretions; found in all plants and animals.

His′to-gen″e-sis (Gr. *histos*, tissue; *gignesthai*, to be born). The origin, development, and differentiation of tissues from undifferentiated cells of the embryonic germ layers.

His-tol′o-gy (Gr. *histos*, tissue; *logos*, study). The study of the microscopic structure of tissues and organs.

Hol′o-zo″ic (Gr. *holos*, whole; *zoion*, animal). Nutrition involving the ingestion and digestion of organic material.

Ho-mol′o-gy (Gr. *homos*, same; *logos*, study). The study of organs which result from common embryonic origin. They may or may not have the same function.

Ho′mo-zy″gote (Gr. *homos*, same; *zeugon*, yolk). An organism formed from gametes containing like genes for a given character.

Hor′mone (Gr. *hormon*, from *hormaein*, to arouse or excite). Chemical substance produced by an endocrine gland which, when transported to another area, produces a specific effect.

Host (L. *hostis*, stranger). The organism upon which a parasite lives.

Hy′a-line (Gr. *hyalos*, clear). A translucent, albumenoid material.

Hy′brid (L. *hybrida*, mongrel). An organism formed from the union of gametes differing in one or more genes; a heterozygote.

Hy′dranth (Gr. *hydra*, water serpent; *anthos*, flower). A vegetative branch of a hydroid colony.

Hy′dro-car″bon (Gr. *hydor*, water; L. *carbo*, coal). An organic compound formed only of hydrogen and carbon.

Hy-drol′y-sis (Gr. *hydor*, water; *lysis*, a loosing). Chemical decomposition by reaction with water.

Hy′oid (Gr. *hyoides*, Y-shaped). A Y-shaped group of bones at the base of the tongue.

Hy′per-ton″ic (Gr. *huper*, beyond; *tonikos*, strength). High osmotic pressure in reference to another solution.

Hy-poph′y-sis (Gr. *hupo*, under; *physis*, growth). The pituitary gland.

Hy-poth′e-sis (Gr. proposal). Tentative solution or proposal concerning a problem.

Hy′po-ton″ic (Gr. *hupo*, under; *tonikos*, strength). A lesser osmotic pressure in reference to another solution.

I-den′ti-cal twins. Twins arising from the same fertilized egg and therefore having the same genetic constitution.

Il′e-um (L. grain). The most posterior portion of the small intestine.

Il′i-um (L. flank). The dorsal bone of the pelvic girdle.

In″breed′ing. The crossing of closely related animals.

In-fun-dib′u-lum (L. *infundibulum*, funnel). A stalk-like evagination of the diencephalon.

In-gest′ (L. *ingestus*, from *ingerere*, to put in). To take in food.

In′or-gan″ic (L. *in*, not; Gr. *organikos*, instrument). Pertaining to substances of non-organic origin.

In-ser′tion (L. *insertus*, from *inserere*, to connect, insert). Point of attachment of a muscle to the movable part.

In′su-lin (L. *insula*, island). Hormone secreted by the pancreatic Islets of Langerhans.

In-teg′u-ment (L. *integumentum*, covering). The outermost covering of an organism; skin.

In′ter-cel″lu-lar (L. *inter*, between; *cellula*, cells). Between cells.

In-ter′nal se-cre′tion. Secretion into the blood stream.

In′ter-sti″tial (L. *inter*, between; *sistere*, to set). Pertaining to intercellular spaces.

In-tes′tine (L. *intestinus*, internal). Part of the digestive tract posterior to the stomach.

In′tra-cel″lu-lar (L. *intra,* within; *cellula,* cells). Within cells.

In′tus-sus-cep″tion (L. *intus,* within; *suscipere,* to receive). Growth by the addition of new materials within protoplasm.

In-vag′i-nate (L. *in,* in; *vabina,* sheath). An inpushing of a cellular layer into a cavity.

In-ver′te-brate (L. *in,* not; *vertebra,* joint). An animal without a vertebral column.

In′vo-lu″tion (L. *in,* in; *volvere,* to roll). A rolling or turning inward of cells over a rim.

Ir′ri-ta-bil″i-ty (L. *irrito,* excite). Ability to respond to a stimulus.

Is′chi-um (Gr. *ischion,* hip). The posterior ventral bone of the pelvic girdle.

I′so-ton″ic (Gr. *isos,* equal; *tonikos,* strength). Having the same osmotic pressure.

Je-ju′num (L. *jejunus,* empty). The digestive tract lying between the duodenum and the ileum.

Jug′u-lar (L. *jugulum,* collar bone). Pertaining to the neck (jugular vein).

Kid′ney. The major excretory organ in vertebrates.

La′bi-al (L. *labium,* lip). Pertaining to lips.

Lab′y-rinth (Gr. *labrys,* double ax). Part of the inner ear in higher vertebrates, composed of semicircular canals, utriculus, sacculus, and cochlea.

Lac′ri-mal (L. *lacrima,* tear). Pertaining to tears.

Lac′te-al (L. *lac,* milk). Pertaining to milk; also referring to lymph vessels in the small intestine.

La-cu′na (L. *lacuna,* cavity). A small pit, hollow, or cavity, as in bone or cartilage.

La-mel′la (L. small plate). A thin layer.

Lar′va (L. *larva,* ghost). An immature, free-living stage of an animal.

Lar′ynx (Gr. *larynx,* larynx). A structure containing the vocal cords located at the top of the trachea and below the root of the tongue in all vertebrates except birds.

Lat′er-al (L. *latus,* side). Toward the side.

Le′thal gene (L. *lethum,* death). A gene capable of bringing about the death of the organism.

Leu′co-cyte (Gr. *leucos,* white; *kytos,* cell). A white blood cell.

Lig′a-ment (L. *ligamentum,* bandage). A tough, fibrous band of connective tissue.

Lin′gual (L. *lingua,* tongue). Pertaining to the tongue.

Link′age (M.E. *linke*). Phenomenon occurring when a series of genes are passed on as a unit.

Li′pase (Gr. *lipos,* fat). Fat-splitting enzyme.

Lip′id (Gr. *lipos,* fat). Pertaining to fat.

Lum′bar (L. *lumbus,* loin). Pertaining to the region of the back between the thorax and the pelvis.

Lu′men (L. cavity). The internal cavity within a structure.

Lu′mi-nes″cence. The property of giving off light by cells.

Lymph (L. *lympha,* water). Fluid found in the lymph vessels containing fat, white blood cells, and plasma.

Mac′ro-nu″cle-us (Gr. *makros,* large; L. *nucleus,* kernel). The large nucleus of a ciliate (such as paramecium) as distinguished from the micronucleus.

Ma-la′ri-a (L. *mal,* bad; *aria,* air). An infectious disease caused by Protozoa (sporozoa) and transmitted by certain mosquitos.

Man′di-ble (L. *mandere,* to chew). The lower jawbone in vertebrates or either jaw in arthropods.

Man′tle (L. *mantellum,* cloak). A sheet-like tissue enclosing soft structures of an animal, such as a mollusk.

Ma-nu'bri-um (L. *manus*, hand). The uppermost part of the sternum; also the structure bearing the mouth in the medusa.

Ma-rine' (L. *marinus*, from *mare*, the sea). Pertaining to the sea.

Mas'ti-ca"tion (L. *masticare*, to chew). Referring to chewing.

Ma-ter'nal (L. *maternus*, of a mother). Referring to the mother.

Mat'u-ra"tion (L. *maturus*, ripe). The final stages in the production of gametes in which the number of chromosomes is reduced to one-half (diploid to haploid) the number characteristic of the species.

Me'di-an (L. *medius*, middle). Pertaining to the mid-line.

Me-dul'la (L. *medulla*, marrow). The distinct inner portion of a structure.

Me-dul'la ob-lon-ga'ta (L. oblong medulla). The most posterior portion of the brain.

Med'ul-la-ry plate, groove, or **tube** (L. *medullaris*, narrow). Neural plate, groove, or tube found in the embryonic development of the vertebrate nervous system.

Med'ul-lat-ed. A nerve fiber with a myelin covering or sheath.

Mei-o'sis (Gr. to make smaller). See Maturation.

Mem'brane (L. *membrana*, membrane). Any thin cellular sheet or layer.

Me-nin'ges (Gr. *meninx*, membrane). The three membranes enveloping the brain and the spinal cord.

Mes'en-chyme (Gr. *mesos*, middle; *engchein*, to pour in). A loose embryonic connective tissue derived chiefly from mesoderm.

Mes'en-ter-y (Gr. *mesos*, middle; *enteron*, intestine). A membrane supporting an organ in the abdominal cavity; also a partition found in certain coelenterates.

Mes'o-derm (Gr. *mesos*, middle; *derma*, skin). The mid-layer of embryonic cells found between the ectoderm and the endoderm.

Mes'o-gle"a (mesogloea) (Gr. *mesos*, middle; *gloia*, glue). A non-cellular, jelly-like substance found in coelenterates.

Mes'o-neph"ros (Gr. *meso*, middle; *nephros*, kidney). A kind of vertebrate kidney found in all embryos and in certain adult fish and amphibians.

Me-tab'o-lism (Gr. *meta*, beyond; *ballein*, to throw). The sum total of the chemical and physical processes occurring in protoplasm.

Met'a-gen"e-sis (Gr. *meta*, over; *genesis*, origin). Alternation of sexual and asexual generations.

Met'a-mere (Gr. *meta*, over; *meros*, part). Homologous segment of the body.

Me-tam'er-ism. The possession of a succession of homologous parts.

Met'a-mor"pho-sis (Gr. *meta*, over; *morphe*, form). The structural changes taking place in the transformation of a larva to an adult.

Met'a-phase (Gr. *meta*, after; *phasis*, appearance). The midstage of mitosis during which there is a lengthwise separation of chromosomes at the equatorial plate.

Met'a-zo"a (Gr. *meta*, over; *zoion*, animal). The multicellular animals in which there is a differentiation of the somatic cells.

Mi'cron (Gr. *mikros*, small). One thousandth part of a millimeter.

Mi'cro-nu"cle-us (Gr. *mikros*, small; L. *nucleus*, kernel). The small reproductive nucleus of certain Protozoa.

Mi-gra'tion (L. *migratio*). Moving from place to place.

Mil'li-li"ter (L. *mille*, one thousand; Fr. *litre*, liter). Thousandth part of a liter.

Mit'o-chon"dri-a (Gr. *mitos*, thread; *chondros*, grain). Small granules or rod-shaped structures found in the cytoplasm, thought to contain enzymes.

Mi-to'sis (Gr. *mitos*, thread). Cell division.

Molt (M.E. *mouten,* from L. *mutare,* to change). To shed an outer covering.

Mo-noe'cious. Containing both sexes in the same organism, hermaphroditic.

Mon'o-hy''brid (Gr. *monos,* single; L. *hybrida,* mongrel). The offspring of parents differing in one character.

Mor-phol'o-gy (Gr. *morphe,* form; *logos,* discourse). The study of form and structure.

Mu'cous (L. *mucus,* slime). Pertaining to mucus.

Mu'cus (L. *mucus,* slime). A watery secretion which covers mucous membranes.

Mu'tant (L. *mutare,* to change). A variation which breeds true.

Mu-ta'tion (L. *mutare,* to change). A permanent transmissible change in the character of an offspring.

My'e-lin (Gr. *myelos,* marrow). A fat-like substance forming a sheath around the axis of a medullated nerve.

My'o-fi''bril (Gr. *mys,* muscle; L. *fibrilla,* a small fiber). One of the slender, protoplasmic threads found in the muscle fiber which runs parallel with the long axis.

Na'res (L. *naris,* nostril). Openings of the air passages in vertebrates, both external and internal.

Na'sal (L. *nasus,* nose). Pertaining to the nose.

Nem'a-to-cyst (Gr. *nema,* thread; *kystis,* a bladder). A stinging body found in coelenterates.

Ne-phrid'i-o-pore (Gr. *nephros,* kidney; *poros,* passage). The external opening of the invertebrate excretory organ.

Ne-phrid'i-um (Gr. *nephros,* kidney). An invertebrate excretory organ.

Neph'ro-stome (Gr. *nephros,* kidney; *stoma,* mouth). The funnel-shaped opening at the inner end of the nephridium.

Neu'ral (Gr. *neuron,* nerve). Pertaining to the nervous system.

Neu'ri-lem''ma (Gr. *neuron,* nerve; *lemma,* covering). The outermost nerve fiber sheath.

Neu'ron, or **neu'rone** (Gr. *neuron,* nerve). The nerve cell.

No'to-chord (Gr. *notos,* back; *chorde,* string). The cylindrical rod of supportive tissue found in chordates, dorsal to the digestive tract and ventral to the nerve cord.

Nu-cle'ol-us (L. diminutive of *nucleus*). A round, conspicuous body found within the nucleus of most cells.

Nu'cle-us (L. kernel). A dense spheroid body containing chromatin found within the cell.

Nu-tri'tion (L. *nutrimentum,* nourishment). Sum total of the processes involved in food assimilation.

Oc-cip'i-tal (L. *occiput,* back of the head). Pertaining to the back of the head.

O-cel'lus (L. a little eye). The simple eye found in invertebrates.

Oc'u-lar (L. *oculus,* an eye). Pertaining to the eye; also the eyepiece of a microscope.

Ol-fac'to-ry (L. *olfacere,* to smell). Pertaining to the sense of smell.

Om-ma-tid'i-um (Gr. *omma,* eye). A small rod-like unit in the invertebrate compound eye.

Om-niv'o-rous (L. *ominis,* all; *vorare,* to devour). Subsisting on food of all types.

On-tog'e-ny (Gr. *onto,* being; *genos,* birth). The evolution of developmental history of an organism.

O'o-cyte (Gr. *oon,* egg; *kytos,* cell). The original cell of the ovarian egg before the formation of polar bodies.

O'o-gen''e-sis (Gr. *oon,* egg; *genesis,* origin). The origin and development of the ovum.

O'o-gon'i-um (Gr. *oon,* egg; *gonos,* offspring). The primordial cell which gives rise to the ovarian egg.

Oph-thal'mic (L. *ophthalmia,* the eye). Pertaining to the eye.

Op′tic (Gr. *optikos,* sight). Pertaining to the eye or vision.

O′ral (L. *os,* mouth). Pertaining to the mouth.

Or′bit (L. *orbis,* circle). The bony eye socket.

Or′gan (Gr. *organon,* an instrument). A group of tissues associated to perform one or more functions.

Or′gan-elle″. A minute organ found in Protozoa.

Or-gan′ic com′pound (Gr. *organon,* an implement; L. *componere,* to put together). A carbon-containing molecule.

Or′gan-ism (Fr. *organisme*). Any living thing.

Or′ga-nog″e-ny (Gr. *organon,* an instrument, implement; *genesis,* birth). The developmental processes involved in the formation of specialized tissue and organ systems.

Or′i-gin (L. *orior,* rise, become visible). Part of the muscle attached to an immovable structure.

Or′tho-gen″e-sis (Gr. *orthos,* straight; *genesis,* descent). Progressive evolution in a given direction.

Os-mo′sis (Gr. *osmos,* pushing). Diffusion through a semi-permeable membrane.

O′to-lith (Gr. *ous,* ear; *lithos,* stone). A small calcareous mass found in the auditory organ of many animals.

O′va-ry (L. *ovarium,* ovary). The primary female sex gland in which the eggs are formed.

O′vi-duct (L. *ovum,* egg; *ducere,* to lead). The tube through which the eggs are carried from the ovary to the uterus or outside the body.

O-vip′a-rous (L. *ovum,* egg; *pario,* to produce). Producing eggs which hatch outside the body.

O′vi-pos″i-tor (L. *ovum,* egg; *ponere,* to place). An organ found in female insects for depositing eggs.

O′vo-vi-vip″a-rous (L. *ovum,* egg; *vivus,* alive; *parere,* to bear). Producing eggs which hatch within the body.

O-vu-la′tion (L. *ovum,* egg). The discharge of the unimpregnated ovum from the ovary.

O′vum (L. egg). The mature female gamete.

Ox′i-da″tion (Gr. *oxys,* acid). An increase of positive charges on an atom, or the loss of negative charges.

Pae′do-gen″i-sis (Gr. *pais,* a child; *genesis,* origin). Reproduction while in the immature or larval stage.

Pa′le-on-tol″o-gy (Gr. *palaios,* old; *ons,* being; *logos,* discourse). Study of fossils.

Palp (L. *palpare,* to feel). One of the pointed sense organs attached to the mouth of some invertebrates.

Pan′cre-as (Gr. *pan,* all; *kreas,* flesh). A digestive gland located behind the stomach and opening by a duct into the duodenum.

Par′a-site (Gr. *para,* beside; *sitos,* food; or *parasitos,* eating beside another). An organism which lives on or in another living organism from which it receives an advantage without compensation.

Par′a-thy″roid (Gr. *para,* near; *thyreoeides,* shield-shaped). A small endocrine gland located near the thyroid.

Pa-ren′chy-ma (Gr. *para,* beside; *enchyma,* infusion). Loose, spongy connective tissue.

Pa-ri′e-tal (L. *parietis,* a wall). Pertaining to the coelomic wall.

Par′the-no-gen″e-sis (Gr. *parthenos,* virgin; *genesis,* origin). Reproduction by development of the egg without its being fertilized by the male element.

Pa-ter′nal (L. *paternus,* from *pater,* father). Pertaining to a father.

Path′o-gen″ic (Gr. *pathos,* suffering; *genesis,* to produce). Disease-producing.

Pa-thol′o-gy (Gr. *pathos,* disease; *logos,* study). The study of abnormal structures and processes.

Ped′al (L. *pes,* foot). Pertaining to the foot or feet.

Pe-lag′ic (L. *pelagicus*, from *pelagus*, sea). Inhabiting the open sea.

Pel′li-cle (L. *pellicula*, small skin). A thin skin, or film.

Pe′nis (L.). The male organ of copulation.

Pen′ta-dac″tyl (Gr. *pente*, five; *daktylos*, finger). Having five digits.

Pep′sin (Gr. *pepsis*, a cooking, digesting). The protein-splitting enzyme of the gastric juice.

Per′i-car″di-um (Gr. *peri*, around; *cardia*, heart). The membranous sac surrounding the heart.

Per′i-os″te-um (Gr. *peri*, around; *osteon*, bone). The tough, fibrous membrane surrounding bone.

Pe-riph′er-al (Gr. *periphereia*, from *peri*, around; *pherein*, to bear, carry). Pertaining to the surface.

Per′i-stal″sis (Gr. *peri*, around; *stalsis*, constriction). The wave of contraction by which the alimentary canal propels its contents.

Per′i-to-ne″um (Gr. *peri*, around; *tenein*, to stretch). The thin epithelial membrane which lines the coelom and invests the viscera.

Phag′o-cyte (Gr. *phagein*, to eat; *kytos*, cell). A type of white blood cell which ingests foreign substances.

Pha-lan′ges (Gr. *phalanx*, long line of battle). Digital bones.

Phar′ynx (Gr. *pharynx*). The portion of the digestive tract located between the mouth and esophagus.

Phe′no-type (Gr. *phaino*, show; *typto*, strike). The total of visible and physiological traits common to a group of individuals.

Pho′to-syn″the-sis (Gr. *phos*, light; *synthesis*, a putting together). The chemical combination, in the green plant, of carbon dioxide and water, to form carbohydrate, in the presence of light and chlorophyll.

Phy-log′e-ny (Gr. *phylon*, race, branch; *geny*, become). The evolutionary history of a race or group.

Phy′lum (Gr. *phylon*, tribe). One of the main divisions of the animal or plant kingdom.

Phys′i-ol″o-gy (Gr. *physis*, nature; *logos*, study). The study of functions of organisms.

Pig′ment (L. *pingere*, to paint). Coloring matter.

Pin′e-al (L. *pinea*, pine cone). An evaginated structure on the roof of the brain.

Pi-tu″i-tar′y bod′y (L. *pituita*, phlegm; A.S. *bodig*). An endocrine gland.

Pla-cen′ta (L. *placenta*, a flat cake). The round, flat organ within the uterus of mammals formed during embryonic development and attached to the embryo by means of an umbilical cord.

Plan′u-la (L. *planus*, flat). The ciliated, free-swimming larva found in the development of certain invertebrates.

Plas′ma (Gr. something molded). The liquid part of the blood or lymph.

Plas′ma mem′brane (L. *membrana*, skin covering). The external cytoplasmic membrane of a cell.

Plas′tid (Gr. *plastides*, to form). A pigmented cytoplasmic inclusion.

Plat′y-hel-min″thes (Gr. *platy*, flat; *helmins*, worm). A phylum of animals.

Pleur′al (Gr. *pleura*, side). Pertaining to the cavity in which the lungs are contained.

Plex′us (L. interwoven). A nervous or vascular network.

Po′lar bod′y (L. *polaris*, axis). The nonfunctional cell formed during the maturation of the egg cell.

Pol′y-mor″phism (Gr. *polys*, many; *morphe*, form). The occurrence of more than two types of individuals in the same species.

Pol′yp (Gr. *polypous*, many-footed). The attached form of a coelenterate usually possessing a mouth and tentacles at the free end.

Pos-te′ri-or (L. latter). Situated behind.

Pre-co′cious (L. *praecox*, ripe before its time). Characterized by early maturity.

Pre-da′ceous (L. *praedo,* prey). Capturing of live animals for food.

Pri-mor′di-al (L. *primordium,* beginning). Original or primitive.

Prin′ci-ple (L. *principium,* beginning). Scientific fact, theory, or law.

Pro-bos′cis (Gr. *proboskis,* trunk). Tubular extension of the lips, nose, or pharynx.

Proc′to-de″um (Gr. *proktos,* anus; *hodos,* way). The most posterior part of the digestive tract near the anus, lined with ectoderm.

Pro-neph′ros (Gr. *pro,* before; *nephros,* kidney). A primordial kidney.

Pro-nu′cle-us (Gr. *pro,* before; L. *nucleus,* kernel). The nucleus of either the egg or sperm cell during the interval existing between the penetration of the sperm into the egg and the subsequent union to form the germinal nucleus.

Pro′phrase (Gr. *pro,* before; *phasis,* appearance). The first stage of mitotic division during which the chromosomes become visible.

Pros′tate gland (Gr. *prostates,* one who stands before; L. *glans,* an acorn). An accessory sex gland found in the male surrounding the neck of the bladder and urethra.

Pro′te-in (Gr. *protos,* first). An organic compound composed of amino acids forming an essential part of the protoplasm.

Pro′to-plasm (Gr. *protos,* first; *plasma,* something molded). The colloidal living substance constituting the physical basis of life.

Pro′to-zo″a (Gr. *protos,* first; *zoion,* animal). A phylum of animals.

Prox′i-mal (L. *proximus,* next). Near the point of attachment of an organ.

Pseu′do-coel (Gr. *pseudo,* false; *koilia,* body cavity). A body cavity not completely lined with mesoderm, as found in the round worm.

Pseu′do-po″di-a (Gr. *pseudo,* false; *pous,* foot). A temporary protoplasmic projection found in amoeba or in some amoeba-like cells.

Pty′a-lin (Gr. *ptyalon,* spittle). Salivary enzyme which acts on starch.

Pu′bis (L. *pubes,* mature). The pubic bone, one of the three bones forming the pelvis.

Pul′mo-nar-y (L. *pulmo,* lung). Pertaining to the lung.

Py-lor′ic (Gr. *pylorus,* gate). Pertaining to the posterior portion of the stomach or the pylorus.

Quad′ru-ped (L. *quattuor,* four; *pes,* foot). Four-footed animal.

Ra′di-al sy′me-try (L. *radius,* ray). The condition in which similar parts are regularly arranged around a central axis, for example, as seen in starfish.

Ra′mus (L.). A branch, as of a blood vessel, bone, or nerve.

Re-cep′tor (L. *receptor,* receiver). A sensory end organ.

Rec′tum (L. *rectus,* straight). The most posterior portion of the large intestine.

Re-gen′er-a″tion (L. *re,* again; *generare,* to beget). The renewal or repair of a structure.

Re′nal (L. *renes,* kidney). Pertaining to the kidney.

Ren′nin (A.S. *gerinnan,* to curdle, coagulate). Enzyme secreted by the stomach wall which causes the coagulation of casein in milk.

Re′pro-duc″tion (L. *re,* again; *pro,* forth; *ducere,* to lead). The production of offspring.

Res′pi-ra″tion (L. *re,* again; *spirare,* to breathe). The gaseous metabolism at the cellular level.

Re-sponse′ (L. *re,* again; *spondere,* to promise). Reaction to stimulus.

Ret′i-na (L. *rete,* net). The innermost layer of the eye containing the light sensitive receptors.

Rh fac′tor (the Rhesus factor). A chemical factor found in the blood of some individuals which has genetic significance.

Rho-dop′sin (Gr. *rhodon,* rose; *opsis,* sight). Visual purple. A substance found in the retina and associated with vision.

Ru-di-men′ta-ry (L. *rudis,* unwrought, rude). Imperfectly developed, or having no function.

Ru′mi-nant (L. *rumen,* throat). A group of cud-chewing animals including the cow, goat, and deer, which have a stomach with four complete cavities.

Sap′ro-zo″ic (Gr. *sapros,* rotten; *zoion,* living being). Living on dead or decaying organic matter.

Sar′co-lem″ma (Gr. *sarx,* flesh; *lemma,* covering). The elastic sheath investing each striated muscle fiber.

Sar′co-plasm (Gr. *sarx,* flesh; *plasma,* liquid). The fluid protoplasmic matter of striated muscles.

Se-ba′ceous glands (L. *sebum,* tallow, grease; L. *glans,* an acorn). Small skin glands associated with hair follicles which produce a waxy secretion for lubrication of the skin.

Se-cre′tin. A hormone produced by the intestinal wall which controls the secretion of pancreatic juice.

Se-cre′tion (L. *secretio,* from *secernere,* to separate). The process of separating various substances from the blood for use by the organism; also the material produced.

Sed″en-tar-y (L. *sedere,* to sit). Permanently attached form.

Seg′ment (L. *segmentum,* a piece cut off). A portion of a metameric organism.

Self′-fer-ti-li-za′tion. Fertilization of an egg by a sperm from the same individual.

Se′men (L. *serere,* to sow). The sperm-containing fluid of male animals.

Sem′i-cir″cu-lar ca-nals″ (L. *semi,* half; *circulus,* circle). Canals in the inner ear of the vertebrate which make up an essential part of the sense organ of equilibrium.

Sem′i-nal (L. *semen,* seed). Pertaining to the semen.

Sem′i-nal re-cep′ta-cles (L. *semen,* seed; L. *recipere,* to receive). Sac-like receptacles in the female used for the storage of sperm after copulation.

Sem′in-al ves′i-cles (L. *semen,* seed; L. *vesica,* bladder). Sac-like structures in the male used to store sperm.

Sem′i-nif″er-ous tu′bule (L. *semen,* seed; *ferro,* to carry; *tubules,* small tube). A small duct used to convey seminal fluid.

Sen′so-ry cell (L. *sensus,* sense). Any receptor cell.

Sep′tum (L. *septum,* partition). A partition between adjoining cavities.

Ser′i-al ho-mol′o-gy (L. *series,* join; Gr. *homos,* same; *logos,* discourse). The serial repetition of structures having the same embryonic origin.

Se-rol′o-gy (L. *serum,* liquid). The study of serums and their actions.

Ses′sile (L. *sedere,* to sit). Attached, as opposed to free-living.

Se′tae (L. *seta,* bristle). Stiff bristle, as, for example, the setae in the parapodia of Neanthes.

Si′nus (L. cavity). A cavity or hollow space.

Sol′ute (L. *solvere,* to loosen). The dissolved substance in a solution.

Sol′vent (L. *solvere,* to loosen). The substance in which the solute is dissolved. It is the continuous liquid portion of a solution.

So′mite. A serial segment or metamere of an animal.

Spe′cies (L. appearance). A primary subdivision of a genus.

Sperm (Gr. seed). Male sex cell.

Sper′ma-ry. Male reproductive gland, testis.

Sper′ma-tid. The male germ cell just prior to the formation of the sperm.

Sper′ma-to-gen″e-sis (Gr. *sperma,* seed;

genesis, origin). The process by which spermatozoa are formed.

Sper′ma-to-zo″on (Gr. *sperma,* seed; *zoion,* animal). A mature male reproductive cell, sperm.

Sphinc′ter (Gr. *sphinggein,* to bind tightly). A ring-like muscle surrounding a natural orifice; the opening is closed by its contraction.

Spic′ule (L. *spiculum,* a little point). A sharp, needle-like body, characteristic of sponges.

Spi′nal col′umn (L. *spina,* thorn, spine). A continuous series of vertebrae in vertebrates which houses the spinal cord.

Spi′nal cord. The tubular part of the central nervous system which extends posteriorly from the brain throughout the length of the spinal column.

Spin′dle (A.S. *spinnan,* to spin). The spindle-shaped threads or fibers associated with the chromosomes in mitosis, radiating out from the centrosomes.

Spi′ra-cle (L. *spiraculum,* air hole). A breathing orifice of insects and the first gill slit in cartiliginous fishes.

Spleen (Gr. *splen,* spleen). A large organ situated in the upper part of the abdomen on the left side and lateral to the stomach having to do with red blood cell disintegration.

Spore (Gr. *spora,* seed). A special encapsulated reproductive body of one of the lower organisms.

Spor′u-la″tion (Gr. *spora,* seed). Reproduction by multiple fission, forming spores.

Stat′o-cyst (Gr. *statos,* stationary; *kystis,* sac). An organ of equilibrium found in invertebrates.

Stat′o-lith (Gr. *statos,* standing; *lithos,* stone). The solid body within a statocyst.

Ste-ap′sin (Gr. *stear,* tallow; *pepsis,* digest). A pancreatic enzyme which acts upon fats.

Ster′num (L. breastbone). Breastbone.

Stig′ma (Gr. a pricked mark). A light-sensitive pigment spot in certain Protozoa.

Stim′u-lus (L. *stimulare,* to incite). An environmental change which causes a response.

Stra′ti-fied (L. *stratum,* a covering). Arranged in layers.

Stri′at-ed (L. *stria,* channel). Cross-striped, such as in skeletal muscle.

Sub-cu-ta′ne-ous (L. *sub,* under; *cutis,* skin). The region immediately beneath the skin.

Sub′mu-co″sa (L. *sub,* under; *mucosus,* mucus). One of the layers of tissue in the wall of the digestive tract.

Su′ture (L. *sutura,* from *suere, sutum,* to sew). The point of fusion between two bones.

Swim′mer-et (A.S. *swimman*). Paired biramous appendage of the crayfish, just posterior to the walking legs.

Sym′bi-o″sis (Gr. *syn,* together; *bios,* living). Living together of two species.

Sym″me′try (Gr. *syn,* together; *meton,* measure). The regular or reversed disposition of parts around a common axis, or on each side of any plane of the body.

Syn′apse (Gr. *syn,* together; *hapto,* unite). The region of contact of two adjacent neurons.

Syn-ap′sis. Temporary union of maternal and paternal homologous chromosomes prior to the first maturation division.

Syn-cyt′i-um (Gr. *syn,* together; *kytos,* cell). A multinucleate mass of protoplasm.

Sys′tem (Gr. *syn,* together; *histanai,* to place). A group of organs having the same general function.

Sys′to-le (Gr. *syn,* with; *stellein,* to set, place). The contraction phase of the cardiac cycle.

Tac′tile (L. *tangere,* to touch). Pertaining to the sense of touch.

Tax-on′o-my (Gr. *taxis,* arrangement; *no-*

mos, law). The science of the classification of living things.

Tel′o-phase (Gr. *telos,* end; *phasis,* aspect). The last stage in mitotic division.

Ten′don (L. *tendere,* to stretch). A fibrous cord of connective tissue which binds a muscle to a bone or to other structures.

Ten′ta-cle (L. *tentare,* to touch, feel). A slender, whip-like organ for feeling or motion found in invertebrates.

Ter-res′tri-al (L. *terra,* earth). Living on the ground.

Tes′tis (L. *testis*). The sperm-forming male gonad.

Tet′rad (Gr. *tetra,* four). The four chromosomes which arise during maturation from the pairing and splitting of a homologous pair of chromosomes.

The′o-ry (Gr. *theoria,* a beholding, speculation). A formulated hypothesis.

Tho-rac′ic (Gr. *thorax,* chest). Pertaining to the chest or thorax.

Tho′rax (Gr. chest). The chest.

Throm′bin (Gr. *thrombos,* clot). A substance produced in shed blood when prothrombin comes in contact with thromboplastin. It is essential in clot formation.

Throm′bo-plas″tin (Gr. *thrombos,* clot; *plastikos,* to form, mold). A substance released from injured cells or platelets that initiates blood clotting.

Thy′mus (Gr. *thymos,* thymus). A ductless gland-like body situated ventral and anterior to the heart and below the thyroid.

Thy′roid (Gr. *thyreos,* shield; *eidos,* resemble). An endocrine gland located in the neck of vertebrates which secretes thyroxine.

Thy-rox′ine. The hormone secreted by the thyroid.

Tis′sue (L. *texere,* to weave). A collection of cells, usually similar, organized for the performance of a specific function.

Tox′in (Gr. *toxicon,* poison). A poisonous substance of plant or animal origin.

Tra′che-a (Gr. *tracheia,* windpipe). The breathing tube or windpipe of vertebrates and the tiny air tubes of certain arthropods.

Trait (L. *tractus,* a drawing). An inherited character.

Trip′lo-blas″tic (Gr. *triplax,* triple; *blastos,* bud). Having three germ layers.

Tryp′sin (Gr. *truein,* rubbing down; *pepsis,* digesting). A protein-splitting pancreatic enzyme.

Tym-pan′ic mem′brane (Gr. *tympanon,* eardrum; L. *membrana,* skin covering). The eardrum.

Um-bil′i-cal cord (L. *umbilicus,* navel). The cord-like connection between the placenta and the fetus of mammals.

U-re′a (Gr. *ouron,* urine). A nitrogenous metabolic waste of mammals found in urine.

U′re′ter (Gr. *oureter,* ureter). The tube which carries urine from the kidney to the bladder or to the cloaca.

U-re′thra (Gr. *oureter,* ureter). The tube that carries urine from the bladder to the surface, and in the male conveys the seminal fluids.

U′rine (L. *urina,* urine). The fluid secreted by the kidney.

U′rin-if″er-ous tu′bule (L. *urina,* urine; *ferre,* to bear; *tubulus,* any small tube). One of the excretory tubules in the kidney of higher vertebrates, consisting of a coiled tube and a capsule.

U′ro-gen″i-tal (u′ri-no-gen″i-tal sys′tem) (Gr. *ouron,* urine; *gignesthai,* to produce). Pertaining to both the excretory and reproductive systems.

U′ter-us (L. womb). The hollow muscular posterior end of the oviduct where the developing animal is contained and nourished.

Vac′u-ole (L. *vacuum,* empty). Small space in the cytoplasm.

Va-gi'na (L. sheath). The canal in the female reproductive tract which receives the penis in mating.

Va'gus (L. wandering). The tenth cranial nerve.

Va-ri-a'tion (L. *variare,* to change). Difference in structure or function exhibited by individuals of the same species.

Va-ri'e-ty (L. *varietas,* difference). One of the sub-divisions of the species.

Vas de'fer-ens (L. vessel; L. carrying down). The tube or duct which conveys sperms away from the testis.

Va'sa ef'fer-en''ti-a (L. vessels; L. *efferens,* bringing out). Small ducts which carry sperms from the testis to the epididymis in higher vertebrates.

Vas'cu-lar (L. *vasculum,* little vessel). Pertaining to vessels.

Vein (L. *vena,* vein). A blood vessel that carries blood to the heart.

Ven'tral (L. *venter,* belly). The lower surface, opposite to dorsal.

Ven'tri-cle (L. *ventriculus,* little belly). A lower muscular pumping chamber of the heart, also a brain cavity.

Ver'mi-form ap-pen'dix (L. *vermis,* worm; *forma,* form; *ad,* to; *pendo,* hand). A small, blind pouch projecting from the caecum in some mammals.

Ver'te-bral col'umn (L. *vertere,* to turn). See Spinal column.

Ver'te-brate (L. *vertebratus*). Animal with a backbone.

Ves-tig'i-al (L. *vestigium,* footstep). A rudimentary or degenerate structure which at one time was functional or better developed.

Vil'lus (L. *villus,* hair). A very small, finger-like projection, especially found in the vertebrate intestinal lining for increasing absorption.

Vi'rus (L. slimy liquid, poison). The simplest living organism composed almost entirely of nucleoprotein. They are capable of reproduction only within cells and are visible only under the electron microscope.

Vis'cer-a (L. internal organs). Internal organs of the body cavity.

Vi'ta-min (L. *vita,* life; M.E. *amine,* a chemical radical). A general term for a number of unrelated organic substances found in many foods and necessary, in small quantities, for normal metabolic activity.

Vi-tel'line (L. *vitellus,* yolk). Pertaining to egg yolk.

Vi-vip'a-rous (L. *vivus,* alive; *parere,* to bear). Producing young that receive nourishment for their development from the uterine wall of the mother.

Warm'-blood'ed. Animals possessing a temperature regulating device which enables them to maintain a constant body temperature.

Zo'o-ge-og''ra-phy (Gr. *zoion,* animal; *ge,* earth; *graphein,* to write). A branch of zoology dealing with the geographic distribution of animals.

Zy'gote (Gr. *zygotos,* united). The fertilized egg.

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