ADVENTURES WITH ANIMALS AND PLANTS

A GENERAL BIOLOGY

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BY

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PREFACE

As you begin the study of biology you begin a most exciting adventure, the study of animals and plants — the living things of the earth. You are one of these living things, so you will learn much about yourself. The study of living things is not only exciting; it is important to all mankind. Our knowledge of biology has made it possible for us to avoid many diseases, to provide more and better food, and to understand ourselves better.

The study and teaching of biology is the lifework of many people. They are professional biologists. It is possible that you will make the study of biology your lifework. If so, you will find much in this book to help you toward that goal. In writing *Adventures with Animals and Plants,* however, the authors had in mind, principally, the much larger number of people who will not become professional biologists. All of us need to know many of the facts and principles of biology in order to understand ourselves and make the best use of many of the things we see, hear about, and read about.

Whether or not you make biology your lifework, you will want to know how a professional biologist works and thinks, how he discovers the facts and principles that are so useful to all of us. Biologists, and other scientists as well, use a special method of discovering and testing facts and principles. It is called the *scientific method.* As you study this book, the scientific method will be brought to your attention many times.

Hygiene, which is the science of maintaining health and the prevention of disease, is based upon a knowledge of many parts of biology. Throughout the book you will find information that will be useful to you in keeping healthy.

We learn the facts and principles of biology by three methods. One is by observing animals and plants, writing down what we observe, and comparing what we see with what others have learned. By a second method we also use observation, but we observe and interpret the results of an experiment which was set up to try to answer some question or problem. A third method is to read what others have learned by the use of the first two methods. In using this book you will make use of all three methods: you will read, you will observe, and you will experiment. Perhaps, if you are a keen observer, or become one, you will discover something no one else has ever learned.

In this book you will read about many of the facts that biologists have learned by observations and experiments; and you will learn what conclusions or principles have been stated to summarize or explain the facts. You will frequently find suggestions for helpful class discussions and for experiments that will either add to the information contained in the text or make the text discussions more clear. These suggestions are grouped at the end of each Problem and are called Exercises. At the most appropriate places in each Problem these Exercises are referred to. You cannot possibly do all of them; the authors hope you will find time to do many of them. Each of these Exercises has been chosen with great care to help you understand some part of biology, to help you to learn how a biologist works (the scientific method), or to help you to find out something new.

The Questions at the ends of the Problems are designed for your use in reviewing what you learn in studying the Problem. If you can answer all the Questions, you can feel pretty sure that you have done a good job on that section of the text.

If you are one of those who like biology very much, you will want to try some of the Further Activities in Biology that are listed at the end of each Problem. You may also wish to read some of the many books and articles that are listed at the end of the book, just before the Index.

Since this book was designed to fit the courses of study in schools throughout the United States, it may contain some topics that are not required in your school. Therefore your teacher may prefer not to assign certain sections of it. Some sections are marked "Optional." These may be omitted, if your teacher so desires, without interfering with your understanding of the parts that follow.

All the authors' long experience in teaching, directing other teachers, and writing for students has been applied to the writing of this text, which is a successor to *Adventures with Living Things*. To insure accuracy, the authors have asked a number of people to read portions of this book. In addition to the large number of specialists who critically read many portions of the authors' earlier text, they wish now to thank: Mr. Maurice Bleifeld, Chairman, Department of Biology, Newtown High School, Queens, N. Y.; Professor A. L. Kroeber, Emeritus, University of California; Professor Laurence H. Snyder, Dean, The Graduate College, University of Oklahoma; and Dr. Charles Tanzer, DeWitt Clinton High School, New York City. The authors thank also Mrs. Charlotte O. Wolff for assistance in preparing the Index.

Elsbeth Kroeber
Walter H. Wolff

TABLE OF CONTENTS

Introduction: *Biologists Study Animals and Plants* 3

Unit

I. THE LIVING THINGS OF THE EARTH ARE MANY AND VARIED 14

Problem 1. *What Kinds of Animals Inhabit the Earth?* 15
The Vertebrates 16
The Invertebrates 39

Problem 2. *What Kinds of Plants Inhabit the Earth?* 72
Flowerless Plants 73
Plants with Flowers and Seeds 80

Problem 3. *How Are Living Things Named and Classified?* 95

II. ALL LIVING THINGS ARE BASICALLY ALIKE 104

Problem 1. *Of What Are All Living Things Composed?* 105

Problem 2. *How Do Their Activities Keep Cells Alive?* 118

Problem 3. *How Are the Cells Arranged in Animals and Plants?* 129

III. GREEN PLANTS MAKE THE FOOD USED BY ALL LIVING THINGS 136

Problem 1. *What Part Do Leaves Play in Making and Using Foods?* 137

Problem 2. *What Part Do Roots and Stems Play in Making and Using Food?* 148

IV. HOW A COMPLEX ANIMAL USES FOOD FOR ENERGY AND GROWTH 166

Problem 1. *How Can We Choose Foods Wisely?* 167

Problem 2. *How Does the Digestive System Make Foods Usable?* 188

Problem 3. *How Are Materials Moved to and from Our Body Cells?* 206

Problem 4. *How Are All Our Cells Provided with a Constant Supply of Oxygen?* 226

Problem 5. *How Does the Body Get Rid of Wastes Formed by Cell Activity?* 237

Problem 6. *What Substances Help Regulate Cell Activities?* 246

Unit

V. WHY LIVING THINGS BEHAVE AS THEY DO 260

PROBLEM 1. *What Are the Simplest Forms of Behavior in Animals?* 261
PROBLEM 2. *What Makes Complex Behavior Possible in Many-celled Animals?* 269
PROBLEM 3. *How Does the Behavior of Complex Animals Differ from That of Simpler Forms?* 286
PROBLEM 4. *How Do Plants Respond to Their Environment?* 301

VI. CONSTANT CARE IS NEEDED FOR MAINTAINING OUR HEALTH 310

PROBLEM 1. *How Are Our Bodies Protected against Microorganisms?* 311
PROBLEM 2. *What Have Scientists Learned about Conquering Some Common Diseases?* 320
PROBLEM 3. (*Optional*) *How Have Recent Discoveries Changed Some of Our Ideas about Disease?* 338
PROBLEM 4. *How Do We Attempt to Stop the Spread of Disease?* 343
PROBLEM 5. *How May We Achieve Better Health for All?* 359

VII. HOW LIVING THINGS AFFECT ONE ANOTHER 372

PROBLEM 1. *What Makes Possible the Continued Existence of Plants and Animals?* 373
PROBLEM 2. *What Are Our Relationships to Other Organisms?* 381
PROBLEM 3. *How Do We Try to Solve Our Insect Problems?* 389
PROBLEM 4. *Why Must We Practice Conservation?* 399

VIII. HOW ANIMALS AND PLANTS MAKE MORE OF THEIR OWN KIND 410

PROBLEM 1. *How Do the Simple Animals and Plants Reproduce?* 411
PROBLEM 2. *How Do the More Complex Animals Reproduce?* 421
PROBLEM 3. *How Do the More Complex Plants Reproduce?* 438

IX. THE ORGANISM IS THE PRODUCT OF ITS HEREDITY AND ITS ENVIRONMENT 454

PROBLEM 1. *Why Do Offspring Resemble Their Parents?* 455
PROBLEM 2. *How Can Some of the Differences between Parents and Offspring Be Explained?* 464
PROBLEM 3. *How Can New Hereditary Characters Appear?* 479
PROBLEM 4. *How Does the Environment Affect the Characters of an Organism?* 485

Unit

PROBLEM 5. *What Have We Learned about Producing New Types of Animals and Plants?* 493
PROBLEM 6. *To What Extent Can Mankind Be Improved?* 508

X. THE EARTH AND ITS INHABITANTS HAVE CHANGED THROUGH THE AGES 520

PROBLEM 1. *What Can We Learn from Rocks about the History of the Earth?* 521
PROBLEM 2. *What Can We Learn from Fossils about Prehistoric Living Things?* 533
PROBLEM 3. *What Puzzling Facts May Be Explained by Our Theory of the Origin of New Organisms?* 547
PROBLEM 4. *What Theories Have Been Offered to Explain the Origin of Different Kinds of Animals and Plants?* 555
PROBLEM 5. *What Were the Stages of Man's Development on the Earth?* 564

BIBLIOGRAPHY 580
GLOSSARY 583
INDEX 599

How To Use This Book

1. How this book is organized. *Adventures with Animals and Plants* is divided into Units, each of which presents a major topic in biology. When you have finished studying a Unit you will have learned the most important facts presented in that Unit, and should understand the important ideas growing out of those facts. To aid you in reaching this understanding, each Unit is divided into two or more Problems. These Problems may be said to be the chapters of the book. Each Problem title poses a question, the answer to which is to be obtained by studying the text that follows. When the answers to all the Problem questions contained in a single Unit are understood, you will have all the information necessary to an understanding of the statement at the head of that Unit.

Each Problem is composed of "paragraphs" headed by a title in boldface type. Each of these paragraphs supplies some information necessary for arriving at the answer to the Problem question. A simple, step-by-step study of the paragraphs, as suggested in the following section, will help to put you on the road to success in your biology course.

2. How to learn from this book. There are many devices in this book designed to help you to learn biology readily. Of these, the Unit headings, Problem questions, and paragraph titles are the most important, because they tell you what you are supposed to learn. From the very beginning of any study period you should know what you are trying to learn. After reading a paragraph title, think over the meaning of the title and ask yourself what you already know about that subject. When you have thought through and organized your previous knowledge, you will be better equipped to grasp the additional information that is supplied by the book. You will find it helpful to do the Exercises referred to throughout the text as you are studying the section those Exercises are intended to supplement. Perhaps the class as a whole can plan with the teacher how to do some of the Exercises. This is more interesting than following directions laid down by others.

If, at first reading of the text, you do not understand a sentence, finish the paragraph to find out if your questions are answered. Then go back and re-read the sentence as it stands in relation to the rest of the paragraph. If you still have questions, make a note of them and have them explained in class. If it is a word that you do not understand, look it up. If that is not possible, make a note of the word so that you can learn its meaning in class. The field of biology makes use of many special words that you will need to learn. These words are printed in *italics* and defined when they first appear. If you do not recall the meaning of a word when it is used later in the book, look it up in the Index to find where it was used first. A good way to learn the special vocabulary of biology is to prepare a glossary for yourself in your notebook. A glossary is simply a special dictionary. You can list the new terms you learn and write their definitions in your own words. As a basis on which to build your own more complete list of words you will find a glossary prepared by the authors beginning on page 583.

There are many illustrations in this book. Every one has been chosen to add to your understanding and information. It will be useful for you to look at them carefully and to study the legends.

Both the printed text and the illustrations will undoubtedly raise questions in your mind. These are the most precious results of study because they lead to interesting class discussions and, later, to a more complete understanding of the subject. Such questions will also emphasize to you that in biology, as in other sciences, there is much that remains to be learned.

Adventures WITH ANIMALS AND PLANTS

FIG. 1 *All animals and plants are subjects for biologists to study. Students of biology learn what kinds of living things there are, how they are constructed, how they remain alive, why they behave as they do, how they reproduce, why they resemble their parents, why there are so many kinds, how they are dependent upon each other, how man affects them, and how they affect man.* (PHOTOS BY CRUICKSHANK-NATIONAL AUDUBON SOCIETY, NATIONAL ZOOLOGICAL SOCIETY, TYRELL-NATIONAL AUDUBON SOCIETY, PHILIP GENDREAU, RALPH ANDERSON, AND MUSEUM OF NATURAL HISTORY)

Biologists Study Animals and Plants

What is biology? Biology is the study of living things. This means that biology is the study of all animals, including man, of all plants, and of those simple living things which we do not know whether to call animal or plant. Since biology is the study of all living things, all of us have been *biologists* (students of biology) in a small way all of our lives. When you learned the name of the robin you were, for the moment, a biologist. To be more exact you were a *zoologist* (zoh-ol′-o-jist), a student of animals. Would it make it seem more important if you knew that this branch of zoology was called *ornithology*, the study of birds? You were learning biology when you noticed that a dog would dash after a ball (the science of animal behavior) and when you noted green leaves come out in the spring (*botany*, the science of plants). You were an unwilling biologist, too, when you had measles or scarlet fever and discovered how other organisms can affect man.

Evidently biology is the study of living things in any way in which a biologist wants to study them. You may think that this makes biology a large and varied science — and so it does. There are many sub-sciences that make up the larger science of biology. You have just read the names of a few of them; there are many others which you will read about in this book.

What to study about living things. Most people will say that one of the first things to learn about a living thing is its name. This is true. Most of the living things you see frequently have common names and you will want to learn some of them. You can learn to know an oak tree from a maple tree and a woodchuck from a skunk. In some cities you will see maples, elms, and poplars along the streets; in others palms and pepper trees. You will enjoy knowing these names as well as the names of common breeds of dogs and cats and of many other animals and plants.

But more important than the names of living things is a knowledge of their *structure;* that is, the parts of which a living thing is made and how these parts fit together to make a whole *organism* (or′gan-ism), a single living thing. Since you are more interested in yourselves than in any other organism, it is especially useful to you to know the structure of your body. When you have completed a year's work in biology, you will know something about how you and all other human beings are constructed: what your heart is like and your stomach and your brain and the other parts of your body. Of course in one year's time you will not be able to learn very much about living things. The men and women who spend their entire lives studying just one part of biology do not then feel that they have mastered it completely.

The knowledge of how organisms are constructed becomes especially valuable when you go on to learn how organisms carry on life activities. If you know how you digest and absorb food, how you breathe, how your blood circulates, how your actions are controlled, how it happens that human beings are like their parents, and how human beings have developed through the ages, you will have important information about yourself. To understand this well you will need to learn something about the structures of other organisms, such as lower animals and even plants, and how they carry on their life activities.

Man and other living things. There are even better reasons for learning how other organisms carry on their life activities. Consider plants; it is important to you and to me that plants be raised for our use. If the wheat crop is a great deal smaller than usual, we may have less bread; if the corn crop fails, cattle and hogs are scarcer and the price of meat goes up. In fact, if there were no plants on this earth we would not be here at all.

Then consider the many animals such as rabbits, moles, and particularly insects, that injure crops and interfere with the production of food and making a living. There are also many organisms that attack man directly, causing disease. It is well to know something about all these organisms and to know how we can protect ourselves and our crops against them. Men are constantly affected by other living things.

The work of biologists. Since the field of biology is so large, the work of biologists is varied. Some biologists live out of doors, exploring and learning about plants and animals at first hand by observation and recording. Some biologists work in the *laboratory*, experimenting with living things or with chemicals in test tubes; some study plants or animals at close range through the microscope to learn the secrets of living matter. Before you plunge into the study of living things let us see how some of these biologists do their work.

Biologists explore the world. Do you know what kinds of plants and animals live on this earth? Do you know what plants and animals live on the island of Borneo or along the Amazon River? Could you describe a scene in the Gobi Desert of Asia or picture to yourself the plants that make summer beautiful within the Arctic Circle?

It seems that similar questions have always interested man. There have always been men bold and adventurous enough to undertake long voyages to distant parts of the earth merely to see and collect the plants and animals living there.

About two hundred years ago Carolus Linnaeus (lin-nee'us), a young student at a Swedish university, was sent by his country to Lapland to make collections of living things. He started alone, carrying in his leather bag a simple microscope, a telescope, paper for drying plants, and writing materials for taking notes. For many months he endured great hardships. During this time he reached the Arctic Ocean on foot. Then he returned to his university with a few specimens of rocks and animals and plants, and complete notes on everything he had seen. He had learned a great deal about the customs of the native Lapps, had become acquainted with the wild animals of the country, and had made a thorough study of the plants, for botany was the subject of greatest interest to him. It is said that he traveled more than four thousand miles.

Linnaeus' accounts of his journey inspired other biologists to explore foreign lands. Often these trips last for several years during which the biologist is far from any civilized country, completely dependent upon his ability to make friends with native tribes. He has to win their confidence slowly, learn their language, and persuade them to take long trips on foot, on horseback, or by boat through parts of the country the natives may fear. Here the explorer devotes himself to his search for new types of animals and plants. Many of these are collected and stored to be taken back to museums and universities. Complete notes are kept of all observations so that no mistake will be made when the scientific reports are later prepared. Some of these exploring scientists are also excellent artists and prepare their own sketches of the strange scenes they see.

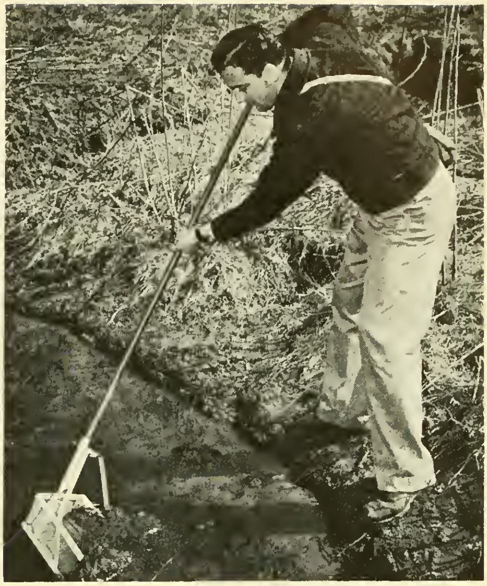


FIG. 2 *What water-living plants and animals might this collector find?* (WARD'S NATURAL SCIENCE ESTABLISHMENT)

Exploring is not at an end. Exploring nowadays is frequently very complex. Large expeditions are organized. They include experts in many branches of science and are equipped with scientific instruments of many kinds. Photographers and secretary-historians are among the specialists included. Despite their size, such expeditions still meet with exciting adventures. Even as you read this, investigators are at work in the field in many parts of the world, searching high in the mountains, and deep in the sea, in the frozen wastes of the arctic and antarctic, and in the hot, wet jungles.

Exploring the depths of the ocean. You may join exploring biologists in imagination, if you wish. Would you care to stroll through a garden in the warm seas twenty feet below the surface? Get into your bathing suit, strap your diving helmet to your shoulders, and climb down the ladder that hangs over the side of the boat. When you reach the last rung, drop off. You will sink gently to the bottom. Take care not to scratch yourself on the corals that are part of the lovely undersea gardens. If you have remembered your zinc pad and lead

Fig. 3 *The Central Asiatic expedition of the American Museum of Natural History meets with an accident in the Mongolian Desert. What abilities must the explorer have besides a knowledge of biology?* (AMERICAN MUSEUM OF NATURAL HISTORY)

Fig. 4 *Exploring in a jungle. Dr. William Beebe and two fellow scientists take motion pictures of living things on the floor of a jungle in Venezuela.* (JOCELYN CRANE —NEW YORK ZOOLOGICAL SOCIETY)

pencil, you will be able to take notes as soon as your eyes grow accustomed to the dim light.

The sunlight filters through this clear tropical water and flashes from the brilliant reds and yellows of the many kinds of fish. The beauty of the ocean floor with its brightly colored animals will delight you as it has the biologists who have gone down many times to study this active world of living things. Some have described its beauties, others have painted its scenes, and still others have photographed the graceful forms so that everyone may now enjoy the gardens undersea. When the water is clear and not too deep, living things in the sea can be seen through panes of glass in the bottom of a boat. Diving in a helmet has many advantages, however. And now that helmets have been perfected almost anyone can explore the shallow seas. But for exploration down to a depth of half a mile a bathysphere is used. This is a ball of steel with thick glass windows and a powerful electric

FIG. 5 *Photographed off the Florida coast. What information can biologists obtain by underwater trips? How else can they get such information?* (MILLER DUNN CO.)

light casting a beam out into the surrounding blackness.

Long before these methods of studying the life of the sea had been developed, other devices were in use. Nets made of steel had been dragged on the bottom of the sea, sometimes as much as three miles down, and then hauled to the surface so that the catch might be studied. Nets had been invented that could be dragged through the water at certain depths and closed before they were pulled in. In this way biologists would know, for example, that certain fish live at depths of half a mile, coming no closer to the surface nor going much farther down. Dredges with steel jaws had been dropped to the bottom and closed so that samples of the sand and ooze (mud) could be collected and examined. This disclosed the fact that the thousands of square miles of ocean bottom is the graveyard of tiny animals whose skeletons sank after death. A single one of these tiny animals is too small to be seen by the naked eye yet the countless billions that have died have formed thick deposits of this ooze. Thus slowly the labors of many men are making it possible to describe life in the darkness of the ocean depths.

Exploring nearer home. Not all biologists interested in getting acquainted with plants and animals have wandered to the far corners of the earth to discover and describe them. Many have remained at home, knowing that with patient observation much could be learned about animals and plants nearby.

One of the most famous of the stay-at-home observers was Jean Henri Fabre (fah'br). For most of the years of his long and useful life Fabre watched the insects in his garden and in the sunny fields. He would crouch, motionless, for long hours at a stretch, intently watching the behavior of some insect. It was by such patient observation that he saw insects hunt food and store it, fight enemies, and mate. He saw how eggs were laid and how they hatched. Then he wrote exact descriptions of what he had seen. He left many simple and interesting accounts of his observations; most of them have been translated from

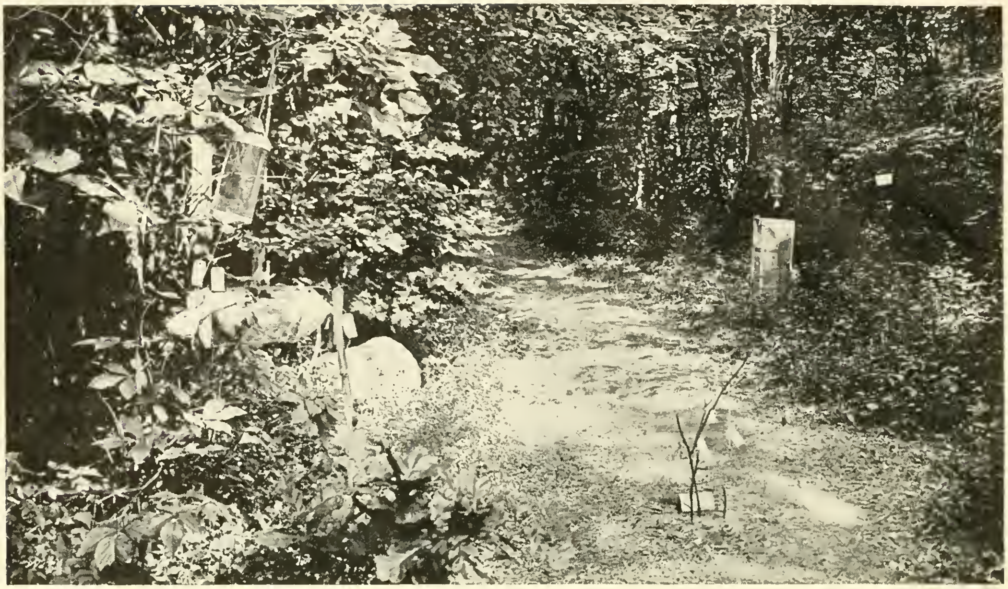


Fig. 6 *An outdoor museum, part of the Nature Trail at Tuxedo, New York. Could you build a simple nature trail? What besides names might be given on the various tags that you see?* (AMERICAN MUSEUM OF NATURAL HISTORY)

the French so that you can read them.

Other stay-at-home observers may study birds, or snakes, or other animals. Such study can satisfy a love of the out of doors and add to the store of biological knowledge.

Backyard exploration for you. Equipped with a pad and a pencil, you too can start on a tour of exploration. You may fill notebooks with your observations of the wild things in a park, in a field, or in a city lot. You can collect specimens and lay out a museum of your own.

Or you may choose to mark off a small plot on the bank of the creek flowing by your house, the edge of a nearby wood, or a city yard. If you study this with care you will be amazed at the many organisms you will find. One biologist collected several hundred different kinds of insects from his own small backyard in three years.

Your backyard may be only a roof or a window sill. A sheltered board regularly supplied with bread crumbs will bring passing birds. A piece of sod brought in from out of doors and watered carefully will grow into a miniature jungle. There will be much for you to observe and many experiments for you to try. With a camera you can add to the pleasure of backyard exploration and provide a treasured album.

A study of biology can lead to many outdoor hobbies: the collecting of insects, fossils, shells, or plants; the raising of pets such as guinea pigs, rabbits, and white mice; the studying of insects in their homes; the planting and care of a garden.

The biologist's laboratory. While some biologists explore, many more work in the laboratory — the workshop of the

FIG. 7 *A corner of the Boy Scout Museum at Bear Mountain, New York. What suggestions for hobbies does this picture give you?* (AMERICAN MUSEUM OF NATURAL HISTORY)

scientist. The well-equipped workshop has sinks with faucets of different sizes; stone tables with vacuum and air pressure outlets and connections for gas and electricity; rows of shelves for bottles of dyes, acids, testing agents, glassware of many kinds, and some reference books; cupboards with microscopes, dissecting instruments and other instruments of various sorts. There may be an incubator, a pressure cooker, a refrigerator. The laboratory is the place in which biologists perform their "labors," in which they investigate, observe, experiment, draw conclusions, and record their studies of living things. That is why boys and girls who set up little places at home for the study of living things may speak of them as biologists' workshops or laboratories.

A peep into a laboratory. The great Russian biologist, Ivan Pavlov (1849–1936), in the early years of the present century wished to learn something of animal behavior. Let us visit him in his laboratory. He used dogs as experimental animals because they were easy to work with. Pavlov wanted to find out how the saliva can be made to flow in a dog. But before he could begin his experiment he had to perform a difficult operation. He opened a small hole in the dog's face and inserted a tube to which a jar was attached. When Pavlov showed food to the dog, the saliva flowed into the jar and the amount could be measured. It took weeks to train the dog to stand still in a harness while he was fed. After these preparations Pavlov was ready for his experiment. He rang a bell each time he put food before the dog. This was continued for some time. Then, one day, Pavlov rang the bell without putting the food before the

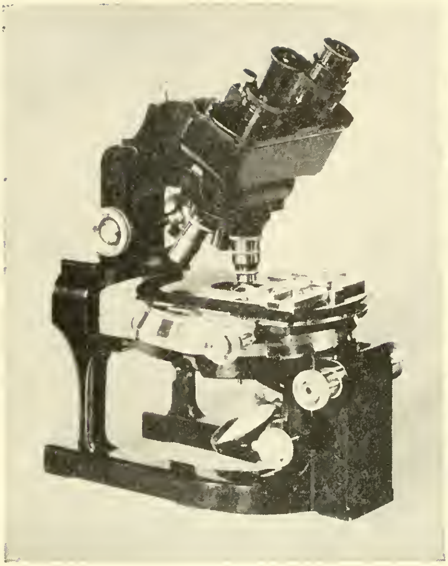


FIG. 8 (left) *The modern research microscope is far different from the simple instrument of Leeuwenhoek's day.* (SPENCER LENS CO.)

FIG. 9 (right) *One of Leeuwenhoek's many microscopes. A lens was fastened into the metal plate. The rest of the microscope is the object holder, which, by the use of screws, was used to place the object in proper position. Compare this with the modern research microscope.* (BAUSCH AND LOMB)

dog. The saliva flowed from the dog's mouth just the same and in the same amounts. This experiment was performed many times, and with many different dogs. Always the sound of the bell made the flow of saliva start.

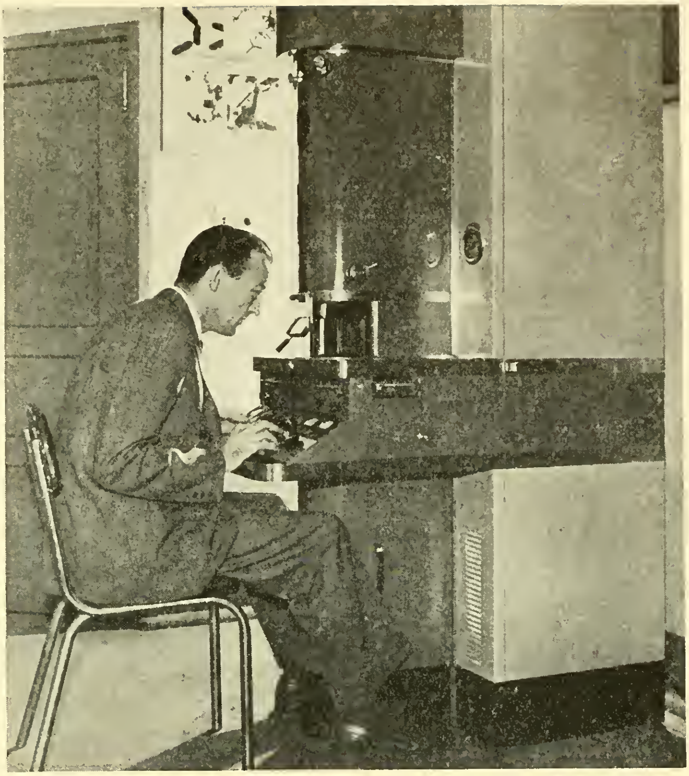
Then Pavlov varied his experiment; in one variation, as he showed the food he touched the dog on its hindquarters instead of ringing a bell; in another variation he showed the food and at the same time showed the dog a paper on which a large circle had been drawn. In each experiment, after enough repetitions there was a flow of saliva even when the food was withheld. Pavlov showed in this way that not only the normal cause, but also an unusual cause, could lead to the flow of saliva in the dog. The experiments taught scientists something about the way in which animals learn. You will read more about this later in the book.

But notice how carefully the stage was set for the experiment. Weeks spent in training the dog; years of study to make possible the delicate operation; skillful construction of the cages and harness; patient watching for results; accurate measurement and recording of the facts day after day; the repetition of the experiment with many dogs — all this was necessary to make successful what may have seemed to you at first to have been a relatively simple job.

Biologists study the "invisible." The man who first saw "invisible" or microscopic creatures was a Dutchman, Anton van Leeuwenhoek (1632–1723), whose hobby was making lenses. When he had ground and polished a small bead of glass until he was sure it would magnify well, he used it to examine all kinds of tiny objects to find out what they really looked like.

It was a great day for him and for biology when he examined a drop of the rain water that had been standing in a barrel. Picture his amazement and delight when he found that the drop was

FIG. 10 *The man is using an electron microscope. With its use it is possible to obtain photographs 200,000 times as large as the objects. You can see that the electron microscope bears no resemblance to the compound microscope.* (R.C.A.)



a little world of wriggling, squirming creatures never before seen by man. When he reported his discovery, men in other countries used their lenses to examine similar drops of water. They, too, saw these living things that had been invisible until then. They studied them, filled notebooks with descriptions of their activities, and drew careful diagrams to illustrate their structures.

The biologist improves his tools. As microscopes were improved, smaller and smaller living things were found and examined. Today, good microscopes enable us to study objects so tiny that 50,000 of them laid end to end would measure only one inch. But increase in magnifying power has not been the only advance. More important than that has been the increase in clearness of vision.

Modern microscopes are impressive instruments of shiny enamel and polished chromium but improvement in appearance is much less important than the improvements in the lenses. They are marvels of fine grinding, far, far better than any in the early microscopes. Modern instruments are unlike the early ones in another way; they magnify twice, by two sets of lenses. They are therefore called *compound microscopes.* The two magnifications are multiplied. If the lens near the object magnifies fifty times and the lens near the eye ten times, the total magnification is 500. The microscope that biologists or physicians use can generally magnify 1800 times.

Fig. 11 *Dr. Alexander Fleming in his laboratory, examining some mold cultures in test tubes. You will read more about his great contribution to the world. He discovered the drug, penicillin.* (WIDE WORLD)

Ultraviolet and electron microscopes. In using the ordinary microscope we use light that the eye can see. A little over forty years ago it was discovered that one could obtain higher magnification by using ultraviolet light. Ultraviolet light cannot be seen by the human eye but can be photographed. By this means magnifications of 4000 or even higher are possible. Objects that had been invisible under the best microscope could now be seen. More recently an electron microscope based on new principles has been invented. Recent improvements have given us a microscope that magnifies 20,000 times. Then by enlarging the negatives a magnification of about 200,000 times can be obtained! In just a few years biologists have succeeded in photographing objects that no one had ever hoped to see. You may expect the newspapers and magazines to carry exciting accounts of new discoveries in the future as the electron microscope is applied to living things and new facts are learned about their tiniest parts.

The study of living things goes on. All the world over there are biologists, both men and women, as well as boys and girls, who continue to study living things. Their activities are as varied as the activities of the living things that they study. There are so many problems to study — there is so much we do not yet know — that biological study is endless and always fascinating.

A glance at the newspaper will disclose the fact that discoveries are being made daily. As this is written it is known that there are four or more kinds of penicillin made by mold plants. They have been used successfully to combat certain types of disease germs. But we do not yet know how these types of penicillin differ or what the chemical make-up of penicillin is. By the time you read this it is likely that much more will be known about this spectacular drug.

The problem of cancer is of tremendous interest to men and women. How can we detect it as soon as it starts so that we can save a human life? What causes it? Do we know exactly how such organs as the liver and the spleen function in man? How do vitamins act to prevent certain diseases? Is "intelligence" — whatever it is — inherited? If so, how? If not, what produces it? What can we do to improve it in boys and girls? What makes us act as we do? And basic to all these questions: What kind of material is the living stuff in all plants and animals? Will we ever be able to make such living stuff in the laboratory?

There are thousands of such questions that can be asked, and, fortunately, there are thousands of men and women in every country trying to answer them.

The most fascinating part of the study of biology is that at any moment a complete or a partial answer to a problem may be provided. When you read this book you may know the answer to a question that the authors did not know when they wrote it. The pursuit of biological knowledge goes on always with continuing success.

In UNIT 1 you will consider these problems:

Problem 1. What Kinds of Animals Inhabit the Earth?

Problem 2. What Kinds of Plants Inhabit the Earth?

Problem 3. How Are Living Things Named and Classified?

UNIT I THE LIVING THINGS OF THE EARTH ARE MANY AND VARIED

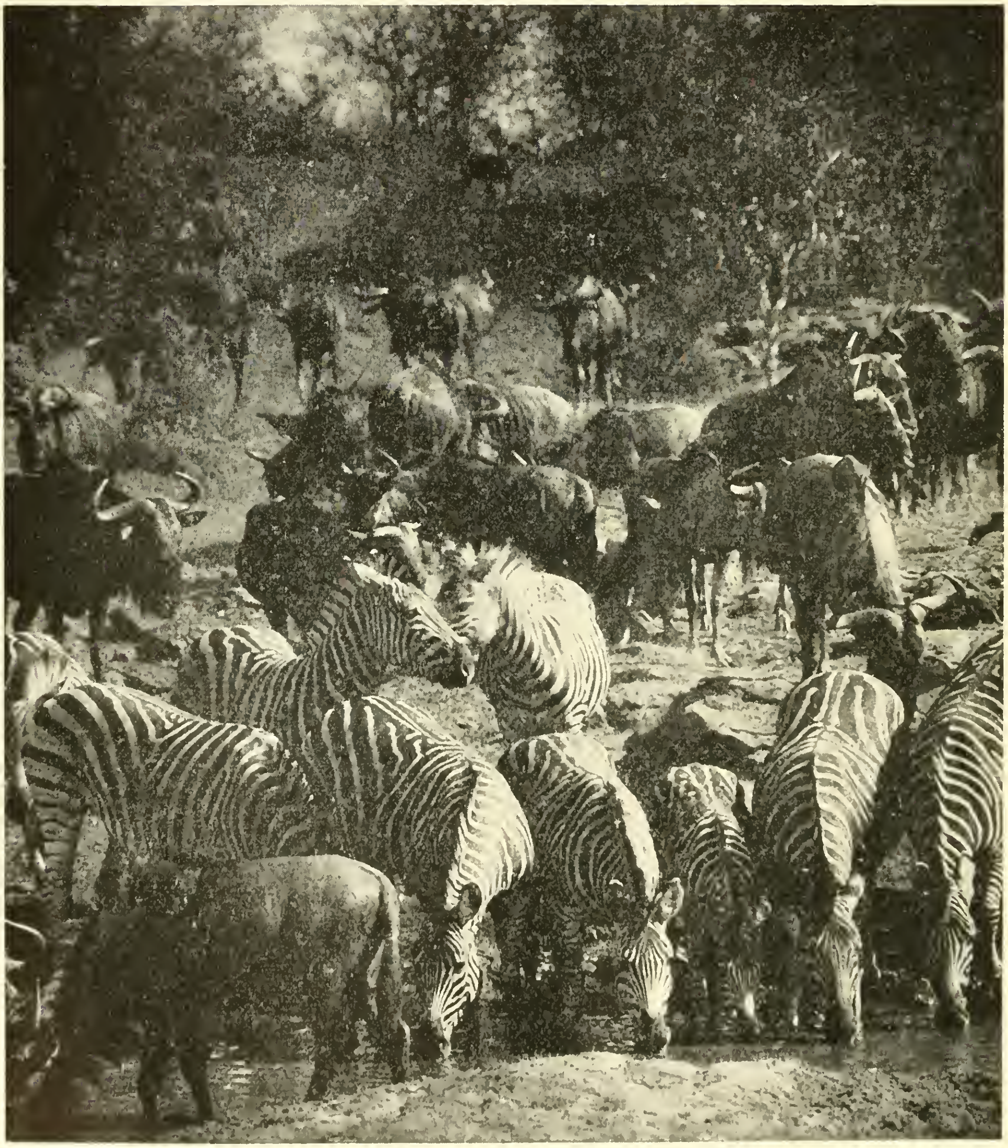


FIG. 12 *Zebras and gnus at a water hole in South Africa. Some biologists prefer to study the animals and plants of foreign lands. Others are most interested in those that live near by.* (SOUTH AFRICAN RAILWAYS)

PROBLEM 1 *What Kinds of Animals Inhabit the Earth?*

The animal kingdom. We often speak of two large groups of animals: the vertebrates, animals with a backbone; and the invertebrates, animals without a backbone. A backbone consists of separate little bones (*vertebrae* — ver'te-bree). The vertebrate group is very large and is subdivided into five classes: the mammals, the birds, the reptiles (snakes and their relatives), the amphibians (frogs and their relatives), and the fish. All these animals, different as they may seem at first glance, have important resemblances. Besides the backbone, they all have a brain in a boxlike skull (*cranium*). Attached to the brain is a spinal cord. It lies along the animal's back, protected by the backbone. All animals having these characteristics are called vertebrates.

The vertebrates, together with some other less familiar animals, are called *chordates* (core'dates). We shall not refer again to the other chordates. The name *phylum* (fy'lum) is given to such a big grouping as the chordates.

The invertebrates are arranged in many groups or phyla (fy'la). There are many more kinds of invertebrates than vertebrates. And the number of individuals is much larger, too. Commonly known invertebrates are the insects, the spiders, the lobsters, the clams, the snails, the starfish, the worms, the jellyfishes, the corals, the sponges, and the microscopic animals known as *protozoa* (proe-toe-zoe'ah). All these belong to the animal kingdom. So the ants which are insects have as much right to be called animals as dogs or horses or birds. All belong to the animal kingdom.

Subdividing the animal kingdom. You read that the animal kingdom is divided into large groups called phyla. A phylum may be divided into subphyla; generally it is divided into *classes*. Now this book and many other textbooks are divided into units and the units are subdivided into problems and the problems into paragraphs. On more or less the same principle a phylum is divided into classes and the class is divided into *orders*. In a later problem you will see that the subdividing does not stop there; it goes right on until you have the following:

Phylum
  Class
    Order
      Family
        Genus
          Species

The word *species* (spee'shees) means kind of animal (or plant) such as the dog species or cat species, the lion species, the horse species, and so on. Sometimes the species is subdivided even further into varieties or breeds.

In reading about animals in this problem you will concern yourselves mostly with phyla and classes and some of the species of animals they include.

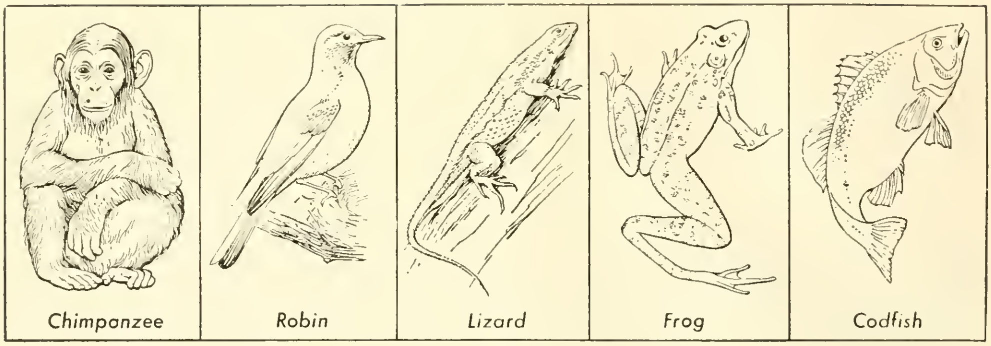


FIG. 13 *Examples of each of the five chief classes of vertebrates.*

THE VERTEBRATES

CLASS – MAMMALS

How we can recognize mammals. Mammals have a backbone; they are vertebrates. But they differ from the other vertebrates in that they have hair or fur. Some mammals have very little hair; there is little hair on an elephant's body and even less on a whale's. But every vertebrate with any hair at all is a mammal. The other striking distinguishing characteristic of all mammals is the *mammary* or milk glands by which the young are fed. Mammals breathe by means of lungs and they are warm-blooded (that is, their body temperature is fairly constant; it does not change much with changes in the temperature of the surroundings) but these are not characteristics that make them different from all other vertebrates because birds, too, have lungs and are warm-blooded. Mammals also have two pairs of legs but so do all frogs and some reptiles as well. There are about 4000 species of mammals. Because of their complex structure they are spoken of as the "highest" animals. This would be a good time for you to begin EXERCISE 1.

Man and the apes. Mammals are subdivided into groups (called orders). The group most important to us is the one containing ourselves. All mammals are somewhat like man in structure but the great apes, such as the chimpanzees, the gorillas, and the orangutans, resemble man in structure much more closely than do any other animals. For this reason man and the apes are placed in the same group. The monkeys also belong to this group.

Mammals with grinding teeth. This is a large group. It really includes several orders. You probably know giraffes, deer, buffalos, cows, gazelles and goats; horses and zebras; elephants; and rhinoceroses. Most of these animals have single or double hoofs. The hoof is an enlarged and thickened toenail. However, elephants, rhinoceroses, and some others lack a hoof and have several toes.

All of them have grinding teeth used in chewing grass and leaves. Many of them, such as cows, sheep, deer, and

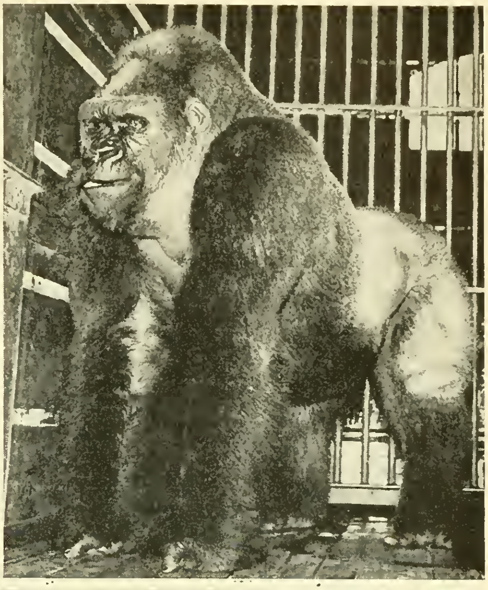


FIG. 14 (above) *The Canada lynx or bobcat.* (U. S. BUREAU OF BIOLOGICAL SURVEY)

FIG. 15 (upper right) *Gorilla.* (CHICAGO PARK DISTRICT)

FIG. 16 (right) *Camel* (NEW YORK ZOOLOGICAL SOCIETY)

Why are all of these animals called mammals? To which groups of mammals does each belong? Why is the gorilla placed in the same order as man?

others have a stomach with a large pouch which serves as a reservoir for the food swallowed while the animal grazes. Later as the animal rests this food comes up again into the mouth and is chewed as "cud."

Mammals with long eyeteeth. These are the *carnivores* (car'ni-vores). The long eyeteeth are used for tearing flesh. But some carnivores eat other foods too. Bears relish berries and small insects such as ants. Some, like the hyena, eat carrion (dead animals). But most carnivores hunt and kill. Bears, wolves, foxes, skunks, and many others have blunt, strong claws. In cats, tigers, and lions the sharp claws are pulled back when not in use.

Gnawing mammals. We all know the gnawing mammals, or rodents. There are about 2000 species spread over practically the whole globe, in the hot desert and in the arctic snow and ice. Some burrow in the ground, some live in trees, and others live in the water. You know rabbits, rats, mice, squirrels, and woodchucks. You may have seen beavers, or perhaps the dams they build. If you live in our West you have heard the whistling marmot; you have seen the prairie dogs on our great plains. Most rodents are small and timid. The two pairs of front teeth (incisors) can inflict an ugly wound but unless cornered the animal will not bite. The front teeth, used for gnawing and chiseling, are worn down by constant use. But they keep growing as long as the animal lives.

Mammals that live in the sea. A whale is so dependent on the water and so fishlike in shape and general appearance that at first glance you might not classify it as a mammal. But it has the two distinguishing characteristics of a mammal: it has mammary (milk) glands and its skin, although mostly naked, has a few bristles of hair. Like other mammals it is warm-blooded and brings forth its young alive. Whales have large amounts of fat called "blubber." This protects them against the cold. Man converts the fat into oil, obtaining as much as 150 barrels of oil from a good-sized whale.

There have been many fanciful stories about whales. A whale cannot swallow a man whole nor does it even attack man except when fighting back. And whales do not spout water. When a whale comes to the surface and breathes out, the water vapor in its hot breath condenses (just as yours does on a cold day) and the little drops of water that are formed look like a stream of water shooting up into the air.

There are other mammals that live in the sea: walruses, seals, and sea lions. Examination of their structure and particularly their teeth shows that they are really carnivores. The seals and sea lions spend part of the time on land resting or waddling about awkwardly by using their flippers as legs.

Mammals that fly. The bats are mammals that fly. They can fly better than many birds. Being mammals, they do not have feathers; they have hair. Bats resemble a tailless mouse with big ears and large folds of skin under the arms which are used as wings. All day long they hang head down, hooked to the rafters of some building or in a cave or hollow tree. Some species sleep in colonies of several thousands, coming out at night to search for food. Most bats live on insects, some eat fruits, and a few, the vampire bats, suck the blood of other mammals. It is not true that bats fly into people's hair nor do our bats hurt you in any way.

Simple mammals. The *marsupials* (mar-soo'pee-els) are simpler than the mammals you have just read about. Among the marsupials the young are born in a very undeveloped and helpless state, and the female carries the young

FIG. 17 *Like all other carnivores, the sea lion is equipped with sharp pointed teeth.* (INTERNATIONAL NEWS PHOTOS)

FIG. 18 *The opossum is the only pouched mammal found outside of Australia. What use does it make of its tail?* (GEHR)

FIG. 19 *This picture of a brown bat shows how the membranes attached to body and legs are stretched out by the long finger bones.* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 20 *The spiny anteater of Australia and a model of the egg it has laid.* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 21 *The duckbill of Australia. This mammal also lays eggs.* (AMERICAN MUSEUM OF NATURAL HISTORY)

in a pouch for a long time after birth. See Figure 384, page 433. The kangaroos of Australia and the opossums of our country belong to this group. In one common species, the Virginia opossum, the animal when discovered pretends it is dead; it "plays 'possum." There are several other kinds of marsupials in Australia besides kangaroos. The simplest mammals lay eggs. Duckbills lay eggs and have bills like a duck but since they have mammary glands and hair they are considered to be mammals. Spiny anteaters and armadillos are other simple mammals. Now do EXERCISES 2, 3, and 4. If you would like to continue your study of mammals, you will find it useful to refer to some of the interesting books on mammals listed in the bibliography at the end of the book.

CLASS – BIRDS

The characteristics of birds. Birds have feathers. There are no exceptions. That is the characteristic by which you recognize them. The feathers are usually lacking on the legs, which are covered with scales. There are two other characteristics almost as striking as the first: birds have beaks or bills without teeth and the forelimbs have the structure of wings.

Birds, like mammals, are warm-blooded; their temperature, in general, is higher than that of mammals. Some of them, indeed, have a temperature of 112°. Like mammals they have four-chambered hearts and they breathe by means of lungs. There is much that you can discover for yourself if you will follow the directions in EXERCISES 5 and 6 carefully.

Subdivision of the class. This class is subdivided into many different orders but the differences between the orders are technical and difficult to learn. In this section, we shall use a simple grouping based mostly on the kind of feet and bill: birds of prey, scratching birds,

birds that wade or swim, perching birds, and birds that cannot fly.

Birds of prey. These are the eagles, hawks, vultures, and owls. Their wings spread wide and firm; their talons (claws) are cruel, curved daggers which can be driven deep into the body of a small mammal or other bird; their strong beaks used for tearing flesh are hooked and sharp. Some hawks, eagles, and vultures are easily recognized in flight because of their remarkable ability to soar, that is, to remain aloft with almost no movement of the wings. They do this by taking advantage of the air currents. In spite of common belief, birds of prey, with few exceptions, are useful to man. Their natural food is rabbits, field mice, other small mammals, and even certain species of insects which are destructive to crops.

The vultures and some of their relatives are scavengers; they feed on the dead and decaying flesh of animals.

Scratching birds. These live on the ground and scratch for seeds and small insects; such birds are the common fowl, the grouse or partridge, and the turkey. Some of these birds are strong and swift flyers, too, but for the most part they rely on their legs instead of their wings. Domestic fowl such as chickens, ducks, and turkeys have practically lost the power of flight.

Birds that wade or swim. These are, mostly, large birds. They squawk and call hoarsely but never sing. Their food comes from the water and they spend much of their time in the water or on it. The storks, the herons, the cranes, and the flamingos (fla-ming'gos) wade. Their tall legs keep their bodies well out of the water and their long pointed beaks and flexible necks make it possible for them to snatch the frogs or fish that make up their diet.

Among the swimming birds are the ducks, geese, and swans. Their legs are

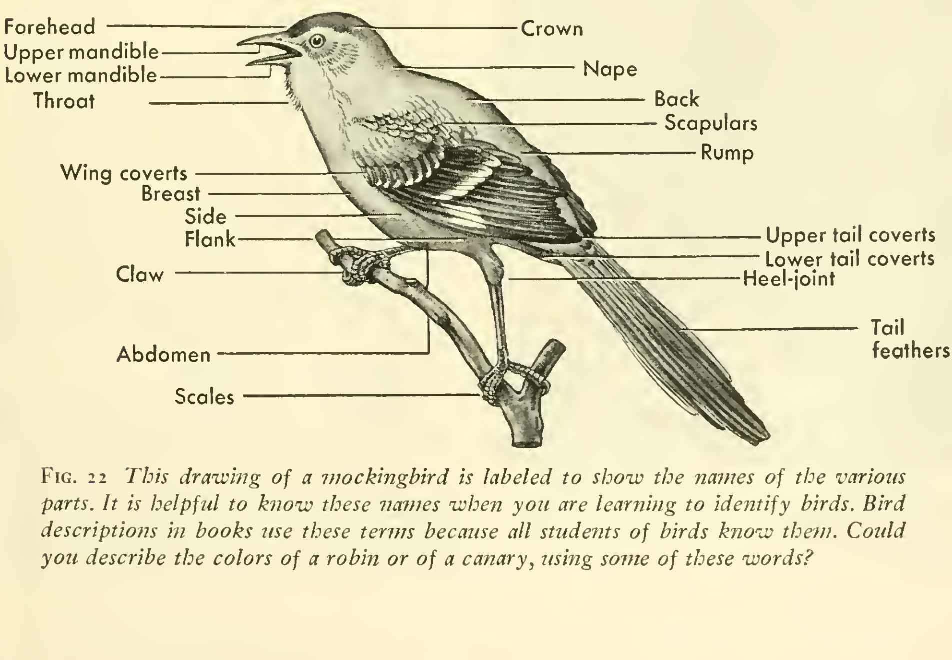


FIG. 22 *This drawing of a mockingbird is labeled to show the names of the various parts. It is helpful to know these names when you are learning to identify birds. Bird descriptions in books use these terms because all students of birds know them. Could you describe the colors of a robin or of a canary, using some of these words?*

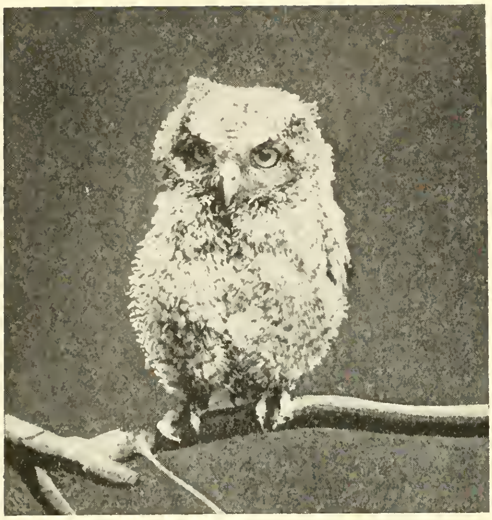


FIG. 23 *A young owl. The owl hunts at night. What do you notice about the size of its pupils? How does this help the owl?* (AMERICAN MUSEUM OF NATURAL HISTORY — OVERTON)

FIG. 24 *The American eagle. In which way is it fitted for obtaining food?* (NATURE MAGAZINE — FISHER)

strong and attached far back enabling them to exert a powerful push against the water. The position of the legs makes it easy for them to tip their heads down for a dive. Their feet are large and webbed.

Water birds all produce much oil which protects their feathers from getting wet. This fact has given rise to the common expression, "as water rolls off a duck's back."

Birds which cannot fly. A few species live wholly on land and never fly. The ostrich, the largest living bird, and its less familiar relatives have wings which are too small to be of any use. But all are good runners, running as fast as sixty miles an hour. When attacked and cornered, an ostrich defends itself by means of a kick which is dangerous to man.

Perching birds. These, for the most part, are the birds that sing. You may know best the house (English) sparrows and the starlings of our crowded cities; the robins and the bluebirds of our suburbs; or the swallows and the crows of the countryside. These, and about four hundred fifty other species, are perching birds. They are the birds to which man owes much thanks for keeping down insect pests and for eating the seeds of weeds that would spoil crops and gardens. The songbirds often steal our fruit, but their bill of fare consists largely of insects or seeds of weeds that are harmful to man.

Migration of birds. Many birds and some other animals migrate. They move from one place to another and back again in the course of a year. The migrating season is generally the spring and the fall. Many of our songbirds spend the summer in the more northerly states and the winter in the south. Some winter over in the northern states and fly to the arctic in the spring. Migrating birds may perform amazing feats of flying. The arctic tern, a water bird, builds its nest in the far north; several months later it flies to the antarctic. Although the route has not yet been completely traced, it is known that these birds fly about 11,000 miles each way. The golden plovers travel a shorter distance, from Canada to South America, 2000 miles or more, but they fly over the ocean in one stretch. They complete the journey in two days and nights without stopping to rest or feed.

There are many interesting questions about migration still unsolved. "How can birds travel so far without food and rest?" "How can they find their way?" "How can some return not only to the same state and town but to the very nest in which they were reared?" And difficult as any: "Why do birds migrate, anyway?"

Bird flight. Upward and forward motion of birds is supplied by a powerful downward and backward beat of the wings against the air. The large wing feathers overlap while the wings beat backward, but the feathers separate as the wing comes forward and up. Because the feathers separate during the forward motion, little resistance is offered to the air and not much speed is lost. When birds soar, they move their wings very little; instead, they depend on air currents, just as a glider does.

What helps the bird in its flight? Its wings are enormously long as compared

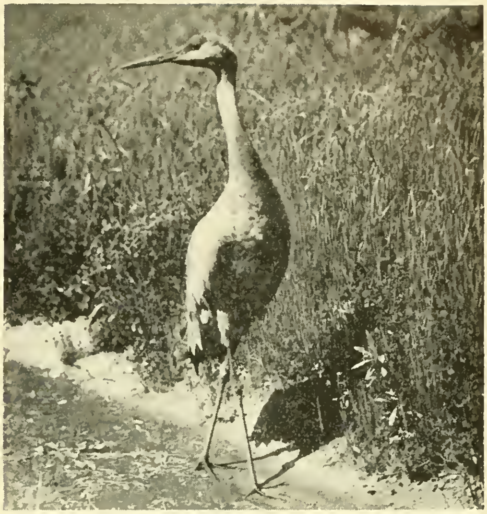


FIG. 25 *Compare the position of the eyes of this sandhill crane with the position of the owl's eyes. Note also the legs and bill.* (NEW YORK ZOOLOGICAL SOCIETY)

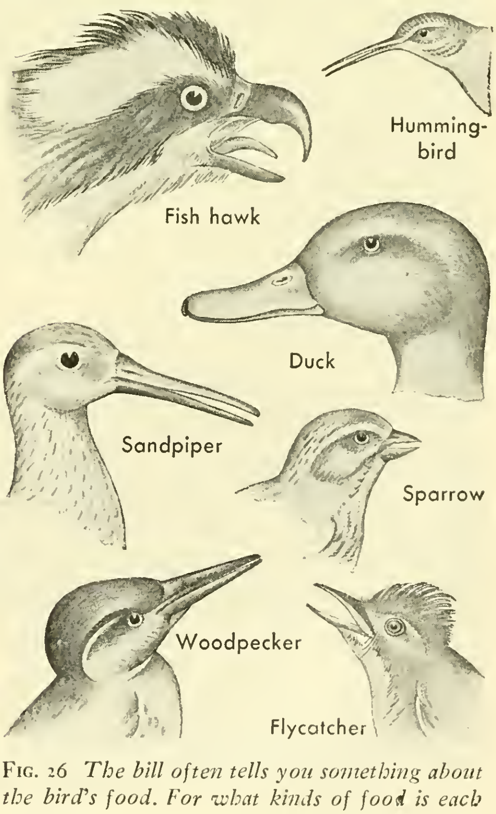


FIG. 26 *The bill often tells you something about the bird's food. For what kinds of food is each bill fitted?*

FIG. 27 *Spring migration routes of some common birds. Some of these birds follow the same routes south in the fall. Which of these birds travel the longest distance? Some of the 60 species which follow route 2 are the bobolink, chuck-will's-widow, the gray-cheeked thrush, the bank swallow, the black-poll warbler, and the night-hawk. The picture above the map is of Canada geese taken during migration. You will find it interesting to find out the migration routes of the Canada goose.* (EWING GALLOWAY)

Fig. 28 *Carolina Wren*

Fig. 29 *Sierra Junco*

The birds of Figures 28, 29, 30, and 32 are called perching birds. What do these birds eat? How are they helpful to man? What can we do to protect them? The birds that built the nests of Figure 31 are also helpful. Can you find out why? (*Fig. 28*, HUGH DAVIS; *Fig. 29*, NATURE MAGAZINE; *Figs. 30, 31, and 32*, AMERICAN MUSEUM OF NATURAL HISTORY)

Fig. 30 *Chickadee*

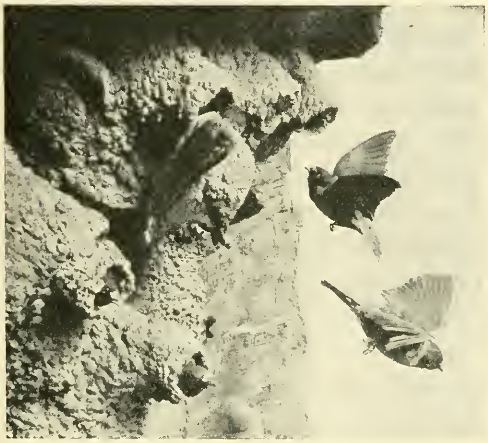


Fig. 31 *Nests of the cliff swallow*

Fig. 32 *Hummingbird*

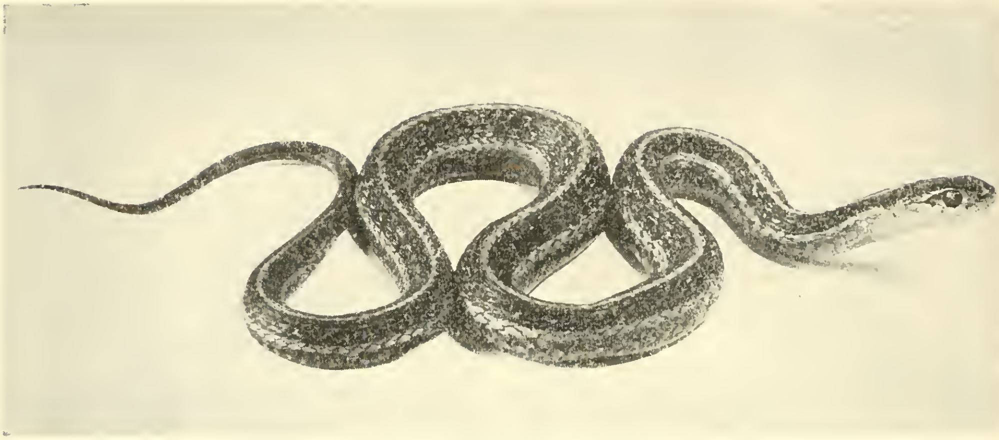


FIG. 33 *The garter snake. This snake is one of the commonest found in the United States. It is frequently seen on farms, even near the buildings, and frequently, also, in lawns and gardens of thickly settled communities. The garter snake may bite when it is handled roughly, but its bite is harmless, except as a possible source of infection. It does not lay its eggs as many other snakes do. The eggs hatch within the mother's body and the young are born alive. All snakes move by wriggling and by many small movements of their ribs which are attached to the sharp scales on their underside.* (U. S. BUREAU OF BIOLOGICAL SURVEY)

to the size of the body; there are very powerful breast muscles which move these wings. The breast bone to which the muscles are attached and many other bones are hollow, making the body exceptionally light in weight.

In the bibliography at the end of the book there are listed several books about birds. Perhaps you will wish to read one of them and learn more about birds.

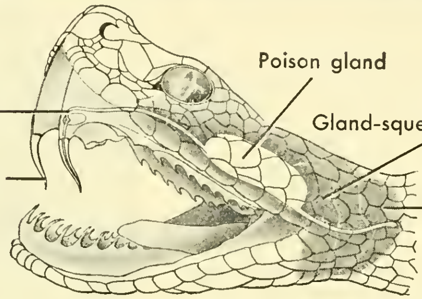
CLASS – REPTILES

What is a reptile? Like mammals and birds, reptiles have lungs. Some lay eggs as do the birds; some bring forth their young alive. But they differ from mammals and birds in that they are covered with scales. Scales, you remember, are characteristic of fish also. How, then, can one distinguish between reptiles and fish? This is easy, for fish in general get air from the water by means of gills, and their scales are slimy. Reptiles have lungs and dry scaly skins.

Reptiles are the first vertebrate animals you have met in this book that are cold-blooded. The body of the cold-blooded animal is sometimes warm and sometimes cold, depending on the surroundings. Reptiles are most common in the tropics; as you go northward you may expect to find fewer and fewer reptiles. In a climate such as that of the northeastern states where winters are cold, reptiles are active and visible during only a short season. As fall comes on they become sluggish and soon go into a state of *hibernation* (winter sleep) underground. Some reptiles run on four legs, some on two, while some wriggle without any legs at all. Many live on land; others dwell in fresh water or in the salty ocean. Zoologists divide them into three main orders which you can easily recognize: the snakes and lizards,

Fig. 34 *How many rattles has this rattlesnake? It is not true that one can tell a rattlesnake's age by the number of rattles.* (U. S. BUREAU OF BIOLOGICAL SURVEY)

Fig. 35 *The head of a rattlesnake ready to strike. Where is the poison gland located with relation to the fangs?*



alligators and crocodiles, and turtles.

Our poisonous snakes. The feeling of horror that snakes arouse in some people is unreasonable. As a child you may have seen your elders shrink at the sight of a snake and you may have learned to imitate them. Children left to themselves have no more fear of snakes than of any other animals that seem strange. Most snakes are harmless; poisonous snakes are the exception. In this country there are only four kinds of poisonous snakes: the rattlesnake, the copperhead, the water moccasin, and the coral snake. On our continent man is rarely bitten, even where poisonous snakes are numerous, for with the exception of the water moccasin our poisonous snakes are timid; they do not attack unless they are disturbed. Still more rarely does any one die of the bite. An understanding of the methods of treating a bite and the courage to remain calm almost always prevent serious results from the poison.

The poison is injected through a pair of large, hollow, very sharp fangs (teeth). These are in the upper jaw, folded back out of the way until the snake strikes. The swiftly-moving little tongue contains no poison; the snake uses it to learn of its surroundings.

Rattlesnakes are widely scattered over the United States. When disturbed, they sound their rattles, which are located at the tip of the tail, so that it is easy to avoid them. It is only when they are taken by surprise that they strike without warning. The amount of poison injected depends on the size of the snake. Large rattlers are therefore more dangerous than small ones. The copperhead is found in various regions in the northern half of the country. The water moccasin and the coral snake are not

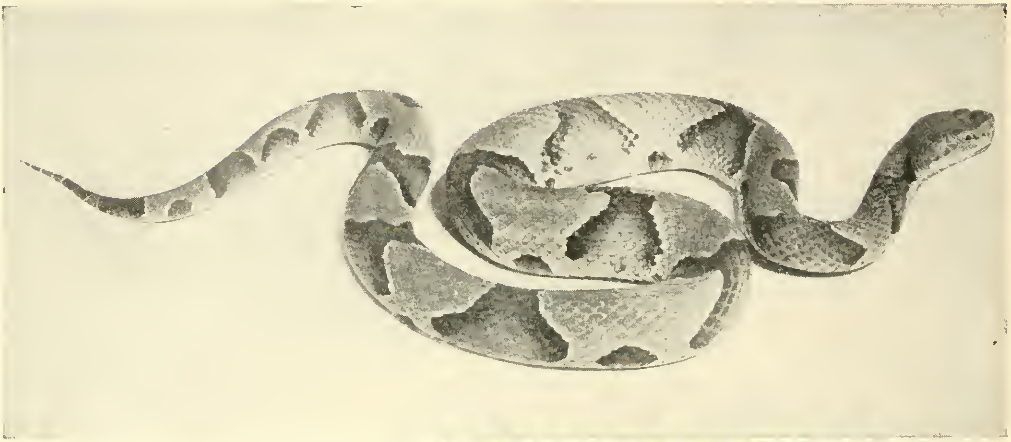


FIG. 36 (above) *An adult copperhead may be two or two and one half feet long. As in rattlers and water moccasins, the head is triangular.* (U. S. BUREAU OF BIOLOGICAL SURVEY)

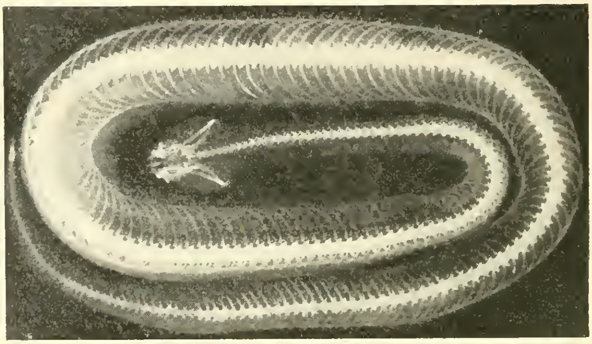


FIG. 37 (right) *This x-ray photograph of a snake shows the long backbone and the many ribs which help in locomotion.* (GENERAL ELECTRIC X-RAY CORP.)

uncommon in the south. The water moccasin, which lives in swamps, is sometimes called "cottonmouth" because the inside of its mouth is white. The coral snake is smaller than the water moccasin and has short fangs but when it bites, it hangs on, and sometimes its bite is serious. It often burrows in damp ground. Do EXERCISES 7 and 8.

Peculiarities of snakes. Snakes have an enormously long backbone, consisting of many vertebrae each of which, except at the tail end, has a pair of ribs. Muscles connect the ribs with the scales on the lower part of the snake. By moving the ribs, the scales are hooked onto the uneven surface of the ground, one after the other. Thus the snake really wriggles on its scales, but this happens so fast and evenly that it looks like a smooth gliding motion. No snakes have legs, although the pythons (pie'thons) of Asia have tiny stumps of hind legs which are not used.

Because of its peculiar formation, a snake's mouth can be opened so wide that it will admit an animal broader than the head of the snake. The animal must be swallowed whole since the teeth are not used for biting off or chewing food. At irregular intervals as snakes grow they develop a new skin underneath the old one. The old skin is then shed as in the photograph, Figure 39.

Snakes of other countries. While snakes in our part of the world are not a real danger, in India, Central and South America, and other tropical regions

Fig. 39 (above) *A hog-nosed snake losing its old skin. As a snake grows its skin becomes too small. A new skin forms under the old one.* (AMERICAN MUSEUM OF NATURAL HISTORY)

Fig. 38 (left) *This swift is a typical lizard. Notice the claws on its toes. What characteristics of a lizard does it have? Why is it classed as a reptile?* (AMERICAN MUSEUM OF NATURAL HISTORY)

snakes are a serious menace. It is estimated that in India alone they kill about 20,000 people every year. One of the most deadly snakes of India is the cobra. It is vicious, and injects a particularly strong venom (poison). There are also huge pythons in India which reach a length of more than thirty feet. They coil themselves around their victims and crush them to death. Some of the boa (boh'a) constrictors and anacondas of the tropical Americas may also reach a large size. Many reptiles, unlike other animals, keep on growing throughout their lives and they live long.

Lizards — the closest relatives of snakes. People often call the little four-legged, soft-bodied salamander, so common in the woods, a lizard; but since it lacks a scaly covering you know it cannot be a reptile, and must not be called a lizard. Lizards have, as a rule, slender bodies with long tails and four rather short legs which can move with great speed. Lizards live in warm climates.

Lizards of the United States are, with one exception, harmless. The one lizard which bites and has poison fangs is the red and black striped Gila (hee'la) monster. It lives in the deserts of Arizona and New Mexico.

Alligators and crocodiles. Alligators and crocodiles are large reptiles which inhabit only the warmer portion of the globe. Even there they are sluggish, resting motionless in shallow streams with their eyes and nostrils above the surface of the water. However, the sight

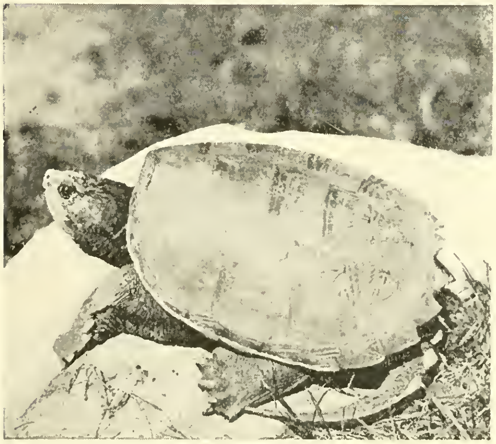


FIG. 40 (above) *These tadpoles are the youn of the green frog. How do they differ from an adult frog?* (HUGH SPENCER)

FIG. 41 (left) *The snapping turtle is found in ponds or rivers. It has a dull brownish shell with notches at the back. Why are turtles classed as reptiles?* (AMERICAN MUSEUM OF NATURAL HISTORY)

of some unwary animal along the banks will quickly rouse them to activity.

Turtles. Turtles have a complete backbone, ribs, and all the other bones you should expect a vertebrate or a "backboned" animal to have. The shell develops from the skin of the upper and lower surfaces and becomes attached to the backbone and the ribs. Head and legs are, of course, covered with the ordinary scales characteristic of reptiles. Turtles may eat plants, insects, frogs, fish, or any other small animals. Their horny, toothless jaws are sharp and strong and are used for tearing and biting, much as teeth are used by other animals. In a few species the shells remain soft. To become better acquainted with reptiles read one of the books listed in the bibliography.

CLASS — AMPHIBIANS

How we can recognize amphibians Amphibians, like reptiles, are cold-blooded vertebrates. Their skin is naked and in almost all species is soft and moist. They are called amphibians because most of them spend the first part of their life in the water and the other

FIG. 42 *A green frog can jump fifty times its length. What structures make this possible?* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 43 *The American toad cannot jump as far as the frog. Can you tell why?* (SCHNEIDER AND SCHWARTZ)

part on land. While in the water stage they obtain air by means of gills; in the land stage they use lungs for breathing. There are a few species which do not develop lungs at any stage and never leave the water; when full grown they resemble a legged tadpole.

Amphibians with tails. Biologists divide the class Amphibians into two orders – those with tails and those without. The tailed forms, the salamanders and newts, might be mistaken for lizards until one discovers the moist, naked skin. They are timid, harmless creatures; their feet have no claws and their jaws are weak, unfitted for biting. They catch insects with the tongue. Some of the tailed amphibians are brightly colored; others, like the hellbender, are dull and unattractive. One that many of you may have found in the woods, under logs or leaves, is the beautiful red newt.

Amphibians without tails. You are much more familiar with this group which includes the frogs and toads. They feed on insects which they catch with their long, slimy tongue. They lay their eggs in fresh water; these hatch into tadpoles which change into adults as legs and lungs form. Frogs when fully developed, continue to spend at least part of their time resting just under the surface of the water with eyes and nostrils raised above the surface. The hind feet are webbed and are equally useful for swimming and jumping. Toads, on the other hand, leave the pond and return only in the spring to lay their eggs. Their skin becomes so dry that it looks shriveled and warty. The statement that you can get warts from handling toads was long ago proved to be untrue. Toads are not only harmless to us but are a great help to the gardener because they eat insects. DO EXERCISE 9.

CLASS – FISHES

What is a fish? As you turned from the most complex vertebrates, the mam-

FIG. 44 *Sharks belong to a group lower than fishes. They have neither true scales nor bones. Gill covers are lacking. This shark has two shark suckers attached to its lower side.* (NEW YORK ZOOLOGICAL SOCIETY)

mals, to the simpler ones, you met first the birds, then the reptiles, then the amphibians. There are other cold-blooded vertebrates even less complex; these are the fishes. Their distinguishing characteristics are slimy scales, fins, and gills. Of course they have a backbone just as other vertebrates do. They are water dwellers, obtaining the oxygen they need from the air dissolved in the water. Out of water, fish die quickly because their gills cannot take oxygen from the atmosphere. Most fish have paired fins, usually two pairs, and other fins which occur singly. Make your own observations of fish by doing EXERCISES 10, 11, and 12.

"Fish" that are not fish. The animals of this group are closely related to fish but have skeletons made of a softer substance called *cartilage* (car'til-aj). You may know cartilage by the name of gristle (griss'l). One of the commonest is the dogfish that destroys large numbers of food fishes along the coast. Sharks are its larger cousins, with reputations often much worse than they deserve. Most species of sharks do not attack man but eat only fish and other animals of the sea.

Fish are numerous and varied. There is three times as much sea as land. You can see that there is plenty of room for fish. Great numbers live in both warm and cold waters; even in the arctic seas there are fish. Some kinds swim near the surface, others far below. It is estimated that at present there are about

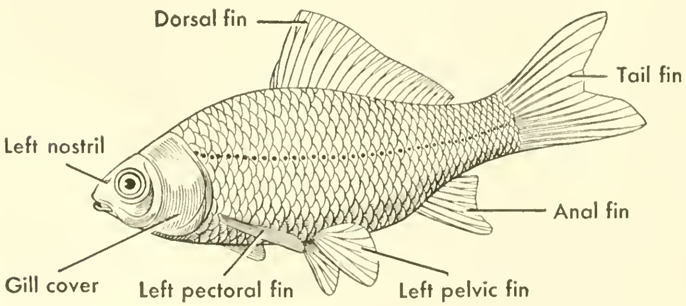


FIG. 45 *Which characteristics of fishes does this goldfish have? Where are the gills? How many fins has the goldfish?*

FIG. 46 *Fish move by means of the muscular tail to which the broad tail fin is attached. They have other fins, both paired and unpaired, which are used principally for balancing.* (NEW YORK ZOOLOGICAL SOCIETY)

two and a quarter billion people in the world. But that is a tiny number compared to fish populations. Of the herring, alone, man catches and kills about eleven billion each year. It has been estimated that 200 billion other herring are eaten annually by larger fish. Yet the ocean remains well stocked with herring. Twelve thousand different species of fish have been described. They range in size from the large tuna fish, which weighs three quarters of a ton, to the guppy of your aquarium which measures a scant inch and weighs so little you could not feel its weight in your hand.

Some interesting fish. The flatfish, that is, the flounders and the soles, are curiously built. They are extraordinarily flat from side to side and spend most of their time lying on one side half buried in the sand. Both eyes are on one side, the side which is always up. In the young fish the eyes are where you would expect them to be, one on each side of the head. Then one eye moves around and joins its mate.

You may have heard of "flying fish," but fish cannot really fly. All fish, when swimming rapidly, push themselves through the water entirely by means of their muscular tails. When near the surface this motion of the tail may drive them out of the water, so that fish are often seen jumping. The flying fish have very long paired fins which they spread as they jump. Thus, they glide through the air. Among the strangest fish are those that can breathe by means of lungs. They also have gills. Plan to do EXERCISE 13.

Fish migration. Fish migrations are as interesting and as puzzling as are bird migrations and, naturally, much more difficult to study. Although eels had been known and caught as a food fish for thousands of years, until about thirty-five years ago no one knew where they laid their eggs or where the young grew to be adults. Each fall thousands of mature eels were seen to swim down the fresh water streams of Europe and America into the Atlantic Ocean. There they disappeared. Finally a scientific expedition tracked them to a region east of the Bermuda Islands where they lay their eggs in deep waters. Then the parents die. The young fish remain for a year near where the eggs hatch. Then they begin the long journey to homes they have never seen in the rivers of the two continents. The American eels turn toward the rivers of our country; their European cousins travel eastward. When they are mature, they swim back to the breeding grounds in the Atlantic Ocean.

The salmon, which live in the ocean when adult, migrate into fresh water at *spawning* (egg-laying) time. They swim far up into the shallow headwaters of streams. Here the eggs are laid. Then most of the parents die. The young develop slowly and eventually swim out to the sea, where they remain until they are ready for spawning. Within the last few years much has been learned by the United States Bureau of Fisheries about the migrations of fish. Thousands of fish are tagged and fishermen are asked to return the tag with information as to the size of the fish and the place where it was caught. Fish are interesting to read about; see the bibliography at the end of the book.

Questions

1. Into what five subdivisions or classes can the vertebrates be divided? What two or three characteristics do all vertebrates have?
2. Starting with the largest group, the phylum, list the subdivisions employed by biologists in classifying animals.
3. In what two respects do mammals differ from all the other kinds of vertebrates? Why may they be spoken of as the highest animals? How many species of mammals are known to scientists?
4. Which mammals are most like man in structure?
5. List nine kinds of mammals that may be grouped together as plant eaters with grinding teeth. What is another characteristic of most of these mammals? Explain.
6. What are the characteristics of the carnivores? List some carnivores.
7. Give the name of the gnawing mammals. What can you tell about the gnawing teeth?
8. Give two reasons why a whale is classified as a mammal. State two interesting facts about whales. What other mammals inhabit the sea? Why are they classified with dogs or cats rather than with whales?
9. Tell what you know about bats.
10. What are the characteristics of marsupials? Where do most of them live? Which animals in our country are closely related to the Australian kangaroo? Why is the duckbill called a mammal? List two unusual characteristics of the duckbill.
11. By which one characteristic can you always recognize a bird? What are other characteristics of a bird?
12. How are birds classified?
13. Describe and give examples of birds of prey. In general, are they useful or harmful to man? Explain.

14. List some of the scratching birds. What do they eat?
15. List some wading birds. What are their characteristics? How do swimming birds differ from wading birds?
16. Which is the largest living bird? What are its peculiarities?
17. About how many species of perching birds are there? What is the importance of these birds to man?
18. What can you tell about bird migration as to: when birds migrate, in which direction birds migrate in the various seasons, and how far birds fly during migration. What problems in regard to migration are still unsolved?
19. Explain how birds can fly. List three characteristics which enable birds to fly. How does soaring differ from flying?
20. By which characteristics do you recognize reptiles? When an animal is called cold-blooded, what really is meant? Where are reptiles most common? Define hibernation. Into what three main groups (orders) are they divided?
21. What are the four kinds of poisonous snakes found in this country? Tell some facts about each of them.
22. State the peculiarities of structure in snakes. Explain how they carry on locomotion and how they feed.
23. Tell something about the important snakes of other countries.
24. Describe how lizards resemble and differ from snakes. Which is the only poisonous lizard in our country?
25. Why may alligators and crocodiles be dangerous to man?
26. Why are turtles called reptiles? What do they use as food and how are they fitted for getting this food? Of what importance are they to man?
27. What are the striking characteristics of amphibians?
28. Into what two groups (orders) are amphibians divided? Give an example of each order. Compare the tailed amphibians with lizards.
29. Discuss the habits of frogs and toads. Of what importance are toads to man?
30. State how you distinguish fish from other vertebrates. How do gills differ from lungs?
31. How do sharks differ from true fish?
32. How numerous are fish as compared to land living vertebrates? How do fish vary in size and appearance?
33. Describe the migration of eels and salmon.

Exercises

Mammals

1. Collect pictures of mammals and group them according to order on charts or in a looseleaf notebook.

2. If possible, visit a zoo or natural history museum. Gather facts of interest about several different kinds of mammals. To which order does each belong?

3. Prepare special reports on topics such as the following: (*a*) The intelligence of the great apes, (*b*) the mammals of a special region, such as Australia, (*c*) the mammals of my vicinity, (*d*) man's use of mammals.

4. When you have finished the section on mammals, gather together all the important ideas you have learned about mammals under the following headings: a list of mammals with those of one order gathered together; the uses of mammals to man; the harm done to man by other mammals; unusual mammals; mistaken ideas or superstitions about mammals.

Birds

5. Study of a living bird. If possible, observe a canary, a pigeon or a chicken. Or study a house sparrow or some other common bird, out of doors. How long is the bird? If you can handle it, find out how large the bird's body is and how wide a wingspread it has. What markings does it have? Describe their location accurately. (Make use of the diagram in the text.) How far down on the legs do the feathers go? In what direction do the feathers on the wings and body point? Where are the longest feathers? the shortest? Describe the toes. Examine the eyes closely. Describe. How far around can the bird turn its head? Describe the beak and method of getting food.

6. Have you ever looked closely at a feather? Cut the quill crosswise to find out why it is so light. Use a hand lens for the study of the other parts. Cut a point on the end of a large quill and use it as a pen.

Reptiles and Amphibians

7. Have you heard about the snake that swallows the end of its tail and rolls like a hoop? Have you heard of the milk snake that steals milk from the cow? Have you heard that horsehairs left in water will turn into snakes? Comment on each of these statements. State: (*a*) What your reason would lead you to believe and why, (*b*) whether in these cases observation or experiment might help you arrive at the truth, (*c*) what else you might do to convince yourself that each story is or is not true.

8. Are there poisonous snakes in your part of the country? Ask the class secretary to write to the nearest college or zoo to find out. What are they? Where are they likely to be found? How can you avoid being bitten?

9. Using the facts presented in this book, write a brief report on the importance of reptiles and amphibians to man. Add more information if you are sure it has been obtained on good authority. State what authorities you consulted so that others can decide whether or not to accept the information.

Fishes

10. Study of a living fish. Examine a goldfish in a bowl of clear water. Where are the paired fins; the unpaired fins? Examine and describe a fin which is spread out. How are the scales arranged? Is this of any advantage to the fish? Try to catch the fish with your hand. What do you notice? Describe the movement of the gill cover. What do you see underneath it when it is raised?

11. State at least four ways in which the structure of a goldfish makes possible rapid movement through the water.

12. Stir the water in the goldfish bowl to make the fish swim quickly. What part of the fish pushes it forward? What part do the paired fins play in locomotion?

13. Organize a class trip to a fish market on a Thursday afternoon after school. List the kinds of fish. Take notes on their sizes, colors, and markings so that you can recognize them again. How much do they cost per pound? Compare the price with that of lamb, chicken, beef, and pork. Why can fish usually be sold more cheaply than meat?

Further Activities in Biology

Mammals

1. Make plaster casts of the tracks of mammals. (See Mann and Hastings, and others.) If you can get dogs, cats, rabbits, and white mice, you can take their footprints by wetting their feet with ink and leading them across sheets of wrapping paper.

2. Since the class Mammals is so large, you and your classmates might organize committees to make a special study of the different orders. If written reports are prepared, they could be organized into one large account of the mammals.

3. Breed white mice, guinea pigs, or rabbits, so that live mammals are available for study.

4. If you can, learn something about the habits of one of the following: rabbit, woodchuck, chipmunk, squirrel, prairie dog, deer. If possible, take "notes" with a camera.

Birds

5. If there is no Junior Audubon Society in your school, ask the class secretary to write to the National Association of Audubon Societies, 1000 Fifth Avenue, New York City, for further information.

6. Are you a Scout? Have you earned the Bird Study Merit Badge?

7. Even if you live in a city, it will be easy for you to keep and breed pigeons on the roof.

8. Write to the Geological Survey, Washington, D.C., about bird-banding. Read the *National Geographic Magazine*, January, 1928. Report to the class on the subject.

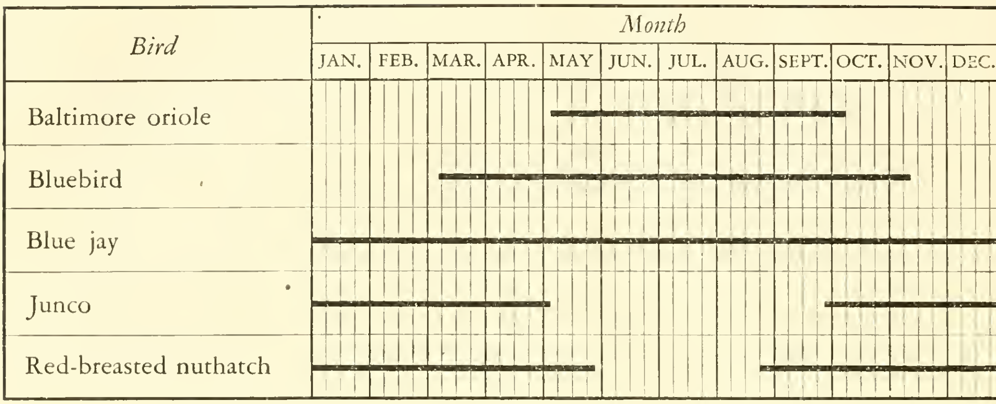


FIG. 47 *A bird calendar for Boston, Massachusetts. Which bird stays the year round? Which leave Boston in the fall? In the spring? See Exercise 13.*

9. Can you get birds to stay in your neighborhood? Establish winter feeding stations. See National Association Audubon Societies leaflets; or A. A. Allen, *Book of Bird Life.*

10. If you are good at making things with your hands, build bird houses and bird baths. You will enjoy watching the birds use them. See L. H. Baxter, *Boy Bird-House Architecture.*

11. Do you know any birds by their calls or songs? Some of them are very easy to recognize. Get phonograph records of bird songs to play in the classroom. Records can be purchased from the Laboratory of Ornithology, Cornell University, Ithaca, New York. In some cities these records can be rented from The Audubon Society.

12. Make a collection of deserted bird nests and show them to the class. How many different kinds of materials go into the making of these nests? (Do not collect nests still in use.)

13. When you have learned to recognize many kinds of birds you will enjoy making a "bird census." List all the birds found in your locality. Examine Figure 47. It would be interesting for you to prepare a bird calendar for your part of the country.

14. Bird photography is a fascinating hobby. Much information can be obtained from the camera department of *Nature Magazine* and magazines on camping, hunting, and fishing. The finest achievement is a series of pictures showing the life of the bird from egg to adult.

Reptiles and Amphibians

15. A terrarium (glass) may be set up for salamanders, newts, and frogs. Mosses and small ferns will help to make a forest floor.

16. Can you plan an experiment to discover the effects of changes in temperature on cold-blooded animals like the snakes and lizards? Use ice and warm water but do not wet the animal. Why must you change the temperature slowly?

17. Report on the best treatment for snake bites.

18. Frogs and toads make excellent subjects for night photography. Use a flashlight to find them, open the lens of your camera, and then burn a photoflash bulb. The flash lasts about one fiftieth of a second. The lens is closed afterward.

Fishes

19. Use a natural history such as Hegner's *Parade of the Animal Kingdom* or copies of the *National Geographic Magazine* to learn more about fish and their relatives, the sharks. Prepare a short talk.

20. Have you ever maintained an aquarium of tropical fish? If you have, report briefly to your class on their structure and habits. Could you start an aquarium?

21. Look up lungfish. Tell your classmates why biologists consider them important.

The Invertebrates

Animals without backbones. You know that invertebrates have no backbone. Whatever skeleton they may possess is either on the outside, like a coat of armor, or is so different from the skeleton of the backboned animals that you would never confuse the two. And while all vertebrates are assigned to a single phylum the kinds of invertebrates are so varied that they are arranged in different phyla. Zoologists are not all in agreement on just how many phyla the invertebrates should be divided into. However, all classifications include the nine important phyla we will study. In the diagram on page 40 there are drawings of one representative of each of these nine phyla. From the many thousands of possible kinds these nine were chosen: a grasshopper, a snail, a starfish, an earthworm, a hookworm, a planaria (a relative of the tapeworm), a jellyfish, a sponge, and an ameba. In this book only a very few of the thousands of species of invertebrates can be described. There are about 800,000 species of invertebrates in contrast with the 40,000 species of vertebrates.

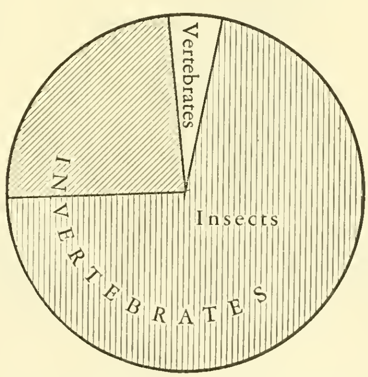


FIG. 48 *This circle graph will help you compare the numbers of species of invertebrates and vertebrates. It will also help compare the number of species of insects with the total number of all other kinds of invertebrates. There are approximately 40,000 species of vertebrates and 800,000 species of invertebrates, of which 600,000 are insects.*

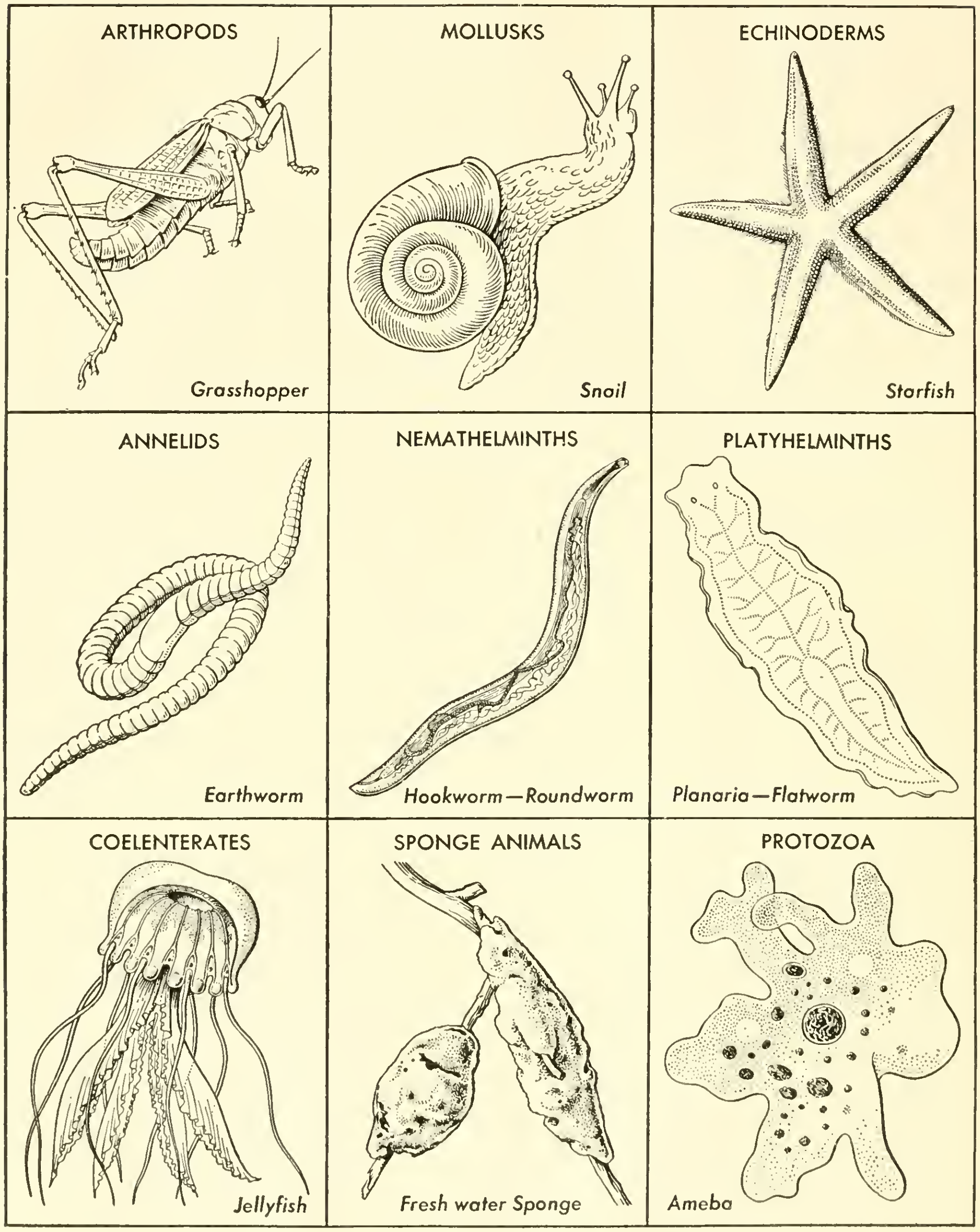


FIG. 49 *The invertebrates are classified by zoologists into numerous phyla. One member of each of the nine principal phyla is illustrated above. Do you know other members of these phyla?*

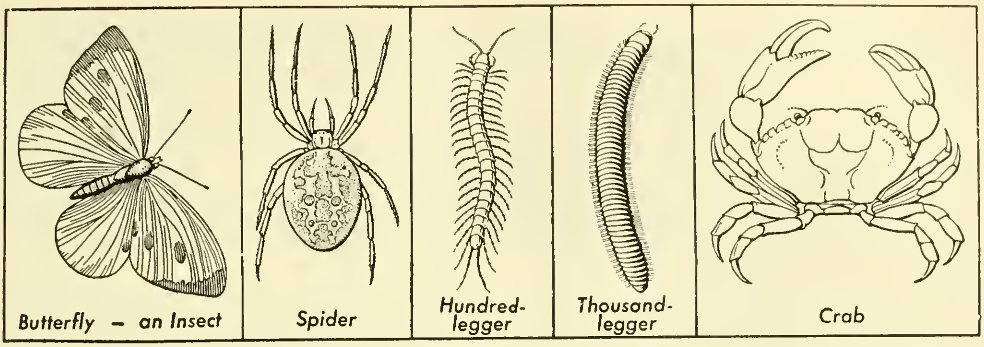


FIG. 50 *These are representatives of each of the five principal groups of the Arthropod Phylum. Which common animal is an example of each group?*

PHYLUM – ARTHROPODS

Jointed-Legged Invertebrates

A glance at the arthropods. The invertebrates with jointed legs, or arthropods, are the most complex invertebrates. You can recognize an arthropod by two characteristics: they have jointed legs and they have an external (outside) skeleton made not of bone or cartilage, but largely of a material called *chitin* (ky'tin). Most of the arthropods can be classified in five groups or classes. Examples of these five classes are represented in Figure 50: the insects, the spiders, the hundred-leggers, the thousand-leggers, and the *crustaceans* (crus-tay'shuns) which include crabs and lobsters.

What is an insect? Let us begin our study with the most common arthropods, the insects. Insects differ from the other arthropods in that they have six legs and three distinct body parts: a head with feelers called *antennae* (an-ten'nee), a *thorax* with three pairs of legs, and an *abdomen* (ab-doh'men). The abdomen never has legs. In the abdomen you can see distinct rings called *segments*. Most insects have two pairs of wings, but you cannot depend on this as a way of recognizing insects, since some insects have only one pair and others have no wings at all. The wings, legs, and feelers are called *appendages* (ap-pend'a-jes). If you examine Figure 59 and the other pictures of insects, you will see the parts mentioned here.

Most insects have large eyes, called compound eyes because each eye consists of many six-sided lenses. Insects can hear, too. Some have eardrums; some seem to use the feelers as organs of hearing. But the feelers seem to serve also as organs of smell and touch.

Insect flight is very different from bird flight. In most insects the wings move with astonishing speed. The house fly's beat is about 330 times a second. You can understand why it makes a buzz. However, the speed is not the same in all insects. The grasshopper has been timed at twenty miles an hour. The "darning needle" can fly at the rate of sixty miles an hour but no insect flies far without stopping.

The life story of an insect. Let us trace the life story of a common insect, a

FIG. 51 *Three stages in the development of the monarch or milkweed butterfly are shown. The changing-over stage (pupa stage) is called the chrysalis. It has a hard coat. Which stage is not illustrated?* (AMERICAN MUSEUM OF NATURAL HISTORY)

butterfly or moth. The eggs laid by the parent develop into wormlike creatures called caterpillars. A caterpillar does not look at all like an insect; it certainly lacks the three-part division of the body and seems to have more than the typical number of legs. It has no wings and no feelers. After a period of steady feeding it either forms a hard protective coat or builds a little house around itself. If the little house is spun, it is called a cocoon (kuh-koon′). Many changes occur within the cocoon and after some time the insect comes out a full-grown butterfly or moth. These insects, therefore, go through four stages: the egg; the caterpillar, called the *larva;* the changing-over stage, called the *pupa* (pew′pa); and the adult. This complicated life history is referred to as a *complete metamorphosis* (change). Many other insects have these four stages in their life history. All the ants, bees, wasps, flies, mosquitoes and beetles have complete metamorphosis.

There are other insects, the grasshopper for example, that lack a pupa stage. In these there are only three stages: the egg, the nymph which is much like the parents, and the adult. This kind of life history is called *incomplete metamorphosis.* If you are interested in insects you will want to do some of the things suggested on pages 68–70.

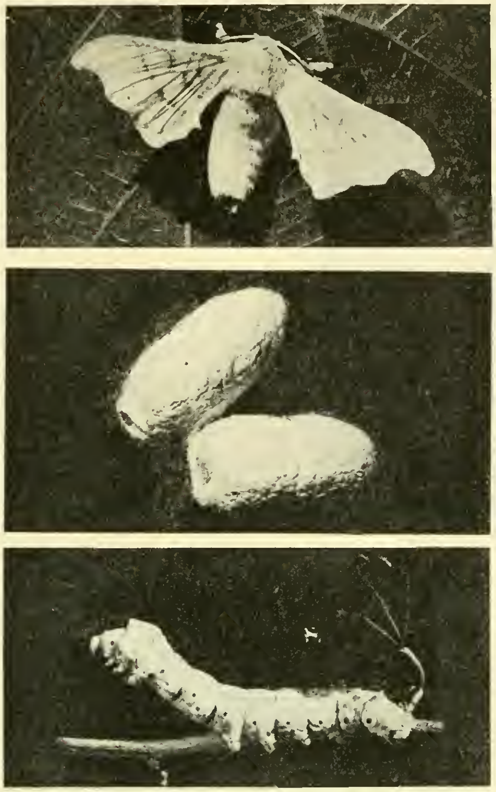


Fig. 52 *Silkworm moth. Adult* (top), *empty cocoons* (center), *larva* (bottom). *The adults lay eggs which hatch into larvae. Each larva spins a cocoon of 2400 to 3600 feet of silk fiber. Do you know what the larvae eat and how silk thread is made from the cocoons?* (AMERICAN MUSEUM OF NATURAL HISTORY)

Fig. 53 *Luna moth.* (BUREAU OF ENTOMOLOGY)

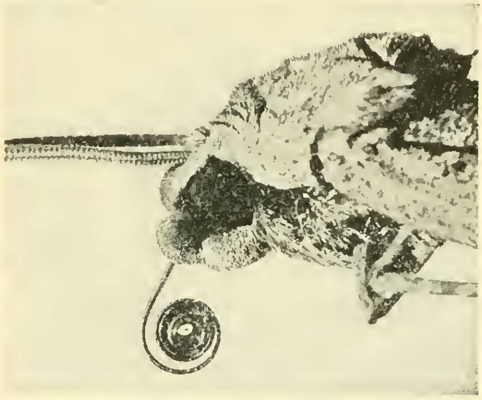


Fig. 54 *Coiled sucking tube of a moth.* (GENERAL BIOLOGICAL SUPPLY)

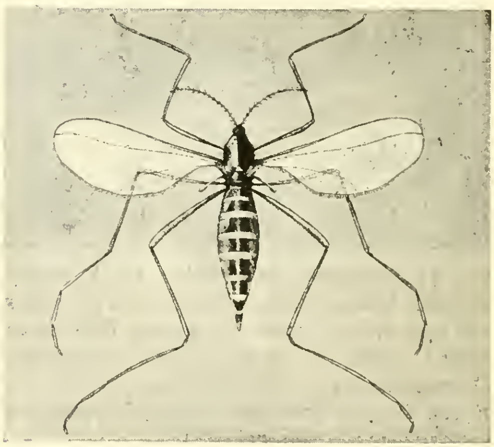
Insects with scaly wings. This group includes moths and butterflies. These insects have large wings covered with tiny scales. The scales are often brightly colored and in some species are arranged in gay patterns. They are loosely attached, as you know if you have ever handled a butterfly or moth. If you use a microscope you can see that the "powder" that comes off the wing consists of these scales. The bodies of moths have much more "hair" on them than have those of butterflies; their bodies are also heavier and often more clumsy.

Butterflies and moths suck nectar (a sugary liquid) from flowers. The mouth parts form a tube, sometimes a very long tube, which is kept coiled up when not in use as illustrated in Figure 54. When extended some tubes will reach the nectar bags at the bottom of deep flowers.

The feelers or antennae of moths are feather-like, while those of the butterfly are smooth and sometimes knobbed at the tip. If you watch moths and butterflies when they alight you will detect yet

FIG. 55 (left) *Have you ever seen the tongue of a housefly moving up and down as it lapped its food?* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 56 (below) *The Hessian fly injures wheat. Its larvae suck the sap from tender parts of the stem. Can you find the halters that take the place of the second pair of wings?* (U. S. BUREAU OF ENTOMOLOGY)



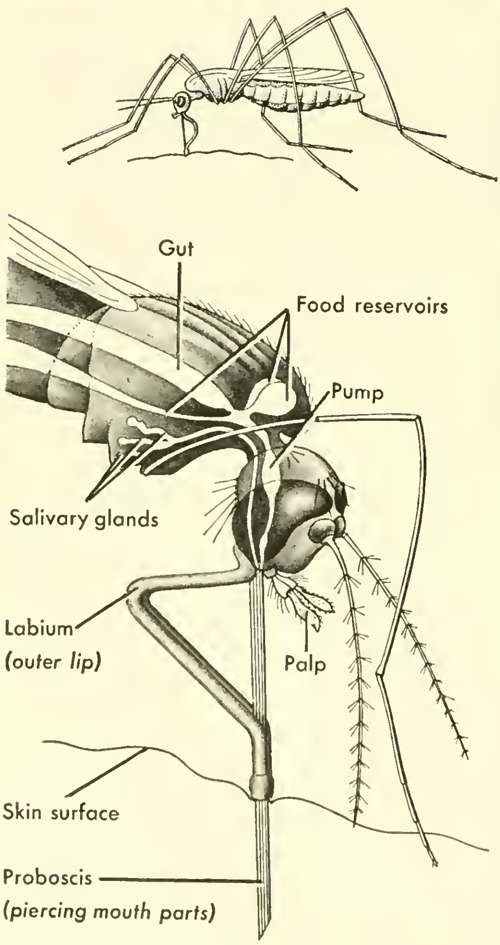


FIG. 57 (left) *The mosquito keeps its piercing mouth parts in a sheath when not in use. The mouth parts form a tube through which blood is pumped from the victim.* (AMERICAN MUSEUM OF NATURAL HISTORY)

another difference: moths spread their wings flat when resting; butterflies hold them upright.

The two-winged insects — flies. The members of this group have only one pair of wings. There are stumps in

FIG. 58 *A praying mantis finishing her nest. How does the praying mantis resemble the grasshopper? How is it different?* (SELENA JOHNSON)

place of a second pair. They have mouth parts of various kinds. Some lap up their food, some chew, while others can only suck. Common examples of this order are the familiar housefly and the tiny fruit fly. Small flies do not become large flies. Increase in size occurs only in the larval stage, and the larva of the fly is a wormlike creature without wings or legs, called a maggot. The mosquitoes, gnats, and midges belong to this order, too.

Grasshoppers and their relatives. Because it is large, the grasshopper is a good insect to examine more closely. Grasshoppers are also called locusts, especially in Europe and Asia. It is likely that the locusts of Biblical times were grasshoppers. See EXERCISES 1 and 2. The grasshopper group (order) includes among others the crickets, katydids, cockroaches, and the praying mantes. Ferocious as the praying mantis looks it will do you no harm. It is the grasshopper that may well be afraid, for off comes its head if the mantis catches it.

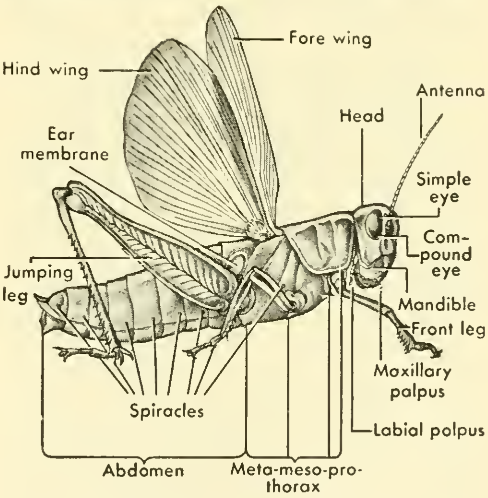


FIG. 59 *In a grasshopper one can easily see head, thorax, and abdomen. How many segments do you see in the abdomen? The appendages of the right side are shown. How many are there of each kind? The hind wings fold up like a fan. What might be the use of the front wings?*

Grasshoppers are equipped with exceedingly muscular hind legs. A grasshopper is capable of a standing broad jump fifty times the length of its body, while man's latest Olympic record is only about twice his length! One grasshopper can do little harm. But sometimes in our western states, and in other parts of the world, they occur in vast numbers and may strip fields of everything green. Crops of wheat or corn or even fruit trees may be ruined within a few hours.

Bugs. All small insects and even disease germs are called "bugs" by many people. The name bugs, however, is properly applied only to one group of insects. It is a group with which, for the most part, you do not want to have much to do. It includes among many others the fleas and bedbugs. The lice which live on birds and mammals are closely related to the bugs. Of course, there are many bugs that do not live on other animals. Some live in the water striding over the surface or swimming near the top.

Closely related to the true bugs, although belonging to a different order, are the plant lice and the scale insects. The plant lice, or aphids, are soft-bodied insects which cling tightly to plants and suck their juices, weakening the plant and often killing it. The scale insects attack many kinds of trees and shrubs. Like aphids they multiply into millions. They cover themselves with tiny scales like shields; thus protected, they feed on the sap.

Beetles. All beetles have hard wing covers which completely cover the upper side of the abdomen and fit so closely that you can scarcely see the seam down the middle of the back. The ladybird beetle made famous by "ladybug, ladybug, fly away home" is common even in cities; and the Colorado potato beetle is often found in the potato patch. Another common beetle is the firefly whose light goes on and off like a tiny flashlight as frequently as once every second or even faster, and sometimes with great regularity. Its light is located on the lower side of the abdomen. In the larva stage they are called glowworms and can be found shining in the grass. If you can collect half a tumblerful of glowworms you will have enough light to read by.

FIG. 60 *The Colorado potato beetle does much damage. How do you know it is a beetle?* (U. S. DEPARTMENT OF AGRICULTURE)

Insect communities. Most insects live quite solitary lives, but ants, most bees and wasps, and the "white ants" or termites live in large communities. They are the social insects. Each insect performs some special job which benefits the whole community.

Of all the social insects, the ants, which are found in almost every part of the world, are the easiest to study. Most of you have had the experience of discovering an ant nest beneath a rock. You may have seen the ants pick up large white bundles, run back and forth, and finally dash off to some safe hiding place. Then they come back for more bundles until shortly the nest has been

Fig. 61 *Aphids (plant lice) and ants on a stem. The aphids produce a sweet liquid (honeydew) which the ants like.* (HUGH SPENCER)

Fig. 62 *An ant tending a mealy bug. Mealy bugs are relatives of the aphids. They also make honeydew.* (AMERICAN CAN CO.)

cleared out. You may have heard these bundles called ant eggs, but they are much too large to be eggs; they are the pupae. Most of you, too, have seen in fields, or at the edge of the forest, mounds of earth with many ants scurrying about. These anthills may be two or three feet in diameter and may house several thousand insects.

Underground, in the dark, passageways are tunneled; chambers of many kinds are dug out. There is much rushing to and fro with bits of food or soil. All this work is done by the *workers*. Every nest houses many workers, thousands of them, and one much larger ant known as the *queen*, a female who does nothing except lay eggs. Sometimes, there are several queens in one nest. And there are, too, a very small number of male ants that do no work. But the vast majority are workers. Some workers devote themselves to the care of the young. All the feeding of larvae and the moving about of larvae or pupae from room to room is done by the workers.

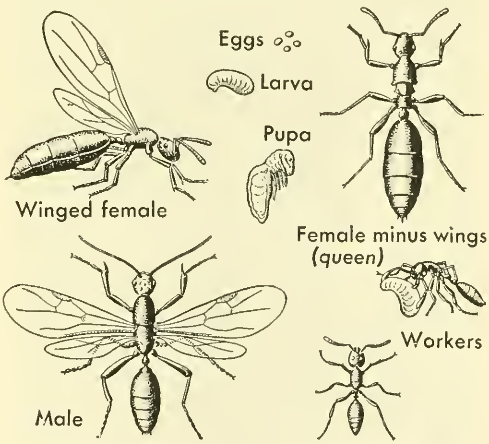


Fig. 63 *The life history of the little black ant. How many kinds of adults are there? What does each do?*

Among some species of ants there are workers that biologists have called *soldiers* because they have very large biting jaws and apparently devote themselves to defending the rest of the community within the nest. Some warlike species even raid the nests of other ants. Among other less warlike species the workers make mold gardens and raise aphids. See Figures 61 and 62.

FIG. 65 (above) *From left to right these are worker, drone (male), and queen (female) bees. How can you tell one from the other?* (ROOT)

FIG. 66 (left) *A swarm of bees. How does the beekeeper take advantage of swarming to start a new hive? How many bees would you judge to be in this swarm?* (U. S. BUREAU OF ENTOMOLOGY)

The life of the bee. Bumblebees are the giants among bees. They live in fairly small colonies in the ground. Honeybees live in much larger communities than do bumblebees; each colony may consist of more than 35,000 individuals. They build their nests in caves or hollow trees or in beehives provided by man. These are the bees that make the honey of commerce. There are males, females, and worker bees. See Figure 65. As among ants, the queen is the central figure in the community. She is fed and carefully guarded. She lays eggs, thousands of them, while the workers toil. They build the honeycomb of wax which forms from a liquid which oozes out of their bodies. They cut the wax into plates with their jaws and build the amazingly exact six-sided chambers. When these rooms are completed the queen deposits one egg in each. Other workers bring in food. Flying from flower to flower they gather nectar, a sweet liquid which they store temporarily in a special honey stomach. When they return to the hive they give it up again to feed to the young. Or they change it into thick honey and store it in the honeycomb. When a cell of the comb is filled with honey they cap it with wax. Often they gather pollen from flowers. This they prepare into special food which is fed to a few larvae which develop into queen bees. In the meantime, they do much cleaning of the hive. The workers also meet the attacks of "robber" bees and other animals. For this, the bee uses the sting on the end of its abdomen.

Most of the thousands of individuals in a honeybee colony are workers. The life of a worker may be only several weeks or at most several months, but the colony increases in number rapidly because of the rapid rate of reproduction. From egg through larva and pupa stages requires only three weeks. Whether because of the crowding or for some other reason, in the early spring and summer large numbers of bees together with the old queen bee leave the hive in a mass and start another colony. This is called *swarming*. One of the young queens that remains takes over the egg-laying duties in the old colony.

For centuries man has domesticated bees for the sale of their honey and their wax, but bees have never been tamed. However, they will sting only when disturbed and frightened, injecting poison with the sting which is left in the wound.

Insects that eat wood. The community life of the so-called "white ant," properly named *termite*, is just as interesting as that of bees or ants. Termites live mostly in the tropics but are spreading through the temperate zone where some of you may have become better acquainted with them. They burrow and build in wood, sometimes wrecking houses or other large wooden structures. Working in the dark, well concealed in the timbers, their presence in a building is sometimes not suspected until some day, when the framework has been weakened, the whole structure collapses. Sometimes, however, they are detected when they swarm in the spring. In warm climates or even in cooler climates where buildings are constantly kept warm, termites are a real danger. We can protect ourselves against them by soaking the timbers in creosote or, better still, by using concrete for foundations and lower floors of buildings. This is effective because termites must have at least a portion of their nest in moist soil or wood.

FIG. 67 *A beam of wood almost completely destroyed by termites. What can be done to prevent damage to wood by termites?* (SCIENCE SERVICE)

How insects make a noise. In the summer there is a steady chorus of crickets chirping. As it gets hot the male cicadas or "seventeen-year-locusts" add their loud, shrill song. When night comes on the katydids call from every tree, arguing endlessly, "Katy-did, Katy-didn't." It is so noisy that many a city dweller has

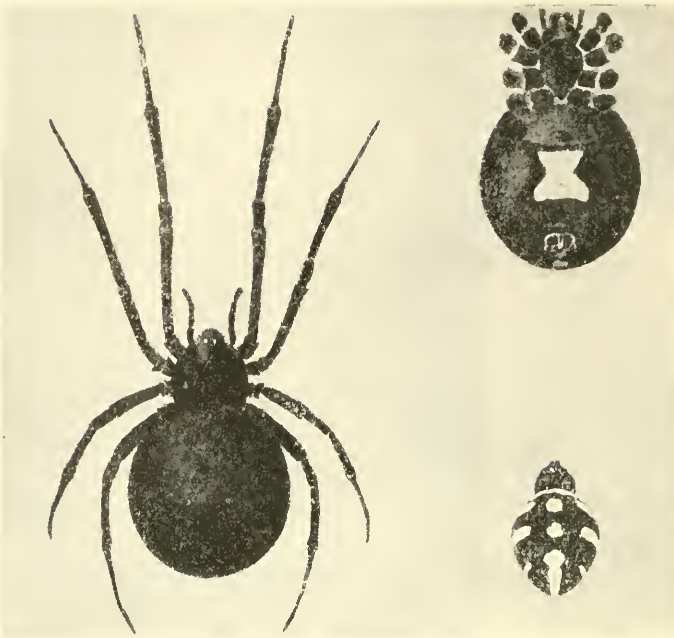


FIG. 68 *The black widow spider magnified. With legs stretched out it is about one and one half inches in size. The lower side of the abdomen with its distinct hourglass is shown at the upper right. At the lower right corner is the body of the male. How does it compare in size with the female?* (U. S. DEPARTMENT OF AGRICULTURE)

wondered what was meant by the "quiet" of the countryside.

The sound-producing apparatus of the cricket is peculiar. The front pair of wings is thickened. The edges of the wing covers have a set of "teeth." As one rough surface rubs over the other the stiff wings vibrate. It is the vibration that is heard as a shrill chirping. In katydids and cicadas the apparatus is slightly different. In these insects it is only the males that are so equipped. Other insects, such as bees and flies, make noise by the rapid beating of their wings.

The insects. So numerous and so varied are the insects that many books have been filled with accounts of their extraordinary structure and fascinating lives. This brief account has only scratched the surface. The biologists who study insects (called *entomologists*, en-toh-mol′o-jists) can tell many exciting tales of the doings in the highly populated insect world. For review do EXERCISE 3.

Other arthropods – the spiders. If you turn again to the chart on page 41 you will see that besides the very large and varied class of insects there are three other classes in the arthropod phylum. One of them is the spiders and their close relatives. Does it astonish you to learn that spiders are not insects? It should not. Being arthropods, of course, they have a firm outer covering and jointed legs; but you will count four pairs of legs (not three), and only two body parts. The head and thorax are joined together. And they lack three structures found in insects: wings, antennae, and compound eyes. Now draw the diagram suggested in EXERCISE 4.

Most spiders can give off a special liquid from the abdomen that hardens in the air into a silk thread. The webs may be used as homes or as a means of

FIG. 69 *The garden spider spins an orb web of this kind. It rests motionless in the center.* (HUGH DAVIS)

FIG. 70 *The bite of the tarantula is rarely fatal. How do you know it is a spider?* (U. S. BUREAU OF ENTOMOLOGY)

catching prey. The house spider spins a tangled mass of threads in some quiet corner; this is a cobweb. Each species has its own characteristic web and many webs are complicated structures woven according to a definite pattern. The trapdoor spider digs a hole in the ground and covers it with a door opening outward on a hinge.

Do spiders bite? The fear of spiders like the fear of snakes is the result of ignorance. Most garden spiders do not bite; or if they do the bite causes no more than a slight irritation. The common house spider does not bite at all. The only dangerous spiders in the United States are the tarantula and the black widow or hourglass spider (see Fig. 68). The black widow thrives best in the tropics, but has been found in many parts of this country. It is easy to identify for it has a black body with a red spot shaped like an hourglass on the under side of the abdomen.

Close relatives of the spiders. The scorpion is a close relative of the spider, though you might not recognize it as one. The scorpions of this country cannot do much harm. But in the tropics, where they may be as much as eight inches long, they may be dangerous. Then there are the tiny mites and ticks. Many of them live on, or just under, the skin of various mammals, including man. Some of them, like the chigger, cause fierce itchings. Some are carriers of dangerous disease germs. Another relative of the spider is the harvestman. You may know it as daddy longlegs, from its unusually long and spindling legs.

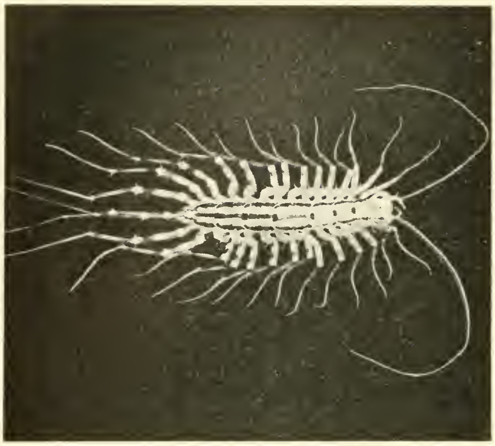


FIG. 71 *The house centipede enlarged. How do you know that this is not a millipede?* (U. S. DEPARTMENT OF AGRICULTURE)

FIG. 72 *Rock barnacles. These are crustaceans. Almost 3000 of them have been counted on one square foot of rock.* (MORRIS)

The hundred- and thousand-legged arthropods. A glance at the chart on page 41 will show you members of two more classes of arthropods, the "hundred-leggers" and the "thousand-leggers." Their bodies are made up of a series of rings; that is why many persons think that they are worms. But they have jointed legs attached to each ring, and their bodies have a firm covering. The hundred-leggers or centipedes, have a pair of legs on each ring. The thousand-leggers, or millipedes, have two pairs of rather short legs to a ring. Both these classes are small and rather unimportant.

The crustaceans. Another great arthropod class, the crustaceans, includes many forms that inhabit the sea, but some live on land and some in fresh water.

It is difficult to state by what characteristics you can recognize crustaceans. About all that can be said here is that if an animal seems to be an arthropod and does not exactly fit into the insect, spider, or centipede groups, it is probably a crustacean. The class includes the lobsters and crabs, the crayfish, water fleas, barnacles, shrimps, and hundreds of other kinds. Study some crustacean at first hand as described in EXERCISE 5.

Some queer crustaceans. Perhaps all crustaceans deserve to be called queer. The lobster is just an ordinary kind of crustacean; but it has eyes that are on the ends of stalks, huge and powerful pincers or claws, and it glues its eggs to its legs. In spite of the saying "as red as a lobster," live lobsters are not red at all; only cooked lobsters are red.

The crab, too, has eyes on stalks. Its body is wider than long, and it seems to have no abdomen. The queerest thing about the crab is its walk. It walks sideways, but it manages pretty well. And in the water it is a good swimmer. Along the coast you can often buy soft-shelled crabs. These are common crabs that have recently lost their shells. All the crustaceans with hard coverings shed their coverings as their bodies become too large for the shells.

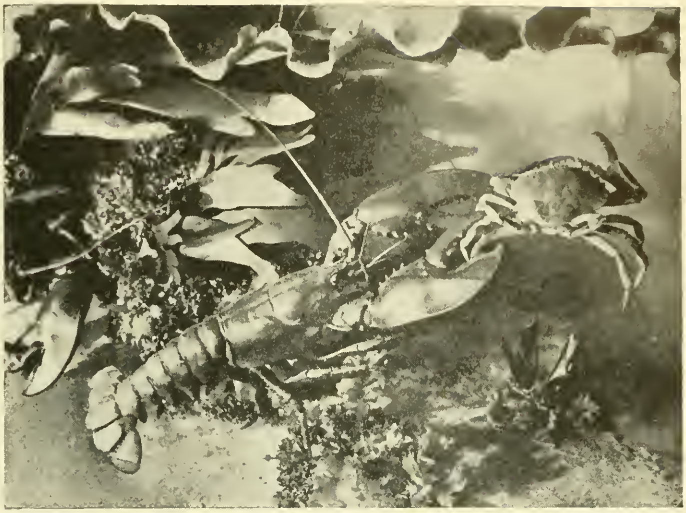


FIG. 73 *Lobster catching a crab. Both are crustaceans. How can you distinguish lobsters from crabs?* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 74 *The scorpion is grouped with spiders, although it looks quite different. It carries its young on its back. The sting at the end of its abdomen can be waved over its head.* (AMERICAN MUSEUM OF NATURAL HISTORY)

For strangeness, the barnacles take the prize. It was a long time before they were recognized as relatives of lobsters and crabs. A famous English biologist, T. H. Huxley, has given this striking description: "A barnacle may be said to be a crustacean fixed by its head and kicking the food into its mouth with its legs."

EXERCISES 6 and 7 would be good review exercises before you leave the group of jointed-legged invertebrates. You will next examine briefly eight other invertebrate phyla. We shall proceed from the more complex to the more simple forms.

PHYLUM – MOLLUSKS

The Soft-bodied Invertebrates

What are mollusks? If you examine Figs. 75–78 you will see examples of three different groups (classes) of mollusks: those that have a foot which is used in creeping, like the snail; those that have feet used in seizing prey, like the octopus; and those that have a hatchet foot used in plowing through wet sand or mud, like the clams. Most have a shell of lime which protects the soft body. The shell takes very different forms; it may be single or double and may even be carried internally.

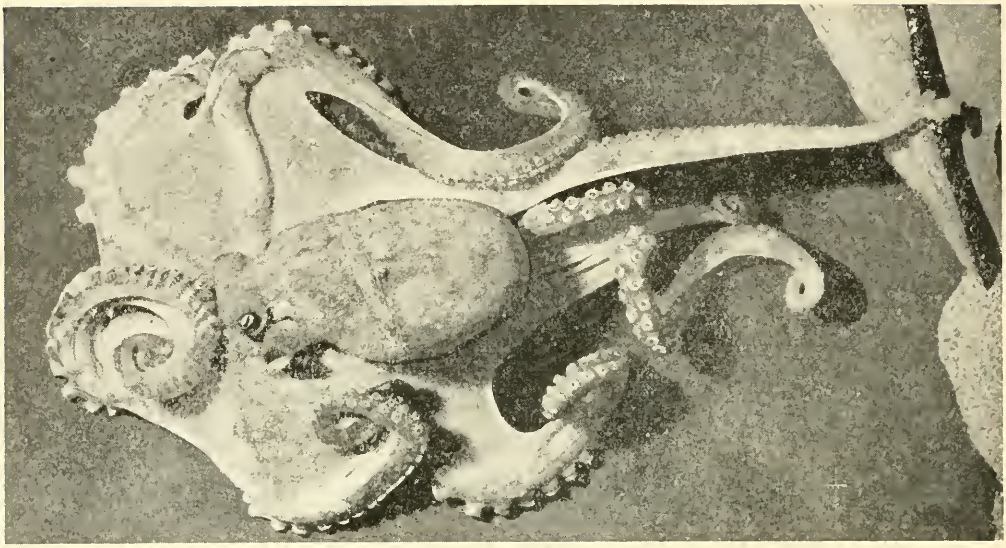


FIG. 75 (above) *The octopus is a mollusk which has no shell. Its eight waving tentacles (or feet) bear sucking cups. With feet and beak it tears its prey to pieces.* (NEW YORK AQUARIUM)

FIG. 76 (right) *This zebra snail is creeping on its foot.* (DAVIS)

Clams, oysters, and mussels. These mollusks have a shell in two parts. Often the shell is left open and the hatchet foot, a thick muscle, may stick out. Oysters and mussels, which spend their lives attached to rocks or other shells, have so small a foot that they can hardly be said to have one. Clams use their foot for locomotion. EXERCISE 8 is interesting although difficult.

Snails with and without shells. Snails live in water and on land. Land-living forms especially have a well-developed foot. They have a well-developed head too, with a real mouth, and eyes carried on long stalks. Many species carry a spiral shell from which the head and foot protrude. When danger threatens, both head and foot are drawn into the shell and the tough, slimy foot seals the mouth of the shell so well that it is difficult to extract the animal. Snails that lack a shell are called slugs. They may do much damage in the vegetable garden.

FIG. 77 *Although the slug is a mollusk, belonging to the same group as the snail, it has no shell. This one has just laid its eggs on a leaf.* (MARY C. DICKERSON)

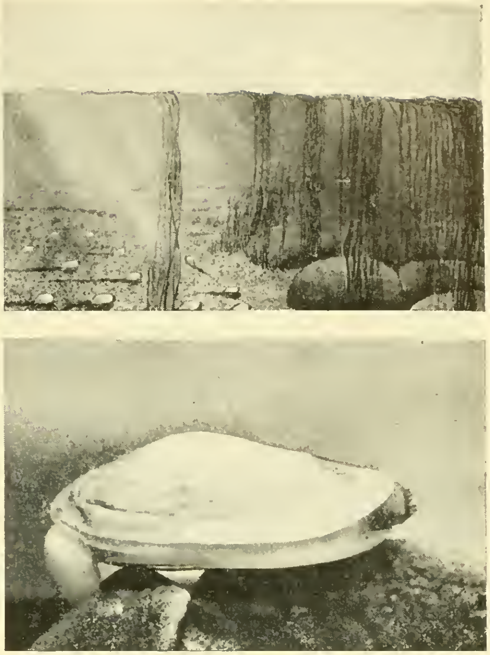


FIG. 78 *The clam has a double shell and a hatchet foot. The clams* above *are using the foot to plow through the sand.* (WARD'S NATURAL SCIENCE ESTABLISHMENT)

Mollusks and man. A great many species of mollusks are eaten by man. Snails are considered a delicacy by some people, and the octopus and squid are eaten in many parts of the world. Oysters, the many species of clams, the scallops, and the mussels are commonly eaten. Oysters are valuable also as the source of mother-of-pearl, from which buttons are made. Precious pearls are found only in certain tropical species and then rarely.

There are comparatively few kinds of pests among mollusks. One of the worst is the "shipworm." It bores into timber which is under water, riddling it with tunnels until the wood collapses. Now that ships are made of steel the damage done by shipworms is confined to wharves.

PHYLUM – ECHINODERMS

Invertebrates with Spiny Skins

A different body plan. The invertebrates with spiny skins are called *Echinoderms* (eh-kine'o-derms). They are built on a plan different from that found in the more complex animals. Most animals have *bilateral symmetry*. This means that if they were cut down the middle the two halves would be about the same in appearance. But the invertebrates with spiny skins have *radial symmetry*, like a wheel. Just as the spokes of a wheel radiate from the hub, so the parts of these animals radiate from a central point. Besides this, these animals have a spiny skin and a complicated system of water vessels that

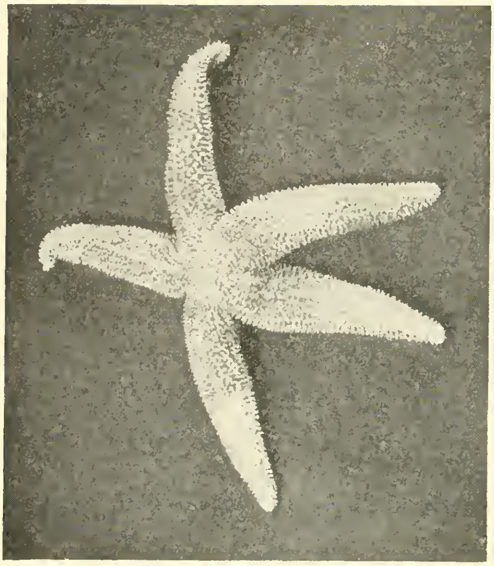


Fig. 79 *The horny, rough upper surface of a common starfish. What kind of symmetry has it?* (AMERICAN MUSEUM OF NATURAL HISTORY)

Fig. 80 *The sea urchin has a beautifully marked shell beneath these spines.* (AMERICAN MUSEUM OF NATURAL HISTORY)

help in locomotion. Some of them are brightly colored and are very beautiful in structure.

If you live near the sea, you are surely acquainted with starfish, sea urchins, and perhaps sand dollars. In tropical waters the beautiful sea lilies, which you might well mistake for plants, grow attached to the sea bottom. All of these are spiny-skinned invertebrates.

The starfish. The starfish lives in salt water near the shore. It is not a true fish, of course. It is a living flexible star with five arms and a spiny covering colored brown or red or purple. Hundreds of tiny tube feet with suction cups at their ends dot the lower surface of the animal. By pulling in and pushing out the many tube feet in succession the starfish moves along slowly and smoothly. These tube feet help in breathing, too, and in food getting. By folding itself over an oyster and attaching its tube feet it pulls the shell open. Then it turns its stomach inside out and digests the living oyster in its shell.

Starfish do much damage by feeding on mollusks. Oystermen formerly tried to destroy starfish by tearing them in half and throwing the pieces back into the sea. Unfortunately, this made the situation worse, for new parts similar to those lost will grow back, or regenerate, making two animals where there had been but one before.

Some starfish relatives. Similar to the starfish group but sufficiently different to be put in another class are the sea urchins and sand dollars. They, too, have their mouths on the lower side. They take in sand, in which they find small animals and plants which are their food. The sand dollar has a circular flattened shell somewhat thickened in the middle. The sea urchin is so covered with movable spines that it looks like a walking pincushion. Sea urchins are eaten by some people; their large masses of eggs are considered a great delicacy.

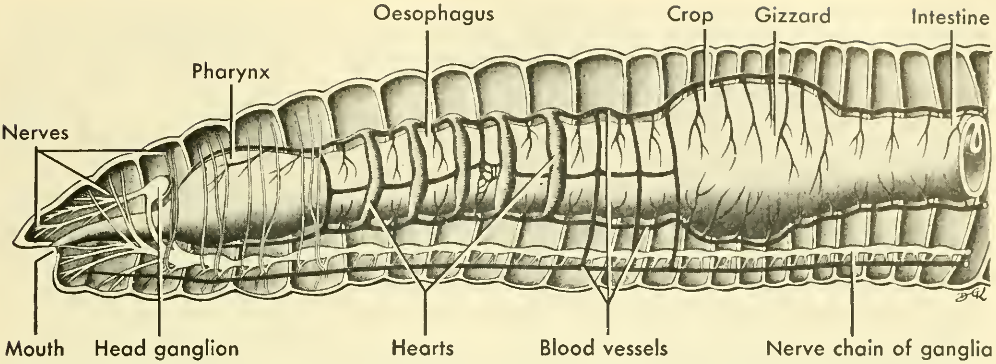


FIG. 81 *Front end of an earthworm cut open. The blood vessels, nerves, and many other parts are similar to those of more complex animals. See Figure 82, also.*

THREE PHYLA OF WORMS

PHYLUM – ANNELIDS

Worms with Segments

Earthworms and their relatives. Perhaps the most important of the Annelids (ann′ell-ids) are the earthworms. You will find them interesting to study. See EXERCISE 9. Most of the time earthworms burrow underground where they literally eat their way through the earth, swallowing soil particles and decaying plant material, which is their food. The food is used and the undigested soil is left behind in little ropes which hold together until they are dry. You may have seen them on the ground; they are called *castings*. Charles Darwin and his sons studied the activities of the earthworm with great care. They discovered that the animal often brought its castings to the surface and that, therefore, on a small scale, earthworms were constantly plowing and cultivating the soil, making themselves useful to man. If you look at Figure 81, you will see that the body is made up of rings or segments. All the worms in this phylum are segmented. One fresh water form that is rather common is the leech. There are suckers at both ends of the body which enable it to stick tightly to the animal from which it sucks blood; that is the origin of the expression, "sticks like a leech." It has teeth with which it breaks through the skin and a substance in the saliva which prevents the clotting of blood; thus it can suck until it is full.

PHYLUM – NEMATHELMINTHS

Roundworms

The hookworm and its relatives. There are other Nemathelminths (nem-a-thel′minths) but the hookworm is the best known of this group. In later chapters you will read more about them. Hookworms and some other members of this phylum live in the bodies of both man and other animals where they may cause disease. Most of the roundworms are tiny, too small to be seen with the naked eye. Their bodies have no segments. They are present in large numbers everywhere, particularly in the soil.

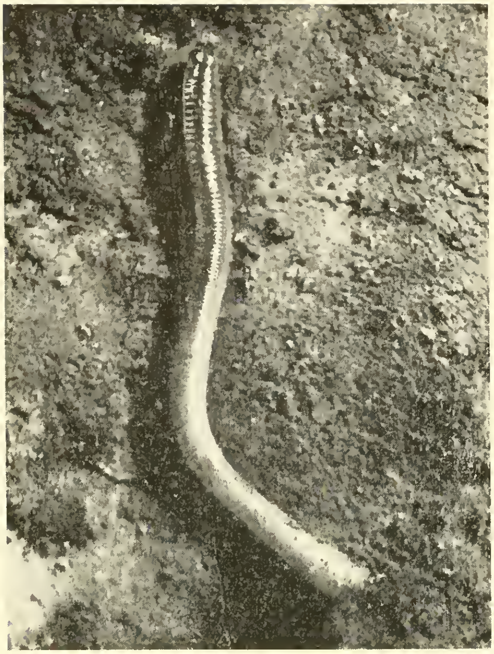


FIG. 82 *An earthworm burrowing in the soil. It looks shiny because its skin is moist.* (SCHNEIDER AND SCHWARTZ)

FIG. 83 *Planaria is less than one inch long. Do you see the eating tube which it can extend?* (AMERICAN MUSEUM OF NATURAL HISTORY)

PHYLUM – PLATYHELMINTHS

Flatworms

Tapeworms and their relatives. The platyhelminths (pla-tee-hel′minths) include the tapeworms and the liver flukes, both of which are parasites. Tapeworms are flat like a ribbon, but it is a ribbon made up of separate pieces which can be dropped off one by one. Tapeworms may reach a length of twenty feet. Some species live in man's intestines, hooked to the wall by the curved spikes and suckers on their heads. They live on the food which man has digested. You will read more about tapeworms later.

Other flatworms that are of great importance to man because they attack him or his domesticated animals are the liver flukes. They are tiny worms that live in the liver of sheep and other animals. They do great damage. One very common flatworm, *Planaria* (plan-air′ree-a), lives in sluggish streams, hidden under stones. Examine Figure 83. Although Planaria is of no economic importance, it has been studied and experimented with by many zoologists.

PHYLUM – COELENTERATES

Animals Whose Bodies Are Simple Sacs

Sea anemones. The coelenterates (see-len′ter-ates) are of great interest to zoologists but most of them are of little economic importance. If you see gaily waving tentacles above a delicately tinted body fastened to the sea bottom you are looking at a sea anemone (a-nem′o-nee), the "flower" of the ocean. Many are brown in color; some forms are pink or rose-colored; others are orange or bluish

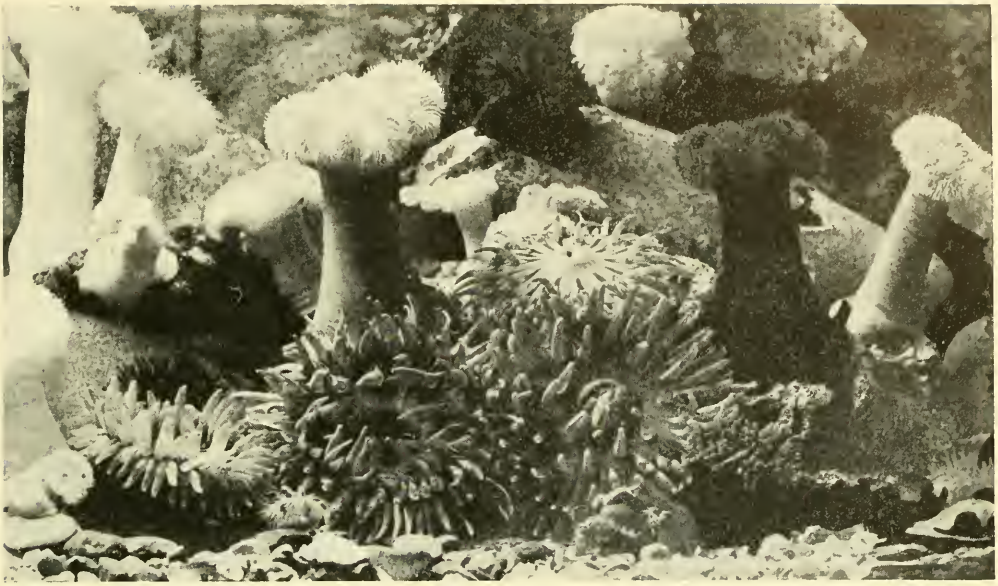


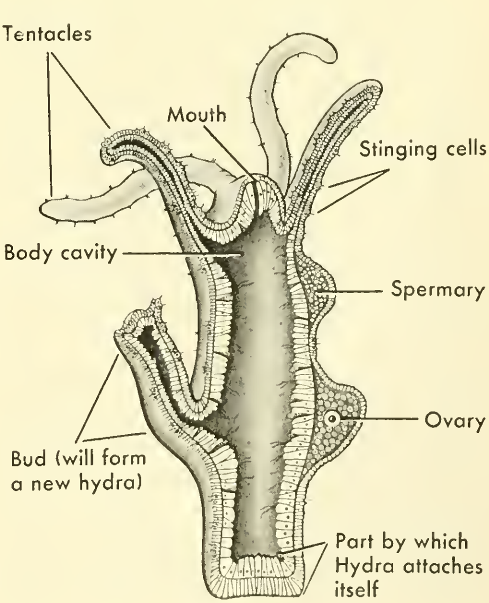
FIG. 84 *Sea anemones. These beautiful animals are several inches high. Where do they live? How do they get their food?* (NATURE MAGAZINE)

green. The body is little more than a sac in which food is digested. The mouth is a slitlike opening in the upper end of the sac; the tentacles that surround it grasp the food which the water may wash within reach. They can shoot out long stinging hairs which paralyze or kill their prey. Once the food is caught the tentacles push it into the mouth. When the tide goes out leaving the little anemone in a rocky pool, it pulls in the tentacles and contracts its body until it is nothing but a small solid mound.

Related to the sea anemones is hydra, a tiny fresh water form. You may have found it attached to the sides of an aquarium. See Figure 85.

Animals that make rock. Coral animals, also, are attached to the sea bottoms. They resemble sea anemones but differ in several ways: they are usually much smaller; they are attached to one another in *colonies;* and they build shells of lime

FIG. 85 *Hydra, cut open and magnified. This is a tiny animal, seldom more than one fourth inch long. Look for the mouth surrounded by tentacles. These have stinging cells which can kill small animals.*



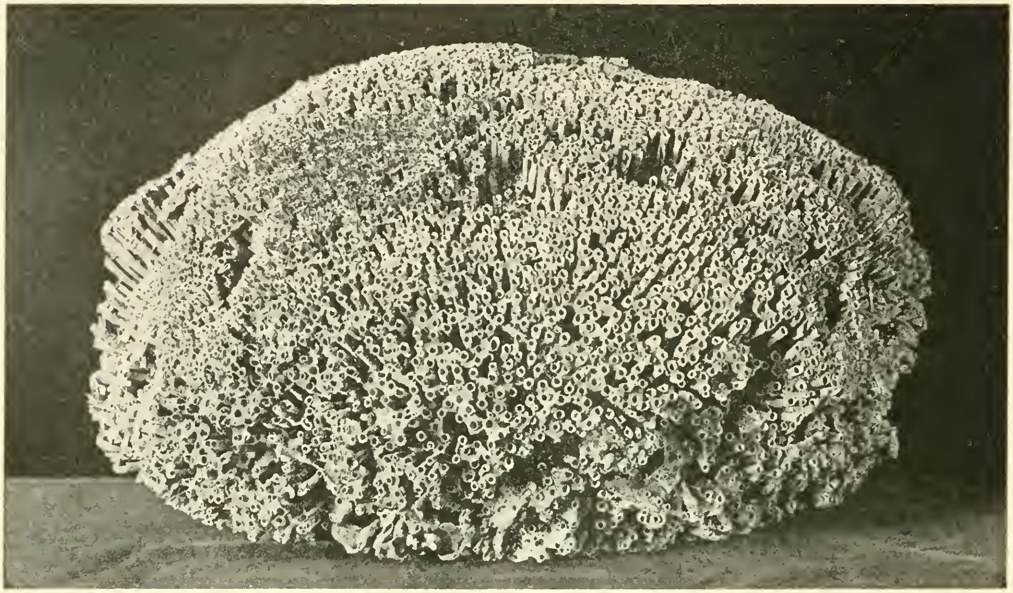


FIG. 86 *Organ-pipe coral. The tiny animal within each tube can extend brightly colored tentacles.* (AMERICAN MUSEUM OF NATURAL HISTORY)

outside their bodies. There are many species of coral animals. Each species constructs of shell of a particular kind.

Most corals inhabit the warm waters of tropical seas in vast colonies containing thousands upon thousands of individuals. When each animal dies its skeleton remains behind; thus slowly but steadily a mass of shells piles up. This turns to stone — limestone. After long ages so much rock gathers that a reef or coral island may rise out of the water. Reefs are sometimes a thousand miles or more in length. The Bermudas are a group of coral islands.

A third class — the jellyfish. Grownup coral animals and sea anemones spend most of their lives sitting down but in their younger stages they can move about. There are other forms, such as the jellyfish, that never settle down. The animal is really jellylike; clear, transparent, and soft. The body of the jellyfish is more than 95 per cent water. When washed up on the dry beach the water soon evaporates away until just a shriveled shadow remains.

Jellyfish look like inverted saucers floating in the water. See Figure 87. They vary in size from about one inch in diameter to several feet. The jellyfish moves through the water by waving its tentacles or by contracting its body. The contraction squeezes water out of the central cavity; this gives the jellyfish a little push in the opposite direction.

Characteristics of the coelenterates. The coelenterates are all water-dwelling animals. Like the starfish they have radial symmetry, but they are far simpler in make-up. Each animal is much like a simple sac. The sac has one opening called the mouth which is surrounded by tentacles with stinging hairs.

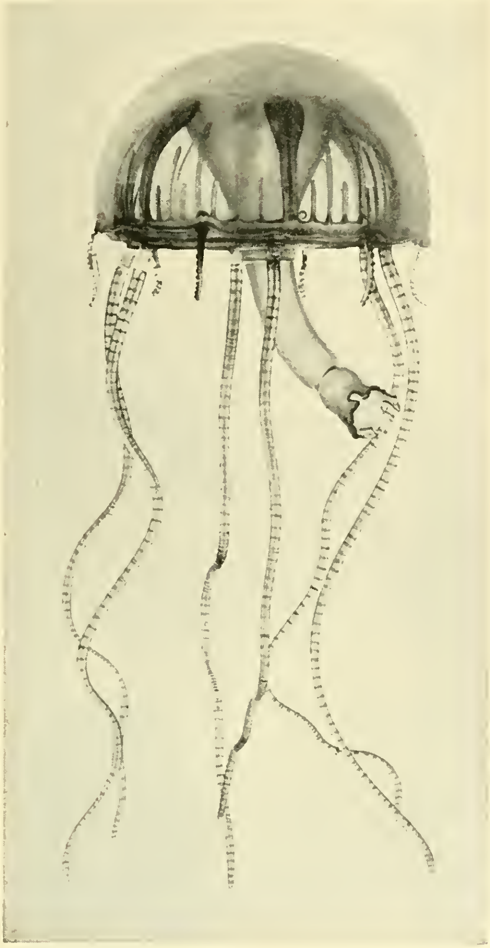


FIG. 87 *This jellyfish has a long tube through which it eats. With its tentacles it catches and paralyzes its prey.* (AMERICAN MUSEUM OF NATURAL HISTORY)

PHYLUM — PORIFERA

Animals Riddled with Holes — Sponges

The sponge. Only a few kinds of Porifera (pore-if′er-a) produce commercial sponges. The commercial sponge is the tough, fibrous covering or skeleton of many sponge animals that live in colonies. The body of a sponge animal, like the body of the sea anemone and coral animal, is a simple sac but this sac has many holes. Sponges grow fastened to the floor of tropical seas from which they are torn by dredges or cut loose by divers. After they have been killed they are hung in the air until the animals have decayed. Then the sponge is washed in water until nothing but the skeleton of the colony is left.

PHYLUM — PROTOZOA

The First Animals

What are the protozoa? The tiny masses of living matter making up the bodies of all animals and plants are called *cells.* The common animals and plants you know are made of billions and billions of cells. But some animals and plants are made of only a single cell. As you would expect, such animals and plants are tiny, usually so small that they can be seen only by means of a microscope. The group of one-celled animals is called the *Protozoa,* which means "first" or simplest animals.

Protozoa are found living in many different places. Ponds and streams are often crowded with them, although the water looks clear. Some parts of the ocean are thronged with protozoa, as you will read. There are protozoa that live in the intestines of animals, and others that may live in our blood and cause serious illness (malaria). Altogether, they are as fascinating a group of animals as we know.

Raising protozoa. It is easy to raise protozoa in *hay infusions.* You can make one by putting dried grass or hay into water which is then permitted to stand. Make a hay infusion according to directions in EXERCISE 10. As the hay decays, some of its food materials dissolve in the

FIG. 88 *Vorticella is one of the most interesting of the protozoa. On the rim of its open mouth is a row of cilia. Vorticella is anchored by a stalk.* (HUGH SPENCER)

FIG. 89 *Three amebae photographed through a microscope. Can you see food vacuoles in the lowest one? The living material streams in all directions.* (GENERAL BIOLOGICAL SUPPLY)

FIG. 90 *Living paramecium photographed through a microscope. The outline is blurred by the movement of the cilia. Can you see the groove leading to the mouth?* (HUGH SPENCER)

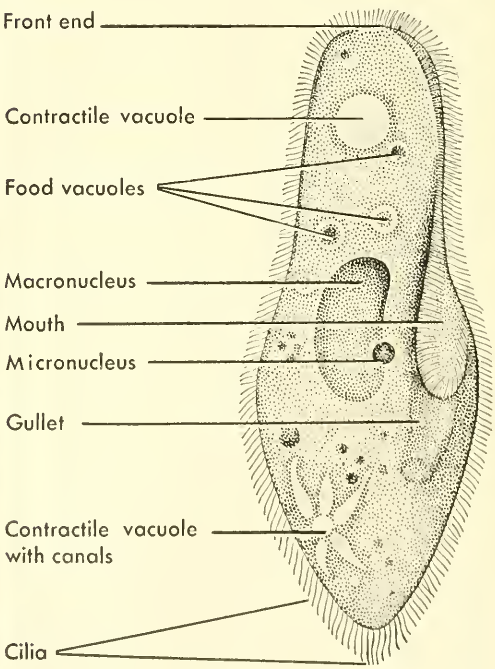


FIG. 91 *This drawing of a paramecium shows the groove through which food enters. How does the food get to this spot? What does a paramecium eat? How does it move?*

water which takes on a brown tint. Many kinds of microscopic creatures will soon be swarming in the infusion.

When pond water is lacking, therefore, you may turn to the hay infusion for your first look at the world of microscopic living things. If you are able to get the use of a microscope you can look forward to many happy hours of discovery.

A giant among microscopic animals. One of the commonest inhabitants of the hay infusion is an enormous *microorganism* (microscopic organism), which is just visible to the naked eye as a white speck darting about in the water. You may have heard its name, *Paramecium* (par-a-mee′see-um). Paramecium is easy to raise and with a microscope fun to study. Do Exercise 11.

It is not easy to examine a lively paramecium with the microscope; it moves too fast. But it is possible to catch it in the fibers of cotton or even to thicken the water so that the paramecium pushes its way through with difficulty. Either one of these tricks will slow the animal enough for you to see that the little submarine-shaped paramecium is covered with tiny hairlike parts or *cilia* (sil′ee-a). The singular is *cilium*. These cilia beat vigorously and thus push the paramecium rapidly through the water. By lashing the cilia hard in the opposite direction the animal can go into reverse. The cilia are arranged diagonally in rows so that as they beat they make the paramecium roll over and over like a barrel at the same time that it moves forward or backward.

As the paramecium rolls over, one can see that on one side there is a groove as though part of its cigar-shaped body had been scooped out. This depression leads to a spot, the *mouth*. Longer cilia line the depression; their beat is inward so that any smaller microorganism caught by the current is swept to the mouth and into the paramecium.

The microorganism of ever-changing shape. Exercise 12 gives you directions for studying this animal: *Ameba*. Because of its habit of clinging to some solid base and because it is almost transparent, it is difficult to find. Ameba is not trim and compact like paramecium, but spreading and shapeless. Its body is soft and jellylike — just a blob of living matter. Some of the living material flows for a while in one direction and forms a projection called a false foot or *pseudopod* (siu′doe-pod). It is a temporary foot which can form on any part of the body; in fact, ordinarily an ameba has several pseudopods at the same time sticking out in different directions. Sometimes, however, the material keeps on oozing in one direction; in this way the ameba, by ever changing its shape, crawls along over the surface of some leaf or stem under water.

The pseudopods are used for feeding too. If some smaller microorganism or other particle of food lies in the ameba's path, false feet flow out above, below, and on all sides of it and join together on the other side. The food particle is then inside the ameba, or, more correctly, the food particle is inside a little drop of water which is inside the ameba; for when the pseudopods join together they enclose a little water too. If the animal picks up some worthless particle like a grain of sand, it simply drops it behind as

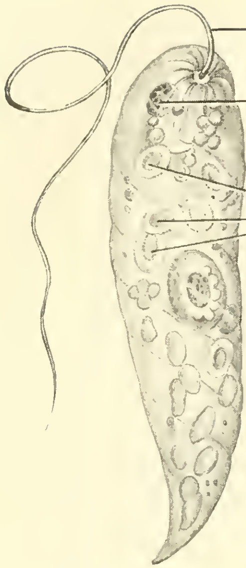


FIG. 92 *Euglena is another of the protozoa. It lashes itself along with the whip-like hair. Because it contains green bodies some biologists call it a plant.*

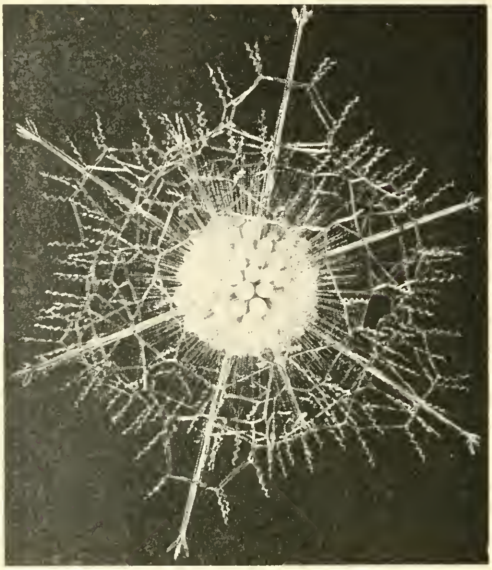


FIG. 93 *Skeleton of a Radiolarian. These and other protozoan skeletons make up much of the material on the ocean bottom.* (AMERICAN MUSEUM OF NATURAL HISTORY)

it flows along. At one moment the sand is inside the animal, the next moment it is out.

There is a giant ameba that your teacher may be able to show you. It is called *Chaos chaos*. It is so large that it can be detected with the naked eye.

Protozoa swarm in the ocean. One kind of protozoan which floats near the surface of the sea builds a complicated shell of lime about its tiny body. Now and again, when there is a sudden change in temperature or in other conditions, these organisms are killed. The millions of shells fall gently to the ocean floor like raindrops in a gentle rain. And so many have fallen throughout the centuries that deep beds of lime shells have been formed. Deposits of these shells can be found at the bottom of the ocean in many places. The chalk cliffs of southern England and the shores of northern France are made of limestone rock composed principally of such shells.

Long ago seamen noted that there were nights when the ocean sparkled with a thousand lights which seemed to dance on the waves as the vessels plowed along mile after mile. The light is produced by enormous numbers of protozoa called *Noctiluca* (nok-ti-loo′ka). The name means night light. As many as three million individuals may be found in a quart of sea water when conditions are just right for their growth. See Figures 92 and 93 for illustrations of other protozoans.

The animals in review. Many pages back you started a study in order to become acquainted with the many living things of this earth. In doing this your circle of acquaintances among organisms grew so rapidly that you would have been hopelessly confused had you not learned some system for keeping them in separate groups. This system is called classification. You first studied the mammals, the animals which are most closely related to you, yourself. Then you spent some time with the birds, the reptiles, the amphibians, and the fish. The fish were the last vertebrates you studied. All of these had a backbone just as you have. You then met the invertebrates, the animals without backbones. It took a long time to get acquainted with man's insect friends and enemies and the other, less familiar, arthropods. From then on you saw mostly water forms: the shelled mollusks, the spiny echinoderms; the worms, some of which burrow in the moist earth; the coelenterates whose beautiful colors and unusual shapes remind one of flowers; and the sponges.

There were still many animals for you to see, but in order to see them it was necessary for you to equip yourself with a microscope. Then suddenly a whole new world opened itself out to you: the world of Protozoa. A glimpse at these and you finished your study of the animal kingdom.

You saw only very few of the almost one million different kinds of animals. If you were to examine each living species for only one minute and if you were to keep at it day and night, it would take you almost two years to review the animal kingdom. Study of the summary below will give you a scientific view of the journey you have just completed.

Our attention must now be turned to the plant kingdom.

Summary

This simplified table will help you review the animal kingdom.

PHYLUM I. Chordates (*Chordata*): The name is from the word "cord" and refers not to the spinal cord but to the notochord which is present in adults of some subphyla and which develops into the backbone of the vertebrates. Most zoologists recognize four small subphyla other than the vertebrates we have studied.

SUBPHYLUM. Vertebrates (*Vertebrata*)

CLASS 1. Mammals (*Mammalia*): Hair covering. Feed young on milk from mammary glands.

CLASS 2. Birds (*Aves*): Feathers.

CLASS 3. Reptiles (*Reptilia*): Dry scaly skin. Breathe by means of lungs.

CLASS 4. Amphibians (*Amphibia*): Thin, moist skin. All spend first part of life in water; most later live on land.

CLASS 5. Fish (*Pisces*): Scaly skins that are moist. Breathe by means of gills.

The sharks discussed on page 32 along with certain other animals make up another small class. All the other phyla are invertebrate phyla. We studied the following:

PHYLUM II. Arthropods (*Arthropoda*): A hard outside covering. Segmented bodies and jointed legs.

CLASS 1. Insects (*Insecta*): Head, thorax, and abdomen with three pairs of legs on thorax. Complete or incomplete metamorphosis in their development. May live on land or in water. Grasshopper and butterfly.

Class 2. Spiders (*Arachnoidea*): Two body parts and four pairs of legs. Spider and scorpion.

Class 3. Centipedes (*Chilopoda*): Segmented body. Each segment has one pair of legs.

Class 4. Millipedes (*Diplopoda*): Segmented body. Each segment has two pairs of legs.

Class 5. Crustaceans (*Crustacea*): Five or more pairs of legs. Two pairs of antennae. Live in salt water, fresh water or in damp earth. Lobster, crab, barnacle.

Phylum III. Mollusks (*Mollusca*): Soft-bodied invertebrates with a shell. In some the shell is internal and reduced in size. Live in fresh or salt water or on land. Snail, slug, clam, octopus.

Phylum IV. Echinoderms (*Echinodermata*): Radial symmetry, usually with five divisions. A spiny skin. Live only in salt water. Starfish, sea urchin, brittle star.

Phylum V. Segmented Worms (*Annelida*): Long cylindrical body with segments or rings. Thin moist skin; most without legs. Earthworm, clam worm, leech.

Phylum VI. Roundworms (*Nemathelminthes*): Cylindrical body without segments. Many very small, causing disease and living within other animals. Hookworm, trichina worm.

Phylum VII. Flatworms (*Platyhelminthes*): Many live within bodies of other animals, causing disease. Planaria, tapeworm, liver fluke.

Phylum VIII. Coelenterates (*Coelenterata*): Baglike with one opening. Tentacles and stinging cells. Some free-swimming, some attached, some forming colonies. Jellyfish, sea anemone, coral, Hydra.

Phylum IX. Sponge Animals (*Porifera*): Baglike with many small openings through the sides. Attached. Some form colonies. Mostly salt water forms. Sponges.

Phylum X. Protozoans (*Protozoa*): Single-celled. Live in fresh or salt water or where it is moist. Some live within bodies of other animals and may cause disease. Some form shells and build up limestone rock.

Questions

1. How do the numbers of vertebrate and invertebrate species compare? Cite an example of each of the nine phyla of invertebrates mentioned.
2. What name is given to the most complex invertebrates? Give the two characteristics in which they differ from all other animals. Into what five groups (classes) do most of them fit?
3. Describe the principal characteristics of the insects. Be sure to use the correct terms. Describe the sense organs of a typical insect. How do some insects make noises?
4. Describe the life story of a butterfly, an insect that has complete metamorphosis. How is incomplete metamorphosis different?
5. Describe the insects with scaly wings. By what three characteristics can you distinguish moths from butterflies? Name a moth of commercial importance.
6. Which common insects belong to the group of two-winged insects? What name is given to the larval stage of the fly?
7. List four relatives of the grasshopper. Describe body regions and appendages of the grasshopper. Discuss the importance of the grasshopper to man.

8. Cite several examples of true bugs. Of what importance to man are plant lice and scale insects?
9. How can you recognize beetles? List some well known examples.
10. List four common kinds of social insects. Why are they called social insects? Describe the life history and the community life of ants.
11. How do bumblebees differ from honeybees? Name and describe the different kinds of bees in a hive. Describe the life of the worker bees. Describe swarming.
12. Of what importance are termites?
13. State three respects in which spiders differ in structure from insects. From what is the spider's web built? How is it used?
14. What can you say of the danger of being bitten by spiders?
15. Describe four close relatives of the spider.
16. How do the thousand-leggers resemble worms? Why are they classed as arthropods? Distinguish between centipedes and millipedes.
17. Name several crustaceans. Where do most crustaceans live?
18. What are some of the peculiar characteristics of lobsters, of crabs, and of barnacles?
19. Mollusks are divided into three groups. Name one example of each. What have these three in common? How do they differ? Describe the shells of mollusks.
20. Describe a snail with a shell. What is a slug?
21. State how the mollusks are useful to man. How are they harmful?
22. Cite an example of an animal that has bilateral symmetry and one that has radial symmetry. Explain these terms. What are the striking characteristics of the invertebrates with spiny skins? Name some examples of this group.
23. Describe the starfish. Include: their appearance, where they live, how they move about, what they feed on, and how they eat. Define regeneration.
24. What are three large groups of worms? What do earthworms eat and how are they of importance to us? Why are earthworms said to be segmented? How are leeches of interest to us?
25. In what two respects do roundworms differ from earthworms? What roundworm causes a disease?
26. What two kinds of flatworms live in other animals? Describe one kind.
27. Describe the appearance and structure of a sea anemone.
28. Which relatives of the sea anemone live in a limestone shell? Explain how coral reefs are formed.
29. The jellyfish is a third type of animal whose body is a simple sac. How does it differ in its habits from sea anemones and coral animals? Explain how it carries on locomotion.
30. Sum up the characteristics of the animals in this group of coelenterates.

31. What are the striking characteristics of sponges?
32. What name is given to the simplest animals? How do they differ from all other animals? Mention the various places where protozoa may live.
33. Give directions for making a hay infusion. What use can you make of it?
34. Define the word microorganism. Explain how the paramecium moves about and eats.
35. Describe the ameba and its habits.
36. Of what importance are the shell-building protozoa?
37. Imagine yourself starting on a long journey to review the animal kingdom, passing your own group – the mammals – first and ending with the simplest forms. Name in order the various groups you would see.

Exercises

1. If possible obtain a large lubber grasshopper for study. Compare the three body regions as to size. To which region are the legs and wings (appendages) attached? How many rings or *segments* in the abdomen? Of how many pieces is each segment composed? With a hand lens find breathing pores or *spiracles.* They are connected with tubes branching through the body (tracheae). How might overlapping segments help the insect take in air? Describe the position of the compound eyes. Of what advantage is this? Look for simple eyes. Describe. What is the advantage of having antennae segmented? Find a smooth oval spot, the

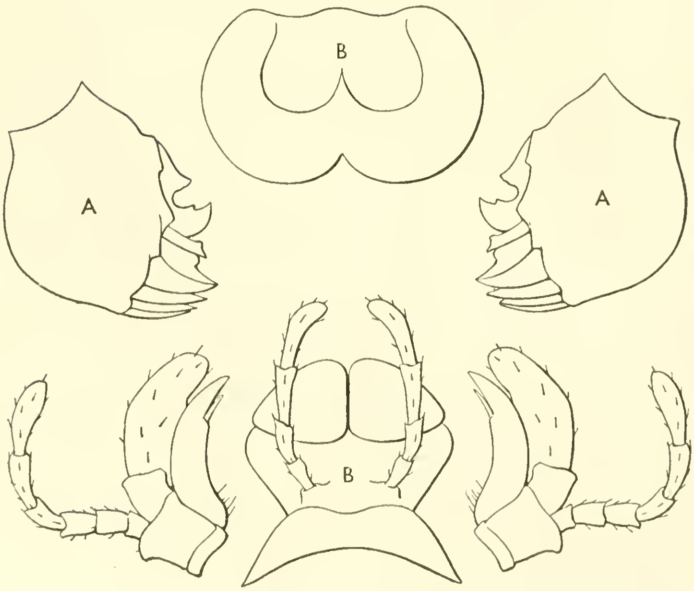


FIG. 94 *Mouth parts of the grasshopper. The two strong, jagged jaws (A) move from side to side. They are covered by the lips (B). The jointed structures like short feelers hold and direct the food. These mouth parts are well protected by being tough and horny.* (ADAPTED FROM TURTOX DRAWING)

eardrum, on each side under the wings on the first segment of the abdomen. Describe the two pairs of wings and discuss their use. Does your specimen differ from the picture in the text? How? How many joints are there in each of the three legs? What is each pair fitted for? Describe the foot closely. Study the mouth parts and compare with Fig. 94. How is each part used?

2. How does a butterfly resemble and differ from a grasshopper? Study a specimen. Follow the directions for study of the grasshopper, and describe each part of the butterfly. Feel the wing. If you have a microscope examine some of the powder which comes off on your finger.

3. Since there are half a million species of insects, it would be difficult to learn much about this large group in a short time. But you will have made a good beginning if you know exactly how you can recognize an insect, that is, if you have become acquainted with grasshoppers and their relatives, moths and butterflies, flies, bugs, beetles, and the social insects and can distinguish one order from another. Remember that becoming acquainted includes recognizing them in all stages of their life histories. Write up all this in your notebook.

4. Draw a diagram of the top view of an insect and another of a spider to show the important differences between the two groups of animals.

5. Shrimp and lobsters are easy to obtain in the market; crayfish are common in fresh water streams. Study and describe the body regions and the appendages of one of these crustaceans. Study the antennae and the eyes and compare them with the antennae and eyes of the grasshopper. What differences can you find among the many pairs of legs of the crustacean? How might it use these various kinds of legs? What is the advantage of jointed legs? Of segmentation in the antennae?

If you have live animals, place them in deep water in a large tank and then in a shallow tray to watch the methods of locomotion. Hold the crayfish in your hand; does it exert much strength in trying to escape? Do you think the animal is well protected by its color? Gently touch the eyes with a pencil. What happens? Have you made any other observations of your own? If so, discuss them with the class.

6. Arthropods affect man in many ways. Prepare lists of those that are useful and those that are harmful, telling how in each case.

7. You have become acquainted with four groups of arthropods besides the insects. Name a few forms in each of the five groups. Tell how they live.

8. Dissection of a clam. If you crack one valve of the shell and remove the pieces gently you will see the mantle, a thin skin next to the shell, and the gills. Can you find the muscles that hold the shells together? Open an oyster and compare its structure with that of the clam.

9. Collect some earthworms and keep them in a box of earth with glass sides. Watch them. Write up your observations briefly but accurately.

10. To study the organisms in a hay infusion. Boil a small handful of hay and two or three wheat seeds in half a quart of water. Allow it to

stand for several days; then add a little pond water. In about ten days you should have a good hay infusion. To slow up the protozoa for study you can add to your slide a little gum tragacanth (ask for it at the drug store). You will find instructions for the use of the microscope on pages 113–114. How many kinds of protozoa do you see? Draw some.

11. How does a paramecium move? Which seems to be its front end? As it swims forward it rolls over. Does it roll clockwise or counterclockwise? Which way does it roll when it swims backward?

12. Perhaps the most fascinating object to watch under the microscope is a large ameba. Do not use a bright light. How many pseudopods do you see? What seems to happen to the particles just inside the tip of a pseudopod at the "front" end of the animal? Does it ever lose a pseudopod? How do you know? How fast does it move? How does it change direction? Does it ever reverse the direction of its movement?

Further Activities in Biology

1. How to raise and observe grasshoppers. Construct a cage. Cover the bottom of a terrarium with sod on which grass is still growing. The grass must be watered regularly for the grasshoppers eat the grass and are dependent on the water which they get from the surface of the leaves. Cover the cage with a wire top or with a mosquito netting. Watch the insects eat. Observe all other activities.

2. How does the grasshopper jump? If you can obtain live grasshoppers, watch them jump. How many times its own length does a grasshopper jump? In what position are the hind legs when the insect is about to jump? Compare a grasshopper with a man doing a broad jump. Explain. Does the grasshopper use its legs for anything but jumping?

3. If you have any plants in the house or garden, examine the stems and leaves carefully for aphids or scale insects. Describe any that you find. Some kinds can be removed by holding the leaves and stems in soapy water.

4. Perhaps your class or biology club could buy an observation beehive to keep at the window of your laboratory. You will learn a great deal about the life of bees.

5. Many books have been written on the social insects. Prepare a full report on one of the social insects.

6. Daphnia is a tiny crustacean that is easy to obtain and raise. Write to any large biological supply house and ask for directions.

7. The development of the snail is easy to follow if you use a hand lens. Keep several snails in an aquarium. The eggs are laid in masses, often on the glass. Note whether all the offspring of snails with right-handed shells also have right-handed shells.

8. Shell collecting is so popular a hobby that there are dealers all over the world who publish catalogues of both common and rare kinds. Encyclopedias contain pictures in color of some of the most beautiful.

Make a collection of your own, using a shell book to learn the names of the animals. By exchanging specimens you may be able to get shells from other parts of the country.

9. The complete story of Charles Darwin's study of the effect of the earthworm on the soil is told in his book, *The Formation of Vegetable Mold*. It is not difficult to read. Prepare a report for the class.

10. If you follow directions carefully you can maintain a salt water aquarium. Starfish, sea anemones, and mussels will live in it if you have plenty of seaweed. A Turtox leaflet (General Biological Supply House, Chicago, Illinois) will provide complete directions. You may buy the plants, animals, and sea water from biological supply houses if you are far from the coast.

11. If you are talented in drawing prepare a mural for the walls of your classroom, showing examples of animals in each of the phyla from the sponges to the arthropods.

12. If you have a good hay infusion and are skillful with the microscope, make daily observations and keep accurate notes. Always take samples of water from different levels in the jar. You will make an interesting discovery in the course of several weeks.

13. Have you ever thought of owning a microscopic pet? It is really easy. Paramecia make the best pets because they are hardy. By heating a piece of glass tubing soften it until it can be drawn out to make a very narrow tube. Break this narrow tube so that you have a pipette with a narrow opening. Put a slide containing paramecia on a piece of black paper so that the paramecia can be seen with the naked eye. They will appear as white specks. Catch one by dipping the pipette into the water near it. Draw the pipette out quickly so that you catch only one paramecium. Gently blow the paramecium out on another slide. Add some cool boiled hay infusion water. Then put the slide in a Petri dish (ask your teacher). The Petri dish must contain a piece of blotting paper soaked in water. This will moisten the air. To keep the bottom of your slide dry, put it on two match sticks that lie on the blotting paper. Cover the dish. The next day you should have *two* or more paramecia. Repeat this process, discarding one of the animals, and keeping the other.

PROBLEM 2 *What Kinds of Plants Inhabit the Earth?*

The two large groups of plants. In describing animals it was convenient to speak of animals with a backbone and animals without a backbone. Later we sorted those without a backbone into different phyla. In describing plants we again very simply speak of two kinds, those with flowers and seeds and those without. People sometimes carelessly use the words flower and plant as though they mean the same thing. The flower, or blossom, is only part of a plant, just as the eye or the heart is only part of an animal. Some plants bear flowers at certain times in the life of the plant. Others never bear flowers. The plants that never bear flowers are not the trees and the grasses which you may be thinking of. Trees and grasses have flowers although they are often so tiny or so unlike ordinary flowers that they may escape your notice. Trees and grasses are therefore flowering plants, together with roses and violets and daisies and many others.

The true "plants without flowers" bear no flowers of any kind nor do they form seeds; and besides, as you will see, most of them differ from the flowering plants in their general make-up. Some differ so widely that you might not recognize them as plants at all. You will study the plants without flowers first. There are three divisions or phyla of flowerless plants.

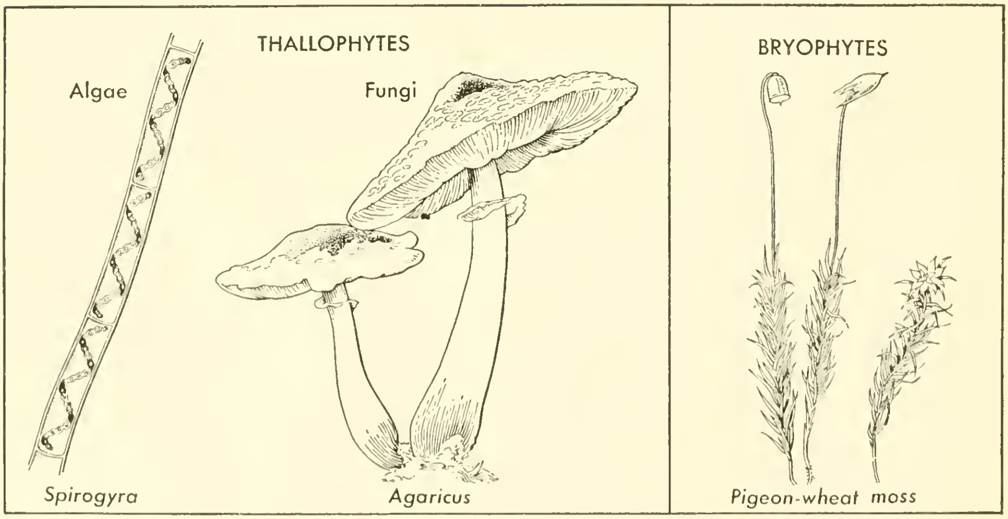


FIG. 95 *Examples of the four large groups in the plant kingdom. Which of these groups*

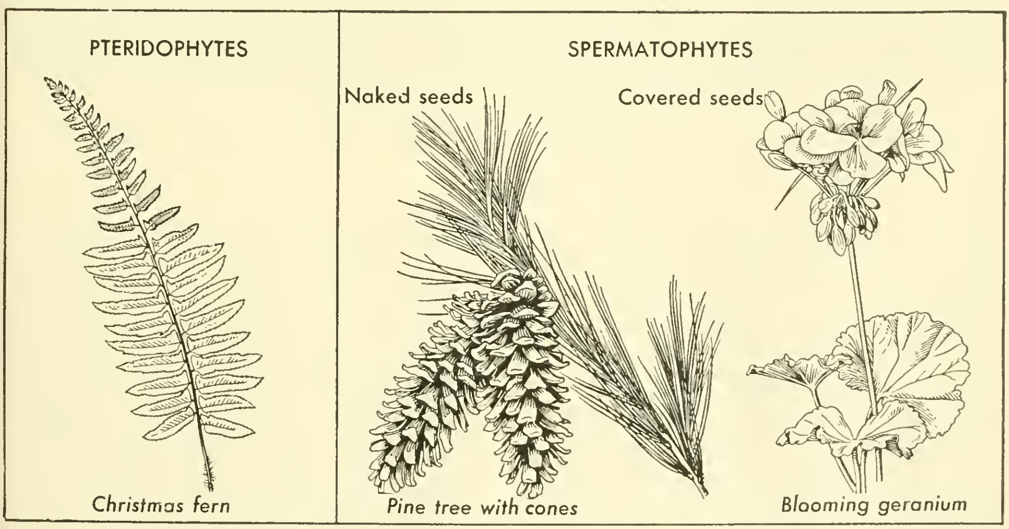
Flowerless Plants

PHYLUM – THALLOPHYTES

The simplest plants. The first division, or phylum, of the plant kingdom contains plants which differ widely among themselves in appearance and in size. Some are single celled and microscopic; others grow to an enormous size. All are alike in that they do not have true roots or stems or leaves and that they never produce flowers or seeds. Some contain the green coloring matter so characteristic of plants. They are called *Algae* (al′jee). Those that lack the green coloring matter are called *Fungi* (fun′-jeye). Of the algae some look bright green; in other algae the green coloring matter is more or less hidden by other colors so that these algae may look bluish green or even brown or red.

The smaller algae. Have you ever seen a green scum on the water of a slowly moving stream or small pond? If you lift the scum on a stick you discover that it is a bright green mass of long tangled threads. Each thread consists of a number of cells all alike. If you examine these threads with a microscope, it is likely that you will see a beautiful plant called *Spirogyra.* Each cell contains one or more green spirals. The plant has neither root nor stem nor leaf. See Fig. 97. It is just a living green thread which grows in the sunny water and may at some time become food for a water animal. With a microscope you can do Exercise 1.

In the plant kingdom as in the animal kingdom, the simplest organisms are usually water dwellers. Some of these simple plants have one or several long whiplike projections by means of which they swim. Yes, many species of simple plants move about. Others, such as the



are flowerless plants? How many other examples of plants in each group do you know?

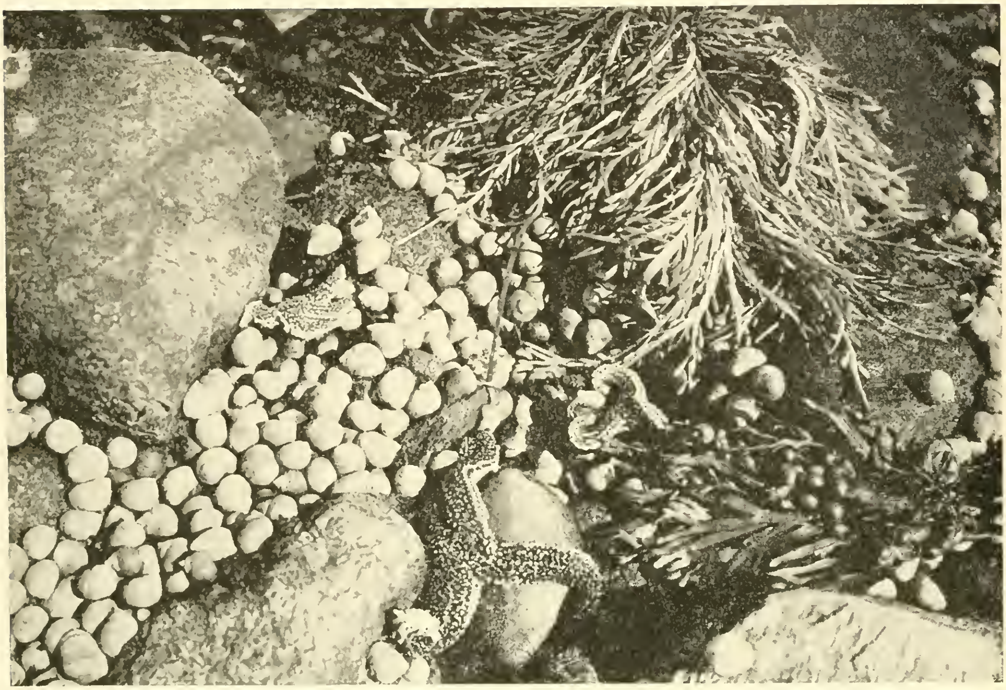


FIG. 96 *Life in salt water. This is a common sight for those who live near rocky ocean shores. Do you see the strands of rockweed? To what large group of plants does it belong? What animals do you recognize?* (AMERICAN MUSEUM OF NATURAL HISTORY)

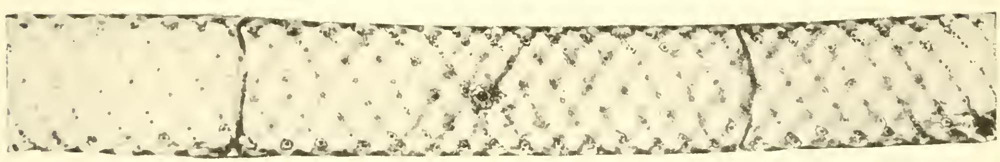


FIG. 97 *Part of a single strand of Spirogyra, one of the pond scums. Do you see the spirals? They are bright green. Spirogyra lives in fresh water.* (GENERAL BIOLOGICAL SUPPLY)

diatoms, have beautifully marked shells. They live in enormous numbers in salt and fresh water, serving as food for animals. The shells of those that lived millions of years ago have accumulated and are quarried and used in many ways.

A few of the simple plants live on land, usually where there is plenty of moisture, although some of them can stand much drying up. The very thin flat green growth found on the bark of trees is a mass of simple plants called *Protococcus.* You may have called it moss, but its structure is very different from that of a moss. Closely related to it are the algae which grow by the millions on the snow during the summer in arctic regions. Explorers call these algae "red snow."

Larger algae. There are other larger algae, that grow in salt water, the sea-

FIG. 98 *This Amanita is very poisonous. It looks much like the common mushroom which you can buy in a market.* (BLAKISTON)

FIG. 99 *The bracket fungus is related to the mushrooms. Most of the plant is under the bark.* (U. S. FOREST SERVICE)

weeds. Some, like the common brown seaweed or rockweed (*Fucus* — few'cus), are fastened to the rocks in the region between the tides. They can hold much moisture and are tough enough to stand the pounding of the surf. Some brown seaweeds, like the kelps, may reach a length of fifty yards or even twice that length. Formerly kelps were burned to yield iodine. They were gathered in large amounts off the coasts of Ireland, France, and elsewhere.

Other seaweeds float near the surface in the open sea. You may have seen pieces of the green sea lettuce (*Ulva*) which have been washed ashore and caught on the sand or rocks. At greater depths live red seaweeds, which are usually delicately branched plants of much smaller size. The agar-agar which the drug store sells and which is used in some experiments comes from a red seaweed found near Japan and near our west coast.

Mushrooms. As you read above, the simplest plants without flowers are of two kinds; those with green coloring matter, the algae; and those without green coloring matter, the fungi. Among the larger more conspicuous fungi are the mushrooms. About one half of the many kinds of mushrooms make good food. Some are too tough to be eaten and some are definitely poisonous. It is often so hard to tell the various kinds of mushrooms apart that no one but an expert should decide which can be eaten. Mushrooms live only where it is damp. Most are small, but some attain a weight of more than thirty pounds. Study a common mushroom. See EXERCISE 2.

Fungi you do not like — the molds. In damp weather stale bread often begins to smell musty — the peculiar smell of a fungus known as *mold*. If you give the mold a chance to develop and then examine it closely you will see that what

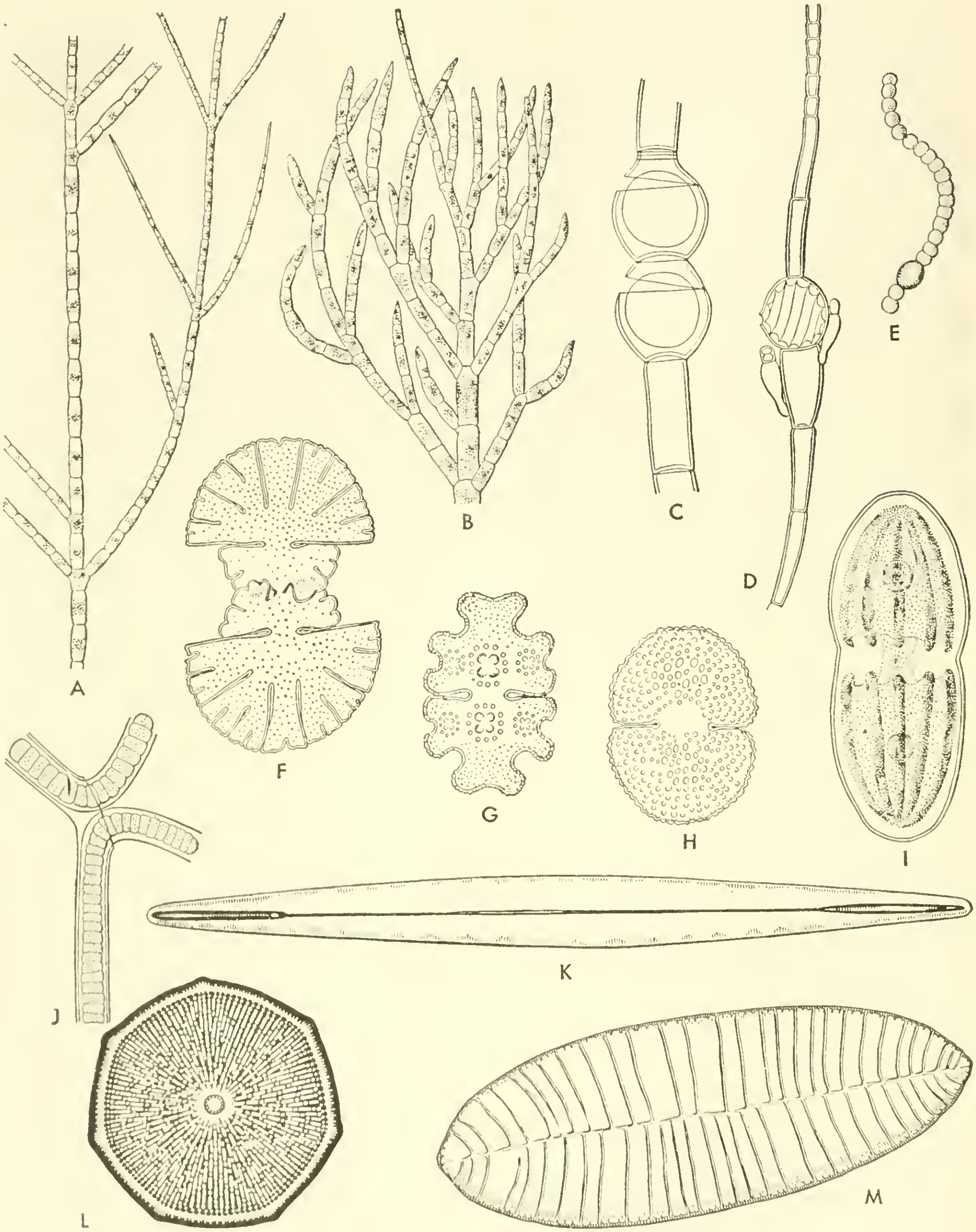


FIG. 100 *Drawings of several kinds of fresh-water algae. Hundreds of kinds of algae are found on soil and in swamps, lakes, ditches, and streams. Algae are the principal food of many kinds of small water animals, and these animals are the food of larger animals. The names of the algae are:* (A) *Stigeoclonium,* (B) *Chaetophora,* (C, D) *Oedogonium,* (E) *Anabaena,* (F) *Micrasterias,* (G) *Euastrum,* (H) *Staurastrum,* (I) *Penium,* (J) *Scytonema,* (K) *Amphipleura,* (L) *Stictodiscus,* (M) *Suriella.* (REDRAWN BY PERMISSION FROM *Textbook of Botany,* TRANSEAU, SAMPSON, AND TIFFANY, HARPER AND BROTHERS)

at first looks like an ugly mass is really a very delicate simple plant. In fact, the bread may serve as a garden for several species of beautiful mold plants. The commonest one, known as the bread mold or *Rhizopus* (ry′zo-pus), consists of a miniature jungle of very fine, glistening, white threads. Little black balls appear at the tips of upright threads. These make the mass of white threads look gray and later sooty.

You can raise a variety of molds by doing EXERCISE 3. Molds grow on many different foods if enough moisture is provided. There are some mold plants that look like patches of bright blue-green felt; others are salmon pink. The drug penicillin is prepared from some of the blue-green molds. In these the threads are shorter and even more interlaced so that without a powerful lens you cannot see separate threads at all.

A plant that is both alga and fungus in one. Strictly speaking, this "plant" is two separate plants, one an alga, the other a fungus, but they are so closely combined that they look like one plant. The combination is called a *lichen* (ly′-ken). It looks grayish or yellowish green. You may have seen lichens on rocks or trunks of trees. Some, like the "reindeer moss," grow on the ground.

Lichens are extremely hardy plants; when all else has been killed by the cold they still survive. They are food for grazing animals, such as reindeer, of the arctic zone. Some are eaten by man.

Fungi that help man bake and brew. The yeast plant is so small and so simple that even under the microscope it does not look like much of anything. It is merely a tiny, colorless, egg or rod-shaped speck which cannot move. See Figure 362, page 413. It is classified as a plant and is clearly a fungus.

There is one special kind of yeast that we raise in vast numbers. Millions upon millions of them are pressed into one yeast cake. Yeasts are useful because when they live in sugar solutions they change the sugar into alcohol and a gas called carbon dioxide. This change is called *fermentation.* When we want to bring about fermentation we often put yeast plants with soaked, crushed corn or other grains. When we make wines we add yeast plants to grapes, although until recently we depended on "wild" yeasts to change the sweet fruit juice into alcohol. Wild yeasts and molds, too, float about in the air. You are now ready for EXERCISES 4 and 5.

Yeasts, as you may know, are also used in baking. They cause fermentation in the dough but the alcohol evaporates during the baking so you never taste it; the carbon dioxide gas forms bubbles in the solid mass of dough, "raising" it and making it light and porous.

Bacteria. These very important plants are usually classed as fungi, although some biologists place them in a phylum by themselves. Most *bacteria* are so much smaller than yeasts that they are difficult to describe. As a matter of fact, there is probably not much to be seen in them. Most of them cannot move about but some can wriggle when in a liquid and a few can swim by means of long whip-like projections. There are giants and pygmies among bacteria, but even the few giants are so extremely small that they can be seen only with a good microscope. It has been calculated that if the

FIG. 101 *Bacteria that cause pneumonia. The photograph was taken through a microscope.* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 102 *Physcomitrium, a tiny moss that you may find in your garden. It is less than one-half inch high.* (HUGH SPENCER)

bacterium which causes one kind of pneumonia were magnified to the size of a tennis ball, and if the man in whom the bacterium lodges were magnified in proportion, the man would be about twenty-five miles tall! But bacteria are interesting to man not for the way they look but for what they do. Some species live in man and cause disease but many more are harmless or even valuable. You will read more about them in Unit VI.

PHYLUM — BRYOPHYTES

The Mosses and Their Relatives

The second large division of flowerless plants. This group includes the *mosses*. They look somewhat more like the plants commonly recognized as plants. For one thing, most of them live on land. For another, they are always green and, like the plants you know best, are anchored to the soil. Then, too, moss plants have simple leaves and rootlike and stemlike parts. Mosses range in size from less than one-eighth inch to more than one and one-half feet high.

Mosses grow almost everywhere except in salt water. There are vast bogs of one kind of moss known as *Sphagnum*. The sphagnums are among the largest of mosses, having a stemlike part that grows to be many inches long. Stems and leaves are constructed so that they absorb water like a sponge and for this reason some kinds were formerly used for dressing wounds. The greatest usefulness of sphagnums arises from the fact that when they grow in water, the plants do not decay when they die. The accumulated dead plants become what is known as *peat*. Peat accumulations many feet deep are common. After draining the bog, the peat can be dug out in small squares, dried and used as a fuel.

FIG. 103 *The hay-scented fern. Not all ferns have leaves (fronds) as finely divided as this.* (SCHNEIDER AND SCHWARTZ)

FIG. 104 *The "scouring rush" is a relative of the fern. It is harsh and gritty to the touch.* (BROOKLYN BOTANIC GARDEN)

PHYLUM – PTERIDOPHYTES

Ferns and Their Relatives

The third large division – the ferns. There is something about a fern that pleases the eye; for that reason you have all noticed ferns. They have been cultivated, too, so that they are often seen in homes. There are almost four thousand different species growing in many parts of the world. Most species need moisture and thrive best in the shade of forest trees. But some, like the sensitive fern, live on the edge of the forest; a few, like the bracken or brake, grow in sunny fields. Most fern leaves (called *fronds*) are divided and often finely subdivided into leaflets. The leaf comes up from the ground tightly coiled like a fiddlehead; as it grows, it uncoils and spreads out its broad surface. In most ferns the leaves are the only parts that are visible; the woody stem lies underground and may extend for many feet just underneath the surface of the soil. Like all the plants you have read about so far ferns never form flowers or seeds.

In the tropics ferns grow to a much greater size and some develop strong stems above ground. In fact they may grow as trees sixty or more feet high. And there was a time some 200 million years ago or more when large tree ferns grew in vast numbers much farther north.

Large portions of the rich coal deposits of Pennsylvania are the remains of these ancient fernlike plants. And in those past ages, two small inconspicuous relatives of the fern also grew as tall trees, the *club mosses* and the *horsetails*.

The club mosses are also commonly called ground pines. They are creeping plants that grow close to the forest floor. It is difficult to say which name is least fitting since they are neither "mosses" nor "pines." They are closely related to the ferns. Another common name for the horsetails is scouring rush (Figure 104). All the species included in this division or phylum have true roots, stems, and leaves, but they never bear flowers and they never produce seeds.

If specimens are available, you should now be able to do EXERCISE 6. The whole class might well make a common project of EXERCISE 7.

PLANTS WITH FLOWERS AND SEEDS

PHYLUM – SPERMATOPHYTES

Characteristics of flowering plants. The plants of this, the fourth large division, not only produce flowers and seeds but they have another characteristic which is not possessed by any of the simpler plants except the ferns: they have well-developed roots, stems, and leaves. There is great variety in the size and appearance of these parts, as well as in the blossoms, as you can imagine when you learn that there are more than 125,000 different species in this division. They are the commonest land-living plants. But some grow in water. In fact they may be found in almost any environment. Some have a stem that is soft, grows rapidly, and dies at the end of the year. They remain small and are called *herbs*. Others have stems that are woody and tough. If they have one main stem, they are trees; if they have several equally thick stems arising from the ground, in which case they usually do not grow very tall, they are called *shrubs*.

Flowering plants vary, too, in length of life. Those that start from seeds, grow, produce flowers and seeds and then die during one growing season are called *annuals*. Examples are the crabgrass, common as a weed in many lawns; radishes, tomatoes, and lettuce of the garden, and farm crops such as oats, corn, and buckwheat. Plants that start from seeds during one growing season but produce flowers and seeds and then die during the next season are called *biennials*. Many weeds are biennials. Among the farm and garden crops that are biennials are winter wheat, cabbage, and carrots. You will note that both annuals and biennials die after flowering. The other seed-producing plants are called *perennials*. These plants may live for many years, producing flowers and seeds each growing season. All of our trees and shrubs are perennials as are certain garden and farm crops such as asparagus, sugar cane, and tulips. Perennial grasses make the finest lawns. Perennial plants may live to a great age. The cypress of Mexico and some of the big trees (sequoias) of California have lived for 3000 to 4000 years.

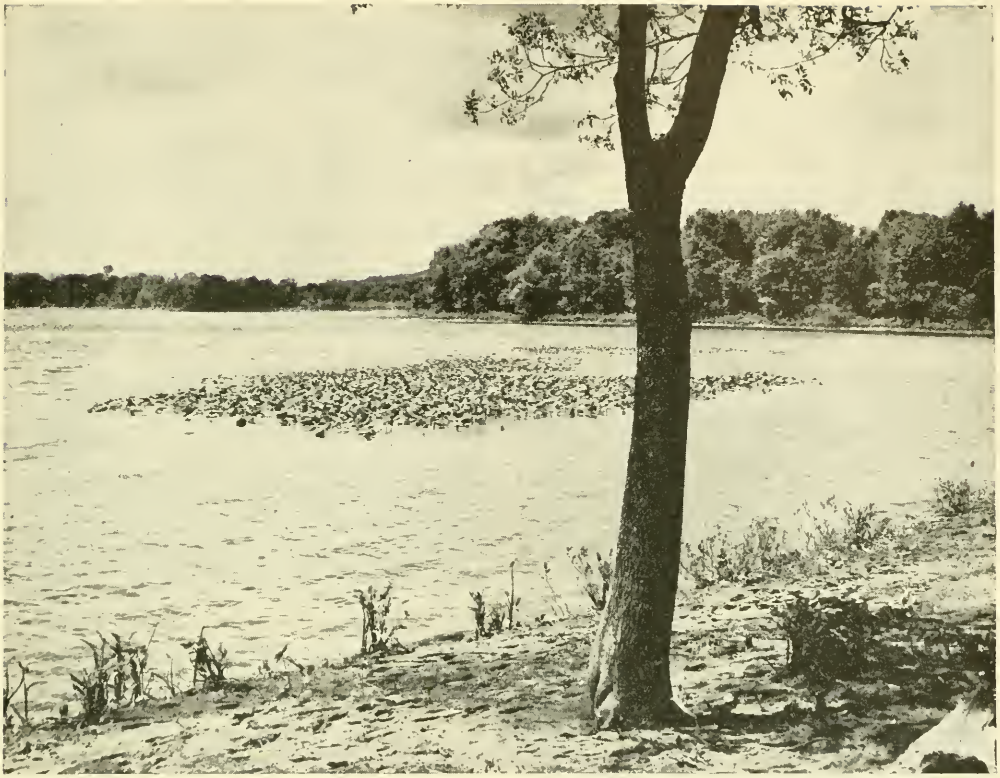


FIG. 105 *All the plants you see in this photograph are Spermatophytes. They bear flowers and seeds. If you were to go to the scene of the photograph, where would you be likely to find algae and fungi, mosses and liverworts, and ferns and horsetails?* (EVA LUOMA)

The two chief groups of flowering or seed plants. This division includes plants that you may not have thought of as "flowering" or seed plants, the cone bearers.

Thus there are two large groups in this phylum:

1. The cone bearers and their relatives (Gymnosperms — jim′no-sperms). Botanists think of them as seed plants with uncovered or naked seeds.
2. The true flowering plants (Angiosperms — an′jee-o-sperms). To botanists they are the seed plants with covered seeds.

The cone bearers. The scales of the cone hold the uncovered or naked seeds. These plants are called *conifers* (kon′i-furs) and most of them are evergreen. The leaves of conifers are usually hard needles or tiny scalelike leaves which can withstand the winter drought (lack of moisture) and cold. The needles live for two or more years, so the trees remain green at all times. There are many different kinds of conifers or evergreens: the giant redwoods of the west, the many kinds of pines, firs, hemlocks, cedars, and smaller plants or shrubs like the yews. Some people carelessly call many of the evergreens "pines." The true pines are

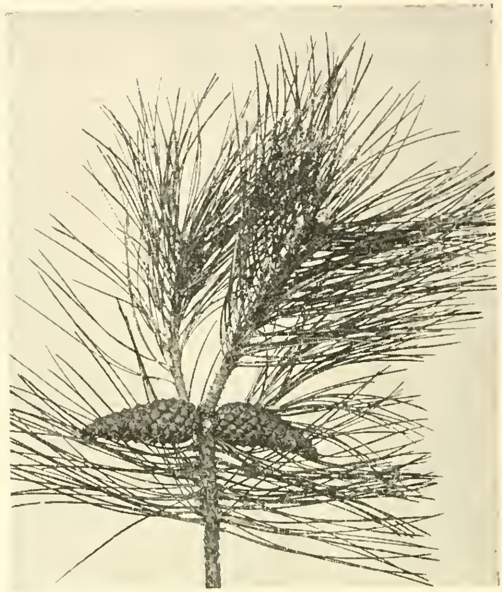


FIG. 106 (above left) *Red cedar. Its cone is hidden within a so-called berry.* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 107 (above) *Pine.* (BROOKLYN BOTANIC GARDEN)

FIG. 108 (left) *Hemlock. How does it differ from pine and red cedar?* (DICKERSON)

easily recognized because they have longer needles than any other cone bearers, and their needles grow in clusters.

In the temperate zones the conifers are of great value for their wood which is known as softwood. Most of them have a very sticky sap which has a strong, peculiar odor; it is called *resin*. The wood burns up too fast to be good firewood, but most of our lumber is sawed from the trunks of conifers. They are of great importance, too, as a source of wood for making paper.

The true flowering plants. The true flowering plants are far more numerous and more varied than the cone bearers. The group includes plants as different as a small grass plant and an oak tree, for both bear flowers and produce seeds, and they resemble each other in various other ways. However, there are impor-

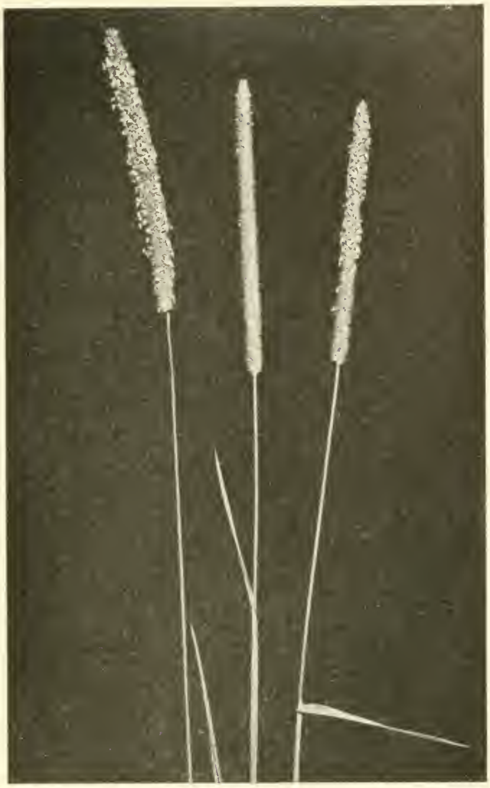
FIG. 109 (above) *Chestnut. These leaves have feather net veining.* (SCHNEIDER AND SCHWARTZ)

FIG. 110 (upper right) *Maple. These leaves have palmate net veining.* (SCHNEIDER AND SCHWARTZ)

FIG. 111 (right) *This lady's slipper, an orchid, has the typical parallel-veined leaves of monocots.* (GEHR)

tant differences, too. Grass plants are representatives of one large division of the flowering plants, the *monocotyledons* (mono-cot-i-lee′dons) or monocots for short. Oak trees represent the other large division, the *dicotyledons* or dicots for short. It is easy, for the most part, to tell these two groups apart. The leaves of the monocots have many long veins running from one end of the leaf to the other and close to one another. See Figure 111. The leaves of the dicots have a few principal veins and a large network of smaller veins. See Figure 110 and do EXERCISE 8. You will learn other differences between monocots and dicots but you must not get the impression that all monocots are small and dicots large. In both groups there are large and small plants.

There are so many kinds of flowering plants that botanists find it convenient



to subdivide the monocots and dicots into families. There are more than two hundred and forty families in the group of dicots alone and many families among the monocots. Each family contains, as a rule, many different kinds or species.

Monocotyledons used as food. The monocotyledons are the source of much of your food. This may astonish you, for many of these plants are small and unimportant looking. But although they are relatively small they occur in great numbers; they grow side by side in endless stretches of field and meadow and lawn. They are food for the cattle, sheep, hogs, goats, and other grazing animals which are raised for their meat or milk.

We use grasses of various kinds as food plants for ourselves, too. The "cereals" or grains such as wheat, oats, barley, rice, and corn are close relatives of the small wild grasses of our meadows and lawns. All of them are monocotyledons as you can see if you examine the leaves. These cereal plants have been cultivated for many thousands of years. The cultivation of these plants has gone on so successfully that over five billion bushels of wheat alone are now produced in the world each year. When you realize that it is only the small kernels or seeds of the plant that are gathered to fill the bushel baskets you can appreciate

FIG. 112 (top) *Timothy, a grass plant. Each spike is a mass of tiny flowers.* (BLAKISTON)

FIG. 113 (bottom) *Sugar cane, like timothy, is a monocot. How tall does it grow?* (U. S. BUREAU OF PLANT INDUSTRY) how many acres of wheat there must be.

In the tropics there grow the large banana plant and a giant grass, the sugar cane, that makes much of the sugar eaten by man. Some monocotyledons, as the date and coconut palms, are trees. They supply much food.

Many dicots are trees. You have already read about the cone bearers; the rest of our native trees are dicots except for one or two palm species which grow in the semitropical climate of Florida and southern California. Most dicot trees in our country shed their leaves at the end of the season and are for this reason called *deciduous* (de-sid′you-us). The deciduous trees are rather generally referred to as "hardwoods" by foresters and lumbermen.

There are several families of trees widely spread through large portions of the United States; you are probably familiar with most of them. If you can recognize oaks, maples, elms, and hickories or walnuts you are acquainted with

FIG. 114 *This shagbark hickory leaf is a compound leaf.* (BROOKLYN BOTANIC GARDEN)

FIG. 115 *Poplar. A very common tree.* (BROOKLYN BOTANIC GARDEN)

FIG. 116 *Oak. This and the poplar and elm have feather net veins.* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 117 *Elm. How can you recognize it?* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 118 *Red maple. How can you distinguish this maple from the one in Figure 110?* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 119 *The wild rose. How does it differ from all the many cultivated roses that you have seen?* (BROOKLYN BOTANIC GARDEN)

FIG. 120 *Strawberry blossoms. Can you see why strawberries and roses are placed in the same family?* (HUGH SPENCER)

at least one member of each of four prominent tree families.

Another family that many of you will know includes the willows and the poplars. You often see willows lined up along the banks of streams. In dry, otherwise treeless regions, a group of poplars always is a sign of water trickling through the soil. Their wood is unusually soft for hardwood trees and is therefore much used for paper making.

All these trees bear flowers although the flowers of many of them are so small that you might not recognize them as flowers.

The rose family. There are some families that contain species ranging in size all the way from a small, soft-stemmed herb to a goodsized shrub or tree. They are grouped together in one family largely because of their similar flowers. The rose family, for example, includes, among many other plants, the trees that bear pears, peaches, plums, or apples; it includes also the shrubs that produce raspberries and blackberries, the bushes which bear roses, and the still smaller strawberry plant. You may not be able to obtain a blossom of this family for study at this time. But you might wish to study some other flower to learn its parts. See EXERCISE 9. In some species of the rose family the flower is small, in others it is large and showy, but on close examination you would see that all the blossoms are similar and most of them are rich in *nectar*, the sweet liquid that can be changed into honey by bees. Farmers sometimes place beehives in apple, plum, or peach orchards in order to get a better fruit crop. You will read later how in obtaining nectar and pollen the bees help to make good fruit.

The clovers and their relatives. Some of the plants in this family are also sweet-scented; and some form edible fruits. The clovers have blossoms that are small, but gathered so closely into a

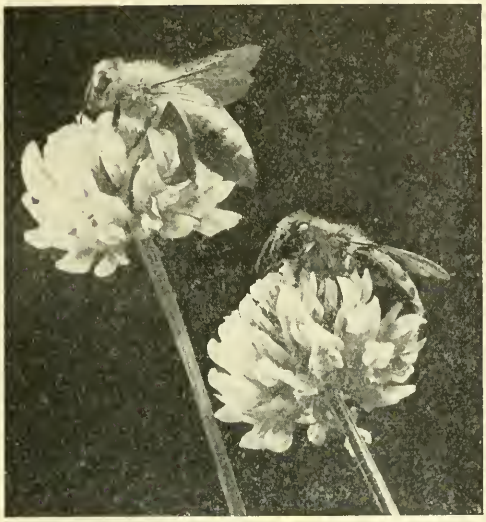


FIG. 121 *Each blossom in a head of clover is not unlike a pea blossom. To what family does clover belong?* (ROOT)

FIG. 122 *The potato plant has white or pale lavender flowers. But the farmer plants pieces of potato, not seeds.* (BLAKISTON)

head that life is made easy for the bee that dips its sucking tube into the nectar bags.

In the same family with the clovers are the sweet peas with their showy blossoms, as well as the more humdrum, practical garden peas, and beans. Both peas and beans produce large fruits, which are the pods we know as vegetables.

Another member of the family is alfalfa (al-fal′fa), which means in Arabic, the best fodder. Alfalfa is now grown throughout our country. The family also includes the decorative woody climber, *Wisteria*, and among the trees, the very useful black locust.

Other families that furnish food – the potato family. The dicotyledon that is now raised, perhaps more than any other, to supply man with food is the potato. You may have read how it was introduced into Europe by the Spaniards and by Sir Walter Raleigh. In the same family with the potato are the tomato, the pepper, the tobacco plant, and the poisonous nightshades.

The **mustard family** contains many members that have been cultivated to supply us with "vegetables." The mustard family usually has small blossoms with four petals arranged in the form of a cross. Among the plants of the mustard family are some of the strong-tasting vegetables: turnips, cabbages, cauliflower, brussels sprouts, and others. Of course, the onion and the leek do not belong here; if you have ever looked at their leaves, you know that they are plants with parallel-veined leaves, monocotyledons.

The **parsley family** is another large, well-known family. Most of its members have deeply cut compound leaves, like the table parsley, and tiny flowers grouped together in a flat-topped cluster. You may have seen the lacy wild carrot dotting the fields with white after

FIG. 123 *Wild carrot. Another name is Queen Anne's lace. This is a member of the parsley family.* (BROOKLYN BOTANIC GARDEN)

FIG. 124 *The white flowers and red berries of the coffee tree. Each berry contains two coffee "beans."* (AMERICAN CAN CO.)

the daisies are gone. Related to it is the carrot which is raised as a vegetable, the many parsnips, both wild and cultivated, and celery. Like the potato family, it also has its "black sheep," the poison hemlock, which yields a powerful poison. The ancient Greeks used a drink brewed from it to put Socrates to death. Of course, the poison hemlock is not at all closely related to the evergreen tree named hemlock.

The mint family. You have met some of the members of the large mint family: peppermint, spearmint, pennyroyal (sometimes used against mosquitoes), and sage. Some are used to lend flavor to food, but some species of this family lack flavor or odor. The flowers are for the most part small. The stems are four-sided.

Plant families that have proved useful in various ways. When Columbus landed on the shores of South America he found the natives playing with a black ball that apparently moved and seemed alive. Several centuries later the substance of which the ball was made came into general use in Europe for "rubbing" out ink and pencil marks. That was the white man's first introduction to "rubber," as he soon learned to call it. Rubber is made from a milky liquid produced by numerous tropical trees belonging to many different families. It can be obtained from other plants also.

Far older than the rubber industry is the raising of cotton plants. The fruits, when ripe, burst open showing a fluffy mass of white threads, which are attached to the seeds. See Figure 339, page 390. The cotton gin is used to separate the seeds from the "cotton." The seeds themselves are squeezed to remove their valu-

FIG. 125 *Camomile is a common composite. About how many ray flowers surround the yellow disc?* (BROOKLYN BOTANIC GARDEN)

able cottonseed oil, which is used for making oleomargarine, salad oils, and for many other purposes. What is left of them can be ground up to make food for cattle, can be used in making plastics, or spread on the ground as fertilizer.

We get threads or fibers in a very different way from the flax plant. It has beautiful bright blue or white flowers. Although its leaves look somewhat like those of a grass, it is a dicotyledon. The threads which are later woven into linen come from the stems which must be "retted" or rotted in water. This loosens the threads. Its seeds are also used as a source of oil (linseed oil) and as cattle feed. Linseed oil is a part of many paints. There are plants of various families like hemp and jute whose stems or leaves contain tough fibers which are used for making rope or coarse bags.

Another family of importance to man is the madder family. Among its useful members is the coffee plant. Originally at home in Abyssinia, it has been carried to many parts of the world where the climate is warm. Two other members of this family are the cinchona (sin-koh'-na) tree, whose bark yields the drug quinine, and the madder, which has been used to dye cloth from the time of the early Egyptians.

The composites. You have seen daisies in the pasture and dandelions in the lawn. What you have probably always called a daisy blossom is really a tiny bouquet of many small blossoms. The daisy is a very closely packed cluster of two very different kinds of flowers. The yellow portion in the center consists of a large number of tiny flowers packed together so tightly that you need to look closely before you can distinguish them as separate flowers. Around them are the much larger white flowers, called "ray flowers" from their position around the center disc. Many plants in this family do not have the striking ray flowers. But all the plants in the composite family bear many small flowers in one head so closely grouped that the head looks like a single blossom.

There is almost no end to the species of composites. Some may grow on rubbish heaps and in uncared-for city lots. Here you will find the burdock, which children often call "stickers," and the cocklebur with its vicious burs. Along the roadside grows the ragweed responsible for hay fever; and where the ground is damp, the wild lettuce. In the vegetable garden you will find the artichoke, oyster plant, lettuce, and chicory. These are all composites. It is by far the largest family among flowering plants.

Now the class might sum up the pages on angiosperms by doing EXERCISE 10.

In the last problem you examined the complex animals first and you ended with the simplest forms. In this problem you began with the simplest forms and ended with the most complex. You learned about algae, simple water plants that never bloom and that have no root or stem or leaf. You learned about many simple plants that were not even green and often did not grow in soil. These were the fungi, the microscopic plants like bacteria and yeasts, the many molds, and the much larger mushrooms. Later you studied the more complex mosses and then the larger ferns. You found that the ferns have leaves and stems and roots but bear neither blossoms nor seeds nor fruit.

Finally you studied two large groups of plants that looked like *plants*. First you looked at the evergreens that bear cones and then at the real flowering plants. You learned something of monocots, the grasses, orchids, lilies, and palms, and of the dicots, which are used in so many ways. There were tall trees and tiny herbs. At first glance these seemed to differ much among themselves but all of them had a root, stem, and leaves; all bore blossoms or cones, and all produced seeds.

In this study you met plants you had not seen before. You were assisted in learning their names by gathering them into groups or *classifying* them. In the next problem you will read how, many years ago, a scheme was devised for naming and classifying the many living things of this earth.

SUMMARY

This simplified table will help you review the plant kingdom.

PHYLUM I. Thallophytes (*Thallophyta*): Plants without flowers and fruit. Also lacking root, stem, and leaf.

SUBPHYLUM I. Algae: Simple thallophytes with green coloring matter. With few exceptions, aquatic. Green, brown, and red seaweeds and other plants.

SUBPHYLUM II. Fungi: Simple thallophytes lacking green coloring matter. The group includes mushrooms, molds, yeasts and bacteria.

PHYLUM II. Bryophytes (*Bryophyta*): Plants without flowers and fruit. Green. Mostly with simple stems and rootlike and leaflike parts. Small and inconspicuous.

CLASS 1. Liverworts (*Hepaticae*): Some have a somewhat branched, ribbon-like structure flat on the ground, with simple rootlike parts. Others have stems and rootlike and leaflike parts.

CLASS 2. Mosses (*Musci*): Erect. More complex in structure with stems, leaf-like, and rootlike parts.

PHYLUM III. Pteridophytes (*Pteridophyta*): Plants without flowers and seeds. Green. True leaves, roots, and stems with conducting tissue much like that in higher plants.

CLASS 1. Ferns (*Filicinae*): In temperate zones, mostly small with horizontal stems. Spores borne on leaves or modified leaves.

CLASS 2. Horsetails (*Equisetinae*): Few species. Jointed stems with leaves reduced to scales. Spores in conelike structures. Stems harsh to touch.

CLASS 3. Club Mosses (*Lycopodinae*): Few species. Creeping herbs with erect stems bearing conelike structures with spores.

PHYLUM IV. Spermatophytes (*Spermatophyta*): Producing flowers and seeds. Practically all are green. Vary in size. Complex structure.

SUBPHYLUM I. Gymnosperms (*Gymnospermae*): Woody plants with naked seeds born on surface of cone scales. Mostly needle or scalelike evergreen leaves. Includes the conifers, ginkgos and cycads.

SUBPHYLUM II. Angiosperms (*Angiospermae*): Seeds develop enclosed in a fruit.

CLASS 1. Monocotyledons: Usually parallel veined leaves. Flower parts in three's. Single cotyledon in seed.

CLASS 2. Dicotyledons: Netted veined leaves. Flower parts mostly in two's, four's, or five's. Two cotyledons.

QUESTIONS

1. Why is it incorrect to use the words plant and flower as though they meant the same thing? Into what two large groups can all plants be divided? In which group are trees and grasses placed?
2. What name is given to the division of flowerless plants that includes the simplest plants? What are the characteristics of the plants in this division? What name is given to the simplest plants that are green? What do you call those without green color?
3. Describe a simple water-dwelling alga and two land-dwelling forms. Do most algae live on land or in the water?
4. Are mushrooms algae or fungi? Give some interesting facts about mushrooms.
5. Describe the common breadmold. What is mildew?
6. What is a lichen?
7. Tell about the yeast plant: its size, how it looks, how it lives, of what importance it is to us. Define fermentation.
8. What is your idea of the size of an ordinary bacterium? What might you see if you examined bacteria under the microscope? What is their importance to us?
9. Which common plants can be classified as Bryophytes? How do these plants differ from the Thallophytes? How is Sphagnum moss used?
10. In general, where do ferns grow and how do they look? What was true of these forms in ages past?

11. What are the characteristics of the spermatophyte? Define the words herb, shrub, annual, biennial, and perennial.
12. What are the two main groups of flowering plants? How do they differ?
13. By what other names are the cone bearers known? How do they differ from one another aside from the difference in the cones? In what ways do we use the cone bearers?
14. Into what two groups are the true flowering plants subdivided? How do the leaves of most dicots differ from the leaves of most monocots?
15. List small monocots that are an important source of food for us. List two monocots that are trees.
16. Define deciduous. What do foresters and lumbermen call the deciduous trees? List five families of deciduous trees that are widely spread through the United States. What is true of the flowers borne by most of these trees?
17. What similarity is there between the species included in the rose family? List one or more herbs, shrubs, and trees that are grouped in this family.
18. List some common relatives of the clovers. Of what importance are they?
19. List other families that include food plants. Mention the names of plants in each. List members of the mint family. What is characteristic of their stems?
20. From what part of a plant is rubber made? What uses are made of the cotton plant? Of the flax plant? Explain the importance of the madder family.
21. What is true of flowers in the composite family? List several composites that are familiar as weeds or as food plants.
22. Review briefly the groups of plants you have studied, starting with the simplest and ending with the most complex.

Exercises

1. If you have the use of a microscope you will enjoy exploring water collected from the surface of various ponds. You can easily recognize Spirogyra, and you will find a number of other threadlike plants. The kind of green alga that grows on tree trunks is *Protococcus.* Scrape some onto a slide; tease apart the material you gathered; mount it in water. How does this plant differ from Spirogyra?

2. Study the common field mushroom, *Agaricus.* This can be bought in the markets during most seasons of the year. What do you find on the lower side of the cap?

3. To become acquainted with various kinds of molds all you have to do is leave food exposed and they will come to you by themselves. On

pieces of moist white blotting paper in bowls, expose some bread, apple, lemon, cheese, and other kinds of food. Cover the bowls and keep them at room temperature. Keep the blotting paper moist. After several days begin to observe closely at short intervals. Describe what you see. Compare with the results obtained by your classmates. Do certain kinds of molds seem to grow best on certain foods? Where do the molds come from?

4. If you crumble a small piece of yeast cake into water and mount a tiny drop on a slide, you will be able to see the yeast cells under the microscope. A magnification of about 400 times is necessary.

5. How can you find out whether or not there are yeasts in the air? Plan the experiment. Discuss your plan with your classmates and teacher to make sure you are on the right track.

6. If examples of mushrooms, mosses, ferns, lichens, horsetails, and club mosses are available, examine them. Can you tell them apart? How? In some cases it may be difficult for you to decide whether or not they are plants without flowers unless you see them at all times of the year.

7. Divide the class into committees, each of which will report on one of the major divisions of the flowerless plants. Special reports would be made by those who have raised molds or completed other projects. You will then as a class have summarized the text on flowerless plants and you will have made a small beginning toward learning to know the plant kingdom.

8. Obtain examples of parallel-veined and net-veined leaves. Compare and draw them. You can skeletonize leaves by soaking them in dilute potassium hydroxide. Only the veins will be left.

9. Examine carefully some dicot flower, such as the sedum or sweet pea or violet. (You will find a description of the flower under plant reproduction.) Can you identify the parts? Compare with a monocot blossom.

10. *Summary*. Visit the vegetable market and make a list of the different plants seen. Perhaps several students could visit a florist shop and list the flowering plants there. In class, see how many of the plants listed you are able to classify into families. Now if you can sum up briefly what you read about cone bearers, you will have summarized the pages on "The plants with flowers and seeds."

Further Activities in Biology

1. Look through the titles of your state publications as well as those of the United States Department of Agriculture for bulletins on mushroom growing. Send for some and report. If you have a cellar with the right conditions you might try raising some.

2. Ferns are common and easy to press. When carefully mounted they make beautiful specimens. They are relatively easy to identify.

3. Look up and report on an industry that makes use of cone-bearing trees, such as papermaking or the making of varnishes.

4. Make an evergreen collection for the class museum. Mount and label a small branch and, if possible, a cone from each kind of evergreen that you can find.

5. Start a collection of leaves of trees. Add descriptions of everything you note about each tree.

6. Instead of pressing the leaves you can make blueprints or spatter prints.

7. When you know your trees a tree map of the streets of your city or town can be made.

8. It is interesting to make a collection of different kinds of woods. You will need tools for smoothing and finishing to show the grain of each.

9. It is interesting to learn how to identify trees during the various seasons of the year. By using a good tree book you can find out the names of nearby trees and follow them throughout the year. If there are trees on the school grounds, why not ask the shop teacher to help you make neat metal signs with the names?

10. You can learn the names of the common spring, summer, and autumn flowers by using a flower book.

PROBLEM 3 *How Are Living Things Named and Classified?*

The variety of living things. If you and your classmates were to name all the different kinds of living things that you could remember you would probably have a list with hundreds of names. Yet as you know from reading Problems 1 and 2 your list would represent only a small part of the number of different kinds of living things that biologists know. Actually, more than one million different kinds of living things have been named and described by biologists.

The need for classifying. In order that anyone may have even a slight knowledge of so many different kinds of plants and animals they must be arranged in groups. Then, by learning the groups in which they are arranged a person can have an understanding of one million plants and animals without knowing the names of more than a few hundred. Such a grouping of a large number of objects in an orderly way and according to some definite arrangement is called a *classification.* You know that plants and animals have been classified, for in the earlier problems you learned something of this classification. Let us look more closely into the methods of classifying.

How all kinds of objects can be classified. If your hobby is collecting stamps, you put together in one place in the album all the stamps of one country; you classify your stamps by putting together those that are alike in some easily recognizable way, some *characteristic.* In classifying stamps the characteristic in which the stamps in any group are alike is that they were printed for the same country. Coins, too, may be classified in this way. They may be grouped as English, French, United States coins, and so on.

But if you have large numbers of coins to take care of you do not stop when you have grouped them according to their countries. You find that the United States coins are not all alike. Some may be pennies, some nickels, and some dimes. So you group them according to their value. In other words, you now make a further *subdivision* by using another characteristic: the value of the coin. But you can go still further in your classification. You can subdivide the pennies, for example, according to the date of issue. You will find Exercises 1, 2, and 3 useful for an understanding of classification.

By looking at the diagram of one coin collection you will see that the first groupings are few in number; there are only three groups according to country. But when you come to the final grouping the groups are very numerous. Only a few groups of the many possible ones are shown in the diagram, Figure 126.

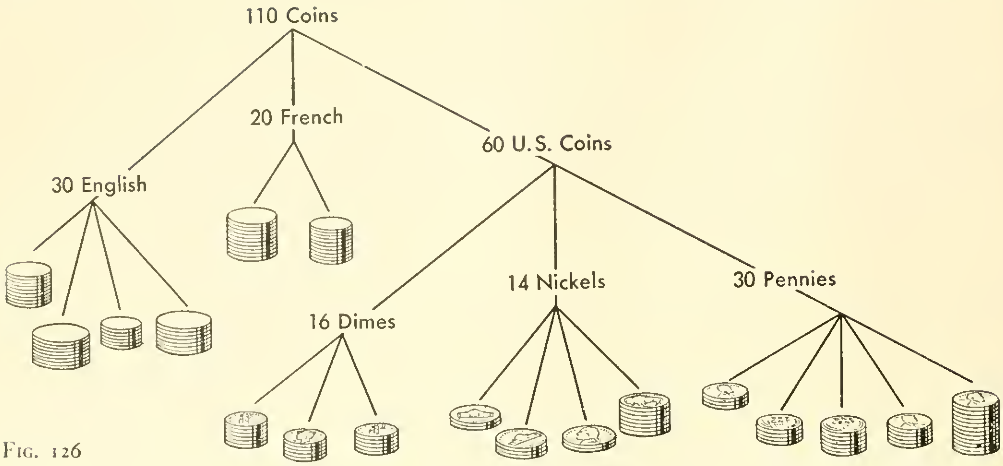


FIG. 126

The diagram shows you something else. The oftener you subdivide, the smaller the number of specimens or individuals in each successive grouping. For example, you start with 110 coins but the number of United States coins is only 60. In the next grouping there are 16, 14, and 30. And of the 16 dimes, divided according to the year they were coined, how many do you count in each pile?

Another important fact to understand about every classification is this: the specimens in the first subdivision have few characteristics in common. For example, the 60 United States coins form a group of considerable variety; they are alike in two respects only, they are metal coins and they are United States coins. But specimens in the final subdivision have many characteristics in common. For example, the three pennies in the final subdivision are alike in being metal coins, of the United States, being made of "copper," having the same size, the same color, the same value, and lastly being of the same age. It should not surprise you that this group contains fewer specimens. They must be matched in many details before they can be fitted into this group.

The classification of plants and animals. It is relatively easy to classify stamps and coins. But plants and animals are so much more complex that their classification is much more difficult. More than two thousand years ago the great Greek scientist and philosopher, Aristotle, wrote detailed and accurate descriptions of many animals. In doing this he came to recognize that certain ones had similar characteristics. For example, he put reptiles, birds, and fishes together into one group, the egg-layers. You will remember from Problem 1 that we no longer classify or group together animals on the basis of laying eggs. We use other characteristics.

As biologists continued their studies they found that they were continually obliged to change the classification because new facts were discovered about the animals and plants then known, and new plants and animals were being discovered. The simple systems of classification originally used were no longer satisfactory. As a matter of fact, changes

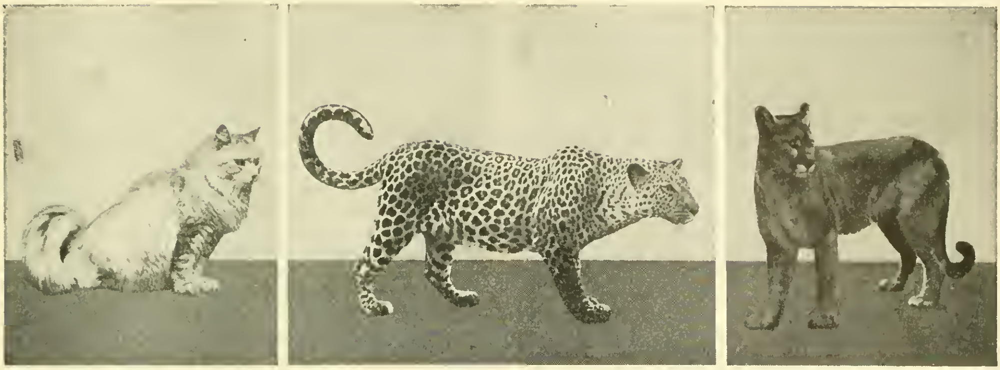


FIG. 127 *The Persian cat, the leopard, and the puma are placed in the same genus because of their similarity. However, they differ from each other, too. For this reason each is placed in a different species.* (NATIONAL ZOOLOGICAL PARK)

in the details of classification are still being made as new facts are discovered.

Just as it becomes necessary to make more and more subdivisions in coin or stamp collections when you get more specimens, so with plants and animals the first large groups had to be subdivided further and further. Of course, this was not all done at one time nor by one man; many contributed. But a more complete scheme than had appeared before was developed and established by Carolus Linnaeus (1707–1778). Linnaeus did two important jobs: he established a system of classification and he established a new method of naming plants and animals. To find out something about Linnaeus, do EXERCISE 4.

Naming in the early days. Centuries ago plants and animals were known only by common names. This is sensible enough for local everyday discussion but it does not work for a biologist, for sometimes the same animal or plant goes by different names in different parts of the country and sometimes the same name is used for different animals or plants. For example, in this country, today, the common name "gopher" is used for several kinds of ground squirrels in the west, means "tortoises" in the far south, and is applied to a snake in the southwest.

To avoid this difficulty biologists formerly wrote a long description of an organism and used that for the name. The more they knew about an organism the longer the description; sometimes it was four or five lines long. This did not make matters simple.

Linnaeus named many animals and plants. Linnaeus' scheme provides a short, simple name for every organism; this name may also partly describe the organism. Let us see how the system works.

Certain animals such as cats, lions, tigers, and leopards are plainly much alike, so Linnaeus put them together in a group called a *genus* (jee′nus – plural *genera* – jen′er-a). In the same way he grouped wolves and dogs together in a second genus. He did this for all the kinds of animals and plants he knew, finally arriving at many, many genera. The subdivisions of a genus he called a *species* (spee′shees). Thus there would

FIG. 128 *Coyote.* (N. Y. ZOOLOGICAL SOCIETY)

FIG. 129 *Dingo. The coyote, the dingo, and the collie, Figure 130, belong to the same genus, Canis. How do all three differ from animals in the genus Felis?*

FIG. 130 *Collie.* (UNITED STATES BUREAU OF ANIMAL INDUSTRY)

FIG. 131 *Red fox. The red fox belongs to the genus Vulpes. All the animals on this page belong to the same family.* (HUGH DAVIS)

be a cat species, a lion species, and a leopard species within one genus. Then Linnaeus named each genus. For example, the genus *Felis* (feel′is) includes such animals as cats, lions, leopards, and tigers. The genus *Canis* (can′is) includes dogs and wolves. Then each kind of animal was given as its first name the genus name and as its second name a special species name. The cat is *Felis domestica;* the lion, *Felis leo;* the dog, *Canis familiaris.*

Now this is a very clever scheme. Once you know that the dog is *Canis familiaris* you know that any animal with the first name Canis must be doglike. Have you ever heard of the dingo? No? Well, its name is *Canis dingo.* You would not have to look at Figure 129 to know in a general way how it looks. And the puma is *Felis cougar.* Again the name tells you a great deal about the puma. Do EXERCISE 5 to see whether you understand this. You may find EXERCISE 6 interesting.

FIG. 132 *Polar bear. Polar and black bears belong to the same family but different genera. Bears, dogs, and foxes belong to one order, Carnivora.* (NATIONAL ZOOLOGICAL PARK)

FIG. 133 *Black bear.* (NATIONAL PARKS, CANADA)

Linnaeus did this for every plant and animal he knew and biologists have expanded and improved the scheme so that now all organisms that have been named have two names: a *genus* name and a *species* name. Very rarely there are three names but these exceptions need not trouble you.

Linnaeus' scheme of classification. You know that the lion species and the cat species resemble one another closely; they fit into one genus. In the same way some genera resemble other genera closely. The genus *Vulpes*, including some foxes, and the genus *Canis*, including the dogs, are two similar genera. Such similar genera are put together, and this new and larger group is called a family. Vulpes and Canis thus belong to the same family. See Figures 131 and 130.

Similar families are put together into a larger group called an *order*. See Figures 128–133. Orders that are alike are included in a still larger group called a *class*. Classes that have certain charac-

FIG. 134 *Bighorn mountain sheep.* (AMERICAN MUSEUM OF NATURAL HISTORY)

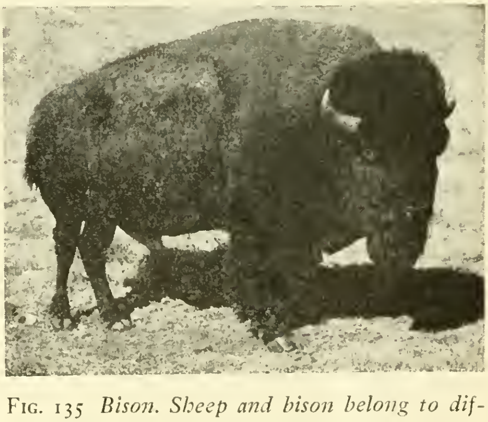


FIG. 135 *Bison. Sheep and bison belong to different genera but to the same family. How are they alike?* (U. S. FOREST SERVICE)

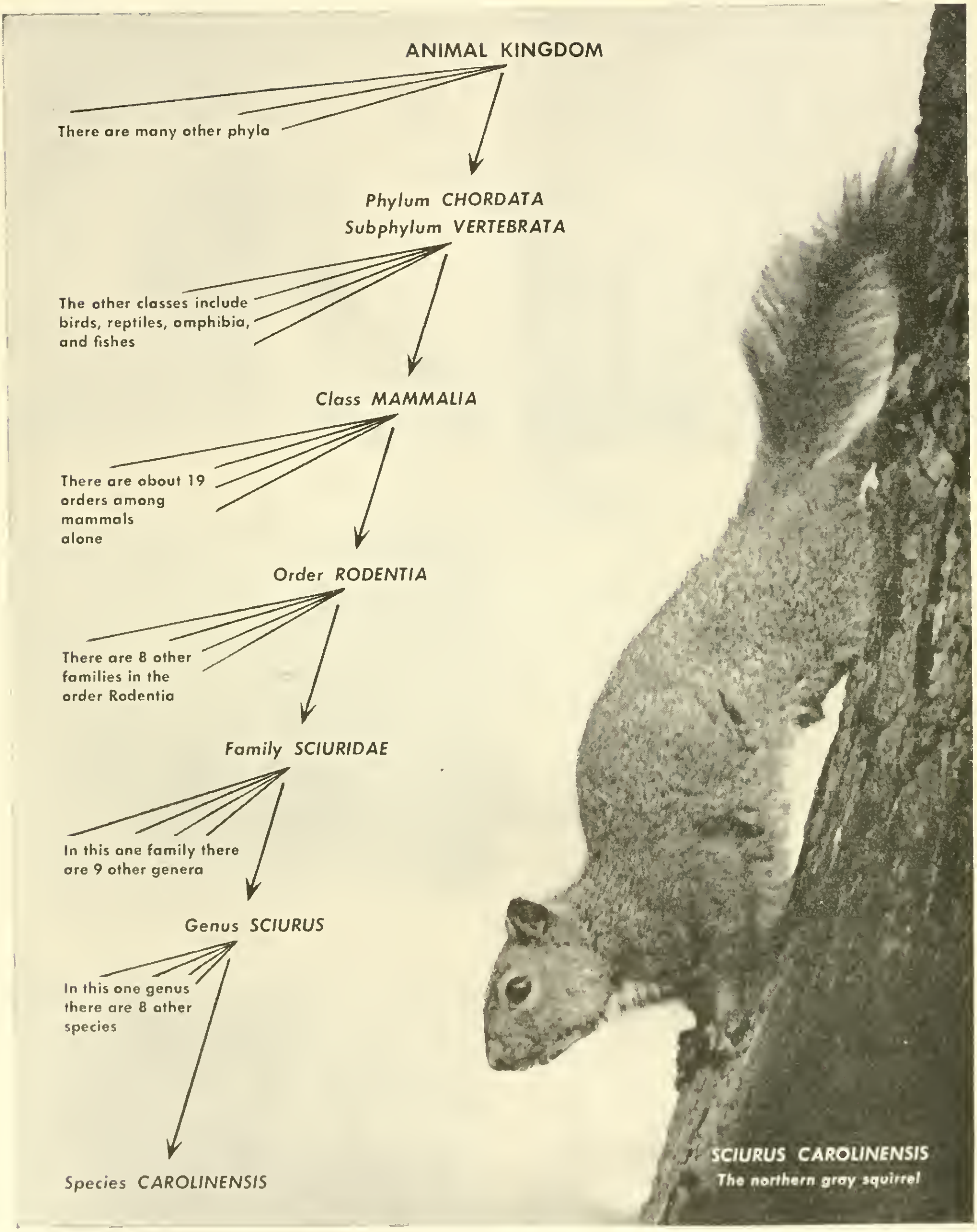


FIG. 136 *This chart shows how the gray squirrel fits into the animal kingdom. The first subdivision is the phylum. Which subdivisions follow in turn? A chart that shows how one animal is classified is simple; but, if you were to make a chart to include the classification of all animals, you would need a sheet of paper at least as large as your room. It would take you many years to do the job.* (PINNEY FROM MONKMEYER)

teristics in common are grouped into a phylum; phyla are grouped into a kingdom. There are only two kingdoms: the plant kingdom and the animal kingdom.

All classification is the same in principle. In describing the classification of animals we began *at the bottom* with the dog species and showed how similar species may be grouped together to make a larger grouping, a genus, and thus we worked up to larger groupings and still larger ones and finally to the animal kingdom. In describing the classification of coins we did the reverse. We began *at the top* with the coin "*kingdom*" and divided it into groups (corresponding to phyla) and so on down until we reached the final subdivisions into pennies coined in a certain year. These would correspond to species. Do you see that the system is the same? Figure 136 will show you how the animal kingdom is divided first into phyla, phyla into classes, classes into orders, orders into families, families into genera, and genera into species. Species are sometimes subdivided into varieties or breeds. Thus you see how the northern gray squirrel fits into the animal kingdom.

As in the case of the coin collection, the first large groupings are few in number; but the smallest subdivisions are very numerous. There are only two kingdoms and only about eleven phyla in the animal kingdom but the number of species runs to about 800,000. Furthermore, the larger the grouping the smaller the number of characteristics which the members have in common. (See Fig. 126.) But when you arrive at the smallest subdivision, the species or perhaps the variety, the animals in such a subdivision have a great many characteristics in common.

The classification of plants. The classification of plants is not quite as clear and easy to follow as the classification of animals, but the principles remain the same and the double naming is also used. All maples, for example, belong to the genus *Acer* (a'sir). One species from which we get maple sugar is *Acer saccharum.* The red maple is *Acer rubrum.* Every oak is called *Quercus* (kwir'cuss). *Quercus virginiana* is the live oak of the southeastern states. *Quercus alba* is the white oak of the northeastern and central states; and *Quercus agrifolia* is the coast live oak of California. Sometimes there are slight but regular differences between members of a species so that we can make a further subdivision into *varieties.* There are two varieties of red maple. Each has a different third name added to *Acer rubrum.*

A quick review of the summary tables at the end of Problems 1 and 2 will help you to remember the important facts about animal and plant groups that have been presented.

Questions

1. About how many different kinds of living things have been named?
2. What is meant by classification? Of what advantage is classification?
3. List the following characteristics in order of importance in grouping coins: date, value, and country of coinage. Are the first groupings or the last more numerous? In which grouping, first or last, are the

individuals most numerous? In which grouping, first or last, do the individuals have most in common?

4. What two important contributions to the science of classification were made by Linnaeus? When did he live?

5. Cite an example to show that common names for organisms are not satisfactory.

6. Using the terms species and genus, explain the scientific name for a cat and a lion. Which animal must *Canis dingo* resemble?

7. Starting with the final subdivision, species, list in order the larger and larger groupings up to kingdom.

8. Contrast the number of species with the number of phyla in the animal kingdom. Which have more characteristics in common, all the animals of one species or all the animals of one phylum?

Exercises

1. Why do not stamp collectors classify their stamps according to color? What characteristics do they use?

2. Choose some group of common objects, such as automobiles (or boats or houses), and prepare a list of characteristics by which you could subdivide them into groups and smaller groups.

3. All schools classify pupils so that they may be sent to the proper grades, classes, and rooms. List the characteristics by which your school classifies you. Be sure to take into account every item in your school program. Can you think of other characteristics that your school might have used?

4. Look up Linnaeus' life and prepare a report. Try to make him a living person in your report. (See Singer, C., *The Story of Living Things*, or Peattie, D. C., *Green Laurels*.)

5. Following is a list of articles of furniture: table, chair, sofa, bed, desk, bookcase, davenport, piano stool, bureau, and dresser. Add any others that you may think of. Classify these into genera according to use (rather than according to size, shape, or where they are found). How many groups or genera will you make? Compare with the answers of your classmates. You may be interested in making up a double name (genus and species) for each piece of furniture, as Linnaeus did for organisms.

6. Look back to Exercise 5. Could you gather these genera into families? What characteristics did you use for putting them into the same family?

Further Activities in Biology

1. With some help in the beginning you can learn how to construct a key for some group of plants or animals. You might first make a key to "key down" one of twenty or thirty assorted books on your bookshelves. (*Hint*: The library uses a key.) Then collect leaves, shells, seeds, etc., and construct a key for each. Have some classmate try it in order to test your skill.

2. Could you prepare a key for keying down each member of your class? (*Hint*: How does the school classify pupils?)

In UNIT II you will consider these problems:

Problem 1. Of What Are All Living Things Composed?

Problem 2. How Do Their Activities Keep Cells Alive?

Problem 3. How Are the Cells Arranged in Animals and Plants?

UNIT II ALL LIVING THINGS ARE BASICALLY ALIKE

FIG. 137 *The sheep, the grass they eat, and the trees by the brook are very much alike in a great many ways. Can you explain in what ways they are alike?*

PROBLEM 1 *Of What Are All Living Things Composed?*

The structure of living things. All but the smallest plants and animals are made up of distinct parts which can be seen with the naked eye. Plants may have roots, stems, leaves. Animals may have arms, legs, a head, and many other parts visible from the outside. If we wish to know their internal structures we *dissect* them (cut them up). By doing this we may see the heart, the stomach, the brain, the liver, and many other parts.

Several hundred years ago the use of magnifying glasses was learned by scientists in Europe and the *lenses* (as they are called) were improved so that they magnified more than a hundred times. Then men began to use them to discover just how the parts of animals and plants are constructed. They examined all kinds of living objects: human skin, blood, parts of insects, leaves of plants, stems, bark, and so on. Robert Hooke (1635–1703), an Englishman, was one of the first to invent and to use a compound microscope. He studied very thin slices of cork, which is part of the bark of a species of oak tree, and discovered that it was made of little boxes. The walls of the boxes seen by Hooke were thick. The boxes were empty. He called the boxes *cells*. See Figure 138, page 106.

What is a cell? It is interesting that Hooke was the first to call attention to "cells" in living things but he never really saw cells at all! The name "cell" has been used ever since but it is now used for something quite different from Hooke's empty boxes. A true cell has been found to be not an empty box but a tiny mass of living matter. This material is difficult to see because it is transparent and usually almost colorless. Sometimes it can be seen flowing; it is semiliquid. It was given the name *protoplasm*. The protoplasm may be surrounded by walls and it was these walls that Hooke first discovered. He failed to see the protoplasm itself because the cork he examined was made up of cell walls only. The protoplasm had disappeared.

As more and more parts of plants and animals were studied it was discovered that they were all composed of little masses of protoplasm and that, very often, there were no thick walls; the protoplasm had the thinnest of walls around it or no wall at all. These discoveries were made over a period of more than 100 years. Thus only gradually did biologists come to realize the comparative unimportance of the walls and the importance of the protoplasm. The name "protoplasm" was chosen for the living material because the word means the first or most important substance.

The use of the microscope disclosed two very important facts. The first was

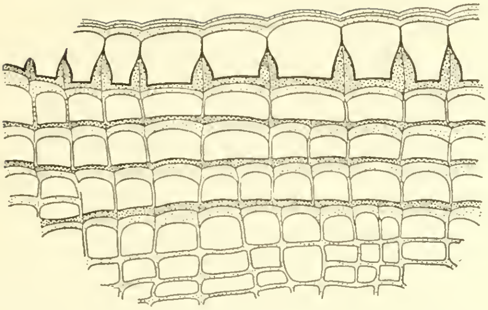


FIG. 138 *A section through cork as seen under the microscope. These are the structures which Hooke named "cells." Do these boxes seem to be filled or empty?*

FIG. 139 *Cells like these are found in the lining of your mouth. What are the three parts of such cells? How are they different from plant cells? (See text below and Figure 140.)*

that all living things are made up of cells; the second was that cells are really little bits of living substance, protoplasm.

The microscope. Before you go further into the study of the structure of living things it is wise to learn about the instrument that has made this study possible. The modern microscope has been described briefly on pages 10–12. It would be well to read those pages again. If microscopes are available in your school you will learn how to use them. Do EXERCISES 1, 2, 3, and 4.

What are the parts of a cell? There are many different kinds of cells, very different in shape and size. But each cell is a tiny mass of living matter called protoplasm. When properly stained with dyes and properly treated it can be seen that each cell has three parts: the *cell body* or *cytoplasm* (sigh'toe-plasm) which is the main part of the protoplasm; a small ball of denser protoplasm, called the *nucleus* (new'klee-us) lying within the cell body; and a *cell membrane* (also called *plasma membrane*) surrounding the cell body. The cytoplasm, nucleus and cell membrane are all protoplasm. Thus these three parts are all living. If you do EXERCISE 5 you will see cells from your own body which like all other cells have the three parts just mentioned.

Plant and animal cells are fundamentally alike; all have a cell body of cytoplasm, a nucleus, and a cell membrane. There are some differences between plant and animal cells, however. In most plant cells the cytoplasm builds up a firm *cell wall* of lifeless material outside the membrane. This lifeless cell wall usually consists of a tough, transparent substance, *cellulose* (cell'you-lohss), or an even harder woody material. Do EXERCISE 6 in order to see some plant cells. By doing EXERCISE 7 you will see that the wall of the plant cell is distinct from the cell membrane. Plant cells differ from animal cells in other ways, too. Usually, they have one or more large bubbles of liquid lying in the cytoplasm. These are called *vacuoles* (vak'you-ohls). Vacuoles are rarely found in animal cells. A third difference between plant and animal cells is that some of the cells of green plants contain small bodies called *chloroplasts* (klor'oh-plasts). These contain a very important green substance, *chlorophyll*, of which you will read much more later. To help you with this paragraph do EXERCISE 8.

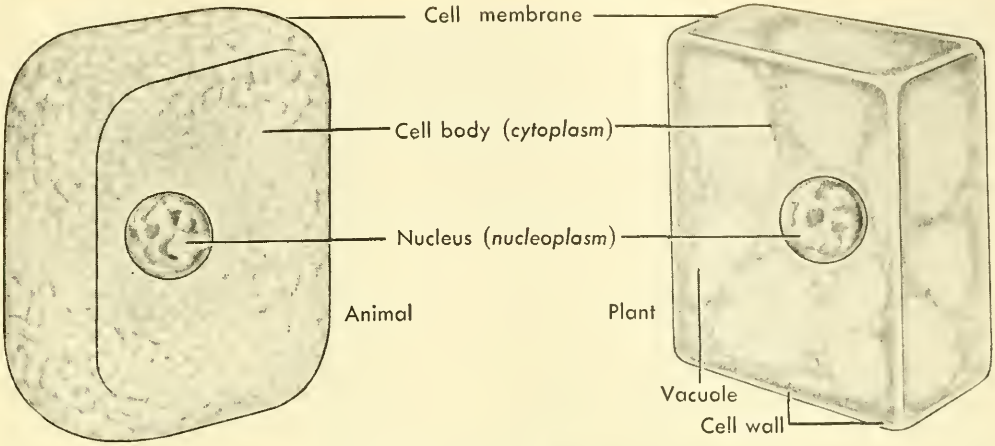


Fig. 140 (above) *All cells have three dimensions. In the animal cell as in the plant cell there are two kinds of protoplasm. What other parts does the plant cell have?*

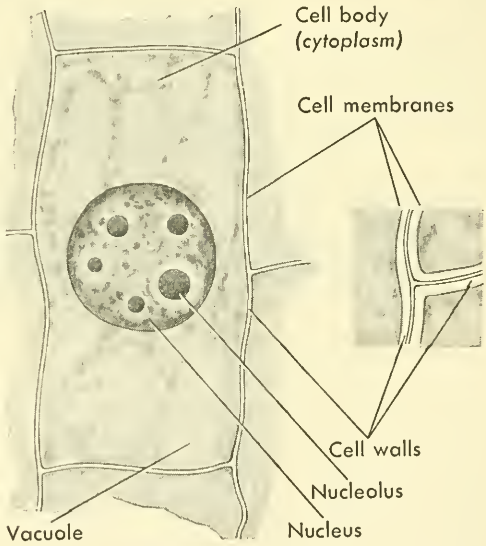


Fig. 141 (right) *Cell from root tip of Tradescantia plant. What are the parts of this plant cell? Which parts are living? Which are lifeless? Compare this typical plant cell with the mouth lining cells of Figure 139.*

The nucleus of the cell. Cell bodies are of many different shapes but nuclei are all much alike in shape and structure. In many cells they lie near the center of the cell with cytoplasm all around. Every nucleus has its own *nuclear membrane* which separates it from the cell body. The protoplasm of the nucleus is denser and less liquid than the protoplasm of the cell body. By means of micro-needles used with the aid of a powerful microscope the nucleus can be pulled out of a cell. This shows that it is of firmer consistency than the cytoplasm.

All nuclei contain a special substance that differs from other substances in the cell in that it stains deeply with certain dyes. Because of this substance a stained nucleus shows up clearly under the microscope. The living unstained nucleus is difficult to see. The material that takes the stain is present in a network or as scattered granules; it is called *chromatin* (crow′mat-in). You will read much more about chromatin later, for the nucleus with its chromatin plays a very important part in the life of the cell and of the organism.

Frequently one or more small round bodies are found within the nucleus. They are called *nucleoli* (new-klee′o-lie; singular, nucle′o-lus). The nucleolus, too, is readily stained. We do not know what work it does in the cell.

The structure of protoplasm. You read above that cytoplasm appears through the microscope to be a thickish liquid, colorless or light grey in color, containing small particles or granules, and that the nucleus looks much like it, only denser. EXERCISE 9 will be helpful now. Staining protoplasm with dyes has helped somewhat to bring out its structure but no one can be certain that the stain has not caused changes or produced substances not present in the unstained protoplasm.

Although it seems to be comparatively simple when seen through the microscope experiments have shown that protoplasm is really a very complicated mixture of many substances. Some of these substances are dissolved in water. Some cannot dissolve in water and they form what is called a suspension. (Raw white of egg is a good example of a suspension.)

The important fact about protoplasm is that it seems to have a very definite and complicated structure and it keeps this same structure, in general, as long as it remains alive. High or very low temperatures, dryness, or other changes in the surroundings, of course, may kill it.

Of what is protoplasm composed? The study of substances, their composition or make-up, is called *chemistry*. To find

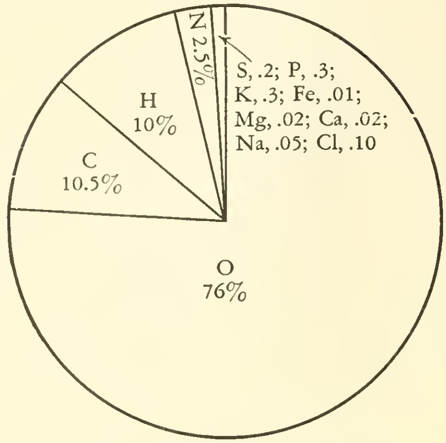
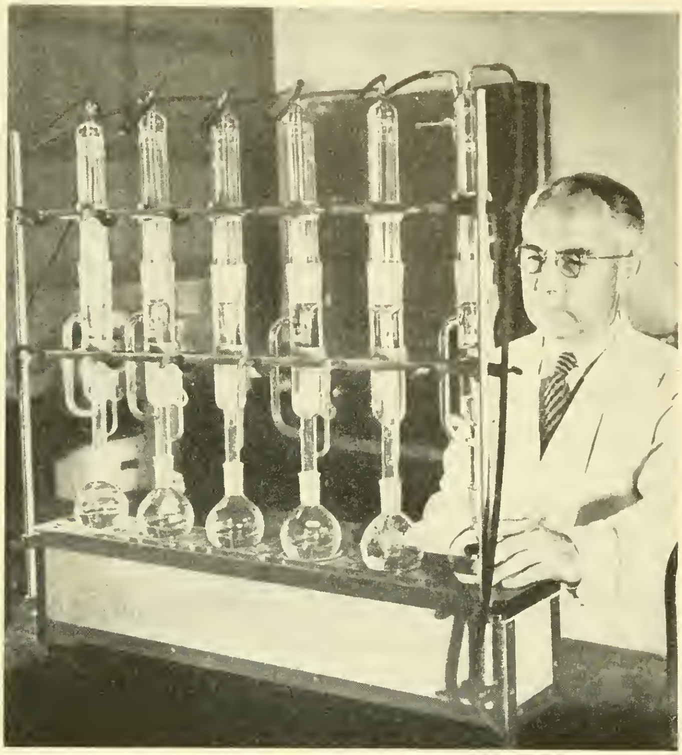


FIG. 142 *The 12 most common elements in plant and animal protoplasm. Calcium (Ca), sodium (Na), and chlorine (Cl) are not always present. Symbols are explained at the bottom of this column. Which four elements are present in the largest amounts? What proportion of protoplasm is oxygen? Percentages are calculated by weight.*

out what substances make up protoplasm biologists have used the methods developed by chemists for their own experiments. For example, protoplasm has been treated with chemical substances, and many other types of experiments have been performed.

Among the first things learned was what elements are present in protoplasm. An element, you may remember, is one of about 98 relatively simple substances of which all other substances in nature are made. Everything in our world, living and lifeless, consists of one or more of these elements. The elements are often represented by symbols which are abbreviations either of the present name or of some name used in the past. Perhaps you already know that the symbol for oxygen is O and that for iron is Fe. The following elements are found in all protoplasm: carbon (C), oxygen (O), nitrogen (N), hydrogen (H), sulfur (S),

FIG. 143 *Dr. Walter S. Ritchie of the University of Massachusetts is studying some of the compounds found in protoplasm.* (UNIVERSITY OF MASSACHUSETTS)



phosphorus (P), iron (Fe), potassium (K), and magnesium (Mg). Many other elements have been found in some protoplasm and traces of certain others may be present in all protoplasm.

Compounds in protoplasm. The elements in protoplasm are usually not found as elements but are combined chemically to form substances known as *compounds*. Compounds are chemical combinations of elements. When elements combine chemically they form a new substance which is different from the elements that make it up. Sodium, for example, is a metal that would burn your skin if you touched it, and chlorine is a poisonous gas. These two substances combine chemically making a compound that is called sodium chloride or ordinary table salt. The two gases, hydrogen and oxygen, will combine chemically forming water, a compound which has very different properties from either hydrogen or oxygen. And so with all other elements; when they unite chemically they lose their characteristics and something new appears. Your teacher can perform EXERCISE 10 so that you can see for yourself how the characteristics of elements disappear when they combine and form a compound. Compounds themselves combine chemically with each other and when they do they form new compounds with definite characteristics.

There are many different compounds found in protoplasm but there are only a few that are always present. The most abundant of these is water; it forms a large part of all protoplasm. Other compounds are salts like sodium chloride.

Both water and sodium chloride are compounds that, as you know, are found in nature outside of living matter. But there are other compounds in protoplasm that are made by protoplasm and that are never found in nature outside of living things; all of them are *organic* compounds. In both plants and animals, we find that the most abundant organic compounds are the *sugars*, the *starches*, the *fats*, and the *proteins*.

Sugars, starches, fats, and proteins. Sugars and starches are much alike; they are grouped together as *carbohydrates*. All of them contain only three elements, carbon, hydrogen, and oxygen; and the hydrogen and oxygen are always in the same proportion as they are in water, that is, two parts of hydrogen to one of oxygen. The chemical formula for a common simple sugar is $C_6H_{12}O_6$, the formula for starch is $C_6H_{10}O_5$. (The chemist would write it $(C_6H_{10}O_5)_n$.) Cellulose, the material found in plant cell walls, is also a carbohydrate.

Fats, too, contain the elements carbon, hydrogen, and oxygen; yet fats are different from carbohydrates. Fats have fewer oxygen atoms in proportion to the hydrogen than carbohydrates have.

Proteins are different from both fats and carbohydrates in this respect: they always contain the element nitrogen. Proteins often have sulfur and other elements as well. They are much more complicated chemically than are the carbohydrates and fats. Proteins are essential for the making of protoplasm.

Tests for the compounds in protoplasm. It is easy to detect water, minerals (salts), starches, certain kinds of sugars, fats, or proteins in living things.

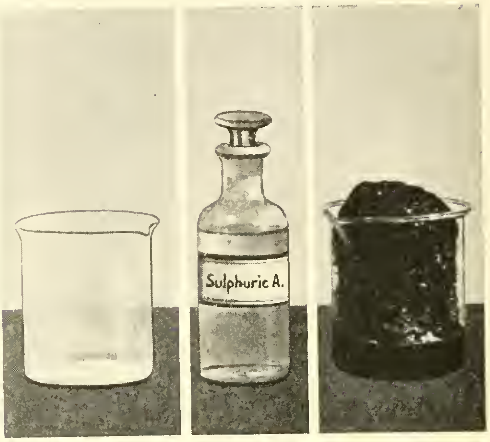


FIG. 144 *When sulphuric acid (H_2SO_4) was added to the sugar, the dark mass of carbon was produced. What does this tell us about the composition of sugar?* (SULLIVAN)

You can do so because a test has been discovered for each of these substances. For example, after much experimenting, it was discovered that when iodine solution and starch are mixed a substance with a deep blue color is produced. Only starch behaves this way with iodine solution. Therefore, iodine solution is a testing agent for the presence of starch.

In the same way tests have been discovered to indicate the presence of simple sugars, proteins, fats, mineral matter, and water. Finding these tests was a difficult task, but applying them is an easy matter. If you follow the directions in EXERCISES 11, 12, 13, 14, 15, and 16 you will be able to discover for yourself how the tests work. Later you will test parts of plants and animals for the presence of these substances in protoplasm.

What are mixtures? You have read that protoplasm is a complicated mixture of substances. It is important that you understand what is meant by a *mixture*. By doing EXERCISE 17 you can get a clear

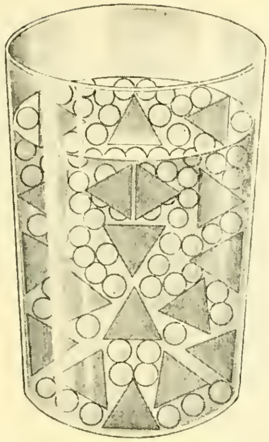


Fig. 145 *Particles of sugar are shown as triangles, particles of water as circles. According to this picture does sugar water seem to be a compound or a mixture? Explain.*

understanding of what chemists mean by a mixture. It differs from a compound. Often when two or more elements are put together they do not unite chemically. In this case they do not form a compound. Instead they form a mixture. In a mixture each element keeps its own characteristics. In a compound where chemical combination has taken place the elements lose their special characteristics. Mixtures may be combinations of compounds, or elements; or they may be combinations of compounds and elements together. But the important thing to remember is that the substances that go into the mixture do not lose their characteristics because they do not combine chemically with one another.

Protoplasm is a mixture of compounds and elements, each substance retaining its own special characteristics because it does not combine chemically with the other substances near it. To test your understanding of the chemistry you have learned, do Exercises 18 and 19.

What have you learned? Let us review all you have learned in this problem. Plants and animals are made up of tiny invisible structures known as cells. All cells, normally, are alike in having three parts: a cell body or cytoplasm, a nucleus, and a cell membrane. These parts are all living and can be called by the general term protoplasm. The nucleus is denser protoplasm than the cell body. It contains a substance called chromatin.

But plant cells often have structures which animal cells do not have. Almost always they have a cell wall of a lifeless material called cellulose. They usually have one or more vacuoles filled with liquid. And many of the cells in green plants have chloroplasts which contain the green coloring matter known as chlorophyll.

Protoplasm seems to be a thickish liquid, colorless, and containing small granules. Little is known about its structure, but we do know of what substances it is composed. Chemists who study the composition of substances define elements as comparatively simple substances of which all other substances are composed. They tell us that the elements which regularly occur in protoplasm are carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, iron, potassium, and magnesium. But these elements are for the most part found united chemically with each other in the form of compounds.

Some of the compounds found in protoplasm, such as salt and other mineral compounds, are found in nature outside of living matter. But some of the compounds found in protoplasm are never found outside of living matter, except as man extracts them from living matter. These compounds which are made by protoplasm are proteins, carbohydrates (starches and sugars), and fats.

Protoplasm is a *mixture* of these various compounds; in other words the compounds are not chemically united with one another in the living stuff, protoplasm. Therefore they keep their characteristics and you can discover the various compounds in protoplasm by applying the appropriate tests.

Thus you have learned what makes up all living things, whether plants or animals; and you have seen that in their structure plants and animals are fundamentally alike. Both consist of the complex mixture, protoplasm.

Questions

1. What can you say about the internal structure of many animals? About when did men begin to examine the parts of animals and plants more closely? What did Robert Hooke discover?
2. What is a cell? What is protoplasm? Why did Hooke not see protoplasm? State the two important facts that were disclosed by the use of microscopes?
3. Name, locate, and describe the nine or ten parts of the microscope with which you must be familiar in order to use it correctly. What are the rules for the use of the low power? What is meant by the words "focus" and "field of vision"? How does a compound microscope differ from a simple microscope?
4. What are the three main parts of an animal cell? What three structures are commonly found in the cells of plants but not in the cells of animals? How does a cell membrane differ from a cell wall? What is cellulose and where is it found?
5. Describe the structure of the cell nucleus. What is the important material found in every nucleus?
6. What are the characteristics of protoplasm? What is known about the structure of protoplasm?
7. With what does chemistry deal? What is an element? What nine elements are found in all protoplasm?
8. What is a compound? Using table salt as an example explain what happens to elements when they unite chemically with one another. What four compounds are found in protoplasm and not in nature outside of living things? What two compounds are classed as carbohydrates? What is true of the chemical composition of all carbohydrates? How do fats and proteins compare with carbohydrates in their chemical composition?
9. What is the test for each of the following: starches, simple sugars, fats, proteins, water, mineral compounds?
10. How does a mixture differ from a compound? Is protoplasm a mixture or a compound?

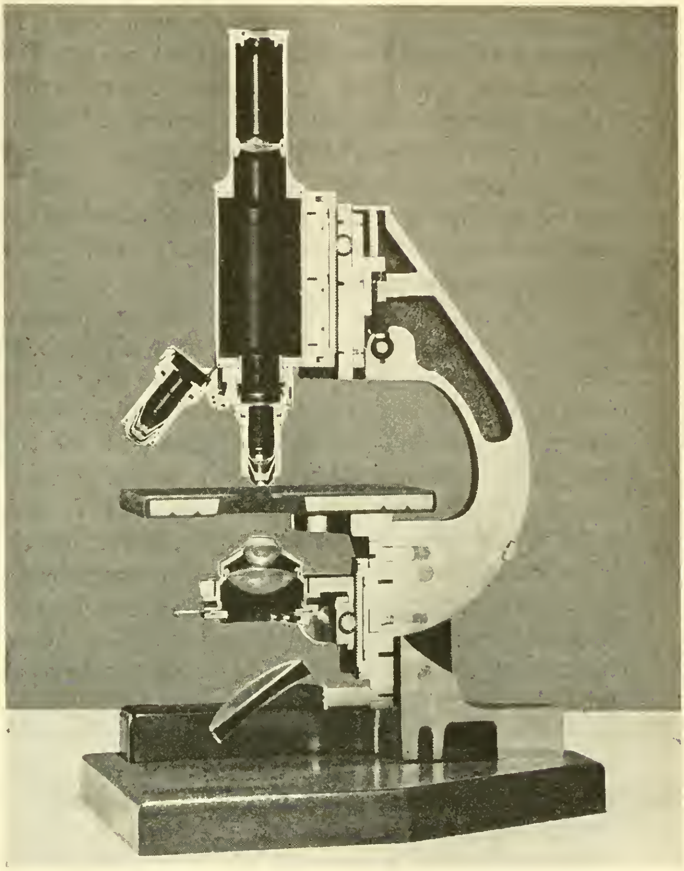


FIG. 146 *The lenses below the stage are not usually attached to high school microscopes. When you look through the microscope you use two sets of lenses. Each set consists of two or more separate lenses. Can you find the sets? This microscope is cut through the middle.* (BAUSCH & LOMB OPTICAL CO.)

11. In review state briefly what you have learned in this problem about: (*a*) Cells, explaining the differences between plant and animal cells. (*b*) Protoplasm, its characteristics and the elements of which it is composed. (*c*) The compounds which are mixed together in living matter. (*d*) Why plants and animals are said to be fundamentally alike.

Exercises

1. If you will have an opportunity to use a school microscope you should be familiar with its parts. Starting at the bottom they are: *base; mirror; diaphragm* (attached to the bottom of the stage); *stage* (which holds the glass slide); *arm* (the part by which you carry the microscope); *barrel* (the thick vertical tube); *nosepiece* (revolving part at the bottom of the barrel); *objectives* (two or more lenses screwed into the nosepiece); *coarse adjustment* (two large wheels on either side of the barrel); *fine adjustment* (two smaller wheels); *ocular* or *eyepiece* (the lens fitted into the top of the barrel).

Examine the mirror. In which directions can it be moved? Note that it has a flat and a concave (hollowed out) surface. Turn the concave surface toward the light. How do the two objectives differ from one another? The shorter one is the low-power objective. Examine the diaphragm carefully. How does it work? What is it for? Slowly turn the coarse adjustment, then the fine adjustment. What effect does each have on the barrel? If the microscope is placed before you so that the arm is toward you, how must you turn the wheels in order to move the barrel up? It is important that you remember this.

2. How to find an object under the low power: (*a*) Place the microscope so that the pillar is toward you with the base resting firmly on the desk or table. (*b*) Place the slide on the stage so that the material on the slide is over the hole in the stage. If the object is small, it must be centered over the hole. Hold the slide in place with the two clips. (*c*) Turn the low-power objective (shorter one) until it clicks into place. It will then be exactly over the hole in the stage. (*d*) With your eyes held at the level of the stage, *not at the ocular*, lower the barrel, using the coarse adjustment, until the tip of the low-power objective is about one fourth inch above the stage. (*e*) With your eye at the eyepiece turn the mirror so that the concave side is up and secure the best uniform bright light by moving the mirror. (*f*) Now, with your eye at the eyepiece, slowly raise the barrel by turning the coarse adjustment *toward you.* Do this until you can clearly see the material on the slide. (*g*) You may have to move the slide to see some other part of the object. (*h*) If the object is not as clear as it might be, turn the fine adjustment no more than a single revolution, now one way, now the other, to see whether you can focus more accurately. If you still do not get a satisfactory focus, try once more from the beginning, this time focusing more carefully with the coarse adjustment before using the fine adjustment.

3. To focus, using the high power: (*a*) With the concave surface still on top move the mirror until the best light is obtained. (*b*) Focus carefully under the *low power.* Make sure that the object you are looking at is in the *center* of the circle (field of vision). (*c*) By grasping both objectives, slowly swing the high-power objective into position over the hole in the stage without shaking or moving the microscope. (*d*) With your eye at the eyepiece, move the fine adjustment toward you slowly until the object becomes clear. Use only the *fine* adjustment. If instead of becoming clearer it becomes less clear, turn the fine adjustment the other way. But do not make more than one fourth of a revolution with the fine adjustment.

4. The magnified image. You can learn some important facts about the image you see through the microscope by preparing a slide of a small piece of newsprint containing the single letter "e." Place the slide so that the letter is upright, as you read it. After you have focused under the low power, write in your notebook a statement that tells how the image is different from the real letter. Now move the slide to the right while you

are looking through the microscope; then move it to the left. Now state in your notebook what the microscope seems to do to the motion of the object. With your eye at the eyepiece, move the object away from you and then toward you. Describe in your notebook what you notice. Compare your statements with those of your classmates so that all can agree on the best one.

5. How can you see the three parts of a cell? Mount some of the cells of the lining of your mouth (mucous membrane). Gently rub the inside of your cheek with a clean tongue depresser. Mount the material in a drop of water on a slide, cover, and examine under high power. Stain with dilute iodine solution (Lugol's). Find a place where the cells are separated from one another. What structure now shows more clearly? Where does the nucleus lie? Since you can see the nucleus in a cell of three dimensions what characteristic must the protoplasm have? The firm edge of the cytoplasm is the cell membrane; it shows as a line. Draw and label several cells.

6. What is the structure of onion skin cells? Cut an onion lengthwise. Separate some of the layers. With forceps peel off some of the thin skin from the inner side of one of the layers. Mount a piece about one quarter of an inch square in a drop of water on a slide. Lay a cover glass over it. Examine under the low power of the microscope. If there are too many black-rimmed circles (air bubbles) mount another piece. Compare with the cells from the mouth studied in EXERCISE 5. How do the onion skin cells differ? Draw what you see.

Now study the cells carefully under the high power. Permit a drop of red ink or a weak solution of iodine to run under the cover glass. What more do you see? Draw and label.

7. To see the cell membrane of a plant cell prepare cells of onion skin mounted in a drop of weak salt solution. Use the low and high powers of the microscope. What is happening within the cell? Can you see the membrane? Why were you unable to see the cell membrane before?

8. Answer the following questions: (*a*) If you can see the nucleus inside of a cell what must be one characteristic of cytoplasm, cell membrane, and cell wall? (*b*) Can you explain how your idea of a cell is quite different from Hooke's? (*c*) What are the important facts given in the paragraph on the structure of a cell? This will summarize a difficult paragraph.

9. The structure of protoplasm. Use the high power of the microscope to examine protoplasm in an ameba or a slime mold. What is the color in bright light? What is the color in dim light? Is the color the same throughout the organism? Do all parts of the protoplasm contain small particles? Are you sure that all protoplasm looks like this? Explain.

10. Can you devise an experiment in which you get two elements to combine to make a compound? (*Hint:* Charcoal is almost pure carbon. Carbon dioxide is a compound consisting of carbon and oxygen. You can detect the presence of carbon dioxide because it turns clear limewater

milky.) Can you put these same elements together without having them combine? How?

11. Try the test which has been discovered for detecting starch. Obtain a water solution of iodine crystals and potassium iodide (Lugol's solution). Add a few drops to a small amount of starch in water. Mix the iodine solution with sugar, protein (white of an egg), fats (butter or lard), table salt, and water. What is your result in each case? Why do you add iodine to these other substances? Note that you have not repeated the chemist's experiment since you have not tried iodine with a vast number of other compounds. Why can iodine be used as a test for starch?

12. Try the test which has been discovered for detecting simple sugars. Dissolve some grape sugar (corn syrup will do) in water. Add either Fehling's solution or Benedict's solution. Heat the mixture until it boils. What is the final color of the substance? Do you get the color change with any substance other than simple sugar? Why do you test these other substances? Do your classmates get the same results?

13. Try the test that has been discovered for detecting proteins. Mix some of the white of an egg with dilute nitric acid. Boil the mixture for a few seconds. (Careful!) What color change do you notice? Now add ammonium hydroxide. What is the second color change? What else must you do? Why?

14. Try the test for detecting fats. Rub a bit of butter on a piece of unglazed paper. Hold the paper to the light. The spot that appears on the paper is called a *translucent* spot. Why? All fats leave a translucent spot on paper. Do substances other than fats produce this kind of spot?

15. Try the test that has been discovered for detecting water. Boil some water in an open dish. Hold a dry, cold glass tumbler over the boiling water. What forms on the sides of the glass? Heated water vapor condenses when it strikes a cold object. If you try this test on the other substances you may get the same results. Explain.

16. Try the test for detecting mineral compounds. Try to burn table salt. Since minerals do not burn, at least not at the low temperature at which other substances burn, they will remain as a white ash. What becomes of starch, sugar, fat, and protein when they are burned?

17. The difference between a mixture and a compound. Examine iron filings and powdered sulfur. They are examples of elements. Describe them. One property of iron is that magnets attract it. Show that this is so. Now stir together some iron filings and sulfur powder until they are thoroughly mixed. Apply the magnet. What happens? In stirring the two elements together did a compound form or did you form a mixture? Explain your answer. Next, heat in a crucible a small amount of iron filings and powdered sulfur. After thorough heating apply the magnet. What happens? Explain. This is a compound. Put into words what you understand to be the difference between a mixture and a compound.

18. Is salt water a compound or a mixture? How can you find out? Do this experiment at home.

19. Answer the following questions: (*a*) Are the gases oxygen, nitrogen, carbon dioxide, and water vapor, which make up the air, *mixed* together or is air a compound? Give scientific evidence for your answer. (*b*) The chemist speaks of water as H_2O. What is the meaning of the 2 after H? Carbon dioxide is CO_2. What are the proportions of C and O? Carbon monoxide consists of carbon and oxygen. The prefix "mon" means one. Write the formula for carbon monoxide. (*c*) Ordinary granulated sugar is $C_{12}H_{22}O_{11}$. What do you know about its composition?

Further Activities in Biology

1. You can easily learn to prepare slides. Which is the best way of putting on the cover glass so that bubbles will not form? Consult books or ask your teacher for further help. In time you will probably want to learn how to make microscope slides which are permanent. This is difficult and takes patience.

2. Can you think of some way of making a model of a cell which will give your classmates a good idea of how a cell really looks? (Do not forget that protoplasm is transparent.)

3. Prepare a report on the history of the microscope.

4. Prepare a demonstration other than that used in the text to show how elements change their nature when combined into compounds.

5. Prepare a demonstration of the compounds found in living things. Try to get many different examples of each class of compounds: many starches, many sugars, and so on.

PROBLEM 2 *How Do Their Activities Keep Cells Alive?*

What do living things do to remain alive? This question might have been asked another way: what is it that living things do that makes them different from lifeless things? You can think at once of many activities that distinguish the living from the lifeless. If you think of animals you will say they move from place to place (without the help of an outside agent); they take in food and grow; they breathe; they produce many substances useful to them; they get rid of wastes; and they make more of their own kind, or reproduce. Plants engage in many of these activities, too, although sometimes in ways different from animals. Trees cannot move from place to place, but they use food and grow, they make substances useful to them, and they certainly make more of their own kind.

Activities of the organism are activities of the cells. You learned in the last problem that all living things are made up of cells—small masses of protoplasm. Therefore, it should not surprise you that all the activities of a living thing are also the activities of its cells. Food enters the cells in your body, and the cells grow; cells make substances useful to cells, and they reproduce. It is true that most of the cells in your body do not move from place to place but the protoplasm within the cell moves. Some of these activities are visible when you study cells with the microscope; others are not visible. If microscopes are available, the movement of protoplasm can be readily seen in the ameba and also in some plant cells. See EXERCISES 1 and 2. Living paramecia can be seen engaging in various activities. See EXERCISE 3. But you must remember that the paramecium is a single-celled animal and performs some of its activities differently from the cells that make up the body of a many-celled animal or plant. Let us study in more detail some of the more important cell activities.

Oxidation occurs in the cell. Some of you may know the meaning of the word *oxidation*. All of you can guess from the sound of the word that it has something to do with oxygen. Oxidation is the chemical union of a substance with oxygen. If carbon unites with oxygen the compound that results from the union is normally carbon dioxide. If hydrogen combines with oxygen, the compound hydrogen oxide (water) results. If iron unites with oxygen, iron oxide (commonly called rust) is produced. And so with other substances; when they unite with oxygen, oxides are formed.

The union may be rapid or slow. You constantly see examples of rapid oxidation, for rapid oxidation is burning or combustion. When you touch a lighted match to a piece of paper, rapid oxidation (burning) usually takes place. The paper unites with the oxygen which is present in the air. In uniting, it forms a variety of oxides and produces heat and light. It is true that the paper does not burn until you touch a lighted match to it; the match serves to heat the paper to its kindling temperature. This is generally necessary for rapid oxidation. Slow oxidation occurs at lower temperatures.

There is another difference between slow and rapid oxidation. In slow oxidation no light is produced. But heat is always produced whenever oxidation takes place; the slower the oxidation, the less the heat. In fact the amount of heat may be so small that delicate instruments are needed to detect it. At this point, unless you have done these experiments before, you will find it profitable to do EXERCISES 4, 5, and 6. Also try EXERCISE 7.

Let us sum up what we have learned about oxidation: Oxygen must be present if oxidation is to take place; an oxide, or compound of oxygen with another substance, is always formed; heat is released; and if the oxidation is rapid, light is also produced.

Oxidation occurs in all living cells. Some of the compounds in the protoplasm, particularly carbohydrates and fats, unite with oxygen. Oxides are formed in the cell and heat is produced. Among these oxides is carbon dioxide. Can you devise an experiment to show that oxidation goes on somewhere in your body? Do EXERCISE 8. Ordinarily, in this oxidation within the cell no light is produced. Oxidation within the cell is of great importance. The whole process is also called cellular *respiration*.

FIG. 147 *This hurdler is using energy. Where does it come from?* (PUBLIC SCHOOLS OF EVANSVILLE, INDIANA)

Energy. What is *energy?* Energy can be defined as the ability to do work, that is, make something move. Energy makes work possible. You just read that when burning takes place heat and light are produced. *Heat* is one form of energy; *light* is another. There are other forms of energy, many of which are of less interest to us in biology.

Let us consider for a moment why heat is thought of as a form of energy. In a simple machine like a steam engine the engine cannot do work unless there is steam to push the piston. You say, therefore, that steam has energy, the ability to do work. The energy in the steam is heat energy. When the steam loses its heat and becomes water again, it can no longer push the pistons; that is, it can no longer do work; it has lost its energy. Light energy is not often used by man for running machines; but

FIG. 148 *Breaking up a log jam. There are active cells in the men and in the trees along the bank. What activities are being carried on in these cells? In which cells is there the greatest amount of oxidation?* (AMERICAN MUSEUM OF NATURAL HISTORY)

you will learn more about light as an important form of energy in a later unit.

You are acquainted with electrical energy, which can be transferred from one place to another in wires. This form of energy can be changed into other forms, such as heat and light, or it can do work directly as in causing a motor to turn. You may have seen the *mechanical* energy of moving water turn a waterwheel or move a boat or even rocks in the stream bed. It is easy to understand that heat, electricity, and the mechanical energy of moving objects can do work.

Energy, or the ability to do work, may be stored. Coal contains stored energy, and, since this energy lies in the chemical make-up of the coal, it is also called *chemical energy*. In biology chemical energy is of great importance; all living things contain it.

All forms of energy can be changed into one another. For example, when coal is used for making steam in an engine its stored chemical energy is changed into heat energy; this heat energy is used in machines to produce electrical energy which is turned into light energy in the lamps in our homes or into mechanical energy in our washing machines.

Oxidation in the cell changes stored energy. You have learned that in all oxidation heat energy is released. You just read that when coal is burned the stored energy of the coal is changed partially into heat energy. The same thing happens in a cell. In a cell it is carbohydrates.

fats, or proteins that are oxidized and their stored chemical energy is released as heat energy. You may wonder how the coal and the living cells got the energy which is hidden within themselves. The understanding of this is an important part of biology. You will learn in the next Unit how energy gets into all living cells. For the present you need only remember that all living cells contain stored chemical energy; this is changed into other forms in the process of oxidation.

Work in living things depends on oxidation in the cells. Have you ever stopped to think that as long as an organism remains alive it is constantly releasing energy? Heat is being released and work is being done. To biologists work means more than earning your living or going to school. Playing ball is much harder work than studying a lesson. Moving your eyes across this page is also work. To keep your body standing upright you must do a considerable amount of work. Even when you sleep your heart keeps working regularly; so do the chest muscles and other parts of the body. Millions of cells are always carrying on oxidation and doing work. In plants, too, the living cells are constantly carrying on oxidation, releasing energy, and doing work. All living things do work as the result of the oxidation which occurs in all their millions of cells.

Why oxidation can go on continuously. You read that carbohydrates, fats, and to some extent proteins in protoplasm serve as fuel in living cells. These compounds are spoken of as food substances for living things. They unite with oxygen and thus they disappear and new compounds are formed. In other words

FIG. 149 *This resting cow is doing work. What kind of work is being done? What kinds of energy are being released?* (SCHNEIDER AND SCHWARTZ)

the food compounds and oxygen are constantly being used up in oxidation. But, under normal conditions, they are constantly being replaced. Evidently, there must be a fairly constant passage of oxygen and of these various compounds into the living cell. They move into the cell by the process known as *diffusion*. If you do EXERCISE 9 you will see diffusion occurring. Let us review it.

Diffusion. You know that when you put sugar into the bottom of a cup of coffee and wait a short time the sugar will sweeten all parts of the drink even without your stirring it. That is, the sugar moves through the coffee. But how is its motion explained? Chemists tell us that all substances consist of tiny particles known as *molecules* (moll'e-kewls). These molecules are in constant motion. In gases the molecules are far apart and they bounce about actively. Each one moves, first in one direction, then in another. In liquids the molecules are closer together; they move, but move less actively than in gases. If two gases are put together, the molecules of both gases move actively and the gases intermingle rapidly. If two liquids are put together, the molecules of both liquids usually move about and intermingle, though more slowly. This intermingling of substances through the motion of their molecules is called *diffusion*. Even in solids the molecules intermingle or diffuse, but they move very slowly indeed. Do EXERCISE 10.

By using liquids which differ in color you can actually watch them diffuse though, of course, you cannot see the molecules. If you carefully put warm molasses with a medicine dropper into the bottom of a tumbler of warm water and allow it to stand quietly you will soon see these liquids intermingling. Each substance spreads or diffuses from the region where its molecules are close to one another (highly concentrated) to where its molecules are farther apart (less concentrated). After some time the molasses molecules are no longer close together at the bottom; they have spread or become less concentrated. The same is true of the water molecules; they have also spread, and eventually the two liquids will have completely intermingled. Both liquids have moved.

Now food and oxygen move into all the living cells by diffusion. But you may raise this objection: in the tumbler there was nothing to separate the molasses from the water; around the cell body there is a membrane and the food and

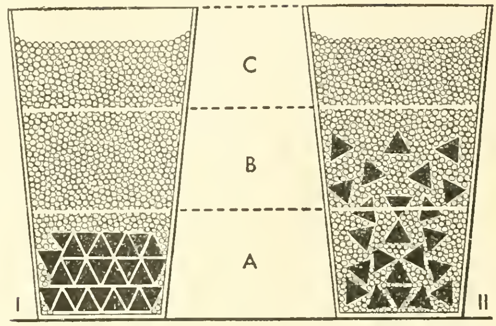


FIG. 150 *Sugar molecules are shown as triangles, water molecules as circles. In I, sugar molecules (molasses) have just been put in with a dropper. II shows what has happened after a short time. Why have sugar molecules appeared at level B? Compare the number of water molecules at Level A in I and II. Explain. Draw the tumbler as it would look after longer standing. Draw it as it would look if half as much sugar had been put in.*

oxygen are on the other side of the membrane. The membrane seems to have no openings. How can substances pass through the cell membrane?

Diffusion through a membrane.* A number of simple experiments can be set up to find out whether liquids can pass through a membrane which has no visible pores. To find out whether water can pass through a membrane, a sausage casing may be used as the membrane. This is the wall of a pig's intestine; it is made of cells, although they are no longer living. If sausage casing is not available a thin cellophane membrane may be substituted. This also has no visible pores. The bowl of a thistle tube may be filled with a mixture of water and molasses with the membrane tied securely over the mouth of the tube. The thistle tube may then be inverted and its mouth placed into a tumbler of

* Osmosis is often defined as diffusion through a membrane. However, osmosis is variously defined and therefore, the authors think it better not to use the term at all, especially since by any definition osmosis is diffusion under special conditions.

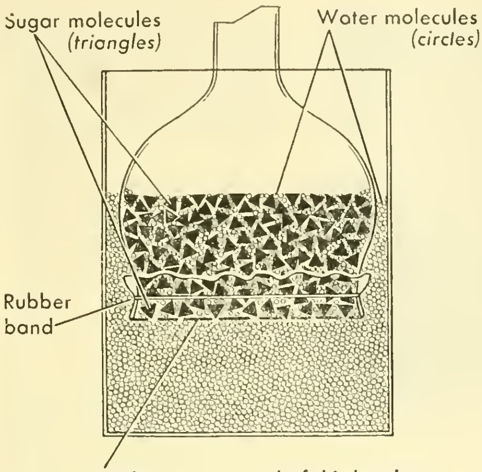


FIG. 151 *Sugar and water molecules are within the thistle tube. Only water molecules are outside it. If only water molecules can get through the membrane, what will happen to the amount of liquid in the tube? What would happen if both kinds could get through the membrane?*

tap water. Where are the molecules of water more concentrated when the experiment is set up? Remember more concentrated means closer together, not more numerous. Are the water molecules more concentrated within the thistle tube where you have some water mixed with thick molasses or are they more concentrated within the tumbler filled with tap water? Since the water molecules tend to diffuse from where they are more concentrated to where they are less concentrated water should move from the tumbler into the thistle tube provided it can get through the membrane. If it does get through the membrane how will this become apparent after a short time?

The same set-up can be used to discover whether sugar diffuses through this membrane. Can you suggest how this could be discovered?

If conditions are suitable sugar will diffuse through the membrane until the concentration of sugar is the same on both sides of the membrane.

Whatever may be true of other membranes and other substances, if you have done the experiment suggested, you now know that water and sugar can diffuse through sausage casing or cellophane membranes. To test your understanding of diffusion do EXERCISE 11.

Diffusion through a living cell membrane. If you place some living plant cells on each of two slides and add distilled water (water without minerals) to one and a very strong salt solution to the second some interesting results will be obtained. If you observe the cells under the microscope, you will find that those placed in distilled water will swell slightly. What may have happened to make them swell? On the other slide the results will depend somewhat on the strength of the solution used, but you will be able to observe a distinct change. The protoplasm will shrink away from the wall and form a small mass; evidently the water vacuole inside the cell disappears. Diffusion of water out of the cell takes place (see Fig. 153). This is good evidence that water diffuses through a living cell membrane. You should now be able to make some practical applications of what you have just read in doing EXERCISE 12.

When do substances diffuse through a membrane? To begin with the only substances that diffuse through membranes in living things are substances that diffuse or dissolve in water. Not all substances dissolve in water. If shaken up in water, they may appear for a time to do so, but after standing the particles will fall to the bottom. Such substances

FIG. 152 *Year after year the pieces of rock are pushed farther apart by the growth of the tree.* (AMERICAN MUSEUM OF NATURAL HISTORY)

are said to be *insoluble;* they do not dissolve. Among many other compounds, starches and proteins and fats, for example, are insoluble in water. Therefore they do not diffuse through a membrane. You can convince yourself of this by doing EXERCISE 13.

But there are some substances that are soluble in water and yet fail to pass through some kinds of membranes. Or let us state it the other way: some membranes allow certain soluble substances to pass through but keep out other soluble substances. The word *permeable* means "allowing substances to pass through." Then we can say that some membranes are permeable to some soluble substances and are not permeable or less permeable to other substances. They are not permeable to certain very large molecules or groups of molecules.

Which substances enter living cells? The cell membrane, made up of protoplasm, is a good example of a membrane which differs in its permeability to different substances. Some compounds pass through; other soluble compounds with molecules of the same size cannot pass through. And what is more, the cell membrane changes in its permeability. Variations in light and temperature or the presence or absence of a great number of substances make it more or less permeable from time to time.

There is much that is not understood about diffusion of substances into a living cell and much that cannot be explained here. But you must remember that many, though not all, soluble substances which come in contact with a cell enter it. Insoluble substances do not enter. Starches, fats, and proteins are insoluble and certainly cannot diffuse into or out of a cell. But you will learn later how they are made soluble and how they enter in their soluble form. Oxygen is soluble in water and diffuses readily into a living cell through the membrane.

Thus you can see that as substances are used up in oxidation in the cell they are constantly replaced by the substances that diffuse through the membrane into the living cell.

Cell activities defined. Now with an understanding of oxidation in cells and how the necessary fuel and oxygen enter them, let us go back and examine again the activities of a cell.

Food, and certain other necessary as well as unnecessary materials diffuse into cells (*absorption*); the protoplasm acts on some of the food, making it usable (*digestion*); the protoplasm makes more protoplasm from food (*assimilation*); some of the food unites chemically with oxygen, releasing energy which keeps the cell alive (*oxidation* which is a part of *respiration*); some of the energy is used in movement of the protoplasm (*motion*); or in moving the whole cell from place to place (*locomotion*); the protoplasm makes materials useful to it or to other cells close by (*secretion*); waste or unused substances diffuse out of cells (*excretion*); as protoplasm grows a cell may become separated into two parts, making two new cells in the place of one old one (*reproduction*); the protoplasm is sensitive to its changing surroundings and its activities are frequently changed when the surroundings change (*irritability*). Through all these activities cells remain alive. Taken together these activities are "life."

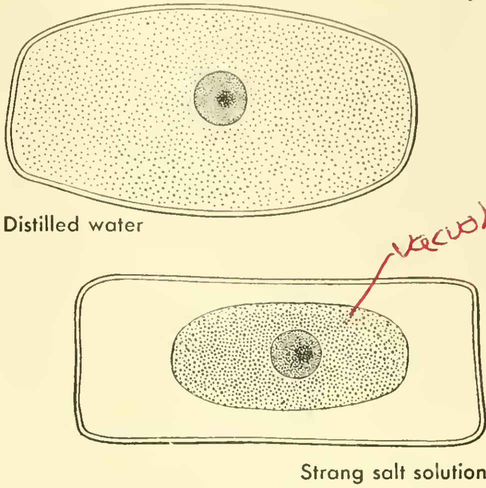


FIG. 153 *The upper cell has been placed in distilled water, the lower cell in a salt solution. Why does the cell wall in the upper cell bulge? Why did the distilled water diffuse inward? What has happened to the protoplasm of the lower cell? Why did water diffuse out of it?*

The cell theory or cell doctrine. When Hooke discovered cells in the second half of the 17th century other men studied the parts of many different animals and plants and saw cells of various kinds. But for almost a hundred years little was added to the simple idea that cells could be found in organisms. No one knew what cells were or how they were related to the life of the plant or animal; the importance of the cell was not understood. About 1820 a French physician and biologist Dutrochet (Dew′-tro-shay), published a statement in which he said that it was clear that all living things were made of cells and that whatever activities a living thing performs must be performed by its cells. This important statement which seems so evident to us was apparently not accepted at that time. Then in 1838 two German biologists, Schleiden, who was a botanist, and Schwann, who was a zoologist, stated that living things are made up of cells and that the cells are the important part of the living thing. Schleiden and Schwann were so well known that biologists everywhere began to accept the *cell theory*, as it was called, the belief that all living things are made of cells and their products. But Schleiden and Schwann still had not understood the true structure of the cell. Little was known about protoplasm; it had not even been named.

From that time to this, many millions of plants and animals have been studied under the microscope and very much has been added to our knowledge of cells. Soon after Schleiden and Schwann made their contributions another botanist

Hugo von Mohl (1805–1872) applied the name *protoplasm* (first substance) to the living matter within the cell. Several years later an English biologist, Thomas Henry Huxley (1825–1895), made popular the statement that protoplasm is "the physical basis of life," which sums up the idea that wherever there is life there is the substance protoplasm. Biologists of every country have contributed to our understanding of the cell and protoplasm. All these studies have shown the truth of the cell theory which states that:

1. Plants and animals are made of cells and materials produced by cells.
2. All the activities of living things are made possible by the activities of cells.

The evidence for this is now so complete that we no longer speak of this as the cell theory. These facts have been so well established that it is better to speak of the *cell doctrine*.

Questions

1. Which activities distinguish the living from the lifeless?
2. What are some of the activities of the cells of your body?
3. Define oxidation. What kind of substances are formed as the result of oxidation? Give three examples. Use the words oxidation and burning in a sentence to show that you understand their meanings. What, besides oxides, is released in all oxidation? Where in living things does oxidation go on? Which substances usually are oxidized in a cell?
4. What is energy? What two kinds of energy are released in burning? What is chemical energy and how does it differ from heat and light? Give examples of changes of one kind of energy into another.
5. What energy change occurs when oxidation takes place in a cell?
6. Give examples of work done by your body; by a plant.
7. What two kinds of substances must enter a cell if oxidation is to continue at all times? By what process do they enter?
8. Give an example of the diffusion of liquids and explain how they diffuse. Describe an experiment in which you can *see* that diffusion is occurring.
9. Do liquids diffuse through a membrane which has no visible pores? Describe an experiment which answers this question.
10. Describe an experiment which shows that diffusion occurs through the living cell membrane.
11. What is the connection between solubility and the ability to diffuse through a living membrane? Define the word permeable. What can you say about the permeability of a living cell membrane? Name three compounds that do not pass through a cell membrane. What must happen to them before they can diffuse through a membrane?
12. Name and define ten cell activities.
13. What are the two parts of the cell theory? Give in order the names and the contributions of the biologists associated with the cell theory. Why is it better to speak of the cell theory as the cell doctrine?

Exercises

1. The behavior of protoplasm. Protoplasm may be seen best in Chaos chaos or in slime molds. Watch the protoplasm first under low, then under high power. Do not use a bright light. How does it move? If it continues to move in one direction note how long it takes to move across the field of vision. Can you then estimate the speed of motion? Draw out a soft glass rod to obtain a microneedle. Touch the edge of the protoplasm with it. What happens?

2. Motion of plant protoplasm. Mount the edge of a young leaf of an elodea plant on a slide. Warm the slide in your hand. Examine under the low power. Move the slide about until you see motion in a cell. What is it that you see moving? Explain their motion.

3. Turn to Exercise 10 on page 69. Make a note of and describe all the activities shown by the paramecium or other protozoan. If you are fortunate you may see it dividing into two.

4. What is one striking property of oxygen? Prepare oxygen by heating a mixture of three parts of potassium chlorate and one part of manganese dioxide. (Consult a chemistry or general science text.) Collect several small bottles of the gas by displacing water. Into one bottle thrust a burning splint. Heat some sulfur in a deflagrating spoon until it begins to burn, then put it into a bottle of oxygen. Into a third bottle put a strip of burning magnesium held with forceps. Thrust a glowing stick of charcoal into a fourth. Describe carefully what you saw in each case. Why does each substance stop burning after a short time?

5. Does the oxygen of the air support burning? Your teacher can provide you with air from which oxygen has been removed. Thrust a brightly burning taper into it. What happens? Why? How may your teacher have removed the oxygen?

6. When does the process of oxidation stop? Fasten a candle to a block of wood. Float the block in a pan of limewater. Light the candle. Invert a jar over it so that the mouth of the jar is under the limewater. Why does the candle go out? What substances are produced by the burning of a candle? Where do these substances go? Why does the limewater rise?

7. To test your understanding answer the following: (*a*) How do the various ways of extinguishing fires take into account the fact that burning requires oxygen? (*b*) Can you suggest a chemical explanation of the fact that substances like carbon dioxide and water do not burn?

8. How can you show that oxidation is going on in your body? Breathe out for a few minutes through a tube into a small bottle containing a small amount of clear limewater. What do you note? Explain. Now shake a similar bottle of limewater so that it is well mixed with the air in the bottle. Why should this be done? What is the evidence from this experiment that oxidation of a substance containing carbon took place in your body? Can you think of any other evidence that oxidation takes place in your body?

9. Do gases move about? Fill a small bottle with oxygen. Cover with a glass and stand on a table. Gently place a bottle of the same size, filled with air, over the mouth of the bottle of oxygen after removing the glass plate. Seal the mouths together with a strip of adhesive tape. Let stand for 15 minutes. Remove the upper bottle without disturbing the lower. At once thrust a glowing splint into the upper bottle. What do you observe? What is lacking in this experiment? What else should you do?

10. Diffusion of copper sulfate and of red ink. Drop a crystal of copper sulfate into a tall jar of water and allow the jar to stand without disturbing it. What happens within a day or two? Into the bottom of a tumbler of water standing quietly on a table carefully place some red ink with a medicine dropper. Do not stir the water. Record observations.

11. Suppose three billion molecules of pure water are separated by a membrane from a salt solution containing six billion molecules of water and two billion molecules of salt. In which direction would the more rapid diffusion of water through the membrane take place? Why?

12. Remembering that fruits and vegetables are made up of large numbers of cells with living membranes surrounding them, answer the following: (*a*) How can you make sliced peaches juicy for serving? (*b*) To freshen lettuce would you recommend fresh water or salt water?

13. Does starch pass through a membrane? Boil some starch in water, making a "starch paste." Fill the bulb of a thistle tube with this. Cover with a membrane. Invert in a tumbler of water. Mark the level of the liquid in the thistle tube. After the experiment has been standing for several hours, find out whether starch has passed through the membrane. How can you do this? Has the liquid risen in the thistle tube? Write your method, results, and explanations.

Further Activities in Biology

1. Can diffusion be speeded up by changing the concentration of water in the thistle tube? Fill one tube with thick molasses (since this has much sugar, the water molecules are not concentrated). Fill another tube with diluted molasses (there is little sugar so that the water molecules are more concentrated). Set each in a jar of water. How soon can you see results of diffusion in each tube? How much rise do you get in each?

2. Set up an experiment to show that several substances can diffuse at the same time. Use sugar and table salt.

3. Will all kinds of membranes permit water and dissolved substances to pass through? Set up experiments using membranes of rubber, cellophane, oiled silk, and so on. Carefully record your results.

4. Locy's *Biology and Its Makers* has interesting material on the early history of the study of cells. Prepare a report. Singer's *History of Living Things* may be used also, or E. E. Snyder's *Biology in the Making*.

PROBLEM 3 *How Are the Cells Arranged in Animals and Plants?*

How animal cells differ from one another. It has been known for a long time that the body of an animal consists of cells and that these cells are not all alike. Blood cells are very different from skin cells; muscle cells are different from either of the other two. Cells vary in shape or structure, in their position in the body, and in the work they do. This is not surprising. But it may surprise you to learn that cells in corresponding parts of mice and elephants are much alike in shape, activities, general appearance, and even in size. You can, as a matter of fact, learn much about cells in your own body by studying the corresponding cells in the bodies of cats or white rats or frogs or other animals. See Figure 154.

The different kinds of cells are found in groups. Examination of the arm of man shows that cells are arranged in groups. The outside of the arm is made up of flattened cells called *epithelial* (ep-e-thee′lee-al) cells lying together in a group. Under these are groups of cells (*gland cells*) that differ from the flattened cells; substances such as sweat and oil come from these cells. Still deeper in the arm are masses of fat cells. All of these together make up what we call by the simple name "skin." Under the skin is what you sometimes call the "flesh." This is composed of muscle cells in groups. Among the muscle cells are nerve cells, blood cells in the blood, and some other types of cells. At the very inside of the arm is the bone. The bone contains a huge number of bone cells which have a very characteristic appearance. Among the bone cells there are also nerve cells, blood cells, and still other kinds of cells. See Figures 157–159. The important fact is that the different kinds of cells are found in groups or masses. Such a group of cells which are similar in structure and which do much the same kind of work in the body is called a *tissue*.

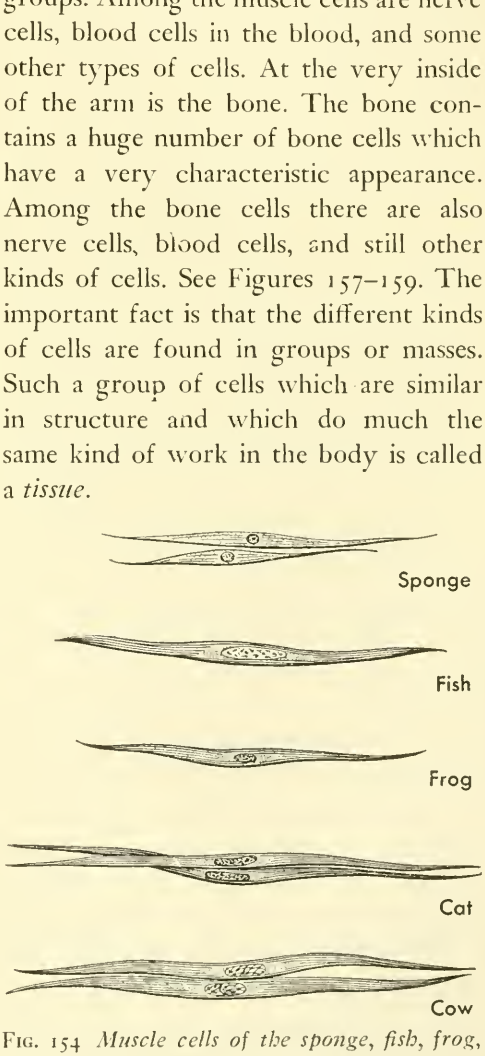


FIG. 154 *Muscle cells of the sponge, fish, frog, cat, and cow. Compare these with muscle cells of man, Figure 157, page 132.*

In studying the arm, you just read about bone tissue, muscle tissue, nerve tissue, blood tissue, gland tissue, fat tissue, and epithelial tissue.

Sometimes the cells making up a tissue deposit some nonliving material around themselves. This nonliving material is called *intercellular* matter. The word "intercellular" means lying between the cells. Bone is a particularly good example of cells that do this. The bone cells surround themselves with a large amount of mineral matter. This lifeless matter becomes an important part of the tissue; the hardness and rigidity which you associate with bone are due to the intercellular matter. Some other tissues besides bone have intercellular material, although the relative amount of intercellular material is smaller than in bone. Thus we must add this new idea to our definition of a tissue and say that a tissue is a group of cells similar in structure and in work, along with more or less intercellular material which is produced by the cells.

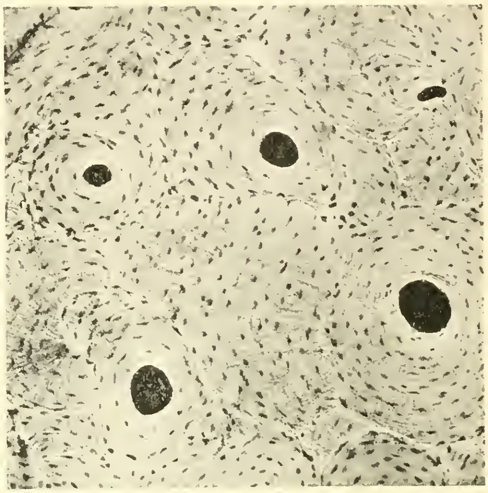


FIG. 155 *A small part of a bone, magnified. Large dark spots are tubes containing blood vessels and nerves. Small dark spots are spaces where bone cells used to be. This tissue has intercellular material.* (RICHARD ST. CLAIR)

Tissues make up organs. You have read of a number of tissues found in the arm. But these same tissues are found in other parts of the body as well. In general, each tissue is found in many places throughout a complex animal like a man or a cat. And wherever the tissue is found it is combined with other tissues, making up a distinct part of the body known as an *organ*. An organ is a part of the body consisting of a group of tissues which work together. The word organ must not be mistaken for the word organism which means a single living thing or individual. The heart, the stomach, and the liver are all internal organs of your body. The skin may be considered an organ too, for it also consists of a group of tissues which work together. You read that a bone consists largely of bone tissue but it has also nerve, blood, and other tissues; it, too, may be considered an organ. Often an organ does more than one kind of work, or is useful to the body in more than one way. For example, the stomach not only helps in digestion but it helps destroy harmful bacteria; in it food is temporarily stored and it is useful to the body in still other ways.

Biologists often use the word *function* (funk'shun) to refer to activities or useful properties of organs, tissues, or even single cells or parts of cells in an organism. The stomach functions in digesting certain kinds of food; protecting other tissues from infection is one function of the skin; enabling a person to hear is one function of the ears. To help you understand this paragraph do Exercise 1.

FIG. 156 *Which of the organs of this geranium can you see? Which cannot be seen?* (SULLIVAN)

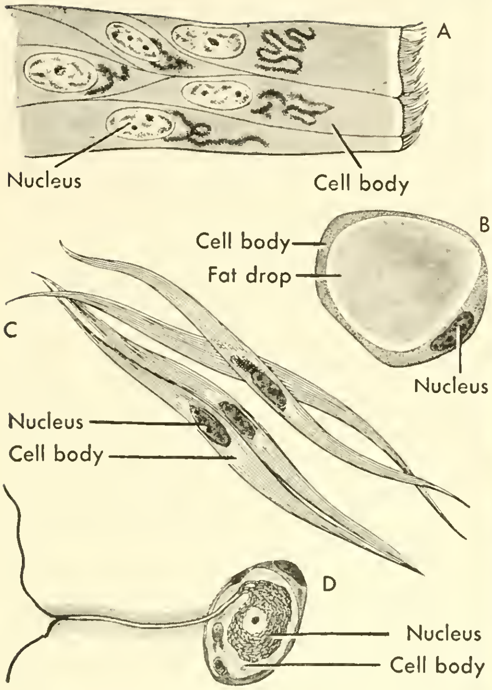
How living things are built up. Thus you see that organisms, except the very simplest, are made up of parts called organs; organs are composed of several or many tissues; tissues are composed of cells; and all the cells of one tissue are similar to one another.

Most organisms are so complex that they have a number of organs working together in an *organ system.* For example, in your body there is the digestive system consisting of the various organs that have to do with digestion. Then there is the skeletal system which includes all the bones of the body. You will read of other organ systems that are composed of a number of organs; the organs are composed of a number of tissues, and the tissues are composed of cells. You have been reading about the construction of your body but other complex animal organisms as well as complex plant organisms are also composed of cells, tissues, and organs.

How differences arise in cells. Most organisms start life as a single cell. This is true even of the complex animals such as the vertebrates. This single cell gives rise to the many millions of cells of which the organism's body consists. It is interesting that this cell should be able to produce types of cells as different from one another as are the cells of such tissues as muscle, bone, and nerve tissue. Many biologists are attempting to solve this problem at the present time. Whatever the explanation may be, we must recognize the fact that there is *differentiation* of the cells in an organism. The cells differ from one another in appearance and in their activities. In the more complex animals the differentiation is very marked. Each type of cell can usually be recognized either by its structure or by the work it does in the animal or plant. The cells are specialized in structure and function.

The main kinds of animal tissues. The many kinds of tissues in an animal such as man can be divided into four or five main tissue groups. Epithelial, muscle, connective, and nerve tissues are four groups. The fifth is blood. Epithelial includes the membrane that covers the body; it also includes *mucous membrane* (the moist membrane that lines such organs as the stomach, the mouth, and other digestive organs); it includes *serous membrane* (the smooth membrane covering some internal organs and lining body cavities); and it includes gland tissue.

Muscle tissue is of three types: voluntary muscle, involuntary muscle, and heart muscle. In Figures 157 and 158 are



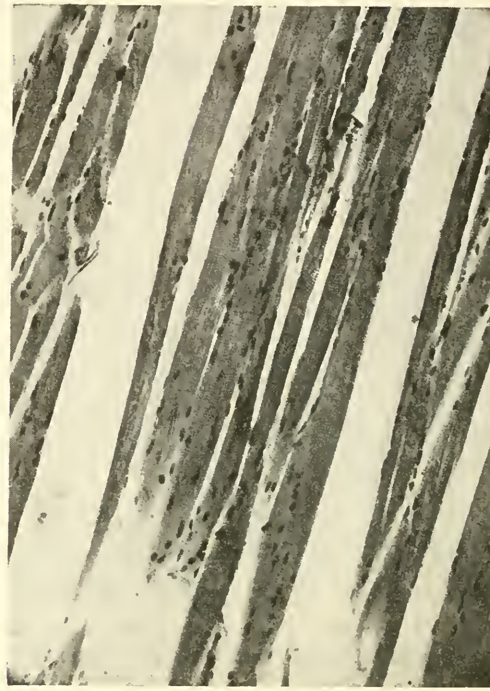


FIG. 157 (upper left) (A) *One type of epithelial cell. How might the cilia be used? See also flat epithelial cells in Fig. 139, page 106.* (B) *A single cell of fat tissue. What fills the greater part of the cell?* (C) *Compare these fibers with voluntary muscle fibers.* (D) *This is a very simple type of nerve cell.*

FIG. 158 (above) *Voluntary muscle fibers. The dark spots are nuclei of cells. Do you see stripes running across the fibers?* (GENERAL BIOLOGICAL SUPPLY)

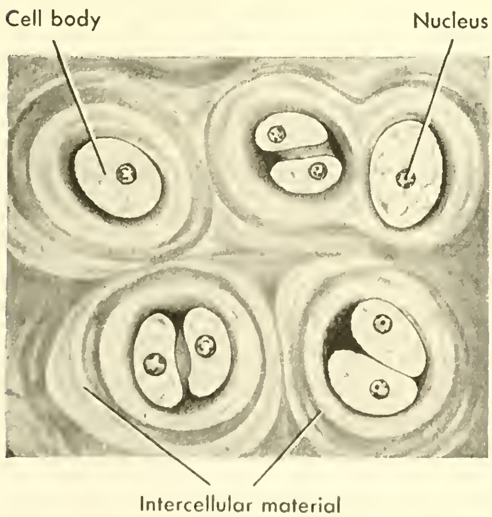


FIG. 159 (left) *Cartilage tissue. Like bone, this tissue has a large amount of intercellular material.*

illustrations of voluntary and involuntary muscle. Heart muscle differs from both voluntary and involuntary muscle in its appearance and in its activity. Connective tissue is a large group which includes tissues of very different kinds. It includes bone and cartilage tissues, fat tissue, and fibrous tissues. By some people blood is considered to be one type of connective tissue. Cartilage tissue is found covering a portion of many bones. It contains no mineral matter but a large amount of firm intercellular matter which makes the cartilage hard, slightly elastic, and very smooth. See Figure 159. You can

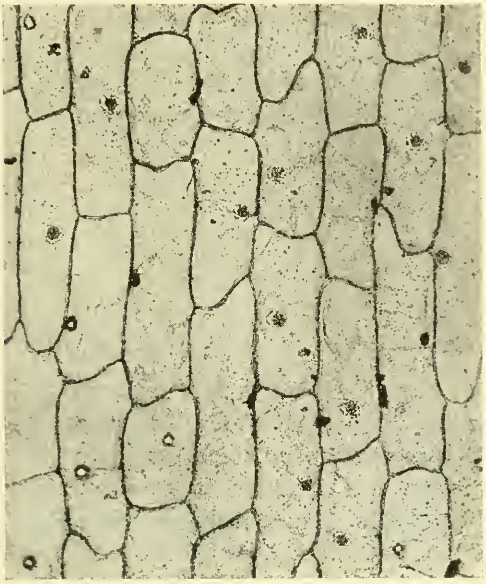


FIG. 160 *Cells of onion skin. This tissue somewhat resembles the epithelial tissue of animals. Which parts of the cell do you recognize?* (RICHARD ST. CLAIR)

get a good idea of several of these tissues by studying the tissues in a frog as described in EXERCISE 2.

Tissues in higher plants. As in animals, plant cells are arranged in groups or tissues; and various tissues together make up the organs, such as the root, the stem, and the leaf. Just as the organs of a plant are quite different from the organs of an animal so are the tissues. Plants have no muscle, connective, nerve, or blood tissues. But they do have tissue which resembles the epithelial tissue of animals. It forms a membrane covering leaves, young roots, and stems and also forms small amounts of gland tissue. If you did EXERCISE 6 in Problem 1 of this unit you have seen it. The other tissues of a plant bear little resemblance to animal tissues. Many parts of a plant have groups of thin-walled cells containing large vacuoles. This tissue is called *parenchyma* (per-en′kim-ma). Parenchyma cells may or may not have chloroplasts. Most roots and stems have large amounts of woody fibers with strong cell walls and they have ducts of various kinds, as well as other tissues. Some of these are shown in Fig. 180, page 155. The tissues consisting of woody fibers and ducts are found, too, in the veins of leaves.

Living things are fundamentally alike. Living things consist of protoplasm. Most of them consist of many cells. In many-celled organisms the groups of similar cells form tissues, and groups of tissues are organized into organs; the organs make up the organism. This is true of both animals and plants.

QUESTIONS

1. In what ways do cells of an organism differ from each other? Why is it possible for you to learn much about your own cells by studying other animals?
2. Define a tissue. Describe a tissue which has intercellular matter. Was your definition of tissue complete? List the tissues found in a human arm, beginning with the outside.
3. Define the term "organ." Explain the difference between an organ and an organism. How is the word "function" used in reference to cells, tissues, and organs?
4. Name an organ system in the human body.

5. What word do we use to state the fact that cells differ in shape and activities?
6. What are the four main kinds of tissues in a complex animal? State which tissues are included in each group. Briefly tell the characteristics of each type of tissue.
7. Name two important plant tissues.
8. Summarize this short problem in your own words.

Exercises

1. Is a bone a tissue or a collection of tissues? Obtain a beef or lamb leg bone sawed lengthwise through the middle. Scrape it clean of meat. Use a strong dissecting needle to detect the covering on the shaft (long part) of the bone. Describe it. This is a kind of connective tissue. What might be a function of this covering? Feel the substance, cartilage tissue, that covers the head of the bone. Describe. Prick the inside of the head of the bone with the needle. Describe this spongy bone. What makes it red? This is known as red marrow. Prick the material outside the marrow; this is true bone tissue. Feel the substance in the inside of the shaft. This is yellow marrow. How does it differ from red marrow? Examine some of the red marrow under the microscope. List all the substances you have found. Is the bone a single tissue or a collection of tissues? Of course, you cannot see the bone cells with the unaided eye. Your teacher will give you a prepared slide of bone tissue. Notice the long dark spots with many fine projections. They are arranged in concentric circles (circle within circle) around a large round opening. In life, blood vessels and nerves run through these circular openings. Each long spot with radiating projections is a space in which a bone cell used to lie. The protoplasm has disappeared.

2. Animal tissues may be studied easily by preparing slides of tissues from a recently killed frog.

Epithelial Tissue: (*a*) *Squamous* (*flat*). Frogs shed their skin continuously. Place on a slide a bit of shed skin found in the water in which frogs are kept. If it tends to roll up be sure to unroll it by holding down the edges with dissecting needles. Stain with Lugol's solution and cover with a cover slip. Examine and draw the flat epithelial cells. (*b*) *Ciliated.* Remove a small piece of epithelium from the roof of the mouth of a freshly killed frog. Make a cut with a scalpel in the region near the eyeball and with your forceps peel it off. Mount the material on a slide, add a drop of Ringer's solution and a cover slip. Observe the beating of the cilia.

Muscle Tissue: (*a*) *Voluntary or striated.* Cut into the muscle which lies under the skin on the ventral side of a freshly killed frog. Strip off a small piece with your forceps. Place on a slide and tease the muscle apart with two needles. Add a drop of Ringer's solution and a cover slip. Note the muscle fibers with their light and dark bands. Add a drop of aceto-carmine stain to one edge of the cover slip and draw it under the cover glass by holding a piece of blotter at the opposite edge. Note the many elongated nuclei within each fiber. Draw what you see. (*b*) *Involuntary or smooth.* With your scissors remove a small piece of the stomach of the frog. On this piece separate the inner coat from the outer coat with your needles. Lay the outer coat on a slide and tease apart the cells of the thick outer coat of muscle. Stain with aceto-carmine and add a cover slip. Observe the long thin cells, packed closely together. Do you see the long nuclei? How do these cells differ from the voluntary muscle fibers? Draw.

Blood Tissue: Place a drop of blood on your slide and add a cover slip. What shape are the red blood cells? Do they have nuclei? Draw.

Further Activities in Biology

1. A useful project is the preparation of models of different kinds of tissue cells. These models can show the shape, relative size, and special characteristics of the cells.

2. By using a magnifying glass and a scalpel, try to learn something about plant tissues. Can you distinguish different tissues in a young stem? Examine a thick leaf for tissues. Describe what you see. If you have a microscope you may be able to see some of the cells after teasing some of the tissues farther apart.

In UNIT III you will consider these problems:

PROBLEM 1. What Part Do Leaves Play in Making and Using Food?

PROBLEM 2. What Part Do Roots and Stems Play in Making and Using Food?

UNIT III GREEN PLANTS MAKE THE FOOD USED BY ALL LIVING THINGS

FIG. 161 *A wheat field at harvest time. Wheat is the basic food for many millions of people. For millions of others the basic food is rice or rye or barley or potatoes. We do not eat the green parts of any of these plants, but the parts that we do eat can develop only on green plants. Do you know why?*

PROBLEM 1 *What Part Do Leaves Play in Making and Using Foods?*

An interesting experiment. Starch, sugar, protein, and fat are all found in plant protoplasm. You learned this in the last unit. Do they get there from the soil? Are they made in the plant from soil materials? Just where do they come from? This question of how these compounds get into a plant and how a plant grows has interested people for a long time. Early in the 17th century Jan van Helmont, a Flemish physician, performed a simple experiment which helped a little toward the answer. He weighed the soil in a large tub and planted a small willow branch in it. For five years he watched it carefully and watered it regularly with rain water. At the end of this time the branch had grown into a small tree weighing more than 160 pounds. Then he weighed the soil once more. He was amazed to discover that the soil weighed only two ounces less than when he started the experiment! The experiment was convincing proof that the soil was not the source of the bulk of the materials used in the growth of the willow tree. Evidently the soil supplied only the tiniest part of the materials used by the willow in its growth. To discover where the rest came from we must study the plant. Let us begin with the leaves.

Differences in leaves. Some kinds of plants, like the Spanish moss and some kinds of cactuses, have little or nothing by way of leaves. The cone-bearing trees, such as the pines, spruces, hemlocks, and others have needlelike leaves. But in general the green plants have broad, conspicuous leaves. Leaves vary considerably in size and shape. In the everglades of Florida there grows a fern, the one from which the Boston fern was developed, with a leaf long enough to stretch the length of a large-sized room, 20 feet. One species of pine has needles 12 inches long, while the needles of cedar may be less than a quarter of an inch long.

Parts of a leaf. Many leaves have two distinct parts: a stemlike part called the *petiole* and a flat, wider part called the *blade*. There is great variation in leaf blades. They may be narrow and pointed as in the grasses or the common iris; they may be almost round or shield-shaped as in the water lily. They may be smooth or hairy, paper thin or relatively thick and stiff. Leaves vary in color, too. When the poinsettia bears its small, inconspicuous, yellow flowers the upper leaves are not green but bright scarlet. The leaves of the purple beech throughout its whole existence do not appear green.

Leaves also differ in veining. You read in Unit I that leaves may be parallel veined (as in the monocotyledons) or net veined (as in the dicotyledons). And net veining may be of two types as shown in Figures 114–117, page 85.

FIG. 163 (above) *Water lily. The leaf blade floats on the water. Its long petiole is attached to a stem at the bottom of the pond.* (NEW YORK BOTANICAL GARDEN)

FIG. 162 (left) *Spanish moss hanging on live oak branches. It is not a moss but a flowering plant.* (NORTH CAROLINA DEPARTMENT OF CONSERVATION AND DEVELOPMENT)

Close study of the leaf blade. Although the variation in leaf shape and size is interesting, we can learn very little about the activities of a leaf from this kind of study. To learn more it is necessary to study the internal structure. This can be done by examining a thick fleshy leaf from a plant such as sedum. We can break or cut the leaf crosswise and, with the aid of a knife, pull off some of the "skin." When we hold this to the light, we discover that it is thin and transparent. This "skin" is found on both the lower and upper sides of leaves. It is a tissue called the *epidermis* (ep-i-der′mis). You will notice that the exposed part under the epidermis feels moist and soft.

If you use a microscope to examine a thin slice made across an ordinary leaf you will have no trouble in identifying the parts of the leaf. You can see the upper and lower *epidermis*, the *spongy* cells with air spaces between them, the *palisade* cells, and the veins. See Figure 164. You can easily study the epidermis by doing EXERCISE 1. Study of many different leaves will be interesting.

Leaf epidermis. Every leaf, thin as it may be, is covered above and below with epidermis. This tissue consists of cells closely fitted together. Figure 165 is a drawing of lower epidermis of a sedum leaf. In addition to the ordinary transparent and usually colorless cells, there are at frequent intervals pairs of green cells, each shaped like a slender kidney bean. These cells lie in such a way that there is an opening left between them. This opening is called a *stoma* (stoh-ma). Each stoma connects an air space within the leaf with the air outside. The upper epidermis of most plants has few or no *stomata* (stoh′ma-ta), plural of stoma; its cells, then, are mostly all alike.

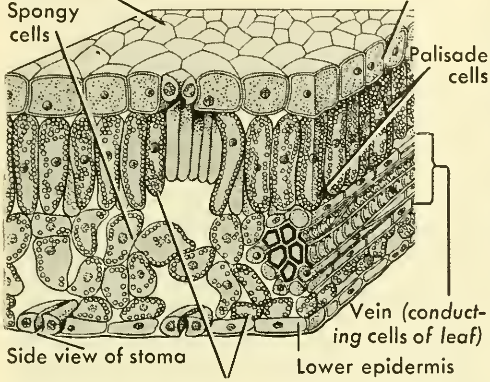


FIG. 164 *Looking into a leaf. Which two layers lie between upper and lower epidermis? What is in the "empty" spaces between the spongy cells?*

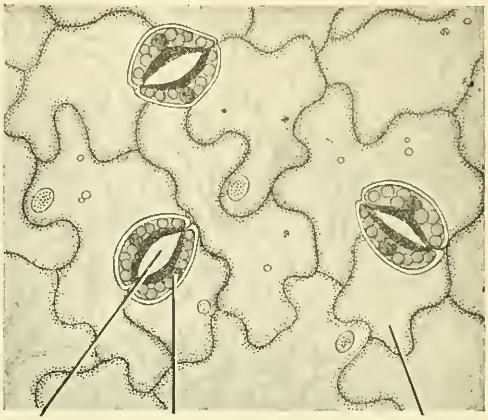


FIG. 165 *A tiny piece of lower epidermis. How many stomata do you see? Are they open or closed? What are the cells on each side of a stoma called?*

In most plants the two cells enclosing the stoma, called *guard* cells, ordinarily take the shape of a half doughnut during the daytime, making the opening larger. At night they straighten out, making the stoma smaller. The opening is never shut completely. The stomata are extremely numerous. A medium-sized cabbage leaf probably has about 11,000,000 stomata, and a sunflower leaf may have up to about 13,000,000. In most land plants the stomata are more numerous on the lower side; in floating leaves they are more numerous on the upper side; none occur on leaves that grow submerged in water. To determine the number of stomata, do EXERCISE 2.

What makes the leaf green? As you study a fresh section of a leaf under the microscope, what strikes you most is the bright green color, particularly of the palisade cells. There is usually less green color in the spongy cells and the epidermis has faint traces of green in the guard cells only. This color is caused by the presence of the tiny green bodies within the cytoplasm, the chloroplasts. They are often oval in shape. They are made of protoplasm containing several coloring matters, one of which is bright green in color. This is the chlorophyll. Chloroplasts are found not only in leaf cells but in all parts of the plant which look green. Fruits are green before they ripen and stems always have chlorophyll when they are young; sometimes they keep their green color throughout the life of the plant. You probably saw chloroplasts in Elodea cells when studying the preceding unit.

(Optional) **Chloroplasts.** In most green cells the chloroplasts are small globular bodies as indicated in Figure 164, but in some cells they are large and of unusual shapes. In the alga Spirogyra, the chloroplasts are spiral bands. There may be one or several in each cell. In certain other algae the chloroplasts are star shaped. But a chloroplast is always a living structure which under certain conditions becomes very active. The chlorophyll itself is a mixture of two compounds,

FIG. 166 *Miles of green plants with their chloroplasts working actively. What are the results of their work? How does the work of the chloroplasts benefit the plants? How does it change the atmosphere around them?* (DEPARTMENT OF CONSERVATION, MICHIGAN)

each made up of the elements carbon, hydrogen, oxygen, nitrogen, and magnesium. The only way you can obtain it in the laboratory is to extract it from the chloroplasts by means of alcohol. Together with the chlorophyll, but hidden by it, are yellow substances; one of these is *carotene*, a substance very important to you (see p. 178). It may be present in the chloroplast in large amounts. It shows clearly in carrots, apricots, sweet potatoes, and yellow corn where there is no chlorophyll present to hide it.

Usually chlorophyll forms only in the presence of light although the yellow substances may be made either in light or dark. If a plant sprouts in the dark it will not be green. On the other hand, strong light causes the chlorophyll to decompose or disappear, and a leaf exposed to strong light is green only because its cells are active and new chlorophyll is constantly being formed. In the fall, as the weather becomes cooler, the leaves form chlorophyll at a slower rate. It is then that the yellow coloring, which has been hidden by the green, shows up, giving the brilliant yellow tints to some autumn foliage. In some leaves, as less chlorophyll forms a new red coloring appears.

The work of chloroplasts. A vast amount of work may be done within a green leaf. Do EXERCISE 3 to learn that green leaves make starch in the presence of light. In the presence of light each chloroplast is working actively. It is combining two simple compounds; water (H_2O), which has risen to the leaf from the roots, and carbon dioxide (CO_2) which has entered the leaves from the air through the stomata. And what is the result of this combining, or *synthesis* as chemists commonly call it?

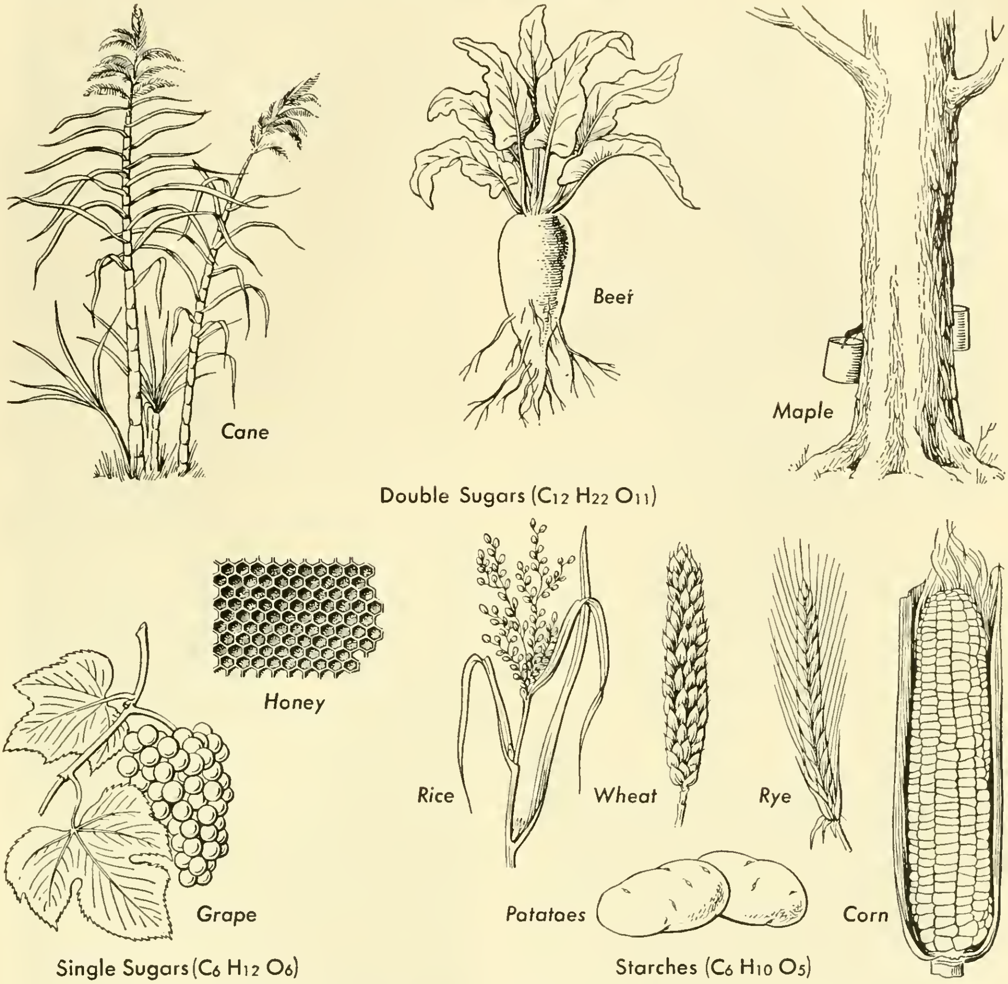


FIG. 167 *Did you believe that sugars and starches were made in factories? They are made in plants. All we do is take them out of the plant, and then refine and pack them in the factory. Which plants supply starches? Which supply sugars?*

It is a compound consisting of the three elements carbon, oxygen, and hydrogen. It is a sweet compound known as grape sugar ($C_6H_{12}O_6$). In most plants this grape sugar is quickly turned to starch $(C_6H_{10}O_5)_n$. Both sugar and starch belong to a class of compounds called carbohydrates as you may recall (see page 110). You can show that the plant needs chloroplasts to make sugar by performing EXERCISE 4.

The process of sugar synthesis in leaves was studied for many years before it was understood. The process is still not clearly understood, and only very recently have chemists learned to imitate imperfectly in the laboratory what plants have always done within their green leaves. Even now chemists can produce only tiny amounts of sugar and starch. Study Figure 167 to see where we obtain most of our carbohydrates.

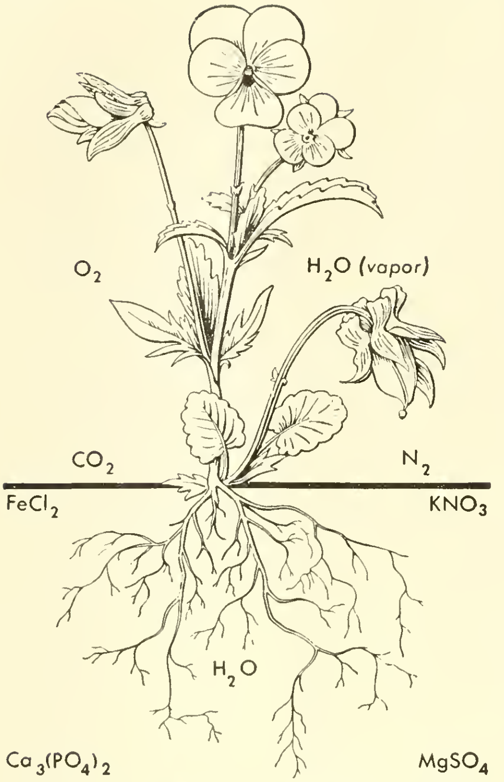


FIG. 168 *Plants make protein as well as carbohydrates and fats. How do they obtain the necessary nitrogen, sulfur, and phosphorus?*

A busy factory. In a factory electrical energy may be changed into mechanical energy, or perhaps chemical energy may be changed into mechanical energy. Work is done. In the living leaf the hum of machinery cannot be heard, the work cannot be watched by the human eye. Yet sugar is being made and energy changes are taking place. It has been estimated that the leaves of a single corn plant within a season make about two pounds of sugar; the leaves of a medium-sized apple tree may make 44 pounds of sugar.

This work goes on in the daytime, while light strikes the plant. Light energy from the sun, or *radiant* energy as it may be called, is absorbed by the chlorophyll. In the manufacture of sugar this light energy is changed into chemical energy, which remains locked up in the food. All day long while the sun is beating on the broad surface of the leaf blade the chloroplasts within absorb the rays of light. Even on gray days when there is no direct sunlight, chloroplasts absorb light energy and continue the synthesis (making) of sugar, though more slowly than in bright light. At night the process stops. Devise and perform an experiment to convince yourself that light is necessary for making carbohydrates. Electric lamps may be used as the source of light.

Because light energy is used in the synthesis of sugar the process is called *photosynthesis. Photo* is the Greek word for light. When carbon dioxide and water are combined during photosynthesis, free oxygen is left over. You can demonstrate this by doing EXERCISE 5.

Protein synthesis. Some of the sugar made by the plant is built up into proteins. You will remember that protein contains more elements than sugar. Besides carbon, hydrogen, and oxygen, it contains nitrogen, sulfur, sometimes phosphorus, and others. These elements enter the plant from the soil in the form of mineral compounds. It is interesting to note that a plant uses only simple compounds, never elements, in making its food. Small amounts of these minerals combine with the sugar. The union does not take place all in one step; compounds simpler than proteins are made first. Among these compounds are *amino acids.* You will read more about amino acids when you study digestion.

The chlorophyll takes no part in the synthesis of proteins. In fact, protein synthesis takes place in all other parts of the plant as well as in the leaves. It occurs in practically all plants, whether green or not green. Yet animal cells, as far as we can tell, never make proteins from sugar and simple mineral compounds.

Proteins are important for the plant. As you have learned in the last unit protein is one of the compounds which is used in making protoplasm. And without the making of protoplasm there can be no growth.

Fat synthesis. Some of the sugar is changed into fats. Fats, like carbohydrates, are made up of carbon, hydrogen, and oxygen. Some of the oxygen is lost from the sugar in the making of fats, so fats have proportionately less oxygen than carbohydrates. This process, too, does not depend on chlorophyll; it can go on in any part of the plant. In some plants much fat forms and accumulates, often in the fruit and seed. The kernel of corn, the fruit of the olive tree, and the seed of the cotton plant among many other seeds and fruits contain large amounts of fat (oil).

Another use for sugar. In most plants, when a certain amount of sugar has accumulated, it is changed into starch. The starch grains in a cell are easy to recognize. See Figure 169. This starch may soon be changed back again to sugar or it may accumulate in the plant. The sugars which are not built up into fats or proteins have another important use in the plant. They are oxidized in the cell. Fats and proteins may be oxidized too, but generally it is sugar.

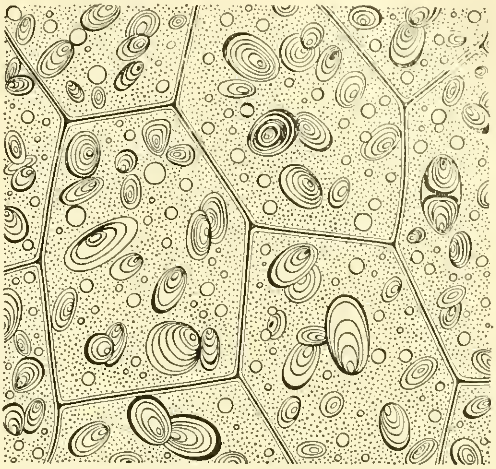


FIG. 169 *Cells of the potato containing starch grains. From what is starch made in a potato?*

In oxidation energy is released. Some of the energy released by oxidation of sugar is used in making fats and proteins. Other small amounts are used in *assimilation*, the process of making protoplasm from food. Some of the energy is lost from the cells as heat. All this energy comes from the oxidation of sugar in the cells in every part of the plant.

Respiration in plants. Oxidation is the union of oxygen with a substance. Oxidation in the plant is called respiration. If the substance oxidized is sugar, two simple compounds result: carbon dioxide and water as indicated in the following equation.

$$\text{Sugar} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Respiration goes on in all the living cells all the time. As a result of photosynthesis in the green parts in the daytime, there is a steady production of oxygen in the cells. Some of this stays in the plant and combines with food in oxidation. But so much is produced that it is easy to demonstrate oxygen passing out of green leaves in bright sunlight. At night photosynthesis stops. Then the concentration of oxygen inside becomes less than outside, and, consequently, oxygen diffuses from the surrounding atmosphere through the stomata into the leaves and into the cells.

Now in respiration carbon dioxide is made. In the daytime it stays inside and at once combines with water in the process of photosynthesis. But at night the carbon dioxide produced in respiration is not used up by the cells and carbon dioxide passes out of the cells. Note: Though respiration goes on all the time, it is only at night that oxygen enters the plant and carbon dioxide leaves.

Now in animals much oxygen constantly enters the animal, and much carbon dioxide is given off. The breathing in of oxygen is followed by oxidation of food all through the animal's body. In animals, cellular respiration is the term applied to the movement of oxygen into a cell, the oxidation of food, and the passage of carbon dioxide from the cell. In plants there are no breathing organs and there is no active breathing, but it is important to remember that there is respiration and that when oxygen is not already present in the plant it diffuses inward, and that when the carbon dioxide is not used in making sugar, it diffuses outward.

Respiration and photosynthesis. The exchange of gases that results from respiration and photosynthesis must not be confused with the processes themselves. The two processes are altogether different. See the table on page 145.

What part do leaves play? You have seen that leaves play a very important part in the life of the plant. The cells in the inside of the blade of the leaf contain chloroplasts. Chloroplasts are tiny bodies of living matter containing chlorophyll. Through the agency of the chlorophyll, sugar is made. The sugar can change to starch. It can also combine with mineral compounds, making proteins. Sugar is also converted into fats. These later changes can take place in other parts of the plant as well as in the leaves. But photosynthesis takes place only in the green parts of the plant; this means that in most plants the manufacture of most of the carbohydrates occurs in the leaves. Photosynthesis takes place only in the stems of such plants as the barrel cactus (Fig. 186, p. 160). Its tiny leaves soon drop off.

The manufactured protein is combined with other substances and changed into living protoplasm by assimilation. The carbohydrates, and to some extent the fats and proteins, are oxidized in respiration. It is by this process that the plant gets the energy needed for its activities.

How green plants are of importance in the world. You have seen that green plants make their own food. But they do far more than this. They make the food used by the whole world of animals and nongreen plants. Carbohydrates are made only by plants containing chlorophyll; proteins are made only by plants. Animals and nongreen plants are completely dependent on green plants for their food, and that means for their energy supply, too. Green plants transform the radiant energy of sunlight into the chemical energy in food. Without chlorophyll this energy transformation could not have taken place. Green plants keep storing energy. Animals and the colorless plants use up the stored energy in growing and keeping alive.

Lastly green plants, besides making foods containing energy, put free oxygen into the air. In photosynthesis much oxygen is set free. To be sure some remains in the plant and is used in oxidation but large amounts are left over. This extra oxygen diffuses into the air. Thus animals and colorless plants are dependent on green plants for food, for all their energy supply, and for the continued supply of oxygen. Now try EXERCISE 6.

	PHOTOSYNTHESIS	RESPIRATION
Materials Used	Carbon dioxide and water	Food and oxygen
Materials Produced	Sugar and oxygen	Carbon dioxide and water
Energy Changes	Light energy changed to chemical energy of sugar	Chemical energy of food changed to other kinds of energy
When Occurring	Only in light	At all times
Where Occurring	Only in green cells	In all living cells

QUESTIONS

1. What evidence have you that green plants do not get their food from the soil?
2. How do leaves vary in shape and size? Describe the veining in the blade of a monocot and in the blade of a dicot. Sketch three leaves to illustrate "feather" veining, "palmate" veining, and parallel veining.
3. What in a leaf blade occupies the place of the two slices of bread in a sandwich? What in the leaf takes the place of the sandwich filling? Locate spongy cells, palisade cells, veins.
4. Describe stomata, giving their appearance and location.
5. Distinguish between chlorophyll and chloroplast.
6. What elements are found in chlorophyll? How can you get the chlorophyll out of a leaf? Explain the effects of light on chlorophyll.
7. Explain what useful work chloroplasts do. To what extent can man duplicate this work?
8. Give one example of an energy change in a factory and another in a green leaf. What simple compounds are combined in making sugar? What substance is left over in this process? What does the word "photosynthesis" mean?
9. What elements are contained in sugar? in protein? What is combined with sugar when protein is made? When sugar is synthesized into protein what simpler substances are produced first? What use does the plant make of protein?
10. Name three plants which contain large amounts of fat. From what is fat made in the green plant?

11. What use is made of carbohydrates besides conversion into other food compounds? Of what importance is oxidation to the plant?
12. Define respiration. Where in the plant does it occur? What gas is used up in respiration? What gas is produced? Explain why carbon dioxide diffuses out of a green plant at night but oxygen diffuses out in the daytime.
13. To sum up, contrast respiration and photosynthesis as to gases used in each process; gases produced in each; energy transformation in each.
14. Review the work done for the plant by the leaf, showing that chlorophyll is essential for making foods and for obtaining energy.
15. Make the following applications of your knowledge: (*a*) What do you recommend for taking out grass stains? (*b*) Why may leaf-eating insects kill a tree? (*c*) How must celery plants be treated to make them white?
16. Why are green plants of such great importance to you?

Exercises

1. What is the structure of the epidermis of a leaf? Narcissus, tradescantia, or many other leaves may be used. With a scalpel and a pair of forceps remove a bit of the epidermis from the lower surface. Mount in a drop of water. Examine it under low power. Do you see the tiny openings or stomata? Study the cells that enclose them. How do these cells differ in shape from the other cells of the epidermis? How many of these cells enclose a single stoma? What are they called? Are the stomata always the same size? Explain. Draw a portion of the epidermis showing all of the structures that were mentioned. Label.

2. Are there more stomata in the upper or lower epidermis? Remove small pieces of epidermis from the lower and upper surfaces of a leaf. Examine each under low power. What differences do you note? Count the stomata in the field of vision. How could you arrive at an estimate of the number of stomata on each surface of the leaf?

3. Do green plants make starch in the presence of light? Keep a geranium or coleus plant in the dark for about one week. Then cover one leaf with carbon paper, and set the plant in strong light for four or five hours. Test the covered leaf and an uncovered leaf for starch. (Hint: boil the leaves in water and extract the chlorophyll with hot alcohol; then test them for starch by adding a weak iodine solution.) What do you find? How can you explain it?

4. How can you prove that the presence of chlorophyll is necessary for carbohydrate synthesis? For this experiment you will need plants with leaves partly green and partly white, such as green and white coleus, silver leaf geranium, or variegated tradescantia. Place the plant in the sunlight for several hours. Remove one or two leaves and test them for starch. You must be sure to dissolve out the chlorophyll first. Does this experiment have a control? Would it be as good to use a leaf that is completely

white? Explain. (Note: You use the starch test because it is easy to test for starch in a leaf. The plant makes sugar first and later changes it to starch).

5. Demonstration by the teacher. The release of oxygen by a green plant can be demonstrated if advantage is taken of the fuming of white phosphorus (DANGER) in the presence of oxygen. (The reaction forms phosphorus pentoxide.) A piece of white phosphorus is fastened to a cork which is then used to close one end of a large tube about one inch in diameter. Water is poured into the tube, leaving an air space of three or four inches. Elodea plants are introduced and the tube then closed by means of a second cork at the other end. When the tube is inverted so that the phosphorus is in the air space, fuming occurs. After a time all the oxygen will have been removed from the air. The glass tube is then turned so that the phosphorus is in water. After having been kept in the bright sunlight the tube is inverted again. Fuming occurs a second time showing that the elodea plant must have released oxygen. The demonstration may be repeated several times.

6. Read again the account of Van Helmont's experiment with the willow twig, page 137. Van Helmont concluded that the plant made its substance from water. This was a reasonable conclusion considering the knowledge available to him. List the facts you know that make Van Helmont's conclusion unacceptable today.

Further Activities in Biology

1. What is the effect of a constant electric light upon the leaves of a plant? Start some bean seedlings in moist sawdust, then transplant to soil. Use plants of the same size. When the cotyledons have shriveled place half of the plants under a strong electric light at night. Keep all of the plants in the light (sunlight, if possible) during the day. Compare the leaves in the two groups of plants. Has the electric light made any measurable difference? Try the starch test on leaves from each of the two groups of plants. What do you find? Explain.

2. Can you detect any difference between the gases that diffuse from a plant not engaged in photosynthesis and one in which photosynthesis is going on? Devise an experiment to demonstrate this.

3. Devise an experiment to show what effect darkness has on chlorophyll formation in growing plants.

PROBLEM 2 *What Part Do Roots and Stems Play in Making and Using Food?*

The plant underground. If we were buried up to our waists, an observer would get a false impression of us. But that is the way you see most plants. Half of the organism or more perhaps, is beneath the ground; the roots often spread out as far as the stem with its branches. The farther out or down the roots extend, the better they anchor the plant in a storm and the more water they can obtain. If you have growing bean plants, uproot one and do EXERCISE 1.

Some plants have one long main root corresponding to the main trunk of a tree; this is called a *taproot.* (See Fig. 170.) The taproot may grow to a length of twenty feet. It is more common for plants to have many medium-sized roots joined to the stem just below the surface of the ground and branching in all directions (Fig. 172). Just as a stem branches into finer and finer twigs so roots divide and subdivide into smaller roots and rootlets. The finer rootlets may be so small that one can scarcely see them; the smallest twigs are thick in comparison. The root systems of some plants are astonishingly large. One biologist estimated that the total length of the roots and rootlets of one rye plant was two million feet; yet the plant was only two feet high.

Sometimes roots are thick and fleshy and contain large amounts of sugar and starch. Man uses such roots as the carrot, sugar beet, turnip and sweet potato as food. However, not every fleshy underground part is a root. The Irish potato and the onion, for example, are stems, not roots.

Roots above ground. Just as stems in certain plants may be underground, so may roots grow above ground. English ivy, Boston ivy, and poison ivy have tiny roots all along their climbing stems. These roots cling to a stone or the bark of a tree and support the plant. In the jungle where the air is always moist many kinds of orchid plants are perched on the limbs of trees. They have roots which hang down but never reach the ground.

Soil. You can learn a great deal about soil at first hand by doing EXERCISES 2, 3, and 4. There are many different kinds of soil. The soil of the forest floor is very different from the soil at the edge of the sandy beach. The black loam of Iowa differs from the red clay of New Mexico. The soil in your back yard may not be like any of them. But soil always contains among other things small particles of mineral compounds. Sometimes these are very tiny, as in clay; sometimes they are large, as in sandy soils. These mineral compounds are nitrates, sulfates, phosphates, and many other compounds; no two samples of soil taken from different

FIG. 170 (above) *You can use the yardstick to tell how far this taproot extends underground. How high is the stem?* (ILLINOIS AGRICULTURAL EXPERIMENT STATION)

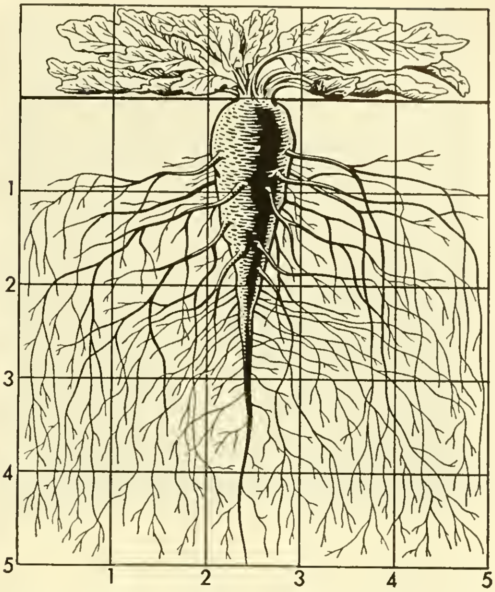


FIG. 171 (above) *The sugar beet has a much thickened taproot. Can you calculate through how many cubic feet of soil these roots spread?*

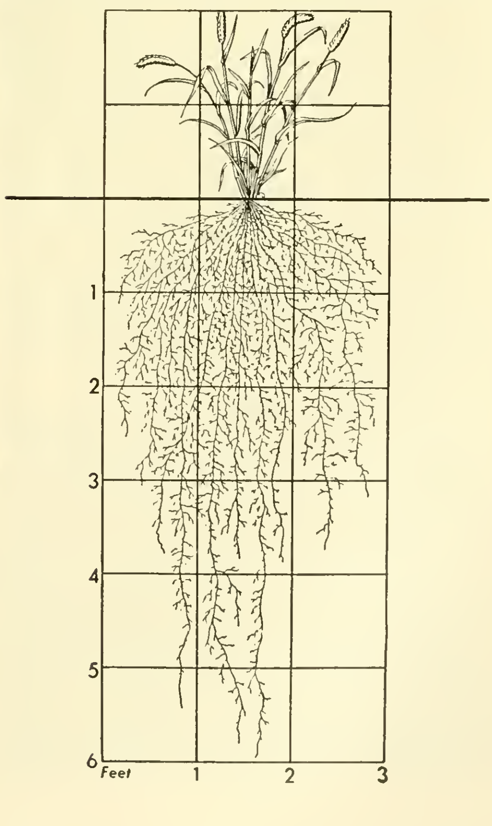


FIG. 172 (right) *The wheat plant has fibrous roots. How do they differ from the roots of the sugar beet? How far down do they extend?*

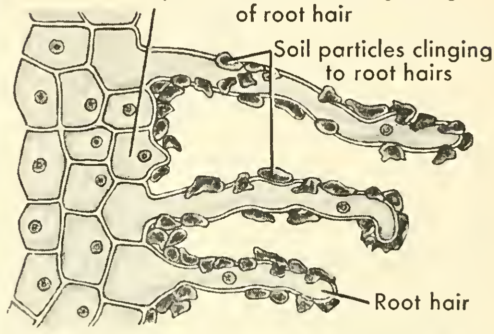


Fig. 174 (above) *Three root hairs magnified Each hair is a single cell.*

Fig. 173 (left) *Sprouting seeds. Each one has a young root with root hairs. Where on each root are the shortest root hairs?* (BLAKISTON)

regions would have exactly the same composition of mineral substances.

Ordinary soil contains much besides minerals. It has varying amounts of dead and partially decayed plants and animals. The soil from the forest floor, called humus, is particularly rich in this. And all soil contains water; even soil that looks and feels dry contains small amounts of moisture. This soil water holds in solution whatever substances in the soil are soluble. It is quite different from rain water. Finally, soil contains varying amounts of air. The nearer the surface and the less closely packed, the more air it contains.

A close-up of roots. When you uproot a plant it is impossible to see one very important part of the root system, the part that is most active. This part can be seen only if the young roots grow in water or on a moist surface under glass. See Exercise 5. You will find that near the end of each little root there is a delicate fuzzy covering consisting of tiny hairs, called *root hairs*. See Figure 173. It is difficult to conceive of the large number of root hairs on one plant even though only a part of each rootlet is covered with them. On the rye plant referred to above there might be, according to some estimates, 14 billion root hairs with a total length of 6000 miles.

Each root hair is an outgrowth from and therefore a part of a single epidermal cell. Like many other plant cells it has only a thin layer of cytoplasm lining the cell wall; the interior is completely occupied by a large vacuole. Figure 174 is a drawing of some of the epidermal cells of a young root.

Diffusion through root hair membranes. In the last unit you read how the molecules of all substances are in constant motion, and how substances, especially gases and liquids, intermingle or diffuse. You learned that many substances diffuse through a membrane which has no visible pores. You showed that water can diffuse through the cell membrane of plant cells, passing both in and out.

Now let us consider what happens in the root hair stretched out in the soil and surrounded by soil water. Does the soil water enter the cell? First let us consider the water itself; later we can consider the dissolved salts (mineral matter). In diffusion the movement of each substance is independent of the movement of every other. The root hair is completely surrounded by a membrane. The vacuole within the root hair contains cell sap which is a solution of various substances in water. Because of the many compounds dissolved in the cell sap the concentration of water is relatively low. The soil water on the other side of the membrane is normally a weak solution of minerals; it has few minerals and a relatively large percentage of water. In other words, the weak solution has a greater concentration of water molecules; it may be 97 per cent water as compared to 80 per cent water making up the cell sap. As a result, water will pass into the root hair.

If the soil water happens to be a very concentrated solution (have a large per cent of mineral matter and a comparatively low per cent of water), water will diffuse out of the cell; the plant would lose water through its roots and dry up in consequence. Diffusion of water from the plant takes place when large amounts of salt are sprinkled on the ground. This is sometimes done to kill unwanted plants but it should not be done if the same soil is to be used for other plants. Under normal conditions, however, water does not diffuse from the root to the soil; it goes from soil to root.

We are now ready for the second question. How do the nitrates, sulfates, phosphates, and other mineral compounds enter the root hair? They are dissolved in the water of the soil and are able to pass through the membrane. The protoplasm lining the cell wall is permeable to them. Each mineral passes independently of the others. When a mineral in the soil water is present in higher concentration outside than in the cell sap, it passes from the soil *into* the root hair. But the movements of minerals are not always simple; electrical charges and other factors play an important part. There is much about their movement that cannot be explained here and also much that is not understood.

What happens to the compounds once they are in? As more and more water enters the root hair, you would expect the cell sap to become a weaker and weaker solution. The water concentration inside, therefore, would gradually become greater and would soon equal the concentration of the water outside. But this does not happen because the water that enters does not remain in the root hair cell. It diffuses to a neighboring cell leaving the water concentration about as it was before diffusion began. Thus water keeps diffusing into the plant.

The same is true of some mineral substances; they do not become concentrated in the root hair. They pass right on to the next cell toward the interior of the root. In this way, both water and minerals pass inward from cell to cell.

What is the structure of a root? By making sections through a carrot, as described in EXERCISE 6, you can learn the general structure of a root. In almost all young roots the tissues are arranged in three distinct cylinders. The outermost cylinder of one layer of cells is the *epidermis;* inside of this lies the *cortex,* several to many cells in thickness; in the

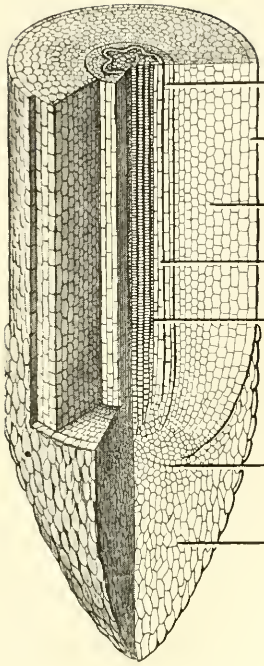


Fig. 175 *The tip of a root. Note the position of the xylem, the phloem, the cambium, the cortex, the epidermis, and the root cap.*

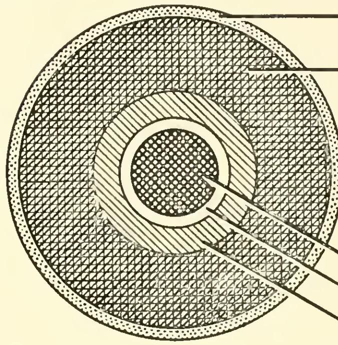


Fig. 176 *In cutting across a young root one can recognize three cylinders. Name them in order beginning on the outside. In very young roots the xylem cylinder is fluted.*

center is the conducting or *vascular cylinder.* In the carrot the cortex is relatively thicker than in most roots; most of the food accumulates there.

The cortex originally consists of thin-walled, closely packed, more or less rounded cells. Later there may develop in it various thicker-walled cells which give strength to the root. Also, cork tissues form just beneath the epidermis. The outer cork cells die, cutting off the epidermis from contact with other living cells of the root, killing it. Most cork tissues are quite impermeable to water, so water can enter only the younger portions of roots in which the cork has not yet formed. The young portion of roots is near the tip where the root grows in length. This is where the root hairs form.

The vascular cylinder has various kinds of cells. Near its center, in most cases, there are water-conducting *tubes.* These tubes form from cells that lie end to end through the length of the root. The cross walls that originally separated each cell from those above and below it disappear in time. Spiral thickenings form lengthwise in the walls, and then the protoplasm within disappears. Thus long, thick-walled tubes are built up. (See *C* in Fig. 180, page 155.) These tubes vary in length from a few inches to several yards, depending on how many cells have joined together. Exercise 7 may help you remember the vascular cylinder.

Among the tubes usually lie *wood fibers.* Each fiber is a long slender cell which loses its protoplasm; its walls change into an elastic, tough, woody material. The fibers give great strength to the root. These fibers, together with the tubes, are spoken of as *xylem* (zye′-lem) the Greek word for wood. The xylem makes up the inner portion of the vascular cylinder.

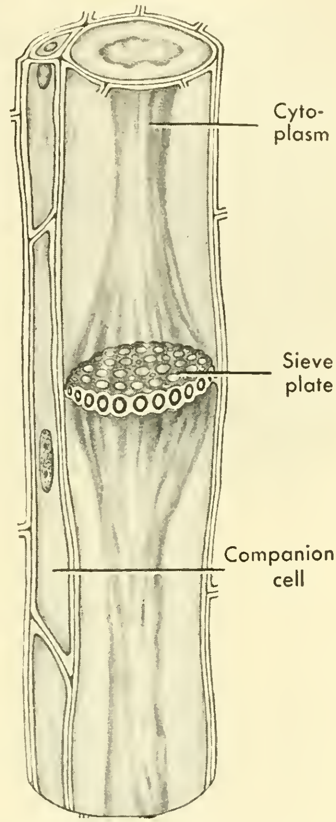
Along the outer portion of the vascular cylinder lie tissues known as *phloem* (flow′-em). In the phloem are several kinds of cells; those of special interest are the *sieve tubes*. A sieve tube is a row of long narrow cells which remain alive. In this respect sieve tubes are different from the xylem tubes. Holes appear in the walls at the top and bottom of each cell so that these walls look like sieves. Strands of cytoplasm pass through the sieve from cell to cell.

Between the phloem and xylem lies a very narrow ring of thin-walled cells, the *cambium* cells, which also remain alive. They, unlike the phloem or the xylem, have the ability to divide. The cambium ring is so narrow that it cannot be seen without the aid of a microscope.

What is the structure of stems? All roots are very much alike in their general structure but there are two distinctly different kinds of stems. The monocot stems are quite different from the dicot stems. First let us study the stem of a dicot shrub or tree. How does this stem compare with the root? It has the same cylinders as the root with which it connects: the epidermis, the cortex, and the vascular cylinder.

The cortex of most stems, being above ground where some light reaches it, has cells that are green. As the stem grows older, just as in roots, cork tissue is formed from cortex cells just inside the epidermis. This cork tissue cuts off the water supply from the epidermis and kills it, leaving cork on the outside. The stomata which are present in the epidermis become lost and new openings through the cork, called *lenticels*, form.

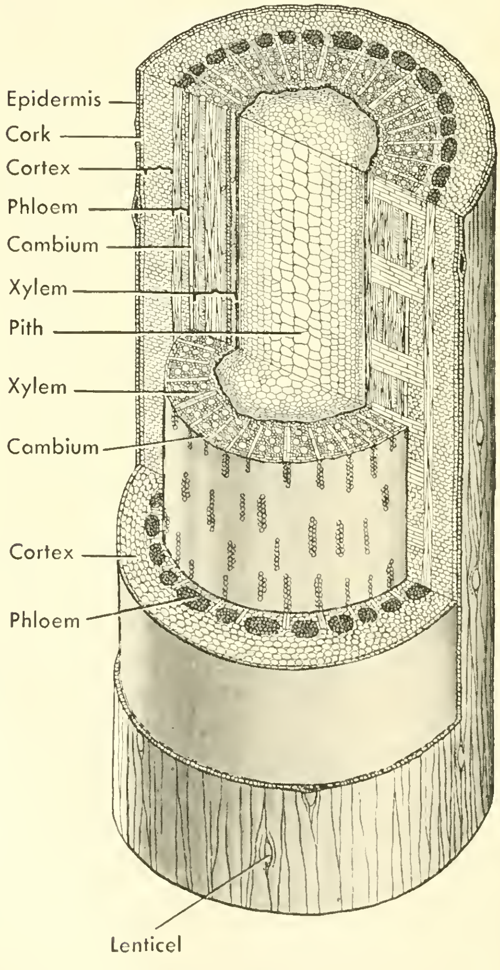
FIG. 177 *Note the holes in the sieve plate which lies between the upper and lower cell. Sieve tubes carry manufactured food through plants. See pages 157–158.*



Cork is not formed in the stems of some herbs. In most herbs it is only a thin layer, but in many woody stems the cork layer becomes quite thick. The cork oak that is native to Spain forms a cork layer that may become several inches in thickness. It is this tissue that is cut into cork stoppers. In some trees new layers of cork form, first from cortex cells nearer the phloem and then from the phloem cells themselves. All the original cortex cells and then the older phloem cells thus are cut off from a supply of water and die. The bark of such trees is rough and furrowed. The cortex of birch and certain other trees lasts for a long time. Their bark is smooth except in old trees. In beech the cortex

FIG. 178 (left) *The smooth paperlike bark of the birch with its conspicuous lenticels. Can you name another tree whose young twigs have conspicuous lenticels?* (SCHNEIDER AND SCHWARTZ)

FIG. 179 (below) *Diagram of a young woody stem. How does this stem differ from most roots? What are the parts of the vascular cylinder?*

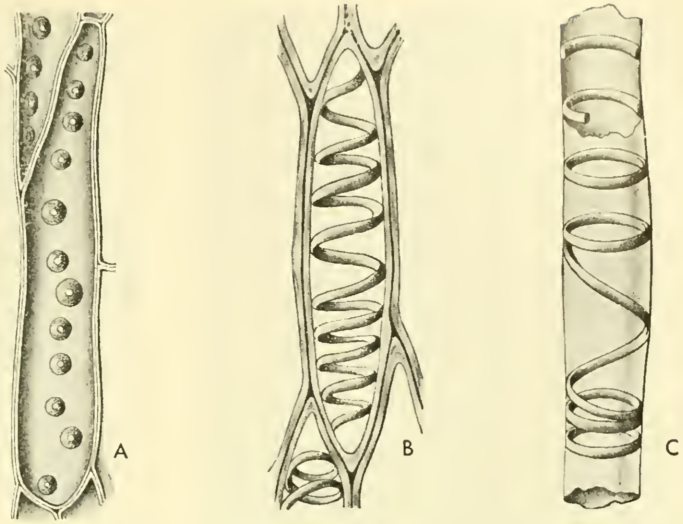


is never lost; the tree keeps a smooth bark throughout its life.

The vascular cylinder is much like the one in roots. It consists of phloem, cambium, and xylem. But in the center there is usually a fourth cylinder of thin-walled cells, the *pith*. Pith is very rarely found in roots but is found in most stems. Compare Figures 176 and 179. This vascular cylinder connects at its lower end with the vascular cylinder of the roots. At its upper end it branches many times and in each leaf branches again, forming the veins of the leaves. You will find it interesting to study a young stem as described in EXERCISE 8.

How stems grow longer and branch. A swing fastened to one of the lower limbs of a tree remains the same distance from the ground year after year; yet the tree grows taller all the time. Evidently the lower portion of the trunk does not lengthen. In fact, the tree lengthens only near its tip. In parts of the world where there are distinct seasons growth ceases during the winter. At this time the cells at the tip of the stem are covered by heavy scales, forming the *terminal bud*.

FIG. 180 *There is variety in water-conducting tubes. A and B are found in conifers (they are called tracheids); C is a tube found in flowering plants. The walls are thickened in different ways.*



See Figure 181. If twigs are available study one carefully by doing EXERCISE 9.

Along the sides of the stem are *lateral* buds containing cells which can grow into stems and leaves. In the spring, when growth begins again some of the lateral buds develop into branches. These stems, like the main stem, lengthen near the tip, form lateral buds, and before the end of the season form a terminal bud. Thus each year the branches extend farther and farther out from the trunk and each branch forms branches along its sides. When a plant lives for many years it may become very tall and wide-spreading. We see that both stems and roots grow in length only at the tips.

How stems grow in width. In dicot trees and shrubs the growing tips are noticeably thinner than other parts of the stem. The thickest part of the tree trunk is at the very bottom; the thickest part of a branch is at its base. The fact that the older parts of a stem are thicker than the newer or younger parts is good evidence that the stem of a tree or shrub is

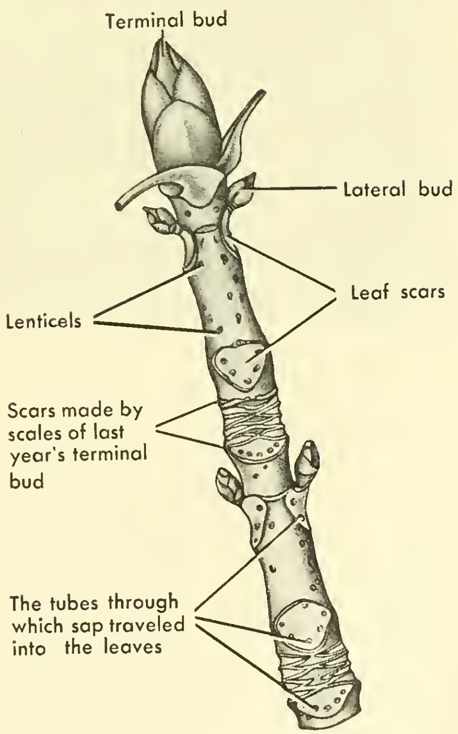


FIG. 181 *Tip of horse chestnut twig, about natural size. At what point would such a stem grow in length? How can you tell how much this stem increased in length during one season? Find the lateral buds. Find where leaves have been attached. Where do lateral buds arise with relation to the leaves?*

FIG. 183 (above) *Cross section of a 30-year-old part of a tree. How can its age be told? Notice the dark center portion, called heartwood, and the lighter outer portions, called sapwood. Notice, too, that the thickness of the annual rings varies. Can you think of some reason for this variation?*

FIG. 182 (left) *California redwoods. Some of these were already tall trees when Columbus discovered America. How do we know this?* (U. S. DEPARTMENT OF INTERIOR)

constantly growing in diameter (width) throughout its entire length.

The growth in thickness is the result of the activity of the microscopic layer of cambium between the phloem and xylem. At the end of the winter when the ground thaws, or at the beginning of the rainy season where there is no frost, water again enters the roots, and sap begins to flow upward. Then the cells of the cambium divide actively and form thick-walled xylem tubes and fibers toward the inside. At the same time they produce more of the sieve tubes and fibers toward the outside. See Fig. 179, page 154. The xylem tubes formed in the spring of the year are wider cells than those formed in the late summer. Even to the naked eye the spring growth looks quite different from the summer growth. The narrow cells formed late in the season show as a darker "ring" (cylinder). These double rings are called *annual rings*. By counting them one can learn how old that part of the tree is. There are, of course, more rings at the base than near the top of a tree. No rings appear in the phloem region because there is no difference in size of phloem cells that are formed in spring and summer. The cork of most trees likewise has no annual rings but in birch bark cork the cells made in spring are thinner walled than those made in summer; that is why birch bark peels into thin sheets. This growth in thickness is known as secondary thickness or *secondary growth.* As it continues only the younger xylem and phloem cells are active. To test your knowledge of stem structure and growth do EXERCISES 10 and 11. In some trunks the number of annual rings cannot be counted because the heartwood may disappear, leaving the tree hollow.

Stem variations. You have studied woody stems of dicots. Herbaceous stems of dicots have the same kinds of tissues but in different amounts. There is usually more cortical tissue and less cork. Some herbaceous stems make little or no cork. Also in most herbaceous stems there is a larger proportion of pith and some have more fibers in or near the phloem than is usual in woody stems. The xylem and phloem with cambium between them, along with some fibers, are found in bundles located in a ring around the pith. These are called vascular bundles. Pith tissue extends out between the bundles.

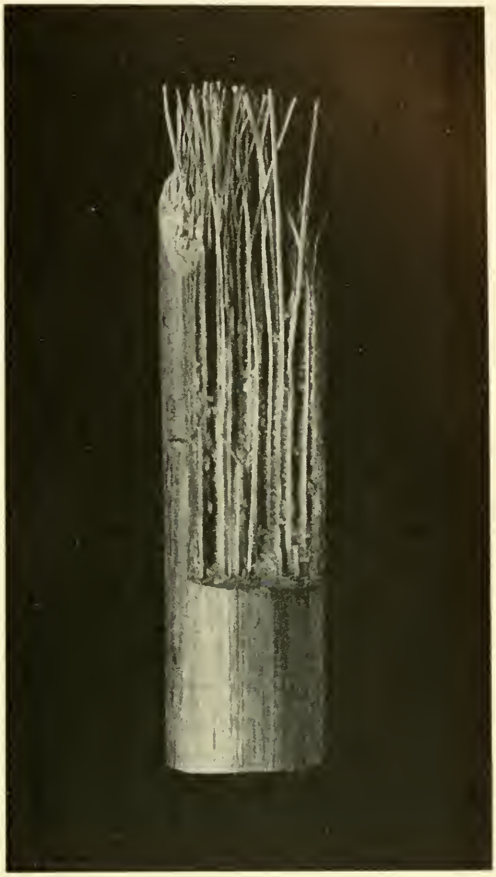


FIG. 184 *The vascular bundles in a corn stem. Corn is a monocot. How do these vascular bundles compare in position with the vascular bundles in a young dicot stem? Where is the pith?* (BLAKISTON)

In monocotyledons, whether they are herbs, shrubs, or trees, the separate vascular bundles are not usually arranged in a ring. They are scattered through the pith. You will note other differences when you do EXERCISE 12. Monocots rarely have cambium and do not, in general, have secondary thickening. The stem of the bamboo and the trunks of many palms have the same diameter along their entire length.

Movement through xylem and phloem. Xylem is continuous from the root through the stem, through its branches, its finer twigs, and into the veins of the leaves. See Figure 185. That is, there is a continuous passageway of xylem tubes starting underground and ending among the green cells of the leaf. Water from the soil travels up through these tubes. When there is enough water in the soil there is a nearly constant stream of water, containing some of the dissolved minerals, through the xylem tubes. And the flow is always upward.

Sieve tubes, too, are continuous from the root, through the stem and directly into the various parts of the leaf. Only

FIG. 185 *The hickory leaflet (part of a compound leaf) was treated to remove all tissues except the veins and epidermis. The dark spots are diseased areas. The smallest veins contain both xylem and phloem. They are connected through the larger vein and the leafstalk to similar tissues in the stem and roots.* (HUGH SPENCER)

manufactured products and some minerals from the soil travel through the sieve tubes of the phloem. Sugar made in the leaves may move down through the sieve tubes to the roots in large amounts. It may accumulate there as sugar or starch and form a thickened, fleshy root. Or the sugar may be combined with minerals into protein; this can happen in any part of the plant. Passage of sugar and minerals through sieve tubes may be up or down. But proteins, fats, and starches cannot move by diffusion since they are insoluble and the protoplasm of the cell is not permeable to them. In general, they are manufactured within the cell in which they are found. All three, however, may be made soluble (digested) in the cells and the soluble products may then move to other parts of the plant.

Digestion of insoluble foods in plants. Most of us are quite aware that digestion of insoluble foods occurs in animals. We have a digestive system (see page 188) in which insoluble foods are made soluble. Plants, too, have digestion although they have no digestive system. During the daytime starch accumulates in the leaves and green stems of plants. Much of this accumulated starch is digested to sugar which moves to other parts of the plant during the night. In temperate climates, starch, protein, and fats accumulate in stems, roots, and seeds in the summer. This insoluble food is digested the following spring and the soluble products are used in the new growth of young stems, leaves, roots, and seedlings. You will study about digestion in the next unit.

The forces that move water in plants. Water and mineral compounds enter the epidermis of the root by diffusion, largely through the root hairs. They pass by diffusion across the cortex and outer part of the vascular cylinder from cell to cell. Here the water enters the xylem tubes. As long as the water supply lasts in the soil, more and more water diffuses into the xylem tubes. The water then rises in each xylem tube. You may have seen water rising several feet in a thistle tube in the experiment showing diffusion through a membrane. But our problem now is to explain the rise of water not three or four feet but a hundred feet or three hundred feet in tall trees. How does it get to the leaves at the very top of a tree?

It has been known for a long time that if a very narrow tube is dipped into water the water will rise in the tube. The narrower the tube the higher the water will rise. This is called *capillary action;* the narrow tube is called a capillary tube. Water may rise in each xylem tube by capillary action. This tube, though extremely long, is the finest kind of capillary tube for it is microscopic in diameter. It is the width of only one cell. Since it is so fine a tube, water readily rises in it for some distance. Do EXERCISE 13 to see capillary action.

Another force that causes water to rise in xylem tubes was discovered about thirty years ago. It was discovered that water in a capillary tube stays together in a column as if it were a wire. If some kind of pull is given at the upper end of such a column the whole column moves up.

The pull on the water in the xylem tubes. Take another look at Fig. 185, page 158. What the picture does not show is that the veins with their vascular tissue divide into such tiny branches that but very few cells lie between any two of the tiniest veins. Water coming up through the xylem tubes constantly diffuses from the tubes to the neighboring cells. All the leaf cells, including the epidermal cells, hold large quantities of water both in the protoplasm and in the cell wall. Now if the concentration of water in the cells is greater than it is in the surrounding atmosphere, the water passes off into the air. We say the water evaporates.

Very little of the water leaves directly from the epidermal cells. Most of it goes out from the air spaces through the stomata. Every air space within the leaf is surrounded by cells from which water molecules are separating and diffusing as water vapor. From the air spaces this water vapor diffuses outward through the stomata. Even when the stomata are said to be completely closed there is still enough of an opening for water molecules to pass through. And at no time would all the stomata of a plant be completely closed. When water leaves the cells and diffuses into the surrounding air we call the process *transpiration.* If you have the equipment you will find EXERCISES 14, 15, and 16 worth while. Transpiration thus decreases the concentration of water in the leaf cells near the upper end of the water column in the xylem tubes. Water then diffuses from the tubes into these leaf cells and thus pulls on the column of water. Because it is transpiration that decreases the concentration in the leaf cells this pull has been called the lifting power of transpiration.

Transpiration important to the farmer. A single corn plant may lose three or four quarts of water on a hot day. A birch tree with about 200,000 leaves loses as much as 350 quarts on a hot dry day in summer. These large amounts of water vapor in the atmosphere condense in time and come down as rain. Can you

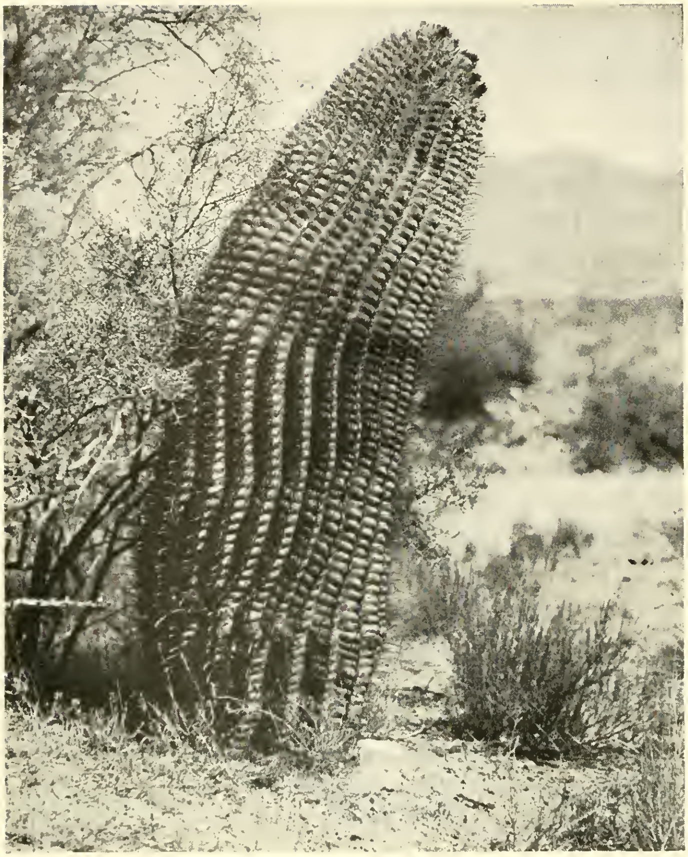


FIG. 186 *The barrel cactus of our desert states is a good example of a plant that loses little water in the hot sun. How do you explain this?* (U. S. DEPARTMENT OF AGRICULTURE)

imagine the effect of square miles of forest land? You can see, too, the effect that transpiration has on the soil. The small plot of soil in which the birch tree grows would remain moist for a much longer time if there were no tree. An acre of barren soil loses water far more slowly than the same acre planted to grass.

But plants do not all lose water at the same rate. The cactus in the desert may lose only 0.02 of a quart in a day, in spite of the desert heat which hastens evaporation. There are two reasons for this. There is little water in the soil and the cactus usually has a very small surface. Making practical use of this knowledge, farmers plant crops like broomcorn with a smaller leaf surface and extensive roots in dry areas. Crops which lose water rapidly can be planted in the moist soil of the Eastern and Central states.

In a drought water is lost faster than it diffuses into the plant; the plant wilts. A cell well-filled with liquid is said to be *turgid*. Turgid cells are swollen and firm. If all the cells are turgid the plant is firm or stiff. As water is lost, cells lose their turgidity and the plant wilts. If this loss continues for a long time, the plant dies. Too rapid transpiration is responsible for a great loss in crops. To test your understanding of this paragraph do EXERCISE 17.

Questions

1. Draw in simple outline a taproot system and a fibrous root system. Name several plants, the roots of which have large amounts of food.
2. Name several plants which have roots above ground.
3. What else makes up soil besides minerals? Name three substances found in soil. What is soil water?
4. Where are root hairs found? Describe their microscopic structure.
5. What is diffusion? Explain how soil water enters a root hair. Remember to explain the movements of water and minerals separately.
6. Why can diffusion into a root hair continue indefinitely?
7. Name the three cylinders that make up the root, beginning with the outermost. Where in the root is xylem found? Name two kinds of cells that make up xylem. Where do you find phloem, sieve tubes, and cambium? How do sieve tubes differ in structure from xylem tubes?
8. Draw and label a cross section of a stem, showing the cylinders usually found. What makes up the vascular cylinder? Explain how in many older stems the cortex is finally lost.
9. How do stems grow in length? How do stems branch?
10. Explain why one can count the rings of wood to determine the age of a tree. Why must one count the rings at the base of the trunk? In a table show the difference between the stems and leaves of the monocots and dicots.
11. Which substances pass through xylem tubes? Through sieve tubes? In which direction is the passage in each kind of tube?
12. When and where in plants is starch made soluble?
13. What is capillary action? In which plant tissues does it occur?
14. Define transpiration. Through which structures does water leave the plant? What is the connection between transpiration and the rise of water through the stem?
15. Give some facts and figures to show that transpiration is important to our lives.

Exercises

1. How do the roots of a young bean plant compare in extent with the parts of the plant above ground? Uproot a young bean plant raised in sawdust and wash the root system clean. Measure the lengths of the main stem and of the root. Now measure the spread of the longest branches and of the longest side roots. Compare the total length of the stems with that of the roots. Make a diagram to show the proportions.

2. To learn the difference in size of particles in various kinds of soil, place a trowel full of ordinary soil in a tall cylinder. Add water until the cylinder is full. Stir thoroughly. Let stand until the particles have

settled. Describe. Does anything float? If so, what is it? Use a hand lens to examine the smaller particles.

3. Does ordinary soil contain air? Pour water into a large battery jar until it is half full. Put a trowel full of soil at the bottom of the jar. Watch. Explain.

4. How does soil water differ from pure water? Soak soil in a flowerpot so that there is more water than the soil can hold. Let it stand for an hour. By pressing the soil, pour off the extra water into a funnel lined with a fine cloth. Collect the water that drips through. How does the water look? If it is not clear, filter it again through filter paper. Boil this water in an evaporating dish until the water is evaporated. Does anything remain?

5. To see root hairs, lay six mustard or radish seeds (peas or corn may be used but will grow much more slowly) on moist blotting paper in a saucer. Cover with a glass plate. Do not allow the blotting paper to dry. Examine the roots every day with a magnifying glass. Do not touch them. Why? Record your observations. Root hairs will also grow on the new roots of a Tradescantia cutting placed in a test tube of water.

6. You can learn something about root structure from a carrot. If possible use young carrots with fresh stems and leaves. After cutting off the tips of the roots place the carrots in a tumbler containing red ink in water. After standing in the bright light for several hours one of the carrots should be sectioned at various levels. Make a longitudinal section through a second. Draw, indicating by means of red crayon, the regions where water rises in the root. Compare with the diagram of the root in the text. How does it differ? On your drawing label vascular cylinder, cortex, epidermis, water tubes. In which region do the stored carbohydrates lie? How can you find out?

7. What is the structure of a young root? Gather some young fibrous roots about $\frac{1}{16}$ inch in diameter. Scrape these with the fingernail. How does this substance feel? What is left when you have removed this substance? What could you call the part that is left? Try to break it and to tear it. What do you notice? Explain.

8. In woody dicot stems the tissues are in cylinders. You can easily see the ends of these cylinders if you make a clean cut across the end of a twig with a sharp knife or razor blade. Note the soft pith at the very center. Which cylinder is outside the pith? Feel its inner and outer part. Describe. The cambium lies between the two parts. Why do you not see it? Outside the phloem in some twigs there is a ring of hard tissue, the fibers, and farther out lying just inside the brown cork is the cortex composed of soft tissue. If the twig is young enough you may be able to see the transparent epidermis.

9. How much does a stem grow in length in one year? Examine a twig which is not in leaf. Measure it from the large terminal bud to the first circular scar on the twig. This scar marks the point where the season's

growth began. It was made by the last year's terminal bud. Do this with several twigs of the same species. Are all the distances the same? What would you have to do before you could draw general conclusions from your measurements?

10. How does a stem grow in thickness? Copy Figure 187, a longitudinal section through the pith and wood of a five-year-old sapling. The bark is not shown. At the bottom of your copy put the numbers 1 to 5 using 1 to represent the wood present when the tree started its existence. *Five* represents the most recently formed wood. Draw a cross section at each of the levels a, b, c, and d. Where ought you to cut the section to determine the full age of a tree? What is the general shape of the trunk? Why?

11. (*a*) Why should you not twist a wire tightly around a young tree? (*b*) When you remove the bark from a twig why does the wood lying just underneath feel wet and slippery? (*c*) How can a botanist by studying a cross section of a very old tree know that the year 1750 in that particular region was a dry year and the year 1820 was a wet one?

12. How does a monocotyledonous stem differ from a dicotyledonous stem? Cross and longitudinal sections of young cornstalks make good material for the study of vascular bundles in a monocot stem. How many bundles are there in your cornstalk? Where are they? How do they feel? Describe the covering of the stem.

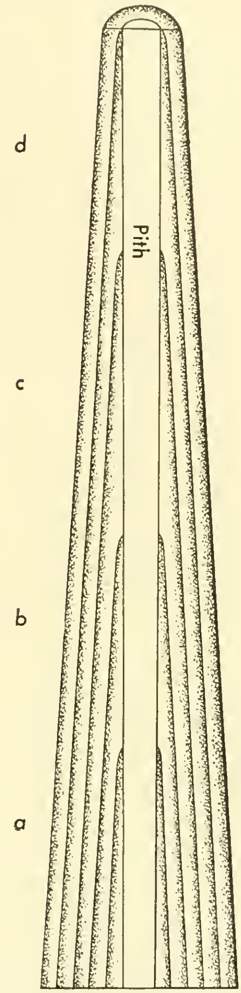


FIG. 187 *Diagram of a longitudinal section through a 5-year-old woody stem. (See* EXERCISE 10)

13. How does the narrowness of a tube affect the rise of water through it? Place hairlike glass tubes of varying thickness into colored water. What differences do you note? Make accurate measurements and record. With a magnifying glass examine the top of the column in the widest tube. What do you notice? Explain.

14. Does water leave a plant? Use a vigorously growing potted plant. Insert one of its branches into a large test tube (one inch diameter). Plug the open end with cotton and suspend the tube in a clamp on a ring stand. Water the plant and place in the light. What do you observe after half an hour and again after several hours? Are you ready to draw conclusions? What else should you do?

15. How much water is lost by an actively transpiring plant? Water a plant. Enclose the plant pot and the soil in a rubber sheet so that

water can be lost only through the leaves (and branches). Keep an accurate record of weights. Discuss your method with the class before proceeding. Can you calculate the amount of water lost per square inch of leaf surface per hour? Weigh the whole set-up at intervals of two or more hours.

16. Is transpiration more rapid through one side of the leaf than the other? Prepare a set-up like the one in Exercise 15. Use a plant with few and large leaves. Be sure to state which kind of plant was used. Prevent transpiration from one surface of the leaves by coating them with a thick layer of petroleum jelly. Measure the amount of transpiration by weighing. Now coat the other side. Explain your results.

17. To test your understanding answer the following questions. (*a*) Do you think the following statement is true? Why or why not? "Transpiration increases with a larger amount of moisture in the soil, and the amount of moisture in the soil in time increases with transpiration." (*b*) What else besides the amount of moisture in the soil determines the amount of transpiration? (*c*) After watering it thoroughly, what else might you do to help revive a wilted house plant?

Further Activities in Biology

1. How does the lack of minerals affect the plant? Plant pea seeds in moist clean sand. When the seedlings are three inches high, transplant them into the following solutions. (Only the roots should be under water.)

Solution 1. (all minerals present)

Water (distilled)	1 liter
Calcium nitrate	1 gram
Magnesium sulphate	0.25 gram
Potassium acid phosphate	0.25 gram
Potassium chloride	0.10 gram
Ferric chloride	2 drops

Solution 2. (no nitrogen) Use calcium sulphate instead of calcium nitrate.

Solution 3. (no potassium) Use sodium chloride instead of potassium chloride and monosodium acid phosphate instead of potassium acid phosphate.

Solution 4. (no magnesium) Use calcium sulphate instead of magnesium sulphate.

Solution 5. (no calcium) Use sodium nitrate instead of calcium nitrate.

Solution 6. (no iron) Omit the ferric chloride.

How is the rate of growth affected by the lack of the various minerals? Are all parts of the plant similarly affected? Make a chart showing your results.

2. Using wax or any plastic substance make a model of a small root.

3. Report on the economic importance of roots.

4. It would be interesting to see whether the amount of moisture affects the development of root hairs. Raise germinated oat or mustard seeds under different moisture conditions under glass.

5. You could show the class the result of sprinkling salt or too much fertilizer on the soil in a pot of growing seedlings. (Plant 20 or 30 lentils. Let them grow until they are two or three inches tall.) Could you set up an experiment with a thistle tube to explain what happens?

6. Are epidermal cells completely waterproof? Some leaves, such as apple and barberry, have no stomata on the upper surface. Find out whether any transpiration goes on. (Cobalt paper turns red when moist.)

7. Does light affect the rate of transpiration? Can you devise an experiment to find the answer?

8. If willow twigs are available you can make a whistle and find out at the same time where the cambium lies. Gently pound a short piece of stem all around. Thus you can separate the wood from the bark and remove it.

In UNIT IV you will consider these problems:

PROBLEM 1. How Can We Choose Foods Wisely?

PROBLEM 2. How Does the Digestive System Make Foods Usable?

PROBLEM 3. How Are Materials Moved to and from Our Body Cells?

PROBLEM 4. How Are All Our Cells Provided with a Constant Supply of Oxygen?

PROBLEM 5. How Does the Body Get Rid of Wastes Formed by Cell Activity?

PROBLEM 6. What Substances Help Regulate Cell Activities?

UNIT IV HOW A COMPLEX ANIMAL USES FOOD FOR ENERGY AND GROWTH

FIG. 188 *Your body consists of billions of living cells, each of which must have a constant supply of food. There seems little connection between the foods on these shelves, all made by plants or by animals that ate plants, and the cells in your brain, your arm, and your toe. Can you explain how your body cells are kept alive and active by food?* (RALPH CRANE FROM BLACK STAR)

PROBLEM 1 *How Can We Choose Foods Wisely?*

The food of living things. You learned earlier that all living things are made of protoplasm and that all need the same compounds, namely, proteins, fats, carbohydrates, mineral matter, and water. The vitamins that you will read about later are also needed. Carbohydrates are oxidized and release energy. Fats and more rarely proteins are used for oxidation too. Proteins, the only food compounds containing nitrogen, are always needed for building up new protoplasm by assimilation.

The source of man's foods. You have read, too, that green plants provide the necessary food for all animals; that the chlorophyll manufactures sugar (photosynthesis); that the sugar may be converted to starch, or to fats; and that the sugar may combine with minerals in the plant in making proteins. Animals get all their food from plants, either directly or indirectly. Either they eat plants or they eat animals which had eaten plants. Thus all animals, including man, are dependent on green plants for the compounds used in assimilation and oxidation and thus for the energy to live.

Two meanings of "food." We eat beefsteak, potatoes, vegetable soup, and hundreds of other substances. These are the things we think of as our "foods." Each food has a slightly different make-up and a different taste from every other food. Yet, in all our foods we get the same kinds of compounds over and over again. They are proteins, sugars, starches, fats, minerals, water, and vitamins. These compounds in their soluble form enter the cells where they keep the protoplasm alive. They are the real food of the plant and the animal. You see, therefore, the word "food" means one thing to the restaurant keeper, the butcher, and the housewife. It means something different in the laboratory and in the classroom. When we think in terms of billions of cells of the body, the word "food" means the essential compounds which make up the beefsteak, potatoes, and other things served to us at the table. In some books the word "nutrient" is used as a name for these compounds used by the cell.

Why is it helpful to make a study of common foods? Throughout the world people eat the foods they are accustomed to eat because of family habit, or they choose foods that are easy to get or that they like. Sometimes they eat certain foods as a fad or because they think the foods have some special value. This was particularly true before there was a scientific study of diet and it is still true of large numbers of people. Since most people appear to be healthy, the diets they follow must be satisfactory in the main. But a great many people are really not as healthy as they could be if they

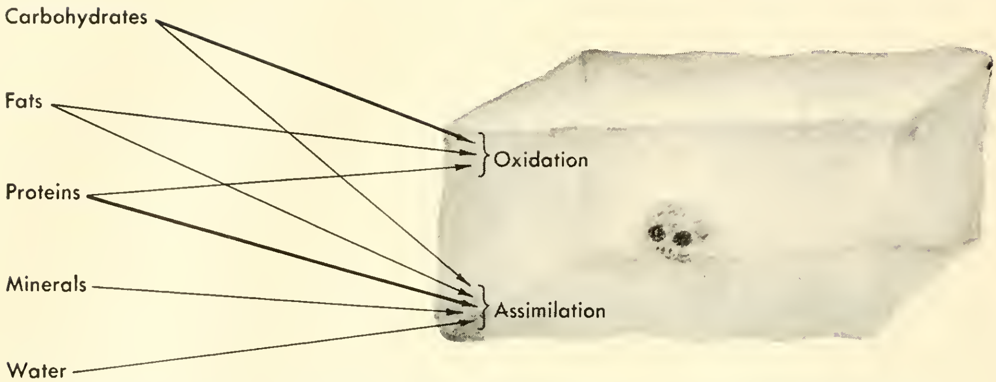


FIG. 189 *How food compounds are used by a living cell. In what two ways are food compounds used? Which compounds are used in each process? Why are two arrows drawn as darker lines?*

were to eat the proper food in proper amounts. Some are actually ill because their diet does not contain the proper foods. Others may succumb to infection because poor diets do not make them as resistant as they should be.

Since the beginning of this century scientists have analyzed all our common foods in the laboratory. They can tell us what compounds are in the food and the proportion of each. They can tell us how much energy there is in a given amount of each food. They can tell us how each substance is used in the body and how much of each is needed to keep the body in good health. All of us can now obtain this information. In this book and in many others there are tables showing the composition of some common foods. Use the table on page 172 to answer the questions in EXERCISE 1.

Measuring heat energy. To measure the energy in a food substance it is necessary to burn the substance. By oxidation (burning) the chemical energy in the substance is changed to heat energy. It is then possible to measure the amount of heat energy produced. The idea of measuring heat energy may be new to you. Do not confuse measuring temperature with measuring heat energy. Heat and temperature are not the same thing.

The difference between temperature and heat can be understood if you consider two cubes of iron, a small one that measures one inch each way and a larger cube that measures one foot each way. If both cubes are at room temperature and both are placed in the same hot oven, the small cube will reach a high temperature long before the large one does. By the time the small cube has reached a temperature of 100° centigrade (boiling temperature of water), the large cube will only be warm. It takes much more time and much more heat to raise the temperature of the large cube to 100° C. When both are at the same temperature the large cube, therefore, contains much more heat. You need not try to define the words heat and temperature as long as you understand this paragraph. Just remember that heat is a form of energy; it can be added to or taken away from bodies, and as that is done the temperature of the body changes.

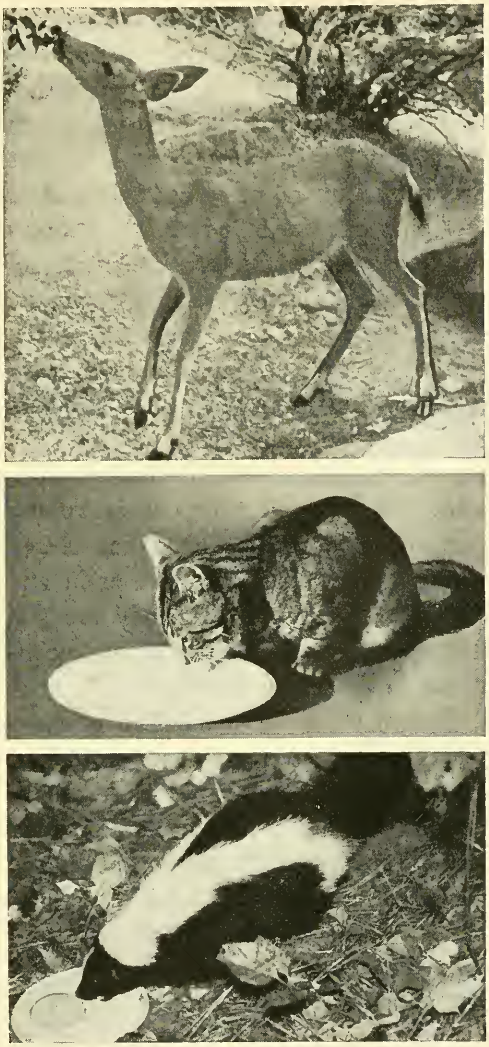


FIG. 190 *What was the original source of the egg eaten by the skunk, and the milk lapped up by the cat? What is the source of all the food eaten by animals?* (JOHNSON, SCHNEIDER AND SCHWARTZ, GEHR)

To measure anything there must be a unit of measurement. Scientists have agreed on a unit for heat energy. They call it a Calorie (kal′-o-ree). It is the amount of heat required to raise the temperature of one kilogram (a little more than one quart) of water one degree centigrade. Thus it becomes easy to measure the amount of heat by measuring with a thermometer the rise in temperature of pure water. When the temperature of a kilogram of water has risen 7° C, we say 7 Calories of heat energy had been added. If you can do EXERCISE 2, you understand something about the measurement of heat.

Measuring the energy in food. To find out how much heat is produced when a food compound is oxidized, some of the pure substance is weighed so that the experimenter knows exactly how much is going to be burned. The substance is then placed inside a chamber in which it can be oxidized. This chamber is surrounded by a jacket containing pure water which catches every bit of heat produced. The outside of the jacket is covered with asbestos or some other material that prevents escape of heat. The temperature of the water is taken before and after the oxidation. The amount of water in the jacket is known. And, since the experimenter knows how much the temperature of this water rises, it is easy to determine how many Calories were produced by the burning (oxidation) of that amount of food. In this way scientists have determined the amount of heat energy to be obtained from a known amount of protein, carbohydrate, and fat. The apparatus used is called a *calorimeter* (cal′o-rim′e-ter).

Besides burning known amounts of pure proteins, carbohydrates, and fats, scientists have also tested most of the common foods for their energy value. For example, a thick slice of white bread may be burned. If the thermometer shows that the temperature of 11 kilo-

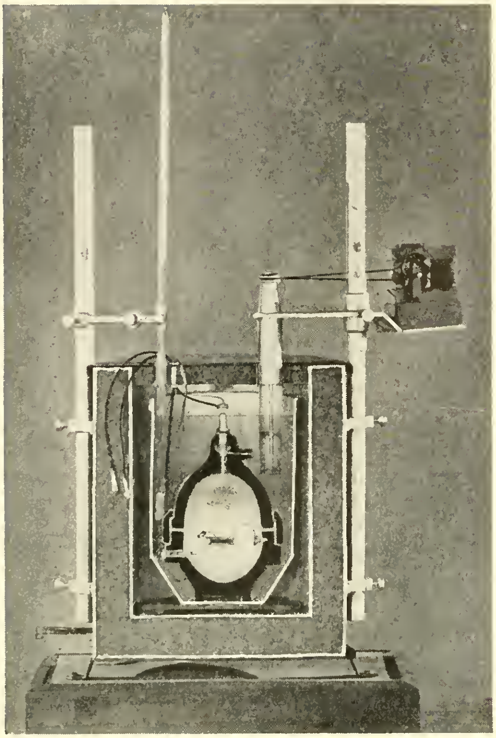


FIG. 191 *Cross section of a calorimeter. Where is the food burned? Of what use is the thermometer? The water is stirred by the electric motor. Why is the outside wall of the calorimeter so thick?* (AMERICAN MUSEUM OF NATURAL HISTORY)

grams of water has been raised 10° C by oxidation of the bread, then we know that this slice of bread contained 110 Calories of heat energy.

Measuring energy output in man. There is a device similar to the calorimeter described above but so large that a person can be placed in it and his heat output measured. This apparatus, however, is so costly that few have been built. Instead, the amount of heat produced by a person is measured indirectly by measuring the amount of carbon dioxide exhaled or the amount of oxygen inhaled. By making various calculations, including calculations as to the size and weight of the person, physicians can determine a person's heat production. These measurements are made when a person has not taken food for some hours and is lying down at complete rest. The heat production under these conditions is as low as it can be; it indicates a person's *basal metabolism. Metabolism* means all the chemical changes that go on in the body. By basal metabolism we mean the amount of metabolism when the body is at rest. But even when the body is at rest there are many active organs. The heart continues to beat, breathing is continued, the digestive organs are doing very little work but have not ceased activity completely, and the brain and some other parts of the body are still doing some work. Besides, oxidation continues in every living cell.

In men the basal metabolism is somewhat higher than in women. It is highest in young babies and grows less throughout life. Naturally as a person becomes more active or exercises, his metabolism increases far above the basal level. In a person living a normal life the actual daily production and use of energy is far above his basal metabolism. This daily production of energy depends upon a person's age, sex, size, weight, types of activity, and health.

Calories in your diet. After growth stops, the intake of Calories should equal the output of Calories. If the number of Calories supplied by the diet is larger than the need for energy, the food supplying these extra Calories is stored and you put on weight. If you get fewer Calories than you need, some of the food stored in your body tissues is oxidized and you lose weight.

FIG. 192 *A basal metabolism test. The apparatus measures the amount of oxygen used by the girl while at rest. How does the physician use such data?* (SANBORN COMPANY)

A man of average size needs:

16 waking hours	1200 C	(basal metabolism)
8 sleeping hours	500 C	

Add to this the Calories required per day according to occupation: Professional or business 600–1200; Mechanics 1200–1500; Athletes or laborers 1500–4000.

The average businessman will need about 1200 plus 500 plus 800 or 1000 (depending on his activity). This adds up to about 2500–2700 Calories per day. Children need more Calories in proportion to their size because they are growing and are usually more active than adults. A 16-year-old boy may need more Calories than a much larger man engaged in light work. You can roughly calculate the number of Calories *you* need per day by turning to EXERCISE 3.

Calculating the Calories in a meal. Some years ago the enthusiasm of dietitians (people who study diets) led some to urge the housewife to study food tables so that she might plan her meals scientifically. But it was soon discovered that this was a difficult task and not at all necessary for the ordinary person. Normally, a person gets the right amount of Calories by following his appetite, although some young people get too few Calories in their desire to keep their weight down. Some older people acquire the habit of overeating. It is well to remember that it takes only 4000 extra Calories to produce a pound of fat.

COMPOSITION

Food	*Measure*	*Calories*	*Protein* (%)	*Fat* (%)	*Carbo-hydrate* (%)
Cereals					
(1) Bread, white, enriched	1 slice, average	65	8	2	52
(2) Bread, whole wheat, 60%	1 slice, average	72	9	3	46
(3) Cornmeal, bolted yellow	$\frac{2}{3}$ cups, cooked	106	8	1	78
(4) Oats, rolled	$\frac{2}{3}$ cups, cooked	119	14	7	68
(5) Rice, white	$\frac{3}{4}$ cups, cooked	105	7	0.3	79
(6) Spaghetti, tomato sauce	1 serving	271	3	5	17
Dairy Products					
(7) Butter	1 pat, average	73	0.6	81	0.4
(8) Cheese, American Cheddar	1 ounce, average	112	24	32	2
(9) Ice cream, plain	$\frac{1}{6}$ quarts	210	4	12	21
(10) Milk, whole	6 ounces, med. glass	123	3	3	4
(11) Eggs, raw, whole	1 medium, average	79	13	12	0.8
(12) Margarine, fortified	1 tablespoon	95	0.6	81	0.4
Fruits and Nuts					
(13) Apple, fresh	1 large, 3″ diam.	97	0.3	0.4	15
(14) Banana, fresh	1 medium	99	1.0	0.2	23
(15) Grapefruit, fresh	$\frac{1}{2}$ small	44	0.5	0.2	10
(16) Grapes, American	1 bunch, 22–24 aver.	78	1.0	1.0	15
(17) Orange, whole	1 medium	76	0.9	0.2	11
(18) Prunes, dried	4–5 medium	149	2.0	0.6	71
(19) Peanuts, roasted	16–17 nuts	89	26.0	44.0	23
Meats and Fish					
(20) Bacon, medium, cooked	1 5-inch strip, crisp	31	14	27	2
(21) Beef, round, fried	1 slice, 3″ × 2″ × $\frac{1}{2}$″	233	23	16	
(22) Chicken, roasted	3 slices, $3\frac{1}{2}$″ × $2\frac{1}{2}$″ × $\frac{1}{4}$″	193	28	9	
(23) Lamb chop, shoulder	1 chop, 4″ × $3\frac{1}{2}$″ × $\frac{1}{2}$″	245	17	22	
(24) Liver, beef, fried	1 slice, $2\frac{3}{4}$″ × 2″ × $\frac{3}{16}$″	82	25	8	8
(25) Frankfurter, boiled	1, $5\frac{1}{2}$″ long, $\frac{3}{4}$″ diam.	121	15	14	3
(26) Codfish cake	1 cake, $2\frac{1}{2}$″ diameter	122	11	11	16
(27) Salmon, canned	$\frac{1}{2}$ cup, scant	102	21	10	
Vegetables					
(28) Beans, navy, pea bean, kidney, pinto	$\frac{1}{2}$ cup, cooked	105	22	2	62
(29) Beans, snap	$\frac{1}{2}$ cup, cooked	42	2	0.2	8
(30) Cabbage, fresh, head	$\frac{1}{2}$–$\frac{3}{4}$ cups, shredded	15	1	0.2	5
(31) Carrots, raw	1 large, $\frac{3}{4}$ cups, cubes	45	1	0.3	9
(32) Cauliflower, raw	4 rounded tablespoons	22	2	0.1	4
(33) Lettuce, head	1 large leaf	2	1		3
(34) Onions, mature, raw	1 large or 2–3 small	49	1	0.2	10
(35) Peas, fresh, raw	$\frac{3}{4}$ cups shelled	101	7	0.4	18
(36) Potatoes, white, cooked	1 medium in skin	129	2	0.1	19
(37) Potatoes, sweet, baked	1 large	213	2	0.7	28
(38) Spinach, fresh	$\frac{2}{3}$ cups, cooked	25	2	0.3	3
(39) Tomatoes, canned	$\frac{1}{2}$ cup	21	1	0.2	4

Figures are given in round numbers. The daily diet for growing boys and girls should include besides proteins, fats, and carbohydrates, the following sub-

* Adapted from *Food Values of Portions Commonly Used* by Bowes, A. de P. and Church, C. F.

OF FOODS *

	Ca (mg)	P (mg)	Fe (mg)	Vitamin A I.U.	Thiamin (mcg)	Riboflavin (mcg)	Niacin (mg)	Ascorbic Acid (mg)	Vitamin D I.U.
(1)	14	25	.5		60	37	0.6		
(2)	14	42	.6		84	49	0.9		
(3)	3	42	.3	90	45	18	0.3		
(4)	16	110	1.6		165	42	0.3		
(5)	3	28	.2		15	9	0.4		
(6)	23	80	1.0	1336	125	76	1.6	19	
(7)	2	2		330		1			4
(8)	247	173	0.2	493	11	142			
(9)	132	104	0.1	540	40	190	0.1		
(10)	212	167	0.1	288	72	306	0.2	2	4
(11)	27	105	1.4	570	60	170			45
(12)	trace	2		258–429					
(13)	9	15	.5	135	60	30	0.3	8	
(14)	8	28	.6	430	90	60	0.6	10	
(15)	17	18	.3		40	20	0.2	40	
(16)	17	21	.6	80	50	30	0.4	4	
(17)	50	35	.6	285	120	45	0.3	74	
(18)	27	43	1.9	945	50	80	0.8	1	
(19)	11	59	.3		45	24	2.4		
(20)	2	16	.1		60	10	0.3		
(21)	13	250	3.5		122	153	5.3		
(22)	22	305	2.7		92	214	10.2		
(23)	9	168	2.3		153	196	4.4		
(24)	6	187	6.1	9600	115	1190	6.8	?	23
(25)	5	98	1.4		111	135	1.2		
(26)	11	71	.8	130	44	49	0.7	?	5
(27)	98	173	.8	48	18	108	3.9		275
(28)	44	139	3.1		180	72	0.6		
(29)	65	44	1.1	630	80	100	0.6	19	
(30)	23	16	.3	40	35	30	0.1	26	
(31)	39	37	.8	12000	70	60	0.5	6	
(32)	15	50	.8	63	70	77	0.4	48	
(33)	2	3		54	6	7		1	
(34)	32	44	.5	50	30	20	0.1	9	
(35)	22	122	1.9	680	360	180	2.1	26	
(36)	17	84	1.1	30	168	55	1.6	17	
(37)	51	83	1.2	8287	143	89	1.1	28	
(38)		55	3.0	9420	120	240	0.7	59	
(39)	11	27	.6	1050	50	30	0.7	16	

stances represented in the above units: calcium, 1300; iron, 15; Vitamin A, 5000; thiamin, 1400; riboflavin, 2000; niacin, 14; ascorbic acid, 85.

Every person, however, should have a good general idea of the composition of common foods and of the comparative number of Calories supplied by each. In planning meals for babies and for people who are not well or who are not normal in weight, constant use of the tables is desirable. By doing EXERCISES 4, 5, and 6 you will learn something about planning meals.

What you should know about proteins. It is generally agreed that a little over 50 per cent of the total Calories should come from carbohydrates, about 30 per cent from fat, and not less than 12 per cent from protein. For the average person there should be about 80 grams (3 oz) of protein daily. Much of the protein is used in assimilation. Therefore, during active growth, children often need comparatively large amounts of protein.

There is something else you must keep in mind about proteins besides the amount. There are many kinds of proteins, those in animal foods being more like your body proteins than are the proteins in plants. You have read that when plants synthesize proteins they first make simpler nitrogen compounds called amino acids. Some twenty-odd amino acids are known to chemists and the combinations of amino acids in plant foods differ somewhat from those in animal foods. In fact, certain amino acids are completely lacking in most plant foods. This means that most plant proteins do not make adequate substitutes for animal proteins. Wheat contains, among several proteins, only one that is as useful as animal proteins. Legumes (the various beans and peas) contain much protein, and the proteins are very good; this is particularly true of soybeans. But with these exceptions plant foods are not as good sources of proteins as are meat, fish, eggs, milk, and milk products, which are the more expensive foods.

What you should know about carbohydrates and fats. You already know that for the most part you depend on carbohydrates and fats for your energy. Fats provide more than twice as much energy pound for pound as sugar and starch. However, although fats contain more energy per pound than any other food, it is not wise to eat large amounts of fat. The body does not deal with them as successfully as with other foods. Proteins, if they are oxidized, give the same amount of energy as carbohydrates. But to get enough energy from lean meat you would need many pounds daily; and meat is always expensive. All in all, therefore, carbohydrates are our best energy producing foods. When energy is needed immediately, there is no food as satisfactory as sugar. Lumps of sugar and bars of chocolate are often given to football players before beginning a game. And you know that, during a war, large amounts of chocolate and other sweets go to the armed forces. Alcohol provides much energy for a short time, but it may also reduce efficiency.

When carbohydrates and fats are not oxidized they are usually converted into body fat which accumulates under the skin, in the muscles, and next to internal tissues (see Fig. 157). Some fat tissue is necessary to keep us warm, and when a person is unable to eat because of illness or lack of food the fat stored in these tissues is changed back into substances which can be oxidized, providing energy.

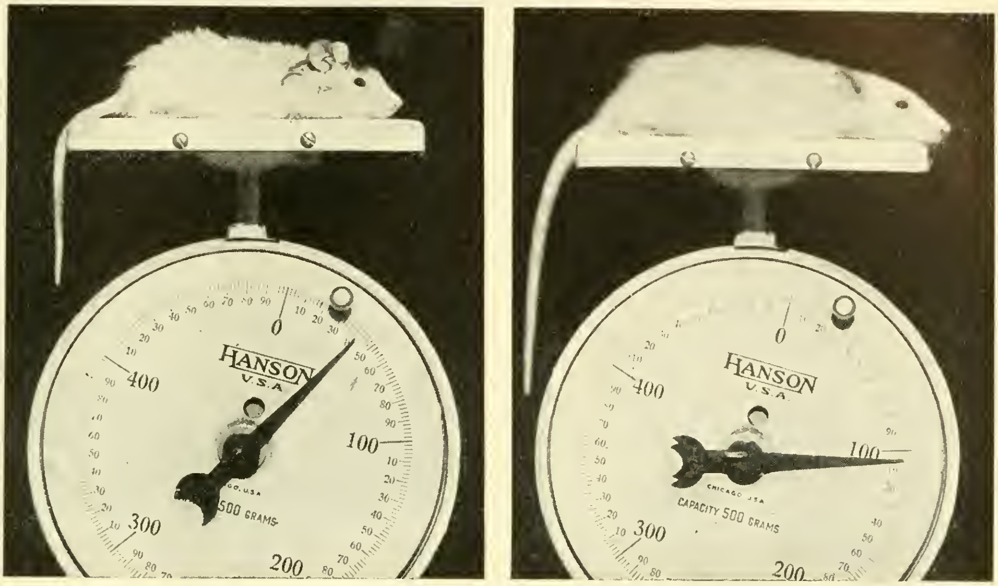


FIG. 193 *Experiments teach much about diet. If the rats are of the same age and sex, what might have caused the differences in weight and appearance?* (GENERAL BAKING CO.)

But to keep on storing fat is useless. And carrying this stored fat about with you at all times is not only useless; it becomes tiring. Older people should be careful not to permit too much fatty tissue to form. It is important to note that when young people are overweight the cause may not be overeating of fat or carbohydrates. This is discussed in a later unit. You can now plan a day's meals which would provide the correct amounts and kinds of carbohydrates, fats, and proteins.

Minerals and water in your diet. Minerals are of many kinds and have many uses in the body. Certain minerals are necessary for assimilation. Some, like calcium and phosphorus compounds, are needed for making bones and teeth. Iron compounds are needed for making red blood cells. Sodium, potassium, and calcium affect the heartbeat. Magnesium, calcium, and chlorides help indirectly in digestion.

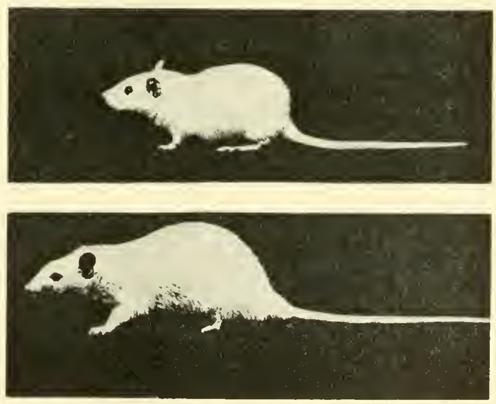


FIG. 194 *These rats of the same sex were born in the same litter. At 22 weeks of age one weighed 2½ times as much as the other. Their diet differed in only one respect. The large rat received more calcium. What conclusions can you draw?* (U. S. DEPARTMENT OF AGRICULTURE)

In any ordinary diet you get enough sodium, potassium, magnesium, and phosphorus. But it is wise to make sure of obtaining sufficient calcium, iron, and iodine. The table on page 172 shows in which foods you may obtain calcium and iron. Iodine, which is needed to prevent goiter, is best obtained from fish and other sea food. To review this information do EXERCISE 7.

Water is still another substance needed by the body. To begin with, it helps in assimilation. Then, too, it helps in dissolving substances so that they can move around by the process of diffusion. You should drink a considerable amount of water each day.

What else is needed in the diet? Foods contain proteins, carbohydrates, fats, minerals, and water; but they contain other useful substances too. They have minute amounts of many different compounds which add flavor. These add to your enjoyment of food. And foods that come from plants have more or less cellulose and woody substances making up the walls of each cell. Potato skins are made up largely of such materials. While you obtain little nourishment from them they are of considerable importance in your diet. These substances are called *roughage*. A certain amount of roughage is valuable for making the intestines push the food along. You will understand this better when you have studied digestion.

But besides the flavoring and roughage, foods contain still other compounds which are not used directly in making protoplasm or in oxidation. Yet, they are necessary to you. These substances are the *vitamins* (vye′te-mins). They were discovered in the course of experiments on diseases which had puzzled people for centuries. There were mysterious outbreaks of disease which seemed to have something to do with diet. Only within the last fifty years have these mysteries been definitely cleared up.

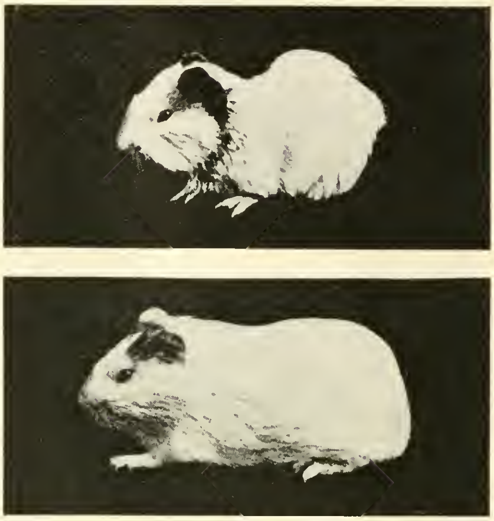


FIG. 195 *The smaller guinea pig has scurvy. What must have been lacking in its diet?* (U. S. DEPARTMENT OF AGRICULTURE)

Mysterious diseases caused by faulty diet. In the dark ages men told of a serious disease which sooner or later attacked sailors on long voyages. Their muscles ached, they became weaker and weaker, and blood flowed from their noses. Often they died. The disease was called *scurvy*. No one knew whether they were poisoned by their food, which consisted principally of salted meat and dry crackers, or grew sick from long exposure to the sea air. It was noted in England in the eighteenth century that if sailors drank the juice of lemons or limes, they did not suffer from scurvy. The reason was not understood. But to prevent further outbreaks of the disease a law was passed in England more than a century ago requiring that a supply of lemons or limes be taken on long voyages. This is why English sailors are called limeys.

Somewhat later the Japanese had similar disastrous experiences with another disease, outbreaks of which occurred i.

FIG. 196 *This chicken has polyneuritis, a disease like beriberi in man. How can it be cured?* (ILLINOIS AGRICULTURAL EXPERIMENT STATION)

their navy in the nineteenth century. This disease was not new either; it had long been known in China, Japan, and other eastern countries; it is called beriberi (ber′ree-ber′ree). It, too, results in exhaustion and eventually in death. There is no bleeding as in scurvy; there is numbness and paralysis.

The diet of these sailors was largely polished rice, the kind you ordinarily eat. Thinking that the disease might be caused by a faulty diet, the officials of the Japanese navy, about 1880, ordered that other foods be provided the men in addition to polished rice. Very soon thereafter beriberi outbreaks became less frequent. Just what was wrong with the original diet no one knew. The government officials were content, since they had hit on a better diet; but scientists were not satisfied; their curiosity had been aroused.

Experiments to clear up the mystery of beriberi. Some years after the new diet had been ordered and its good results had been proved, a Dutch scientist by the name of Eijkman (ike′-man) became interested in beriberi. He was stationed in one of the Dutch colonies in the East Indies where he daily saw hundreds suffering from beriberi in the hospital. He had noticed that chickens living on a diet of polished rice showed the same effects as the patients. He used chickens, therefore, in a carefully controlled experiment. First, he fed many of the birds a diet consisting only of polished rice. They developed a disease very much like beriberi. Then he divided his birds into two groups; with half he continued the diet of polished rice; to the other half he gave not only the polished rice but also the "polishings" or coatings of the rice which are removed when the rice goes through the mill.

Shortly after they had received the rice coatings this group of chickens recovered from the disease. The other group died. Eijkman concluded that there was something in the skin covering the grain that prevented the disease. When he ordered his patients to eat the coatings of the rice, they too, recovered from beriberi.

Other biologists studied the chemical make-up of the rice polishings in an attempt to find out what substance in them prevented beriberi. In 1911 Casimir Funk, a Polish biologist, extracted the substance and called it a "vitamine." Later this word was changed to vitamin and the substance was called vitamin B.

What other experiments showed that vitamins existed? About this time scientists made another discovery in nutrition experiments on rats. They gave the rats measured amounts of pure carbohydrates, proteins, fats, minerals, and water. By using the prepared substances instead of ordinary foods they were able to control the amounts more accurately. To their astonishment the rats developed an eye disease, sickened, and died.

The experiment was repeated but this time as soon as the rats became sick some of them were given small amounts of raw milk each day in addition to their regular diet. These rats regained their health and remained normal. It was plain that rats needed something more than proteins, fats, carbohydrates, minerals, and water. Although the experimenters did not know what that substance was, the experiment indicated that it was contained in raw milk. Also, it was apparent that the substance was needed in small amounts only. It was concluded that this substance was a vitamin and it was given the name of vitamin A.

In the meantime others had discovered by experiment that the citrus fruits like oranges and limes contain a vitamin which prevents scurvy. This vitamin was called vitamin C.

Beriberi, scurvy, and the eye disease caused by lack of vitamin A are called *deficiency diseases.*

The importance of vitamins. These experiments definitely established the presence of tiny amounts of important substances in our foods besides the well-known food substances. There followed a vast amount of experimentation which still continues. Important discoveries followed one another in close succession. We now know of about a dozen vitamins necessary to our good health and our general well being. By the time you read this others may have been added to the list. All of us must know the following about each vitamin: the foods in which it occurs; how we are affected by insufficient amounts of it; and to what extent cooking or the aging of the food destroys it. By applying this information we may hope to keep ourselves much more fit. Most of us are not likely to become afflicted with beriberi, scurvy, or the eye disease described above because most of us eat a variety of foods. In any normal, fairly varied diet at least small amounts of the necessary vitamins are almost sure to appear. Our problem is to get the full amount of each vitamin needed to keep us in the best of health.

Vitamin A. Vitamin A is one of the vitamins that can now be made in the laboratory. It is composed of the same three elements as carbohydrates (C,H,O). In animals vitamin A is made in the liver. But it can be made only if *carotene* (care′o-teen) is present. Carotene is a yellow substance found not only in carrots and other yellow vegetables and fruits, but also in the green parts of all plants. Vitamin A or the unchanged carotene can accumulate in the liver, in the fatty part of milk, in egg yolk, in kidneys, and in the pancreas. All of these foods are, therefore, good sources of vitamin A. And since your liver can make vitamin A out of carotene, you can also be sure of getting your supply of the vitamin by eating yellow and green plant foods. In spite of the many foods that supply vitamin A, many people suffer from a slight deficiency of it.

You read above that in rats, a deficiency of vitamin A resulted in a serious eye disease. In man, too, a serious vitamin

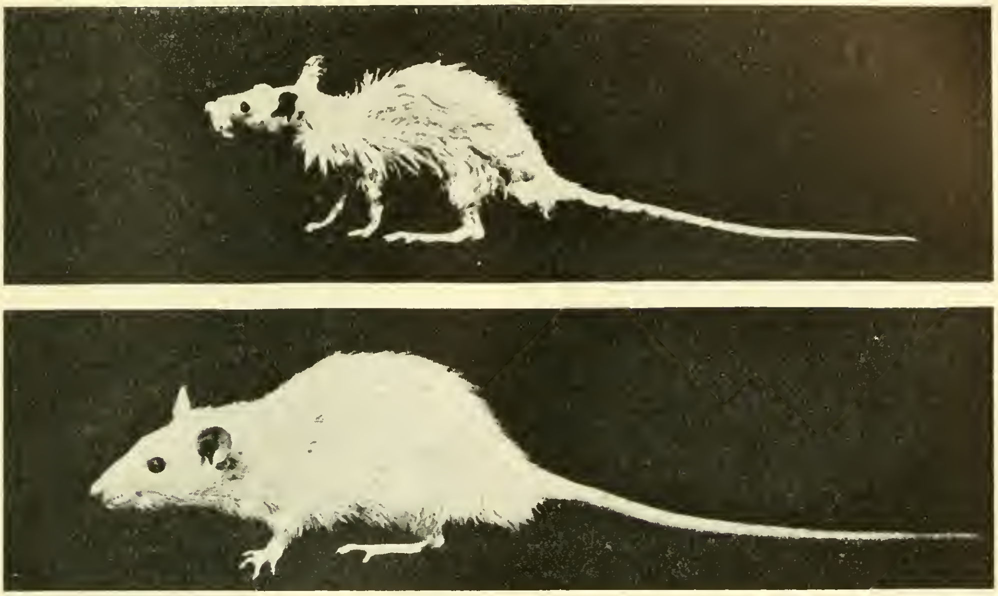


FIG. 197 *This rat was fed a diet lacking vitamin B_2. During six weeks of a diet rich in vitamin B_2, its weight increased from 63 grams to 169 grams. Why should several rats be used in such an experiment? Explain.* (U. S. DEPARTMENT OF AGRICULTURE)

deficiency causes drying up of the tear glands and damage to the eyes. And insufficient amounts of vitamin A in the body result in the inability of the eyes to produce a substance called *visual purple;* this is needed for vision in dim light. Furthermore vitamin A keeps the mucous membranes of the body normal and healthy.

The vitamin B complex. What was formerly called vitamin B is really a group of vitamins. The one in the group associated with beriberi is now called vitamin B_1 or *thiamin.* People getting an insufficient amount of thiamin are easily fatigued and have a poor appetite; this may be followed by loss of weight, irritability, and mental depression. A deficiency of thiamin in the diet is common. The best concentrated sources of thiamin are liver, wheat germ, and yeast. It occurs quite abundantly in wheat, rice, barley, peanuts, dried beans, peas, and soybeans. Unfortunately, the grains are often refined before they are used. In the refining process the vitamins, which are in the covering of the seed and in the germ, are removed.

Niacin (formerly called nicotinic acid) is another vitamin of this group. Deficiency of niacin causes the disease known as *pellagra.* In the United States alone about 100,000 people suffer from this disease. There have often been outbreaks of pellagra in institutions where too strict economy was practised and no fresh vegetables, milk, or fruits were included in the diet. A less marked deficiency causes loss of appetite and a general breakdown of morale. As in the case of thiamin its best source is liver and yeast. Other good sources are kidneys, sweetbreads, milk, and cheese, as well as the unrefined grains which contain thiamin.

FIG. 198 *The x-ray to the left was taken on Feb. 3. This child had a bad case of rickets as shown by the fuzzy edge of the two bones in the arm. Treatment was begun. The second x-ray was taken June 25. What difference can you see in the ends of the arm bones? What treatment was probably given the child?* (GENERAL BAKING CO.)

There are other vitamins in the vitamin B complex: riboflavin, pyridoxin, pantothenic acid, and others. All of them dissolve readily in water and are often lost in boiling. Thiamin may be added to foods such as flour and bread. Adding vitamins to food is called "enriching" it.

Vitamin C. This vitamin, associated with scurvy, is now generally known as *ascorbic acid.* It is not only sailors on long voyages who have suffered from scurvy. Throughout the ages there have been outbreaks of scurvy wherever and whenever there have been wars, famines, or minor shortages of fresh growing foods. At all times mild deficiencies of ascorbic acid are very common. It seems to be needed for the forming of connective tissues in the walls of the blood vessels.

The best sources of ascorbic acid are grapefruit, oranges, and the other citrus fruits. Parsley, tomatoes both canned and raw, peppers, and raw cabbage are particularly rich in it. Dried seeds like peas and beans have no vitamin C, but if they are allowed to sprout they form it and become a good source. It is completely lacking in eggs and meat, though very small amounts are found in liver and milk. Spinach and broccoli contain large amounts but much of the vitamin C is lost in cooking.

Ascorbic acid (vitamin C) is the most easily lost of all the vitamins. It dissolves readily in water and is therefore lost if the water in which vegetables are cooked is thrown away. In the presence of acids, however, heat and oxygen of the air have less effect on the vitamin. For this reason tomatoes, which contain much acid, keep their ascorbic acid after being exposed to the high temperatures of canning. In commercial canning, and most canning in the home, oxygen is excluded

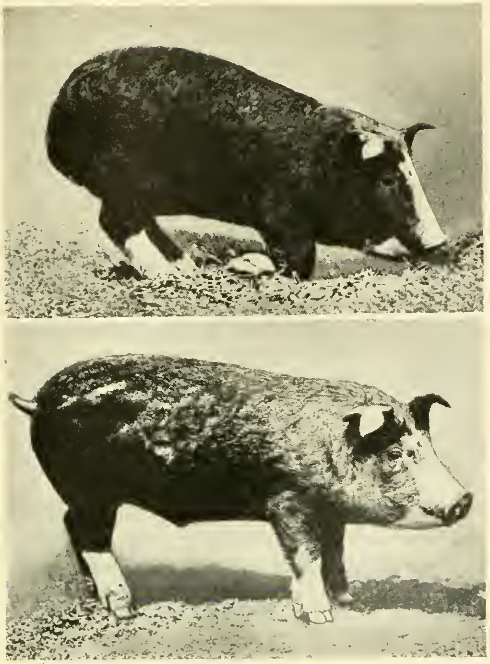


FIG. 199 *Above is a pig suffering from rickets. Below is the same pig after small daily doses of cod liver oil. What did the oil supply?* (WISCONSIN AGRICULTURAL EXPERIMENT STATION)

while heat is applied. This, too, saves some of the ascorbic acid. Adding soda to boiling vegetables helps to destroy the vitamin.

Vitamin D. The lack of vitamin D in babies and young children causes rickets, a condition in which the bones and teeth remain soft and there are malformations in the skeleton. Minerals containing calcium and phosphorus are needed for strength and rigidity in bones and teeth. But these minerals cannot be used in the body if vitamin D is lacking. Ordinary milk contains both calcium and phosphorus but has very little vitamin D. In fact, no natural food, even of the many foods eaten by adults, contains very much vitamin D.

But we have learned two important facts in recent years about vitamin D. In the first place, fish oils such as halibut-liver oil and cod-liver oil are excellent sources of this vitamin. They are often given particularly to babies to supply the much needed vitamin D. In the second place, many plant foods contain a substance (*ergosterol*) which turns into vitamin D in the presence of the ultraviolet rays of the sun. Many animal tissues contain a similar substance (*cholesterol*).

Both plant and animal foods can be exposed to ultraviolet light for the production of vitamin D. Such exposure to ultraviolet light is called *irradiation* (ir-ray-dee-a'shun). Milk is often so treated in fresh or evaporated form. Bread is sometimes irradiated and so are some of the cereals. But not all irradiation is successful. Sometimes fish-liver oils or yeast are irradiated and fed to cows which then produce milk richer in vitamin D.

We, being animals, contain this same substance (cholesterol) which can be turned into vitamin D. In the bright sunshine, which contains ultraviolet light, we are constantly making this vitamin. That is why vitamin D is called the "sunshine vitamin," although, of course, sunshine contains no vitamin. Many people, however, do not get enough sunshine. The ultraviolet rays do not pass through ordinary window glass. And those of us who live in cities, particularly smoky cities, and in climates with a long winter season, lack the sunshine we need for making vitamin D.

Vitamin D seems to be a vitamin of which you can get too much. Vitamin A, if taken in excess of one's needs, accumulates and can be used at a later time;

and most of the other vitamins if taken in larger quantities than needed merely pass through the body. Vitamin D has been made in the laboratory.

To see whether you are getting your needed supply of vitamins, list all the foods you ate yesterday. Using the food table state: (*a*) of which vitamins you got a large amount; (*b*) of which you got only small amounts; (*c*) which vitamins were probably lacking.

Other vitamins. Vitamin E complex has been shown by experiment to be needed by rats for reproduction, and probably by most other animals, too. We know that eggs produced by hens lacking E complex do not hatch. What effect it has on human beings we are not yet sure. But it would seem wise to include it in the diet. It is found in lettuce, carrots, tomatoes, egg yolks, peanut and other oils, and in all whole-grain cereals.

Vitamin K is necessary for the proper clotting of blood as you will learn later. Its richest source is the green leaves of our common vegetables. EXERCISE 8 is a very important exercise for you to do.

Loss of vitamins. The care and cooking of food is as important to you as the choice of food if you want to have your full supply of vitamins. In general, exposure to oxygen seems to destroy vitamins, and the higher the temperature the more rapid is the destruction. Therefore, keeping vegetables without refrigeration means a steady and rapid loss. Vegetables should, if possible, not be peeled or cut up before cooking; the smaller the pieces the more surface is exposed to oxygen. Furthermore it is desirable to cook in closed utensils because in this way air is excluded. And since water contains air

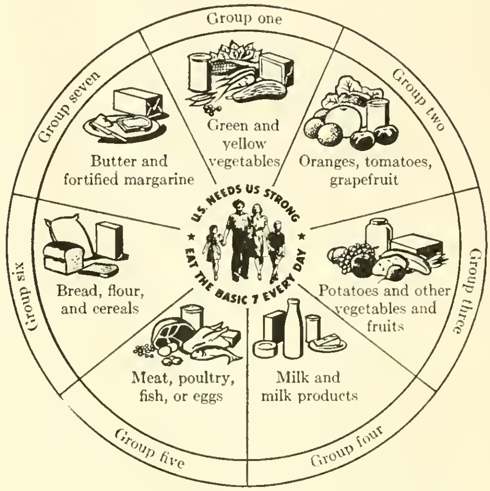


FIG. 200 *The Basic Seven. Everyone should eat a generous serving from each group every day. Can you explain, in the case of each group, why these foods are included among the Basic Seven?*

(oxygen) until boiling drives it out, it is best to start your vegetables in boiling water.

Extreme heat, especially in the presence of oxygen, destroys some vitamins, particularly vitamin C and vitamin A. For this reason cooking should not be continued longer than necessary and should be done rapidly. This is possible in a pressure cooker.

Most vitamins, with the exception of vitamins A and D, are soluble in water. We should, therefore, cook in small amounts of water and whatever water is left should be kept and used, since vitamins (and minerals) are dissolved in it. Do EXERCISE 9.

Vitamin pills. It is true that by paying for capsules one can get the known vitamins. However, there may be many undiscovered vitamins in our foods which are necessary to us. For this reason, as well as for the sake of economy, it is better to depend on natural foods than on the drug store for one's vitamins. A natural, widely varied diet should contain all the vitamins that any of us will need under normal conditions, except possibly vitamin D. We must, however, remember that the freshness and the method of preparing foods are just as important factors as the kinds of foods selected. Before finishing this problem do EXERCISES 10 and 11.

REVIEW TABLE OF VITAMINS

	VITAMIN	Foods Rich in Vitamins	How Stable	Results of Deficiency in Vitamins
Thiamin or B_1 *In B complex*	Made by yeasts and other fungi; can be extracted from rice polishings; water soluble; has been made in laboratory; little storage	Whole grains, seed germs, tomatoes, spinach; not much in most vegetables; liver and yeast	Dissolves easily and in cooking goes into water; can withstand heat of cooking if no alkali is present	Loss of appetite, nervousness; beriberi
Niacin (Nicotinic acid) *In B complex*	Made by green plants and yeast; has been made in laboratory; water soluble; stored in liver and muscle	Liver, meat, fish, milk, eggs, green vegetables, yeast, and tomatoes	Resistant to heat and exposure to air; in cooking goes into water	Pellagra
Riboflavin (originally G) *In B complex*	Can be extracted from milk, eggs, yeast, etc.; stored in liver	Same as niacin	Rather stable; in cooking goes into water	Digestive disturbances, nervousness, and weakness
C Ascorbic acid	Not made in our body; has been made in laboratory; water soluble; no storage	Citrus fruits, tomato, germinating seeds, and leafy vegetables	Easily destroyed by heat, especially when alkali present; rapidly destroyed in air; dissolves in water	Retarded growth, irritability, lack of energy, and scurvy
A	Body makes it from carotene; fat soluble; not water soluble; stored in liver	Milk, milk products, eggs, liver, yellow vegetables, and green leafy vegetables	Resistant to much heat; destroyed slowly in air	Night blindness; sometimes special eye infection
D	Made in skin under ultraviolet light from ergosterol; fat soluble; not water soluble; stored in liver, kidneys, and other body parts	Fish liver oils; very little in egg yolk; milk, butter, and meat	Can withstand high temperatures	Poor teeth and rickets
E	Can be extracted from wheat germ; has been made in laboratory; fat soluble; stored	Germ of grains; green vegetables, and eggs	Can withstand high temperatures and drying	Reproduction in rats fails
K	Made by bacteria in intestine; fat soluble	In considerable amounts in most foods	Rather stable	Blood does not clot, but it is not lack of vitamin which starts this condition

Questions

1. What are the two uses of food in all living things?
2. What is the original source of all foods eaten by man? Explain.
3. In what two different ways can the word "food" be used?
4. Discuss how people get along without a knowledge of foods.
5. What energy change occurs in the oxidation of food? What is the unit of measure for temperature? What is the unit of measure for heat? How much heat does a Calorie represent?
6. What facts are obtained by the use of a calorimeter?
7. How do physicians determine your minimum energy output? What is meant by metabolism? By basal metabolism? How does the basal metabolism of men and women, old people and young people, differ?
8. An average-sized man doing sedentary work needs 2500–2700 Calories per day. Explain how this figure is obtained. Compare the energy needs of people of your age with the energy needs of adults. When should Calorie tables be consulted?
9. Why should we not depend on fat, the most efficient fuel food, for our chief source of energy? Which food compound is used largely for energy release in the body?
10. Why are the proteins of animal foods better for us than plant proteins? Which plant proteins are good substitutes?
11. What does the body do with carbohydrates and fats not used in oxidation?
12. Of what special use to the body are calcium, phosphorus, iron and iodine? Of which minerals are we likely to have a shortage in our diet? For what purposes is water used in the diet?
13. Give examples of roughage. Of what advantage may it be to you?
14. What has long been known about the disease called scurvy? About beriberi?
15. Explain the object, the method, the observations, and the conclusions of Eijkman's famous experiments. Who named the substance extracted from rice polishings? What was it called?
16. How was vitamin A discovered? What serious disease is caused by lack of vitamin A?
17. What is meant by deficiency diseases? What facts must we all know about the various vitamins?
18. In what part of the body is vitamin A made? From what is it made in the body? What are the best food sources of vitamin A? How does the lack of vitamin A affect us?
19. What do we now call the vitamin that prevents beriberi? What are the early symptoms of an insufficient amount of this vitamin? Name the four best sources of thiamin or B_1. Name *seeds* of plants which serve as food for man. Why are seeds good food for us? Which disease is caused by a deficiency of niacin? Which foods are good sources of niacin?

20. What do we now call vitamin C? From which foods do we generally get most of our vitamin C? Which other foods are rich in vitamin C? Name four ways in which much of the vitamin C is often destroyed in the preparation of vegetables.
21. Explain fully what is needed for proper bone development. If sunshine contains no vitamin why is vitamin D called the sunshine vitamin? Name three foods which are frequently irradiated and state the effect on these foods.
22. What do we know about vitamins E and K?
23. List all precautions to be taken to save vitamins in keeping and preparing foods.
24. Why should we not depend on vitamin pills for our supply of vitamins?

Exercises

1. In what proportions are proteins, carbohydrates, and minerals found in common foods? Using the table in the text answer the following questions: Do animal or plant foods contain larger percentages of protein? Do animal or plant foods contain larger percentages of carbohydrates? What foods contain large amounts of such important minerals as iron and calcium? In general, what are the differences in composition between leafy vegetables and root vegetables? *Caution*: The table is not complete. How does this affect your answers?

2. (*a*) A piece of hot iron when plunged into half a kilogram of water raised the temperature of the water 6° C. How many Calories of heat were added to the water? (*b*) How many Calories of heat would have to be taken from a kilogram of water to lower its temperature from 75° C to 69° C?

3. The average Calories required per hour for each pound of a person's weight are about as follows:

In sleeping or lying awake	$\frac{1}{2}$ Calories
Sitting	$\frac{2}{3}$ Calories
Typewriting	$\frac{9}{10}$ Calories
Standing	$\frac{3}{4}$ Calories
Walking at a moderate rate	$1\frac{1}{2}$ Calories
Active exercise	$1\frac{3}{4}$ Calories

If you weigh 120 pounds and sleep 9 hours, you would require for those 9 hours $120 \times \frac{1}{2} \times 9$ Calories. Decide about how many hours of the day you spend in each kind of activity and, considering your weight, calculate about how many Calories you need in 24 hours.

4. Select five foods one normal portion of which supplies more than 100 Calories. Arrange them in order according to the number of Calories supplied, beginning with the highest.

5. Suppose that in the three meals in one day you ate 9 pieces of 60 per cent whole wheat bread, 5 average pats of butter, 2 sweet potatoes, 4 strips of bacon, a portion of rice and 2 bananas. How many Calories would this supply? Explain why you would not recommend this diet.

6. (*a*) Name five foods which your physician might tell you to cut out of your diet if you had to reduce your weight. (*Caution:* No one should attempt to change his weight except under a physician's guidance.) (*b*) Consult your family and friends for other "rules" for losing weight. By reasoning and consulting your tables see whether you can find any scientific basis for their statements.

7. By consulting your text, including the food table, make a table in your notebook as follows: In the first column list vertically calcium, iron, phosphorus, iodine, sodium, potassium, and magnesium; in the second column next to each mineral state how it is used; in a third column state which foods contain the mineral in large amounts.

8. Using the chart, page 172, or a more complete food table, list in a vertical column the foods available to you that provide the largest amounts of each of these vitamins: thiamin, niacin, ascorbic acid, vitamin A, and vitamin D. You should then learn this list by heart.

9. Answer the following: (*a*) When a baby's diet consists only of pasteurized milk, what food should be added to the diet? Why? (*b*) Explain why factory canned vegetables are presumed to be better for you than those cooked by an inexperienced cook.

10. There are fads in diet as in everything else. By talking to your friends, see how many of these you can learn about. Discuss each one in class, in order to discover, if you can, whether there is any scientific basis for it. In some cases it will be possible for you to test the truth of a statement by experiment.

11. Study the advertisements of foods in cars, magazines, etc. Copy them exactly and bring your copy to class for discussion. To what extent are these advertisements scientific? To what extent can you trust them? What information should you get about these advertised foods?

Further Activities in Biology

1. As you know, the diets of various peoples differ. Make a critical report on the diets of several national or religious groups, like the Eskimos, Arabs, Jews, Germans, Yankees, etc.

2. If your school has no charts showing the percentage composition of common foods, a group might make some. Draw the outline of common foods such as a rib roast, a fish, glass of milk, carrot, etc. By consulting the table show the proportion of protein, fat, carbohydrate, mineral, and water (including waste) in each food. Use different colors to indicate each food substance.

3. A few of you working together can determine the effect of the lack of vitamins upon certain animals. Report the results of your work to

your class or club. If you have a school science paper, have your results published. There are a few points that all of these experiments have in common that you ought to know. You must choose animals that are in a good state of health. Wherever possible, the animals should be from the same litter and of the same sex. The animals are then divided into two equal groups. One group receives the diet lacking a particular vitamin while the other group gets the same diet plus the vitamin. You must remember that the conditions under which you keep the animals are as much a part of the experiment as the diet which you feed them. Therefore, keep them under normal conditions of temperature and in clean cages. Always keep an accurate daily record. Do not cause animals pain or permit them to suffer. These experiments and others can be performed without harm to the experimental animals if you change the diet as soon as evidence of the effect of poor diet is obtained.

4. What is the effect of the lack of vitamin A upon rats?* Choose rats about three weeks old. Feed one group a diet consisting of the following:

Casein (pure protein)	20%
Lard (fat)	15%
Starch (carbohydrate)	56%
Yeast (for vitamin B)	5%
Salt mixture (for minerals)	4%

The salt mixture should be mixed with the other food. Your teacher will help you to get the chemicals you need to make the salt mixture.

Sodium chloride ($NaCl$)	5.19 gm
Magnesium sulphate ($MgSO_4 \cdot 7H_2O$)	16.00 gm
Sodium dihydrogen phosphate ($NaH_2PO_4 \cdot H_2O$)	10.41 gm
Potassium hydrogen phosphate (K_2HPO_4)	28.62 gm
Calcium lactate	39.00 gm
Ferric lactate	3.54 gm

The other group is fed butter instead of lard. When you have achieved your results, return both groups to a normal diet.

5. What is the effect of the lack of vitamin C upon guinea pigs? Feed one group a diet consisting of oatmeal, sterile hay, pasteurized milk, and water. Add orange juice to the diet of the second group. Do the two groups begin to show any signs of difference in activity, in weight, in the condition of the fur? If so, add orange juice to the diet of the first group. How long does it take for recovery?

* These diets are taken from *Adventures in Biology*, New York Association of Biology Teachers.

PROBLEM 2 *How Does the Digestive System Make Foods Usable?*

Food in the digestive tube. The food you swallow enters a long, irregular tube which runs right through your body. This is the digestive tube. It is also called the *alimentary* (al-i-men′tary) *canal.* The tube is narrow in some parts, wider in others. In a person of average size it is about thirty feet long; evidently it must be coiled, at least along part of its length. From the diagram, Figure 201, you can learn that food goes from the mouth through the throat into a long straight food pipe (*oesophagus* — ee-sof′a-gus). This connects with the stomach. As you continue your meal the food collects in the stomach where it remains for some time. The last of it does not leave until two to four hours after eating. The food does not lie quietly in the stomach. It is being squeezed and moved around until it is a pulpy mass. Then the stomach begins to push the food, bit by bit, into the long narrow tube known as the small intestine. You can readily see that this is coiled. It, too, has muscular walls and by their contraction the food is pushed along the twenty feet of narrow tubing. It takes about another eight hours before the last of the meal has reached the large intestine. The large intestine, or *colon*, is a much wider and shorter tube into which the small intestine opens at the lower right-hand side of the abdominal cavity. Here lies the appendix, a small fingerlike pocket attached to the large intestine. The large intestine extends up the right side, across the abdomen under the stomach and liver and down the left side, ending in the rectum. The rectum opens to the exterior by an opening known as the anus. It took you a few minutes to trace these parts of the digestive tube. For a meal to travel the length of this tube takes twelve hours or more. If possible examine a model (manikin) or large chart of the digestive tube.

What happens to food in the digestive tube? Food in the digestive tube is not yet really in your body at all. It is merely in a tube that runs through your body. Yet the billions of cells in your brain, in your hands, in your heart, all over your body need this food to carry on oxidation and other activities. How does the food get to them? Of course, the blood carries it. Our problem, then, is to learn how food gets from the digestive tube into the blood. The walls of the tube are made up of many layers of cells. Blood vessels lie among these cells. By the time the meal you ate reaches the large intestine most of it has diffused through the walls of the tube into the blood stream.

When you studied diffusion you learned that water, some minerals, and simple sugars pass through cell mem-

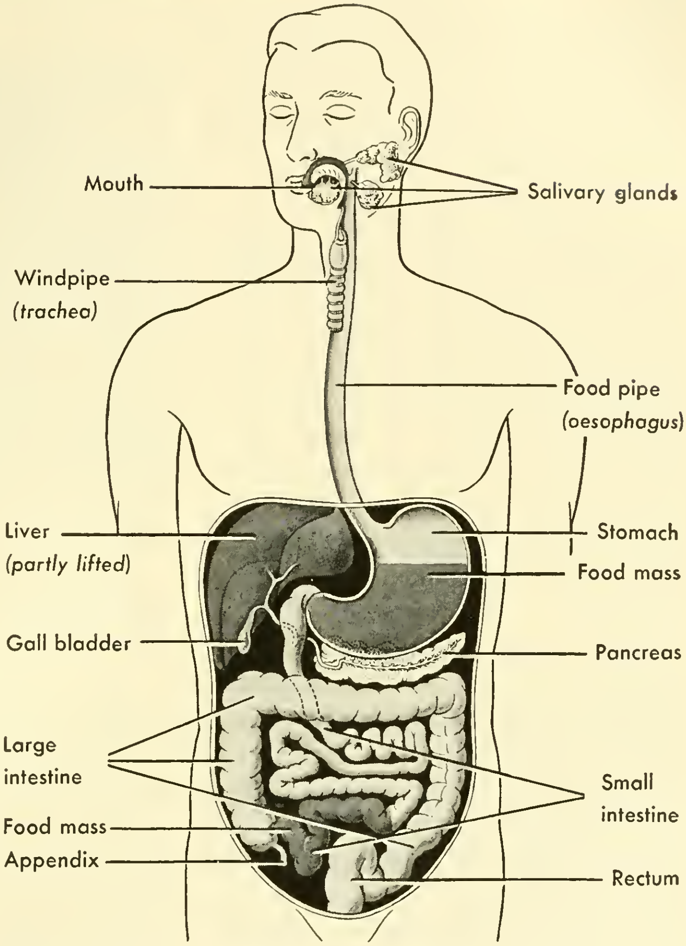


FIG. 201 *Man's digestive system. The organs are not drawn in correct proportion or in exact position. Food masses are indicated in the stomach and at the lower end of the small intestine. How long does it take food to travel the full length of the alimentary canal? What digestive organs are shown that are not part of the canal?*

branes. But the more complex sugars, the starches, the proteins, and the fats do not diffuse through cell membranes. Make an artificial cell and see for yourself whether starch, for example, is able to enter it. See EXERCISE 1. Those food compounds that do not diffuse through a cell are first digested in the tube and then pass into the blood.

What is digestion? You have just read that starches, proteins, fats, and some of the more complex sugars are changed in the digestive tube. Without this change they could not get into the blood nor could they later be used by the body cells for oxidation and assimilation. The chemists would say that the molecules of protein, starch, fat, and some of the sugars are large. These large molecules are broken up into smaller molecules making new substances. The process by which the large molecules are changed into smaller molecules of other substances is called *digestion*.

Digestion is a chemical change; that is, it changes the nature of the substances that are digested. If a piece of bread is broken into crumbs the change is a physical change. The crumbs are still bread. No matter how tiny the crumbs may be made, it is still a physical change. The nature of the crumbs is still the same. But if the starch in the bread is converted to some other substance the change is chemical. The nature of the starch has been changed.

End products of digestion. An interesting and important fact about digestion is that it occurs in steps. A food substance is first changed into smaller molecules; then these molecules are changed into still smaller molecules. These are called *intermediate products* of digestion. Finally the substance is changed into molecules small enough to diffuse into cells and to be usable by them. These last products of digestion are called *end products.*

There are other interesting facts about digestion. You may eat proteins from a hundred different kinds of animals and plants. The proteins are all slightly different from one another. And all of them are so different from your body proteins that they could not be changed directly into your body proteins even if they could diffuse into your cells. In digestion all of these many different kinds of proteins from various organisms are broken up into the same few compounds. These simpler chemical compounds which are the end products of protein digestion are called amino acids. Do you remember that plants in building up proteins first make amino acids? It may help you to think of amino acids as "building stones" of proteins. A large variety of buildings may be built out of the same kinds of stones. It should not surprise you then that a large variety of proteins can be built out of the same few amino acids. This is shown when the various proteins are broken up or digested in the body. You see then that they are all made out of the same twenty odd building stones or amino acids.

In a similar way carbohydrates and fats, too, are broken up into a relatively small number of end products. No matter what kinds of carbohydrates are broken down or where they come from, the same few end products are always produced. All fats, too, from every kind of animal or plant are broken down into the same few end products. And the end products are the same whether the process occurs in us or in a dog or in any other kind of animal.

Digestion shown in a test tube. If you mix some saliva with a little cooked starch in a test tube and warm the tube in your hand for four or five minutes, digestion of almost all the starch occurs. The starch is changed to a sugar called maltose. EXERCISE 2 will show this.

Saliva has been studied carefully and found to contain a small amount of a substance that can change starch to maltose. The substance in saliva that changes starch to maltose is called *ptyalin* (ty'a-lin).

What is an enzyme? An enzyme is a substance made by a living cell. It acts on another substance in such a way as to cause a chemical change in it. The enzyme itself is not changed. Thus, given time, a small amount of an enzyme can change a very large amount of a substance, since throughout, it remains just as it was originally. Chemists are familiar with substances that behave in this way in the laboratory. There are many of them. They call all of them *catalysts* (cat'a-lists), and reserve the name en-

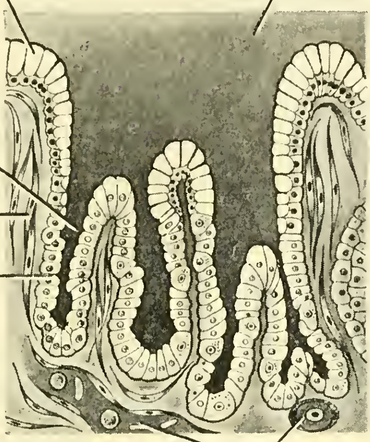


FIG. 202 *A magnified section through the lining of the stomach. Four tiny glands are shown. What lines each gland? The juice secreted flows into the stomach cavity.*

zyme for the special catalysts that are made in a living organism.

The enzymes that change food substances into other and simpler substances are called *digestive enzymes.* Ptyalin is one of these. Many different digestive enzymes are produced in the human body; each digests, that is, changes some particular food substance into simpler compounds. One set of enzymes digests protein, another fat, another starch. Others cause the digestion of the various complex sugars.

Digestive enzymes are made in other animals and in plants as well as in man. You can discover the effects of a plant enzyme by doing EXERCISE 3. Man has learned to extract some of the digestive enzymes from living animal and plant cells. In fact, some of them are extracted in such large quantities that they can be bottled and sold.

Not all enzymes are digestive enzymes. Some make it possible for oxidation to go on and there are many others that are necessary for the various cell activities.

Where digestive enzymes are made. When the lining of the stomach or the upper part of the small intestine is examined with a hand lens it is seen to be dotted with pores. Each of these opens into a microscopic bag or pocket sunk into the wall of the digestive tube. In the stomach alone there are approximately 35,000,000 of such pockets. The pockets are lined by cells whose protoplasm makes enzymes. We say the protoplasm of these cells *secretes* (see-creets′) enzymes. When they are dissolved in water this mixture of water and enzymes, together with some other substances secreted by the cells, is spoken of as a *digestive juice.* As the digestive juice diffuses out of the cells it fills the bag or pocket. The juice then trickles out through the pore into the stomach, or small intestine, as the case may be. Such a group of secreting cells is called a gland. Those in the stomach are called *gastric glands.* Those in the small intestine are *intestinal glands.* It is interesting to note that the glands of one part of your body secrete certain products; those of another part secrete different substances.

Large digestive glands outside the tube. Digestive glands are not always microscopic pockets like those just described. Sometimes secreting cells are massed together, forming one large organ composed of many microscopic "bags" or "sacs." These tiny bags are clustered together much as the individual grapes might be in a bunch of grapes. As the cells of each bag secrete, the juice flows through the little "stem" into the larger stem. The large stem serves as a tube or *duct* which carries the juice into some part of the alimentary canal. Examples of this type of gland organ are the three pairs of *salivary* (sal′i-very) glands, the *pancreas* (pan′cree-as), and the *liver.* Locate these organs on the diagram of the digestive system, page 189.

The salivary glands empty their juice, saliva, into the mouth. Some of the glands open into the inside of the cheek; others open under the tongue. The pancreas lies behind the stomach, more or less crosswise in the abdominal cavity. Its juice, the pancreatic juice, enters the small intestine close to the opening from the stomach. The liver is by far the largest gland of all; it lies above the stomach mostly on the right side. Under it and connected with it is a little storage sac known as the *gall bladder.*

As the liver continues to secrete, the juice known as *gall* or *bile* leaves the liver and accumulates in the gall bladder. After digestion is well under way the gall bladder, which has thin muscular walls, contracts slightly and releases the bile. The juice flows along a duct which joins the duct from the pancreas and thus it reaches the alimentary canal. While the liver, pancreas, and salivary glands are not part of the alimentary canal through which the food is pushed, they are just as necessary to the whole process of digestion as the canal itself. This would be a good time for you to dissect a frog to see the internal organs in a freshly killed animal. See EXERCISES 4 and 5.

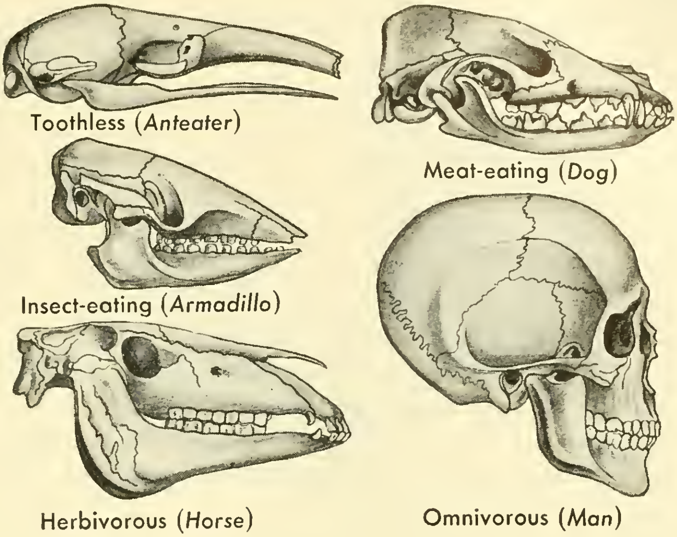
Food in the mouth. If you explore the inside of your mouth with your fingers you can feel a smooth, moist membrane. This delicate lining membrane is called *mucous* (mew′kus) *membrane.* It lines not only the mouth but the whole alimentary canal from beginning to end. The membrane secretes a slimy, thickish substance called *mucus.* It is the mucus which keeps the membrane smooth and helps the easy passage of food.

Now provide yourself with a mirror and some food. You can learn at first hand how the mouth deals with food. You can discover what the tongue does in chewing and swallowing and in tasting by doing EXERCISE 6. It will be worth while also to make a study of the teeth as suggested in EXERCISES 7, 8, 9, and 10. The food an animal eats is often partially determined by the kind of teeth it has. See Figure 203. Chewing is a purely mechanical preparation of food for digestion. Chewing breaks up food and mixes it with saliva. Digestion begins when saliva touches the food. Normally the food remains in the mouth for so short a time that not much of the starch can be digested before the food is pushed on toward the stomach. You can learn by the simple experiment outlined in EXERCISE 11 how long it takes for starch to be changed into sugar in the mouth.

As soon as you begin to eat, juice flows from the salivary glands very freely. The presence of food in the mouth starts the glands secreting actively. But the smell and thought of food also is enough to start their increased activity. Surely you have seen a hungry dog watching the preparation of its food. Why does it lick its lips?

Food leaves the mouth. Although you usually do not think about swallowing,

FIG. 203 *How do you think these various kinds of teeth are associated with the different kinds of food eaten?*



you can swallow when you decide to do so. But, once you have swallowed and the food has entered the lower part of the gullet you cannot control its passage. You can understand why this is true when you learn more about the muscles making up the walls of the digestive tract. At the upper end are voluntary muscles. At the lower part of the gullet and along the rest of the tract the muscles are involuntary. You can control voluntary muscles as you wish. Involuntary muscles are not under conscious control. They are, however, controlled by other parts of the nervous system; they need messages sent to them before they contract or relax.

Figures 157 and 159 show that the cells of voluntary and involuntary muscles are quite different in appearance. The voluntary muscles are often spoken of as striped, or *striated* (stry′ay-ted), muscles; the involuntary are said to be *smooth.* What other important difference is there in the appearance of these two kinds of muscles?

The various muscle fibers which make up the walls of the food pipe lie in rings. One ring contracts after another, thus producing what seems to be a wave running along the tube. The wave is slow but steady. If you have ever watched a worm crawling, you will know how the contracting food pipe looks, for the same thing happens in the worm's whole body. This wave of muscular contraction is called *peristalsis* (perr-i-stall′sis). The food is caught in this wave of contraction and forced onward toward the stomach. You will hear about peristalsis again in connection with the intestines.

Digestion in the stomach. If you could look at the inside of your stomach with a magnifying glass at the moment the food arrives there, you would see *gastric juice* trickling from the microscopic gastric glands through the microscopic pores. And if you are enjoying the sight and smell and taste of your food, you would see the juice flowing even more freely. One of our first American surgeons, William Beaumont, in the early part of the last century was fortunate enough to see all this happening in a human stomach. At an army post in Michigan a trapper, Alexis St. Martin, was shot through the stomach. It was a large wound, right through the wall of the stomach, large enough to put a fist into. The man recovered but the hole never completely closed and there was left an opening through the body wall between the ribs into the stomach. The hole was so large that Beaumont could look into the stomach. He could pour water through the opening or introduce food. He could suspend food in the stomach for a certain length of time and then recover it; he could siphon out digested foods; he could measure the contents of the stomach and could test the juice chemically. While Beaumont was performing all these experiments St. Martin made his living by chopping trees.

Because the composition of gastric juice is known, a rather good imitation of it can be made in the laboratory. You will be interested in trying the effect of imitation gastric juice on the various food substances. See EXERCISES 12, 13, 14, and 15.

Gastric juice, like salivary juice, is largely water. In it are *hydrochloric* (hy-dro-klor′ric) *acid*, and several enzymes. One of the enzymes, *pepsin*, changes insoluble protein, a very large molecule, into the somewhat smaller molecules of a substance called *peptone*. Peptones are intermediate products of digestion. They cannot be used by the body, nor will they diffuse through the walls of the intestine. Another enzyme, *rennin*, curdles milk and helps in its later digestion. The third, a fat-splitting enzyme, is of very little importance in an adult. The hydrochloric acid is not an enzyme. But it is of great importance in digestion in at least two ways. Unless it is present, protein is not digested by pepsin. And besides, hydrochloric acid reacts with a number of insoluble minerals, calcium phosphate among others, producing soluble minerals.

Scientists have long wondered why gastric juice which digests proteins does not also digest the cells of the stomach since protoplasm is made up largely of proteins. No satisfactory answer has been found. Some protection to the lining of the stomach is probably provided by the mucus secreted in large amounts by some of the lining cells. This mucus spreads itself over the inside of the stomach.

(Optional) Tissues making up the stomach. The organs of the digestive tube are complex organs composed of a variety of tissues. You will find it helpful at this point to review the section on tissues in Problem 3 of Unit II. On the outside of the stomach is a form of epithelium, serous membrane. This thin and very smooth, moist epithelial tissue covers all the internal organs and lines the body cavity. As the organs slide over each other or against the inside of the cavity there is little friction. The serous membrane covers three distinct layers of involuntary muscle. In one layer the muscle fibers run lengthwise, in another they are arranged in a circular fashion around the stomach, and in the third they are diagonal. In between these muscle fibers there are fibers of connective tissue which are always found in conjunction with muscle cells. Lining the

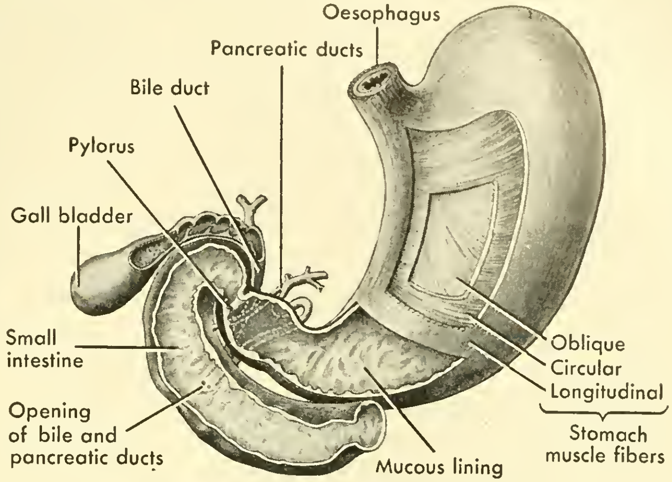


FIG. 204 *The stomach and the upper end of the small intestine. Note especially the mucous lining and the muscle layers in the stomach. How do bile and pancreatic juice get into the intestine?*

stomach there is a different epithelial tissue called mucous membrane. This consists of several layers of epithelial cells laid on a foundation of connective tissue. The epithelial cells secrete mucus. When a large amount of mucus has accumulated each cell is shaped like a flask and for this reason these cells are called *goblet cells*. Finally the cell bursts and the mucus is discharged. Figure 228 on page 227 shows two goblet cells discharging. Scattered through this mucous layer are the microscopic glands that secrete gastric juice. These are sunk into the thick wall of the stomach. These glands are made of epithelial cells of various kinds. Blood vessels and the fibers of nerve cells run through and between all these many kinds of tissues. Thus, in this one organ are found examples of all the different kinds of animal tissues except bone and cartilage.

Stomach movements. When the food reaches the stomach much of it is still in large pieces even if it has been well chewed. During the two to four hours that the food mass remains in the stomach it is moved back and forth and around. As the sets of muscles contract and relax in turn, the stomach goes through several kinds of movements but only some of these movements are of the type that move the food onward. The churning movements break up the pieces of food still further and mix them thoroughly with the gastric juice. The importance of these regular muscular contractions is now recognized. Many of our digestive disorders are the result of the improper action of the muscular walls. By doing EXERCISE 16, you can demonstrate the importance of the mechanical breaking up of food.

While stomach movements and digestion continue, the rings of muscle at each end of the stomach are more or less contracted. Only liquids can pass through the ring into the small intestine. Whatever liquid food you eat passes on almost immediately after its arrival in the stomach. After a while when digestion has been going on for some time a ring of muscle (the *pyloric sphincter*) between the stomach and intestine relaxes more. As the softened and well-broken-up portions of food are pushed forward by peristalsis they are forced through the opening, a small amount at a time. After several hours the last of the meal will have been delivered to the small intestine. The stomach is empty and ready to receive more food when the next mealtime comes. It is important to know that fats slow up secretion of juices and muscle contraction; a meal rich in fats, therefore, will remain in the stomach for a longer time.

Food in the small intestine. Let us take stock of what changes have occurred when the food has reached the small intestine. A good many of the minerals have been made soluble by hydrochloric acid in the stomach. A very little of the starch has been changed into a complex sugar by saliva in the mouth. Most of the sugars are just as they were when eaten. Some of the proteins have been split up into peptones by pepsin in the stomach. Fats have, probably, scarcely been touched. Much of the food has not been acted on at all; some has been partially changed but it is not yet completely split up into compounds simple enough to be used.

Having taken stock of what happened before food arrives in the small intestine, let us trace the food further. In the first part of the small intestine the food comes in contact with pancreatic juice, intestinal juice, and bile. Let us note the effect of each of these in turn. The pancreatic juice has three types of enzymes: one kind acts on proteins, one on starch, and one on fats. The fats are changed by fat-splitting enzymes into end products. The starch is converted into complex sugar, an intermediate product. Proteins, even peptones, are changed into still simpler intermediate products. If you wish to know the details and the names of enzymes they are as follows: the enzymes which split fats are *lipases* — ly′paces. They change fats into fatty acids and glycerin. The starch is converted by a starch-splitting enzyme called *amylase* — am′i-lace — into a complex sugar which is still an intermediate product, not the kind of sugar a cell can use. Proteins and peptones which had been formed in the stomach are changed into intermediate products even smaller than peptones, but still intermediate products. (One of the enzymes in the pancreatic juice that does this is *trypsin* — trip′sin.)

You can see that pancreatic juice does not complete the job of digestion. Much of the food is still insoluble. The intestinal juice which works in partnership with the pancreatic juice completes digestion. Sunk into the walls of the small intestine are microscopic glands like gastric glands; these secrete intestinal juice which contains three kinds of enzymes. One kind (erepsin) makes amino acids, which are end products, out of the protein intermediate products. Another kind breaks down complex sugars into the end product, glucose or other simple sugar. The third acts on the fats not yet digested by the pancreatic juice. Thus, while the food is in the small intestine it can be completely broken down into end products that can find their way through the intestinal walls and into the blood.

The bile from the liver contains no enzymes but it aids in preparing fats for digestion and it is important in various other ways.

Preparation of fats for digestion. When fats are warmed by the heat of the body

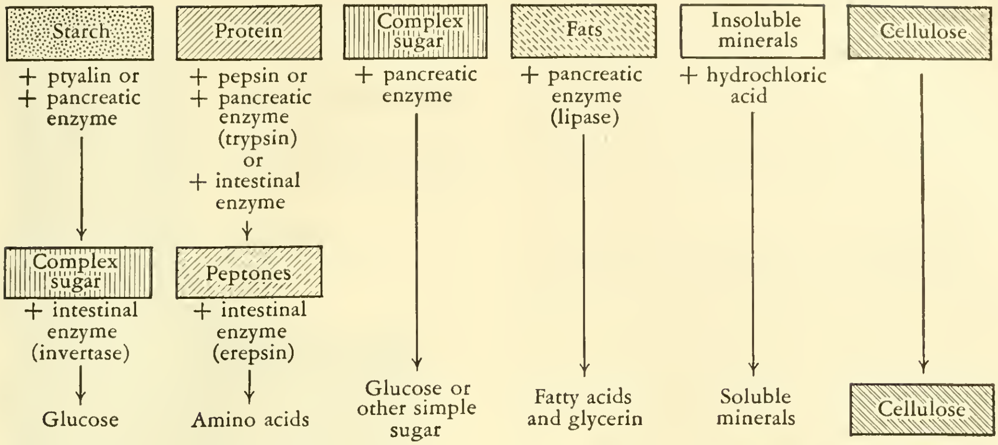


FIG. 205 *This chart shows what happens to the principal food compounds in the alimentary canal. Which are intermediate products and end products of digestion?*

they turn into liquids; that is, they become oils. Sometimes you eat fat already in a liquid form as when you eat olive oil. When an oil is mixed with water it soon separates from the water so that a few large drops are formed. Enzymes cannot act quickly on such large drops of oil because they can act only at the surface. The oil must be broken up into little droplets before much digestion can go on.

When bile is thoroughly mixed with an oil it forms a thin film around each droplet of oil so that the droplets can no longer come together. When oil has been broken up into tiny droplets in this way it looks milky. It is in a state of *emulsion* (ee-mul′shun). Milk is a good example of an emulsion. The fat in milk is in very tiny globules. You can easily make an emulsion in a test tube by doing EXERCISE 17. Could you demonstrate the principle that by emulsifying fats you increase the digestive surface? See EXERCISE 18.

The bile salts help in another way. The fat-digesting enzyme of the pancreatic juice is made active (activated) by the salts. Without this activation the enzyme does not digest fats.

Absorption of digested food. You have learned that in digestion large molecules are broken up step by step into much smaller ones. Proteins are changed into amino acids, fats into fatty acids and glycerin, and starches and sugars into simple sugars (such as grape sugar or glucose). Insoluble minerals are made soluble. As these end products of digestion are produced they may begin to diffuse through the walls of the alimentary canal into the blood. This movement through the walls into the blood is called *absorption.* Wherever there are digested foods lying close to the lining of the digestive tract for any length of time some absorption takes place. But there is little absorption until the food reaches the small intestine. While food is still in the stomach not much of it is ready for absorption, nor does it have an opportunity to stay in close contact with the mucous membrane since the stomach is a large pouch instead of a narrow tube.

Absorption is more than simple diffusion through a lifeless membrane. The cells that absorb take an active part in the absorption as is shown by the fact that they use more oxygen and produce more carbon dioxide while they are absorbing.

Absorption by the small intestine. If you were to slit open the small intestine along its length and examine the inside with a powerful magnifying glass, you would find it moist and pink like the lining of your cheeks. But in other respects it would be different. The inside of your mouth is smooth; the lining of the small intestine is wrinkled into deep folds, sometimes one third of an inch deep. If you rubbed your hand over the folds and if your sense of touch were delicate enough you would discover that the folds feel like a soft brush or like plush, for they are covered with microscopic, hairlike projections. These are called *villi* (vill'eye), plural of *villus.* They are soft because they are made of delicate cells. They sway back and forth, now lengthening, now shortening. They and the folds increase the lining surface enormously. It has been estimated that the surface of this narrow tube is more than five times as great as the skin surface of your whole body. Study the drawing of a villus (Fig. 206) to see how the digested foods can diffuse through the thin layer of mucous membrane covering the villus and go into the tiny blood vessels just underneath. Once the food is in the blood vessels it can be carried to larger and larger vessels and sent to every part of the body. In the center of the villus is a *lacteal* (lack'tee-al) into which the fatty acids and glycerin go.

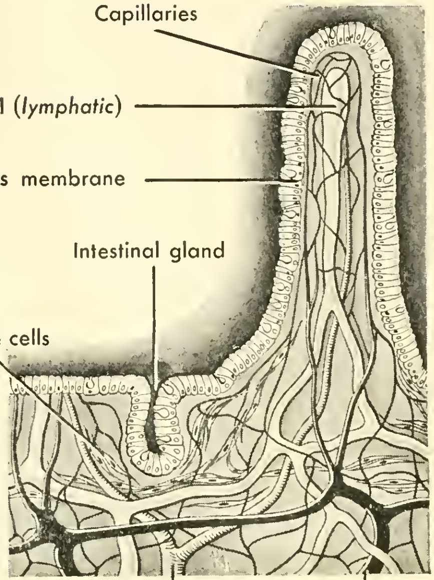


FIG. 206 *One of the villi of the small intestine cut through lengthwise. How many kinds of tubes does the villus contain? Can you see the opening of one intestinal gland alongside the villus?*

These products of fat digestion reach the blood stream later.

The large intestine. Parts of our food are never digested because we have no enzymes to act on them. This is true of the thick cellulose walls of plant cells, known as roughage, and other portions of our food. These substances that have not been digested are pushed on into the large intestine. Here much water is absorbed and the residue is ejected, or eliminated, through the anus. But the nondigestible foods have actually been useful. While in the small and large intestines they stimulated the walls to contract, helping peristalsis.

How does the liver function? You have read how the bile helps in emulsifying oils. It is of even greater importance in the absorption of fats. But the liver is helpful in still other ways. Besides containing gland cells which make bile it has ordinary cells which serve as a storehouse of carbohydrates. You have read that the end product of carbohydrate digestion is a simple sugar, mostly glucose. This is the kind of sugar that the cells of the body can use. However, the blood cannot hold more than a small amount of glucose at one time. Under normal conditions, much of the sugar that is absorbed into the blood leaves the blood stream in the liver. Here it is changed into an insoluble material similar to the starch found in a plant. This insoluble substance is called *glycogen* (gly'-ko-jen). Converting glucose into glycogen is the opposite of digestion. An enzyme brings about the change. Later, as the amount of sugar in the blood decreases, the glycogen is changed back into glucose and diffuses into the blood. In this way the sugar concentration in the blood is kept almost constant.

The liver functions in another way. It changes certain amino acids which would otherwise be wasted into a useful substance, glucose. On page 190 amino acids were compared to "building stones" as parts of protein molecules. When you eat protein and eventually build up your own body protein, it is much as though you wrecked a number of houses and then used some parts of one and other parts of another to build your own new house. Your new house has a special design which makes it impossible for you to use all the parts of the house or houses you wrecked. So when you eat and digest (wreck) proteins from various animals and plants you get "building stones" (amino acids) of different kinds. You can use some for assimilation; the others are changed in the liver into two substances. One is a nitrogen compound called *urea*, a waste product. The other is glucose which can either be oxidized immediately or stored as glycogen.

What stirs the glands to action? Secretion in the glands must be well timed, or much digestive juice will be wasted. You have already read how the sight and smell or even thought of food sends messages along the nerves to the salivary glands and the gastric glands which then begin to secrete actively. This goes on without your thinking about it or knowing what goes on inside of you. The mere presence of food against the mucous lining also stirs these glands to action.

But digestive glands may be made to secrete actively in still another way. At the beginning of this century two English scientists performed a very interesting and important experiment. They had been led to believe that there were substances in the blood which stimulated the pancreas to secrete. To test their theory the following experiment was performed. Two dogs were operated upon and a large blood vessel of one dog was joined to the corresponding blood vessel of the second dog. In this way the blood of each dog flowed through the body of the other. Then one animal was fed and the other was left unfed. After some time, when the digested food arrived in the small intestine of the dog, there was a flow of juices in both dogs! Since the only connection between the two dogs was their blood vessels it seemed as though something to stimulate the pancreas must have been carried by the bloodstream from dog to dog. This experiment and similar ones were repeated, always with the same results. For this reason the experimenters concluded that there is a substance carried by the blood which stimulates the pancreas; they called it *secretin* (see-cree′tin).

Secretin gets into the blood from the mucous membrane of the small intestine. When the first food materials from the stomach arrive in the small intestine, they stimulate some mucous membrane cells to form secretin. The secretin enters the blood. It circulates with the blood and promptly reaches the pancreas. When it arrives there it causes that gland to secrete very actively. Secretin may also be partly responsible for the stimulation of the intestinal glands. Secretin is one of many "chemical messengers" in the body. Such substances that are carried in the blood and act as chemical messengers are called *hormones*. There is believed to be a different hormone which stimulates the liver and perhaps another for the gastric glands.

The action of digestive glands can be slowed up as well as increased. Dr. Walter B. Cannon of Harvard University has demonstrated that anger or other excitement interferes seriously with the secretion of gastric juice in a cat. You can read an account of his experiments in his book, *The Wisdom of the Body*.

Questions

1. Name in order the parts of the digestive tube or alimentary canal. How long is it? How long does it take food to pass from end to end?
2. Where in the body is food constantly needed? If it is carried by the blood, explain through what it must pass to get into the blood. Which substances can diffuse through the walls of the digestive tube and blood vessels? Which cannot?
3. What is meant by digestion? Why is this called a chemical change?
4. Explain intermediate and end products of digestion. Give examples. How does the number of amino acids compare with the number of different proteins?
5. What is the result of adding saliva to cooked starch? What kind of substance in saliva changes starch to sugar? What is the name of this substance?
6. Define catalyst. How do enzymes differ from other catalysts? In which cell activities do enzymes help?
7. What is the work of a gland? Define the word secrete. Describe a microscopic gland and name two kinds of microscopic glands that help in digestion.
8. Name three gland organs that lie outside the digestive tube and that help in digestion. How do they differ from gastric glands? How does the gall bladder function?
9. State four ways in which the tongue functions. Describe the lining of the mouth and the whole digestive tube. Name three substances making up a tooth. What starts the secretion of the salivary glands?

10. Why are the muscles of the digestive tube beyond the throat called involuntary muscles? Distinguish between voluntary and involuntary muscles in appearance. What is the other name for voluntary muscles; for involuntary muscles? Describe peristalsis.
11. What starts the secretion of the gastric glands? Of what is gastric juice composed? What is the importance of each substance?
12. Name and describe the tissues which are found in the wall of the stomach. Which important tissues are not found?
13. Describe the muscles in the walls of the stomach and tell how they function. How does food get into the small intestine?
14. Sum up the changes that have taken place in food by the time it reaches the small intestine. Name three juices it meets there. Explain the changes brought about by pancreatic juice in three kinds of food. Explain how intestinal juice completes the work of the pancreatic juice.
15. Is emulsification a physical or a chemical change? Explain. How does emulsification help? In what two ways is the bile of help in digestion?
16. Why is there little absorption of food in the stomach?
17. The small intestine is long and narrow; it has folds; it has villi. Explain how each of these structures is useful in digestion or absorption.
18. Normally, which parts of our food reach the large intestine?
19. What is glycogen? Explain its relation to the liver. In what sense are amino acids building stones? How does the liver put amino acids to good use?
20. Where is secretin made? How does it function? Why is secretin called a hormone? Explain three means by which digestive glands can be stirred to action. How is the secreting of the digestive glands sometimes stopped?

Exercises

1. Can starch enter an artificial cell? Prepare an artificial cell by filling a gelatin capsule with some white of egg and sugar solution. Make a thin starch paste by heating a small amount of starch in a large amount of water. Cool. Place the capsule in the paste. After two hours remove the capsule and test the contents for starch. What test will you use? What do you observe? What conclusions can you draw about the entrance of starch into the cell?

2. Does saliva change starch into sugar? Prepare a solution of boiled starch. Pour some into each of two test tubes. Add saliva to one test tube and let it stand in a warm place for half an hour or more. Now test part of the solution in each of the test tubes for sugar. (Use Benedict's or Fehling's solution.) Test another part for starch. Before you draw a conclusion make sure that you have eliminated every other possible conclusion. What else must you do?

3. Do active plant cells digest starch? The cells of a dried grain of corn are living but quite inactive. They will become active when the grain is soaked; it will then sprout. Soak grains for 24 hours. Keep them moist. After 4 or 5 days test dry and sprouted grains for sugar and starch. What do you notice? Be sure to keep accurate notes. How can you explain what happens? Did you use a control? What was it?

4. *How to dissect a frog.* Lay a dead frog in a shallow pan with ventral (lower) side up. With your forceps grasp the loose body wall in the extreme lower part of the body cavity where the legs arise. Cut into this body wall with the point of your scissors making a large enough incision for you to introduce the point of one blade. Now remove the body wall, cutting out a complete rectangle. *Caution*: As you cut, the scissors must be held horizontally and with the forceps you must raise the body wall in front of the scissors. In this way you will not damage the organs within. Cut from the point of incision to your right (the frog's left) across the lower portion, then up along the side until you reach the head. In the region of the arms you will be obliged to cut through the bones which make the shoulder girdle. Then cut the third side of the rectangle and back along the left (the frog's right) side. When you have removed this large piece of body wall the internal organs of the frog will be exposed.

5. *Study of the internal organs.* During the breeding season the female frog will have large masses of eggs. These must be removed before you can see the other organs. The heart may attract your attention since it may be beating. In the region of the heart toward the front end of the body cavity are the large, flat, dark red lobes of the liver. How many are there? Attached to the liver you will find the gall bladder which is green. What is its shape? Partly under the liver on the frog's left side is the long, whitish tubular stomach. Feel it with the dull point of the forceps. How does it feel? At its lower end it narrows to form the tubular intestine. Trace the coils of the intestine. You will find that it is held down and held in place by a very thin membrane called the *mesentery*. Do you see fine blood vessels in the mesentery leading to the intestinal wall? The small intestine widens into the large intestine. Caught in the folds of the mesentery in the region of the stomach is the long narrow pancreas.

Other organs you will see are: the spleen, a dark red ball; lying against the back wall in the region of the heart, two narrow pointed pinkish lavender bags, the lungs; against the back wall two dark red, rectangular organs close together, the kidneys; close to the kidneys, perhaps, a pair of yellow organs if you are studying a male frog, the male reproductive organs. Try to inflate the lungs by inserting a tube through the frog's mouth and blowing into it.

6. Study your tongue with a hand mirror. Where and how is your tongue attached? Which parts of your mouth can be touched by your tongue? When would these movements of the tongue be of help to you? Explain. Put a drop of sugar water on the front of your tongue; on the

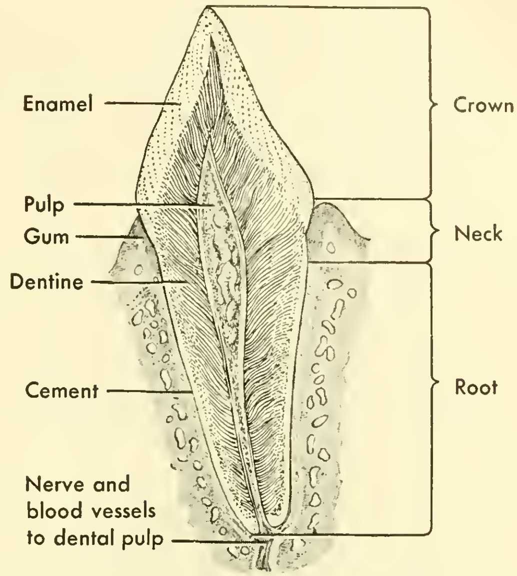


FIG. 207 *Longitudinal section of an incisor. The different kinds of teeth all have the same three regions. What are they? All are alike in structure.*

back. Do you note any difference? Now put a grain or two of granulated sugar on your dry tongue. What do you discover? Blindfolded, and with nose tightly shut, taste the following substances (someone must put them on your tongue without telling you which is which): salt, lemon juice, vinegar, sugar, something bitter, grains of ground coffee, farina, etc. Rinse your mouth after tasting each substance. Which can you recognize? Repeat, with your nose no longer held shut but still blindfolded. What do you conclude? All of your observations must be carefully recorded. Compare them with your classmates'. Why? Can you now name four different ways in which the tongue functions?

7. What can you discover about the number and the arrangement of your teeth? It will help you in your study to know that the teeth in the upper and lower jaws are alike. Use a mirror to discover how you bite off a piece of bread. Which teeth do the work? How are they fitted for it? You have four such teeth at the front, in each jaw. They are called *incisors*. Which group of mammals has the incisors well developed? Right behind the incisors, you have a single tooth on each side which is somewhat more pointed. It is a *canine*, the tooth which is so large in cats, dogs, and their relatives. How do the back teeth differ in shape from incisors and canines? How many back teeth are there in each jaw? How do they function? Bite into a piece of hard chewing gum. What impression does each kind of tooth make on the gum? Can you see that the two teeth directly behind the canine differ from those still farther back? How? Those farthest back are the *molars*. Between the molars and the canine lie the *bicuspids*. If you have your last molars, called wisdom teeth, and have lost no teeth, you can count 32 teeth in all. How many have you? Write a report of your observations.

8. How are the teeth fitted for their work? How does the surface of your tooth differ in appearance and in structure from the surface of a bone? Your tooth is covered with a substance much harder than bone. It is called enamel. Study the diagram of the tooth. Where does the enamel end? Explain. *Dentine* is a substance much like bone. Like bone it contains cells. But enamel is pure mineral matter. What is found in the very inside of the tooth? Which are the living and which the lifeless parts of the tooth? When you have a toothache, you feel pain through the nerve. Where does the nerve lie? What has probably happened to make the tooth ache? What might cause a toothache while you were eating?

9. What can you do to make sure that your teeth are covered with a good layer of enamel? Write a paragraph on the connection between good teeth and diet. (See Problem 1 of this unit.) Since enamel is pure mineral matter it is not only hard but brittle. What might tend to crack it? Ask your teacher to do the following: Put into a test tube a small amount of calcium phosphate (the mineral that makes up enamel). Shake it well with a little water. Examine. Add some strong hydrochloric acid. What do you observe? Add weak acid to a very small amount of calcium phosphate and let it stand. What conclusions do you draw? When bacteria decay food they often form acids. If small particles of food left in your mouth decay, what might happen?

10. You will find it interesting to make a list of all the rules you can think of which would help to keep your teeth in good condition. Of course, unless you can give a good reason for your rule no one will be interested in it.

11. How quickly does saliva act in the mouth? Grind up a small piece of soda cracker and moisten it. Lay it on your tongue. Look at the clock. What do you taste? Leave it there several minutes. What do you notice? Explain. Did other members of the class get similar results or is this a peculiarity of your saliva?

12. What is the effect of gastric (stomach) juice on starch? Ask your teacher to make some artificial gastric juice by adding to a test tube of water a few drops of hydrochloric acid and a little powdered pepsin. Add some of this to starch in a clean test tube. What happens? State clearly what you did to arrive at a conclusion. What was the control? State your conclusion.

13. What is the effect of gastric juice on protein? Cut some hard boiled white of egg into small pieces. Put a quarter of a teaspoonful into a test tube, add two inches of artificial gastric juice, and plug the tube with cotton. (The experiment will be more successful if you boil the water and take all precautions to exclude bacteria.) Keep the test tube in a warm place. Why? What temperature would you suggest? What would you suggest as a control for this experiment? Examine it after 10 minutes, several hours, 24 hours, and 48 hours. Make a note of any changes you observe. Explain what you see.

14. What in the gastric juice digests protein? Are you convinced that it was the pepsin that digested the white of egg? Can you prove that it was not the water? Or the hydrochloric acid? Try each of the three substances alone. What happens? Now plan an experiment to discover what is really necessary for the digestion of protein. Include in your report of this experiment a statement of the control experiments that were used. Tell why they were necessary.

15. What is the effect of hydrochloric acid on the minerals in the food? Test such minerals as table salt and calcium phosphate. Use dilute acid and very small amounts of mineral. Describe what happens.

16. How does the mechanical breaking up of food affect digestion in the stomach? Can you devise an experiment to answer this question? (Hint: Use hard boiled white of egg and gastric juice. Use two tubes. How must the white of egg in the two tubes differ when you set up the experiment?)

17. How can oil be emulsified? Place about one-half teaspoonful of olive oil in a test tube half filled with water. Shake the contents and allow to stand for several minutes. What happens? If it is possible to obtain the gall bladder of a chicken, add this bile to the oil and water in the test tube. If not, use a weak alkaline solution obtained in the laboratory. Hold your thumb over the mouth of the test tube and shake the tube thoroughly. You now have an emulsion. What is its color? Examine after several minutes. Does the oil again rise to the top? Examine a drop of the emulsion under low power of the microscope. What do you see? Can you explain the emulsion? Explain how emulsification prepares oils for digestion.

18. Does emulsification appreciably increase the surface to be acted on by digestive juices? Fasten together several board erasers or books with an elastic. Measure their total surface area. Separate them and measure the surface of each one. Add together the measurements of the separate objects. Compare this sum with your first measurement. Can you explain? A cube whose side is one inch has a total surface area of six square inches. If this cube is cut up into small cubes whose sides measure 0.01 of an inch there will be one million such cubes. What will be the total surface area of all of the small cubes? How does it compare with the area of the original cube?

Further Activities in Biology

1. Devise an experiment to determine whether the enzyme in saliva really acts like a catalyst; that is, whether a small amount can be used over and over again without being used up in the process.

2. If saliva is swallowed with starch, can its work continue after it reaches the stomach? You must expose saliva and starch in a test tube to the surroundings they would have in the stomach. What will you do? Ask to have your experiment tried in class.

PROBLEM 3 *How Are Materials Moved to and from Our Body Cells?*

The transportation system. You have learned that in the human alimentary canal there is large scale digestion of food and that digestion produces materials that may be assimilated or oxidized in the cells. But there are billions of cells in the body, most of them far removed from the alimentary canal where digestion takes place. Digested foods are transported to the cells by a transportation system called the *circulatory system.* There are really two systems. One system is composed of the heart and blood vessels through which blood moves. The other consists of tubes called *lymphatics* which carry lymph. Let us study the circulation of the blood first.

Blood circulates in a system of two connected sets of tubes. It is pumped to all parts of the body by the heart through one set, the *arteries.* It flows back to the heart through another set, the *veins.*

How food enters the blood system. Digested foods in the small intestine are absorbed by the villi. Each villus contains tubes of two kinds. There is a network of tiny blood vessels which are part of the blood system; and there are tubes called lacteals which are part of the lymphatic system. The blood vessels in the villi are microscopic with very thin walls. Such tiny blood vessels with extremely thin walls are known as *capillaries* (cap′ill-a-rees). Digested foods easily enter them and become part of the blood.

Capillaries in all organs. Just as there is a small network of capillaries in the villi, there are networks of capillaries in every organ, such as the brain, the internal organs, the muscles of the whole body, and the skin. You cannot see these capillaries in your body because they are microscopic but by doing EXERCISE 1 you can get a very good idea of how they must look. They are so tiny and branch so widely that they are spread through every part of the body. Every cell is more or less closely in contact with capillaries.

The digested foods diffuse out through these capillaries which lie among all the cells of the body; thus the food substances reach the living cells. Every ordinary cell engages in many activities, but the activities are on so small a scale that you are not aware of what is going on. One of these activities is oxidation. Not only food but oxygen as well diffuses out of the capillaries into the neighboring cells. As a result of oxidation, energy is released and new substances are formed. Some of these are harmful to protoplasm; at best, they are useless. They are the waste products. The wastes

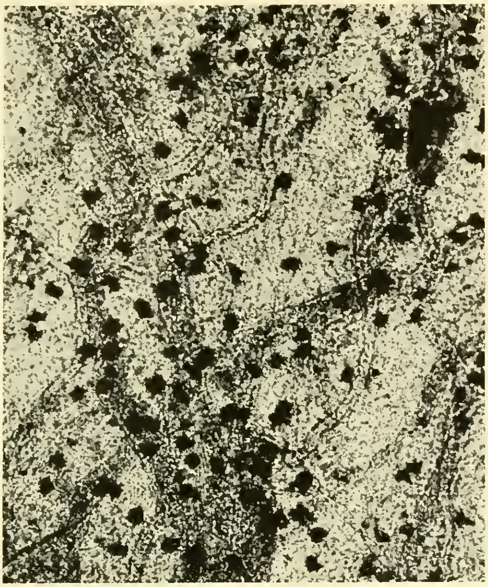


FIG. 208 *Part of the web of a frog's foot magnified 75 times. The irregular dark spots are coloring matter in the skin. The very faint, narrow vessels are capillaries. What are the wider vessels? In what ways is the blood changed while it is in the capillaries?* (HUGH SPENCER)

formed in oxidation diffuse through the capillary wall into the blood. As you continue to learn how the human body performs its life activities you will discover that there are still other substances which enter and leave the thin-walled capillaries in all the organs of the body.

Long distance transportation to and from the organs. The tiny, thin-walled capillaries connect the longer and wider arteries and veins. Transportation from one region to another is through the wider tubes. The walls of arteries and veins are much thicker than the walls of capillaries. Blood flows through arteries and veins over long distances to and from the organs. Within each organ the artery branches into smaller and smaller arteries. The smallest of these arteries connect with capillaries within the organ. The

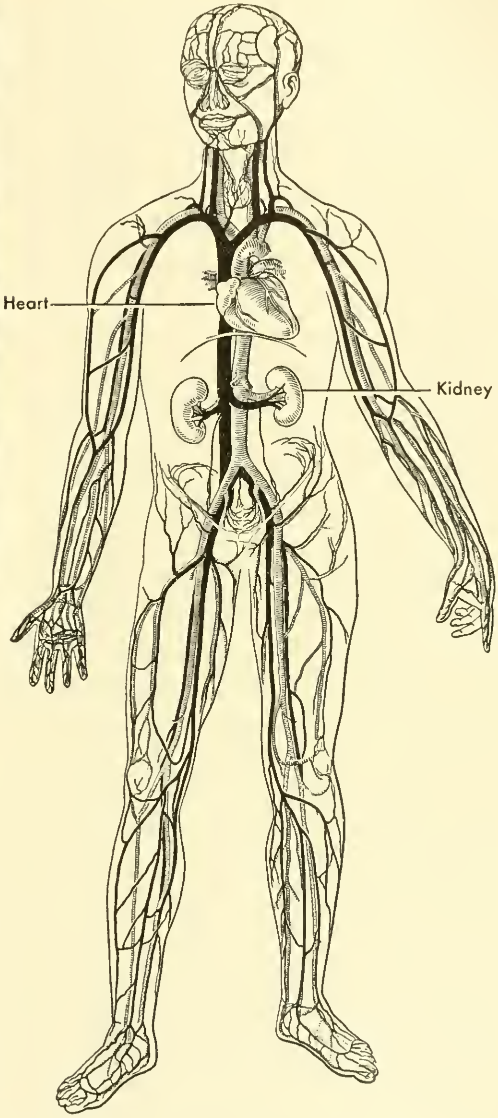


FIG. 209 *The heart and some of the large veins (dark) and arteries (light) of the main circulatory system. The heart is the organ which pumps the blood to all parts of the body through the arteries. The blood flows back to the heart through the veins. Connecting the arteries and veins are the capillaries (see Fig. 208). Every cell in the body lies near one of these microscopic tubes. How are digested foods and oxygen obtained by the living cells, and how are waste products carried away? The lymphatic system is not shown in this diagram.*

capillaries, in turn, are joined to small veins. More and more veins join, forming larger veins through which the blood flows away from the organ.

Substances are transported through the arteries and veins very rapidly. Within a few minutes drugs absorbed by the digestive system or gases breathed into the lungs can be found in any organ of the body.

What is blood? Blood consists chiefly of an almost colorless, slightly straw-colored liquid, called *plasma.* Plasma is about 90 per cent water. In it are dissolved the digested foods which have been absorbed in the small intestine and the various wastes which are constantly being added from the working cells. Plasma also contains various types of proteins which are of great importance in a number of ways. One of them, for instance, helps in blood clotting. It is called *fibrinogen* (fye-brin'o-jen). Besides all these substances, plasma contains hormones (one hormone, secretin, was discussed on page 200), and it carries substances which help us fight disease.

You can see that plasma is not a simple substance. The make-up of plasma is not always the same; plasma is constantly changing. If the cells in some part of the body are carrying on oxidation at a rapid rate, wastes will be added to the plasma in large amounts. During sleep the amount of waste material present in the transportation system is less. Some hours after a large meal, when the digestion of food is well on its way, the plasma will contain large amounts of substances produced by digestion. If the meal was largely beefsteak the plasma will be rich in amino acids which come from protein digestion. If the meal was largely starches and sweets the plasma will contain more sugars. When you are exercising, the absorbed food substances are rapidly entering the working cells. You have seen the loading and unloading of a baggage car at a station. The contents of the car change at every stop; just so with the plasma. Only the blood does not have to

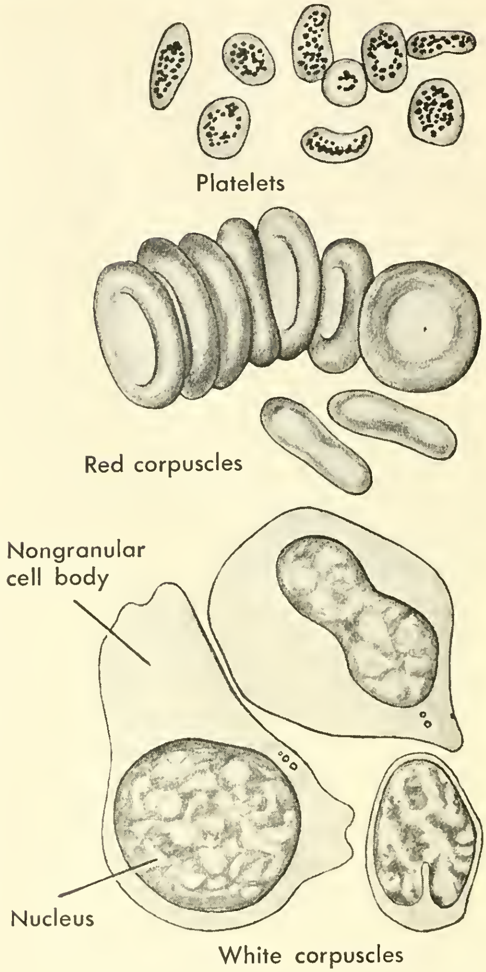


FIG. 210 *Three kinds of blood cells. How do these cells differ in size and shape? What part usually found in a cell is missing in the red corpuscles? Of what use is each kind of cell?*

stop in its course to load and unload. As it moves through the capillaries there is a constant passage of substances in and out.

Blood is more than just plasma. In the plasma there are three kinds of cells: *red corpuscles* (core′pus-ls), *white corpuscles*, and tiny *platelets* (plate′lets). The red corpuscles are very numerous and give the red color to the blood. If you follow directions in EXERCISE 2 you can study a drop of blood with a microscope and see the two kinds of corpuscles.

Almost half of the volume of the blood is cells. For this reason blood is thought of as a tissue. Some of the other tissues which you think of as "solid" tissues have almost as much liquid around their cells. If your school has an instrument known as a *centrifuge* (sen′tre-fewj) you can easily separate the blood plasma from the mass of cells. If you can get blood from a slaughter house, do EXERCISE 3.

Red corpuscles. A red corpuscle is shaped like a coin which is much thinner in the center than around its edge. The red corpuscles contain a special protein substance, rich in iron, known as *hemoglobin* (he′mo-globe′in). Hemoglobin is unlike other proteins in that it unites with oxygen very easily and releases it just as easily. It is because of this that the red corpuscles can be the transporters of oxygen. When hemoglobin unites with oxygen it forms a new compound (*oxyhemoglobin*) which is bright red in color. If, later, this red compound is in surroundings where there is little oxygen, it again separates into oxygen and hemoglobin. When blood flows from a cut it is at once exposed to oxygen and therefore takes on the color you think of as blood red. When examined under the microscope, however, red corpuscles are disappointing, for each single cell is quite pale even when in contact with oxygen. It is only when there are large numbers of red corpuscles close together that we can see the brilliant red color of fresh blood.

Red corpuscles are much smaller than most other body cells. One drop of blood normally contains more than 5,000,000 of them. Since there are more than five quarts of blood in the average man he has about twenty-five trillion (25,000,000,-000,000) red blood cells, a number too large to hold any meaning for most of us. It may mean more to learn that if all the red corpuscles of a normal person, small as they are, were laid out flat next to one another they would cover an area as large as a baseball diamond.

Red corpuscles are made in the red marrow of the bones. Before they enter the blood they lose their nuclei. They live, on the average, only about a month. In healthy people about a million cells may be destroyed every second. If they are destroyed too rapidly, or are not manufactured fast enough, or if a large amount of blood is lost, a person may have too few red corpuscles. He then has too little hemoglobin, a condition called *anemia* (an-ee′me-a). Since iron is an important part of hemoglobin, an insufficient amount of iron in the diet can also cause anemia. The organ known as the *spleen* is a reservoir of blood and particularly a storage chamber of red corpuscles. During muscular exercise and in people living at high altitudes the spleen contracts more vigorously than usual and thus increases the number of red cells in circulation. This is interesting because in both cases it is an advantage to the person to have more corpuscles. When exercising he needs more oxygen. At high altitudes there is less oxygen in the air and a large number of corpuscles is desirable.

White corpuscles. We have many kinds of white corpuscles, or *leucocytes* (lew′-ko-sites). Those that are most numerous are large cells that resemble an ameba in shape; that is, they have no definite shape, since their soft protoplasm streams now in one direction, now in another, forming pseudopods. Their protoplasm is quite granular and the nucleus is large and usually shaped like an irregular club. These white corpuscles move about much as an ameba would. The great Russian biologist Eli Metchnikoff (1845–1916) discovered these cells near the end of the last century and called them phagocytes (fag′o-sites). They can push their way between the cells that make up the walls of the capillaries and get in among the tissue cells. Here they engulf and gradually digest bacteria or any other particles that are present. They serve as tiny scavengers (eaters of unwanted substances) in the body. When bacteria enter the body, millions of the phagocytes and some of the other kinds of white cells are soon attracted to the spot. The other kinds are helpful in surrounding this whole region and keeping it separated from the neighboring tissues. The large white corpuscles begin at once to devour bacteria. As many as twenty bacteria have been found within one corpuscle. Often the white corpuscles

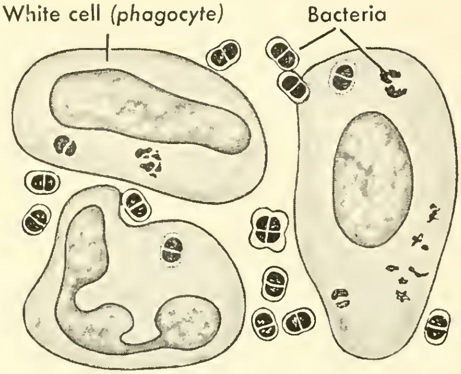


FIG. 211 *Three white cells (phagocytes) destroying bacteria by engulfing and digesting them. How is this activity of the white cells of benefit to the body?*

are killed by the poisons secreted by the bacteria. The dead bodies of the white corpuscles together with destroyed tissues is *pus*. This whole region, or *abscess* (ab′sess), is red, swollen, and hot to the touch. Much blood is present.

Some kinds of white corpuscles are, like the red corpuscles, made in the red marrow of the bones. Other kinds of white corpuscles are made elsewhere, in what we call lymph glands. You will read of this later.

Blood platelets and clotting. The third kind of blood cell, the platelet (small plate) is the smallest. It has no nucleus. Platelets are connected in some way with the *clotting* of the blood. You have seen how the blood which oozes out of a small cut hardens or clots. If it did not clot and thus plug up the blood vessel, the blood would keep right on flowing.

According to one theory of clotting, the platelets together with other cells start the process of clotting by breaking up when the blood vessel is damaged. As they break up they release a substance. This substance indirectly causes one of the dissolved proteins of the plasma, fibrinogen, to harden and form threads. These are known as *fibrin* (fye′-brin) threads. They entangle the red and white corpuscles, and this tangled mass is the clot.

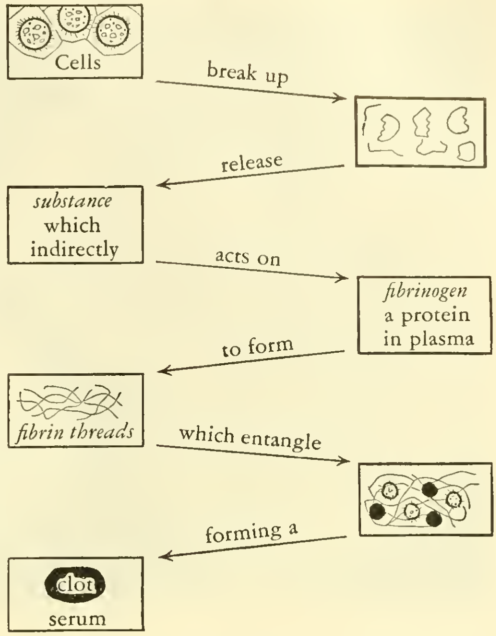


Fig. 212 *How blood is supposed to clot. Begin at the top. Cells, mostly platelets probably, start the process. Of what is the clot composed? What surrounds the clot?*

When a large quantity of blood is allowed to stand in a tumbler a solid mass of fibrin threads and corpuscles forms in the way just described. This mass shrinks and you then see it as a clot floating in a faintly yellow liquid which looks like plasma. But it is not plasma because it has lost the fibrinogen which hardens into threads. It is *serum*, a substance which does not clot. You may have heard that a doctor sometimes injects purified blood serum into a person.

In most people bleeding from small wounds stops soon because of clotting. Bleeding from larger wounds may often be stopped by various methods used by physicians. Sometimes vitamin K is injected to hasten clotting. Some people are known as "bleeders" because their blood clots very slowly. The cause of this condition is not definitely known.

Transfusions and blood banks. The transfer of blood from one person into the veins of another is practiced when large amounts of blood have been lost, in treating for shock, and under various other circumstances. Great care must be taken to choose the right person to give blood. If the blood of the donor (the person who gives) is not of the right type it clots or coagulates within the body of the patient, causing death. There seem to be four main groups of people, classified according to the chemical composition of their blood. This has nothing to do with the race to which they belong because the same four groups are found in all races. It was once thought that one type of person, called the universal donor, could give blood with safety to any other person. While in general this "universal" blood, called also "O" blood, can be mixed with any of the four types, occasionally there are disastrous results. For this reason tests are made before the transfusion. A second type of blood is "A" blood; this can be used only for a person who also has "A" blood. A third type called "B" blood can also be mixed only with its kind. The fourth kind is called "AB." The person with "AB" blood can receive blood from every other type and is called the "universal recipient." Here again there are occasional exceptions. This knowledge of the four kinds of blood is the result of the

FIG. 213 *This photograph was taken while the man was donating blood for the third time at a Red Cross Center during World War II. How was the blood used? Is there still a need for blood donations?*

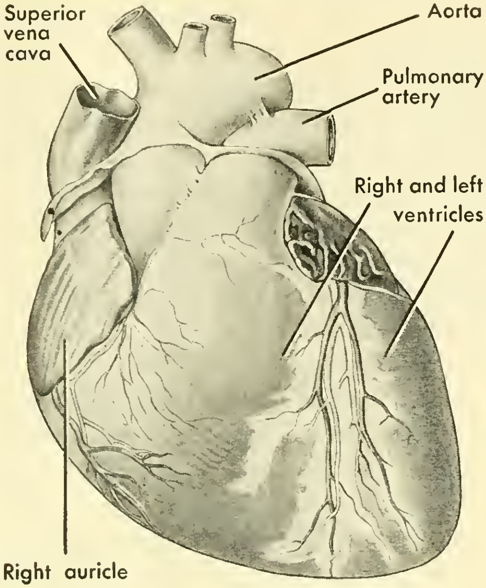
work of a great physiologist, Karl Landsteiner, who died in 1943.

Also it was discovered recently that there is a substance in the blood of most people called the "Rh factor." A few people lack it. The name comes from the animal, the *Rhesus* monkey, used in the experiments which led to the discovery of the substance. If the mother lacks the Rh factor, the development of the unborn child may be interfered with; sometimes the child dies.

When transfusions were first given it was necessary to introduce blood from the donor directly into the patient. Since the first World War, thanks to an important discovery made by a scientist in Argentina, Dr. Luis Agote, we have learned to preserve blood so that the red cells do not die. Now blood can be collected and kept in blood banks.

Using parts of the blood instead of whole blood. At the present time plasma and sometimes serum is used rather than whole blood because neither plasma nor serum need be matched. Besides this, plasma has the great advantage that it can be easily dried and readily preserved without spoiling. With the addition of distilled water dried plasma is ready for use. In this kind of transfusion the wounded receive no red blood cells but this is often not as important as you might think because ordinarily the body has a large supply of these in reserve. During World War II most of the blood which was given through the Red Cross was used to produce dried plasma.

Very recently chemists have gone one step farther. They have learned to separate the proteins in plasma from each other. Professor Edwin Cohn of Harvard University has been a leader in this work. It has been found, for example, that not the whole plasma but only one of its proteins is needed for treating shock. This one protein when separated from the rest will occupy far less space and



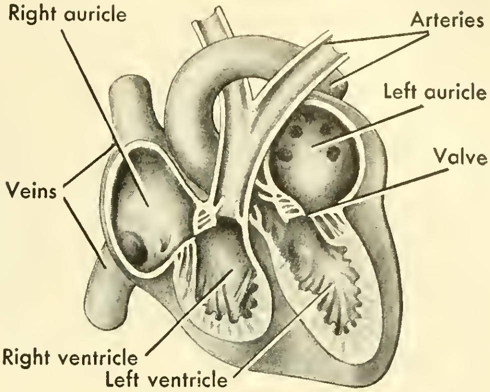


FIG. 215 (above) *The heart cut open. Note the four chambers. From which chambers and through which tubes does blood leave?*

FIG. 214 (left) *The heart. This is the pump that keeps the blood in constant motion.*

be easier to carry; and the other proteins can be used for other purposes.

The blood is in constant motion. The plasma with its blood cells travels to the farthest regions of your body and reaches every living cell. In organisms like us that walk upright blood travels long distances directly uphill. The blood is in constant rapid motion; a drop of blood may make the rounds of the body in less than half a minute. How is it done?

Blood is moved in the simplest way; it is pushed. If a liquid is put into a bag and the bag squeezed, the liquid will squirt out of the bag through any opening. If all openings but one are closed and the bag is squeezed hard, the liquid will squirt out with force. The heart is so constructed that this happens every time it "beats." The walls of the heart are made of powerful muscles which by contracting do the squeezing themselves. It is so easy to obtain a beef heart which is constructed like yours that you will want to do EXERCISES 4 and 5 to learn about your heart.

The heart of a human being consists of four parts. Two of these, the upper ones, push the blood into the lower ones; they do this gently. They are the right and left *auricles* (or′i-k′ls), thin-walled chambers which collapse when not filled with blood. The other two chambers lie below the auricles. They are called *ventricles* (ven′tri-k′ls), the right and left ventricle. They are larger chambers with much thicker walls. By contracting they squirt the blood into big vessels carrying blood away from the heart. They contract with great force. The right and left sides of the heart are completely separated from one another by a thick and solid wall. Blood cannot pass directly from one side to the other. It is just as though there were two distinct hearts.

The outer walls of the two auricles and the two ventricles are continuous so that from the outside the heart looks as though it were one big mass of muscle. Connected to this mass are numerous blood vessels. They all seem to be connected to the upper portion, but when you cut the heart open and trace each vessel to its origin you will see that they are connected with different chambers. Some are connected with the auricles; they are called veins. Veins carry blood to the auricles. Each ventricle has one large vessel connected to it; through these vessels blood flows away from the heart. Any blood vessel that carries blood away from the heart is known as an artery.

You can gather from what you read above that the contraction, or beat, of the heart occurs in two stages: the contraction of the two auricles, followed by the contraction of the two ventricles. This occurs about 70 times per minute and never stops throughout your life. A frog's heart, which is slightly different from ours in structure, shows this double beat very clearly. It will be worth while to dissect a frog and do EXERCISE 6. This demonstration shows another interesting thing about heart muscle, whether in us or in the frog. It can contract rhythmically by itself without being connected to the nervous system. This is not true of the voluntary muscle in the arm or leg or other parts of the body; nor is it true of the involuntary muscle in the walls of the alimentary canal. Heart muscle not only acts differently from the other muscles but looks different from voluntary and involuntary muscle under the microscope.

William Harvey. You have probably known for a long time about the beating of the heart and how the blood flows through the arteries and veins. But it took very many centuries for us to gain an understanding of what seems so commonplace now. Before men knew that the body is made of living cells which are supplied with digested food and oxygen by the blood, they imagined all kinds of possible uses for the blood and for the heart. For a long time the heart was believed to be the seat of intelligence. Later it was supposed to add "vital spirits" to the blood. The Greeks believed that the arteries carried air, the veins carried blood. Theories such as these had been largely discarded, and studies of the structure and uses of the heart had been begun by the beginning of the 17th century but had never been carried very far. William Harvey (1578–1667), an English physician, after careful studies and after performing many accurate experiments, published the book which explained the circulation of the blood as we now understand it. He showed that the heart is muscular and serves as a pump. He calculated that if the heart contains two ounces of blood and beats sixty-five times a minute, then it drives ten pounds of blood out into the body in less than a minute. Evidently, the same blood is continually being pumped around; this amount of blood could not possibly be made anew in that space of time. He knew, therefore, that blood which leaves the heart must return to the heart. If the arteries carry it away from the heart, the veins must bring it back. Harvey did not see the microscopic capillaries but he suspected that there must be tiny blood vessels, too small for him to see, through which blood from the arteries flows to the veins in all parts of the body.

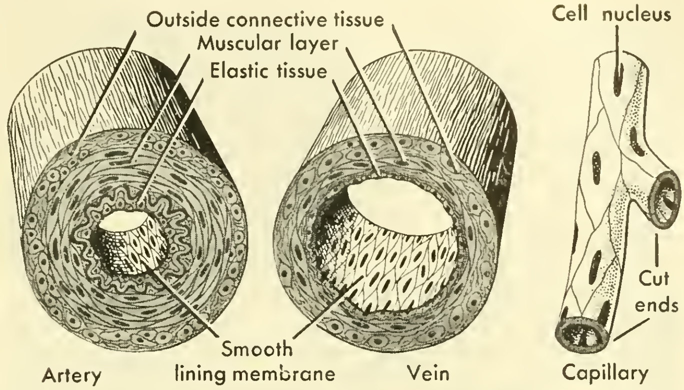


FIG. 216 *What layers do you find in the walls of arteries and veins? Which have thicker walls? How do capillaries differ from arteries and veins?*

Arteries help move the blood. The ventricles contract so forcibly that the blood is squirted well along the artery. When a large artery is cut you can see the blood coming out in spurts. Do you know what first aid procedure to use when an artery is cut? Various procedures may be used: pressure at certain points or a tourniquet are most common. It would be well if all of us joined a first aid class and learned how to stop bleeding.

The arteries which are attached to each of the two actively pumping ventricles have walls which contain a large amount of elastic tissue. This is true of all arteries, even those that are at some distance from the heart. As each rush of blood strikes these elastic walls, the artery stretches and at once comes together again, as any elastic substance tends to do. In this way the blood is squeezed within the artery and helped along its course. You can feel the walls of an artery pulsating (beating) whenever you put your finger over an artery that lies near the surface. In most parts of your body the arteries are buried deep within the tissues, but in your temples, in your wrists, and in some other places they are close to the skin. Here you can feel them stretching with each squirt of blood.

FIG. 217 *A piece of a cat's intestine showing branching arteries and veins. William Harvey saw small arteries and veins, but he could not see that they were connected. How are they connected?* (CLAY ADAMS CO.)

This stretching of the artery is called the *pulse*. Each pulse beat is caused by the rush of blood sent along the artery with each contraction or pump of the heart. Thus, counting your pulse is a convenient way of counting your heartbeats. Whenever your heart beats faster you can notice this difference in your pulse. Try EXERCISE 7.

A closer look at arteries. The arteries which arise in the heart soon branch so that the blood goes in several directions.

FIG. 218 *Taking blood pressure. What causes blood pressure? Why should persons who have abnormally high blood pressure be careful not to exercise strenuously?* (ENCYCLOPAEDIA BRITANNICA FILMS, INC.)

These branches subdivide again and again so that small arteries reach all parts of the body. In the figure of the cat's intestine you see a small artery subdivided into still smaller arteries.

The walls of an artery are thick compared with those of veins and especially compared with the capillary wall. An artery is lined inside with a thin and very smooth membrane (*serous* membrane) which obstructs the flow of blood very little. Outside the inner membrane is the elastic tissue. Outside the elastic tissue lie rings of involuntary muscle. See Figure 216. Nerve messages that cause the muscles to contract make the bore of the artery smaller; in other words the artery can carry less blood. On the other hand when these muscles are completely relaxed the artery is a far wider artery. In which condition is the artery leading to your face when you are blushing? In which condition, normally, would the artery to the small intestine be when digestion and absorption are going on? Since these muscles in the walls of arteries are involuntary, all the changes in the size of arteries go on without conscious control and often without your knowing it.

Blood Pressure. When the heart pushes blood into an artery it does so with great force; the blood, in its turn, pushes against the wall of the artery. The pressure against the wall of the artery is very great; if the wall were rigid and brittle it might break. An elastic artery wall expands, however, thus reducing the pressure on it. When we are young our arteries are very elastic and our blood pressure is said to be low. As a rule after we are about forty years of age our arteries slowly become less elastic and our blood pressure grows greater. This is normal; only unusually great increases in blood pressure are dangerous. Physicians measure blood pressure by using a device that stops the flow of blood in an artery by pressing against the artery wall. A mercury gauge measures the pressure it takes to press the walls of the artery together so that the flow of blood is stopped; this indicates the pressure of the blood against the artery wall.

Of course, your blood pressure rises when your heart beats harder. For this reason a person whose blood pressure is abnormally high should not engage in strenuous exercise. The pressure may rise so much that some smaller vessel may burst, allowing the blood to escape into surrounding tissues. If this happens in the brain there is a cerebral hemorrhage. As the blood escapes and clots, it causes temporary or permanent paralysis by damaging the delicate brain cells.

Fainting. It sometimes happens, for a variety of reasons, that the heartbeat is not forceful enough to push the blood uphill into the arteries running into the head. You may have seen a person's face and lips grow pale suddenly. Blood in sufficient amounts is not being sent up into the head; the person loses consciousness and loses control of his skeletal muscles; he faints. Frequently he can avoid fainting by holding his head down between his knees or lying flat on his back. Fainting in most cases is not a sign of any special defect. But it should be called to the attention of a physician if it occurs repeatedly.

An aviator may have a similar experience. When he makes a very fast and sharp turn or pulls out of a fast dive sharply, the blood in his body is pushed toward the outside of the curve. Since this is away from the head, the blood pressure may not be great enough to force blood to the arteries of the head. As soon as the brain cells fail to receive the necessary oxygen unconsciousness occurs. This is the "blackout" pilots talk about. They "see black" as they faint. As soon as the pressure of blood coming from the heart is greater than the force pushing the blood back the aviator recovers.

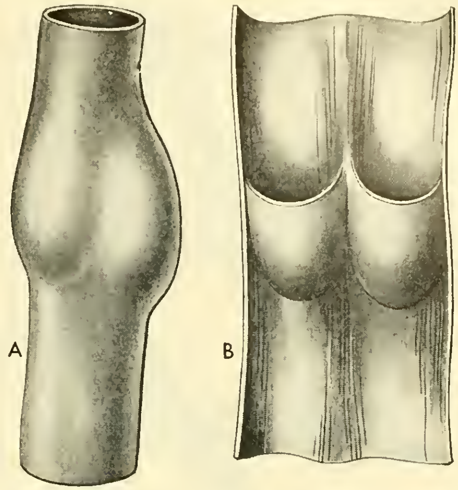


FIG. 219 *In* A *a vein is bulged at the point where a valve has stopped the backward flow of blood. In* B *a vein is cut open through the valve. In which direction does blood flow in this vein?*

Blood returns by means of veins. The finest branches of arteries open into capillaries. Here the spurting motion of the blood is lost. It flows more slowly and smoothly, pushed by the force of the blood behind it in the arteries. From the network of microscopic capillaries which lie in every part of the body, the blood flows into wider vessels, the veins. These unite with one another, forming larger and larger veins, the largest of which empty into the heart. Their walls contain some elastic tissue, but since the blood lost its spurting motion in the capillaries it flows smoothly through the veins, forced onward largely by the pressure of the blood behind.

But the pressure of blood flowing in the capillaries is not always sufficient to push blood uphill. The blood in the veins of the legs, for example, may tend to stop and flow backward. This is prevented by valves which are flaps like

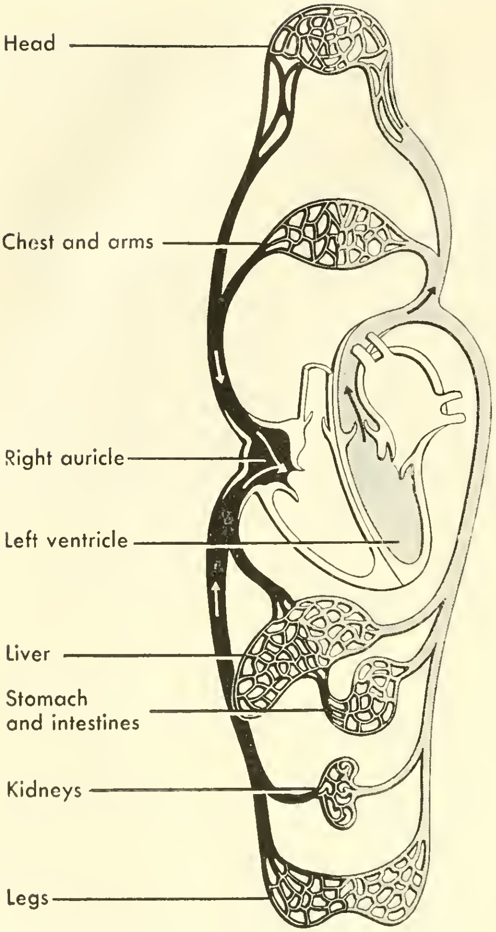


FIG. 220 *Diagram of circulation of blood from left ventricle to right auricle. Blood is forced out of the left ventricle through the aorta. Through what large organs does it flow? Branches to some of the smaller organs are not shown here. What kind of blood vessels are shown in black? Does the blood in them contain much or little oxygen? See Figure 221 for circulation from right ventricle to left auricle.*

patch pockets on a coat. The valves occur at regular distances all along the veins. See Figure 219. If now you will take time to do EXERCISE 8, you will learn how to find the location of some of the valves in the veins of your arm or hand.

Valves can prevent the blood from flowing backward but they have no force to move it onward. There is another force that keeps the blood moving onward to the heart. When you move about, particularly when you exercise actively, the inner parts of your body press against one another. Muscles, and even many of the internal organs, change size and shape constantly. As they do this they squeeze the veins within them or next to them. When the vein is squeezed the blood moves forward toward the heart since the valves prevent it from going backward.

Eventually it reaches the auricles and flows into them with a steady flow. But when the auricles are full, the muscles of their walls contract and force the blood into the ventricles below.

The course of the blood. Imagine that you are small enough to seat yourself on one of the red corpuscles for a ride around the body. Suppose you started from the left ventricle and were shot into the large artery known as the *aorta* (ay-or'ta). Soon the aorta branches, one branch leading to the head, another to the arms. At this point you might part company with some of your friends who were riding on other corpuscles. You continue, let us say, down the main artery toward the legs. But immediately you are saying good-by again to more of your friends, some of whom turn off to the stomach, some to the intestine, and some to other internal organs. The artery along which you are travelling has become a narrower tube and now branches equally, one branch leading down each leg. You happened to go into the left branch and soon find yourself in the left foot, in a very small artery. Suddenly things look different to you.

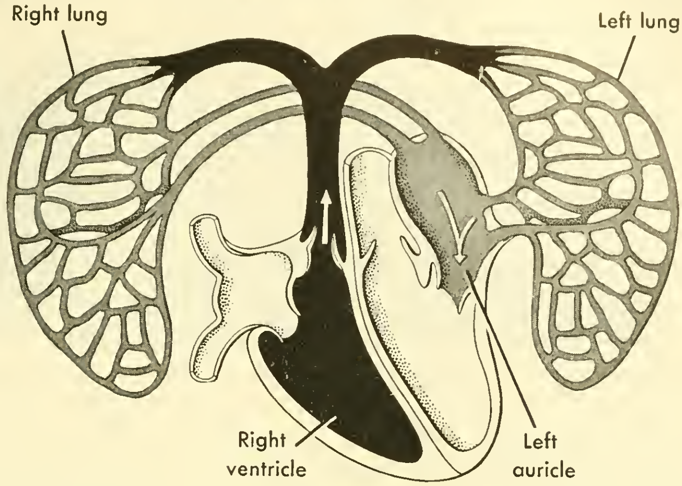


FIG. 221 *Circulation of blood from right ventricle to left auricle. Blood from the right ventricle goes only to the lungs. The black vessels are arteries. Does the blood in the shaded vessels contain much or little oxygen? Are the shaded vessels veins or arteries? What happens to the blood as it passes through the capillaries of the lungs? To which chamber does it go from the lungs?*

The tube is extremely narrow and you can look out through its walls. You are now in a capillary with very thin, transparent walls. Here the corpuscle on which you are riding changes color. Oxygen leaves the hemoglobin and diffuses into the neighboring cells. The plasma in which your corpuscle is floating is also undergoing changes, for foods are diffusing out of the capillary and the wastes of oxidation from the neighboring cells are entering the capillary. But you never stop for any of these changes to take place. On you go, noticing soon that you are again in a slightly wider tube and you cannot look out any more. You have left the capillary. You are in a vein and you are travelling straight uphill. You soon notice that you are joined again by corpuscles that had been down to the right foot. Then you meet the friends who had travelled through the stomach, the intestines, and other organs in the abdominal cavity. You are by this time riding in a very wide tube. This wide tube (called the *inferior vena cava*) connects with the right auricle and you soon find yourself dropped into the right auricle. Examine Figure 220 to trace your course and that of some of your friends. Figures 220 and 221 are diagrams to make clear the course of the blood.

You are now back in the heart but not where you started from. You are on the right side; you started from the left. In this right auricle occurs another reunion. For a large vein (*superior vena cava*) is bringing back your friends who had travelled to the head and arms. Without stopping you are forced by the heart contraction into the right ventricle. You will soon be on your way out of the heart once more. Continue tracing your route by studying Figure 221. You go into an artery. This time it is the pulmonary artery. Again there are branches and the artery gets narrower. Soon you find yourself for a second time in an extremely narrow, transparent tube, a capillary. But this time you are in a capillary in the lung. You would know that you are in the lung for your corpuscle becomes bright red once more as oxygen diffuses into your capillary and unites with the hemoglobin in your corpuscle. Carbon dioxide, carried both by the red blood cells and by the plasma in large amounts ever since you were close to the working cells in the foot, diffuses out of the capillary into the lung. Riding on a bright red corpuscle you go from the capillary into a small vein lying among the lung tissues, then into a larger and larger vein (the *pulmonary vein*). This vein connects with the left auricle. Having just gone through a second set of capillaries you are again on the left side of the heart. One contraction of the auricle sends you back to your starting point, the left ventricle. All your friends riding on different corpuscles have shared one experience with you; they have all been through a lung capillary. The only difference is that instead of having gone through a capillary in the foot they have gone through a capillary in some other part of the body. You have all been through two loops of blood vessels and by doing this you have made one complete circuit of the blood circulatory system.

If studying this paragraph took you ten minutes, the auricles of your heart filled and emptied themselves into the ventricles about 700 times while you were reading. Since the contraction of the auricles is immediately followed by a contraction of the ventricles your ventricles pumped blood into the arteries the same number of times in this interval. To test your understanding of this paragraph do Exercise 9.

What prevents backward flow of blood in the heart? When you studied the beef heart you probably found an answer to this question. In a normal heart all the blood in the auricles is pushed into the ventricles; none of it can return from

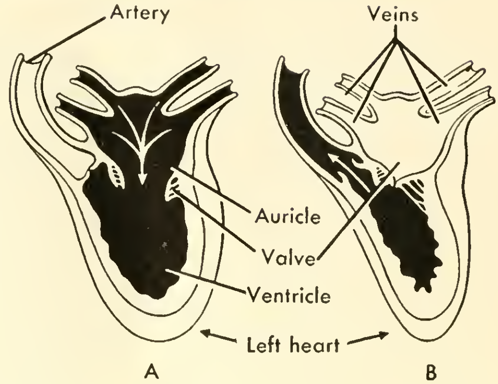


Fig. 222 *In* A *the valve between the left auricle and ventricle is open. In* B *the left ventricle has contracted. Why is blood not forced back into the left auricle? Where is it being forced by this contraction?*

the ventricles to the empty auricles because there are flaps of membrane called valves which act as doors. When the ventricles contract, the valves completely shut off each ventricle from the auricle above it. See Figure 222. With the contraction of the ventricles the blood, therefore, enters the arteries. And none of it has a chance to leak back into the ventricles because there are pocket valves at the mouth of each artery. They are like the valves found inside the veins. When blood starts to flow backward toward the heart it catches in the pockets which open up and block the way back. If the edges of any of the valves do not close tightly some blood "leaks" back.

Body cells are surrounded by a liquid. Many of the cells in the body tissues seem to be very closely packed together. They are not. Tissue cells are always surrounded by a liquid. The liquid is called lymph. Lymph is mostly plasma which has diffused from the capillaries. It is considerably diluted with water. You have seen it; it is the liquid which fills blisters. Lymph contains white cor-

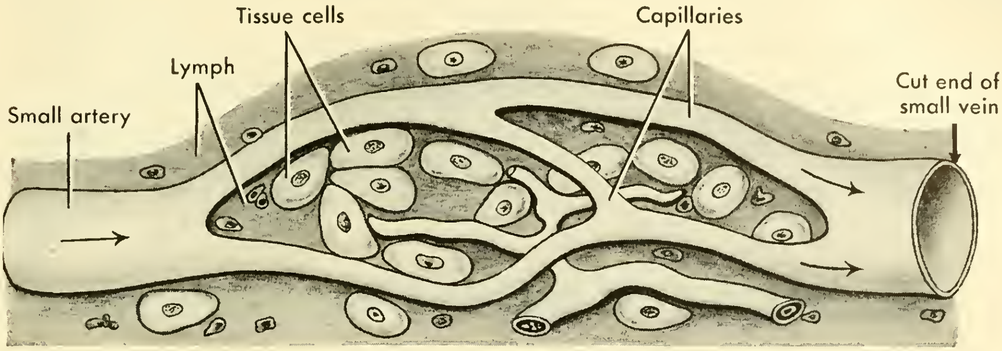


FIG. 223 *Body cells are surrounded by lymph. Find the tubes (lymphatics) through which lymph is returned to the blood.*

puscles too. They are constantly pushing their way through the walls of the capillaries by means of their pseudopods. Like plasma, lymph is an everchanging mixture of water, digested foods, wastes, and other substances. Various gases are dissolved in it. Its composition in different parts of the body varies according to the activities of the nearby cells.

Substances could not move into and out of cells were it not for lymph, since diffusion occurs only when there is a liquid on both sides of a membrane. That is, lymph makes possible a constant interchange of substances between tissue cells and capillaries.

How lymph is removed from tissues. After washing over the cells some of the lymph diffuses back into the capillaries. But much of it is drained off by special thin-walled vessels which carry nothing but lymph. They are called *lymphatics.* Tiny lymphatics are found among the cells in all parts of the body. They meet, join together, and form ever wider and wider tubes. Finally, one good-sized lymphatic (the *thoracic duct*) connects with one of the large veins on the left side of the body under the collar bone. A second one connects with a vein on the right side. The lymph enters the blood at these points.

If you now look back at the diagram of a villus (see Fig. 206) you will see tubes called *lacteals* (lac′tea′ls). Lacteals are microscopic lymphatics which connect with other lymphatics. Digested fats pass into the lacteal instead of into the capillaries. In this way absorbed fats reach the blood stream in a roundabout way, by means of the lymph system.

Lymph in the lymphatics is pushed along by the pressure of the liquid behind. Since there is no pumping, the lymph sometimes tends to stand still. Exercise of the whole body helps to prevent this just as in the case of blood in the veins. And, as in the veins, there are pocketlike valves along the length of the lymphatics which keep the lymph from flowing backward. The movement of lymph is slower than the movement of blood.

Lymph glands and the spleen. Along the course of the medium-sized lymphatics there are roundish bodies called *lymph glands* or *lymph nodes* as Figure 224 shows. These act as sieves separating

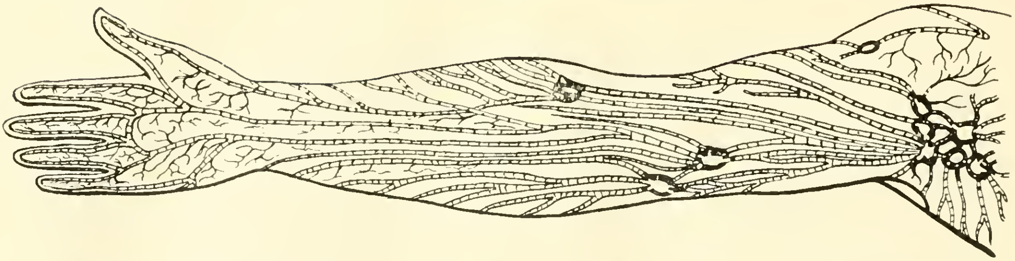


FIG. 224 *Lymphatics in the arm. Lymph glands or nodes occur at definite places. Where is there a group of lymph nodes?*

out the bacteria and other foreign bodies which have been swept up by the lymph. You read before that when bacteria enter the body many of them are engulfed by the white corpuscles and digested. Those that escape are normally caught in the lymph glands. They are digested there by the white blood cells found in the nodes in large numbers. Some kinds of white blood cells are made in the nodes; some kinds are brought from the spleen. When these glands swell after an infection you may become aware of their location in the neck, in the crook of the elbow and knee, and in various other regions.

The spleen is an organ about the size of your fist, found behind the stomach. You know that by contracting it increases the amount of blood and especially the number of red cells in the circulation. Besides this it manufactures in large numbers the special white cells which do their work in the lymph glands. It also destroys worn-out red corpuscles and probably has other activities not yet understood.

Note that the blood circulatory system and the lymphatic circulatory system are linked so that both blood and the tissue fluid, lymph, serve to keep materials moving about the body.

QUESTIONS

1. What are the two circulatory systems in man?
2. Where and how does food enter the circulatory system of man? What are two important characteristics of capillaries?
3. What does the circulatory system of man transport besides food?
4. Which tubes serve for long distance transportation of blood? In what three respects do they differ from capillaries?
5. By means of a table show the composition of human blood. Show also the composition of the liquid part.
6. State facts about the size, number, composition, origin, and storage of red corpuscles in man. How may anemia be caused?
7. Describe the appearance and behavior of phagocytes. Who discovered them? What is pus? What do some of the other white corpuscles do?

8. Explain clotting of blood, using the terms platelet, fibrin, and serum.
9. Why must blood be tested before it is used for transfusion? What are the four types?
10. What are two advantages in using plasma instead of whole blood? What can be used instead of plasma?
11. What is the relative position and the structure of auricles and ventricles in man? How does human heart muscle differ from other muscle?
12. When and by whom was the circulation of the blood first correctly explained? How were his conclusions arrived at?
13. How do arteries help to keep the blood moving? Why can the pulse be felt only in certain parts of the human body? What causes the pulse?
14. What three kinds of tissues are found in the wall of an artery? Of what importance is each?
15. What may make the blood pressure rise above normal? What is a cerebral hemorrhage?
16. What should a person do who feels faint? Explain. Explain the pilot's blackout.
17. How do veins differ from and resemble arteries in structure? What keeps the blood flowing through veins? Explain how the valves help.
18. Through how many sets of capillaries does the human blood go in one complete circulation? In which organs are these capillaries? Explain. Which veins carry bright red blood? Which arteries carry maroon colored blood? Explain.
19. What is accomplished by the valves in the human heart?
20. What is lymph? Of what is it composed? Of what importance is it?
21. What is accomplished by the lymphatics? What keeps lymph flowing through lymphatics?
22. What happens to foreign particles in the lymph glands and spleen? What other functions have these glands?

Exercises

1. How can you see capillaries? Wrap some wet absorbent cotton around the upper part of the body of a goldfish. Tie the fish down (with a bandage) in a Petri dish and cover its spread-out tail with a glass slide. Examine the edges under low power. Why are the edges best to look at? Do you see motion? Of what does the blood seem to be composed? In what directions does the blood travel? Are the vessels through which blood travels all of the same width? Since you can see the blood inside them what can you conclude about the walls of the capillaries? Does the blood ever stop for a length of time? Does it reverse its direction anywhere?

2. What is the composition of blood? Wash your hands in soap and water. Sterilize the tip of one of your fingers by washing it with alcohol. Press the blood toward the tip and then prick it with a sterile needle. Smear a drop of blood on a clean slide and cover with a cover glass. Examine under low and high powers. What is the color of the blood as you see it now? How do the corpuscles differ in appearance when they are massed in the drop? What is the name of the substance in which the red corpuscles are floating? Examine, if you can, a stained slide of blood. What other type of cell do you now see? In what ways does it differ from the red corpuscle?

3. Do oxygen and carbon dioxide in blood change its color? Obtain fresh blood from the slaughter house. To keep it from clotting add 10 cc of a 2 per cent potassium oxalate solution to every 100 cc of blood. Let it stand and observe. Then bubble oxygen through it. Does it change? Now do the same with carbon dioxide. Does the blood lose its color?

4. What is the structure of the heart? Examine a manikin or chart showing the heart in its normal position. Where does it lie? If the chart is carefully drawn, estimate the actual size of the heart. Examine a fresh beef or lamb's heart, which is similar to yours. If necessary use chicken's heart. In general, what is the color of the heart? Find the auricles; these are the light-colored structures, shaped like bent ears, at the broad end of the heart. Ask your teacher to help you distinguish the right auricle from the left. How do auricles compare with ventricles in size? Feel the auricles and ventricles. What do you notice? Explain. There is usually fatty tissue along the line where left and right ventricles touch. Unless the heart has been cut open when you buy it, make incisions (cuts) about three inches long in the right and in the left ventricle. Compare the muscular walls of the ventricles with those of the auricles. Compare the right ventricle wall with the left. What differences do you note? How thick are the walls of the blood vessels attached to the heart? Are they all the same thickness? Insert a glass rod into each blood vessel to determine the chamber with which it connects. Find the vessels which enter the heart substance itself. Study the valves. Notice the flaps of tissue held down against the sides of the ventricle by thin cords. These are the valves. When the valves close, what position is taken by the flaps? What effect would this have on the blood which tends to go back into the auricles?

5. Find and describe the tissue that forms the covering of the heart. What is it called? You would probably be unable to separate this from the tissues underneath. What kind of tissue makes up the walls of the heart? Feel it and describe. If possible, examine some prepared slides of heart muscle. How do these cells differ from voluntary muscle fibers? How do they resemble them? This kind of muscle, called *cardiac* muscle, is found only in the heart. Examine the inside lining of the heart. Does it seem to be mucous membrane or serous membrane? Explain. In examining the outside of the heart you saw fat tissue. And you know there must be blood among the cells. Name at least five tissues that make up this organ.

6. To see the heart beat in the frog. Dissect a frog as directed on page 202. Though the frog is completely dead, its heart continues to beat for hours, especially if kept in Ringer's or Locke's solution. The frog's heart is more nearly triangular than ours. It has two auricles but only one ventricle. In which part does the beat start? Do the two auricles contract separately or together? Which contracts more forcibly, auricles or ventricle? How long is the pause between heart beats? How could you explain this? What difference is there in the color of the auricles and the ventricle? Explain.

7. What is the effect of various activities upon the pulse rate? To take your pulse place the tips of your fingers (except the thumb) on the inner part of your left wrist below the base of the thumb. Why can the pulse be felt easily here? Where else may the pulse be taken? Take your pulse while lying down, while sitting quietly, while standing quietly for five minutes, after bending and touching the floor five times, after running swiftly for a short distance, after listening to some exciting event over the radio, and so on. Vary the activity in any way that is convenient. Record your observations. Explain the differences. Compare your sitting pulse rate with that of the other students. What is the most common rate for your group?

8. How can you demonstrate the presence of valves in the veins? Find a place on your arm or hand where the veins show most prominently. Place your thumb on one vein and while pressing down slide it toward the fingers. Observe what happens. Release the pressure. What happens now? Repeat this several times using different veins. What conclusions can you draw from your observations?

9. Copy Figure 220 which shows the course of blood from the left ventricle to right auricle. Now draw in Figure 221 fitting it together with the first. Color with red crayon all blood which carries much oxygen. Color with blue all vessels carrying blood which has lost its oxygen. Under your diagram list the arteries which carry bright red blood. Now list arteries and veins which carry blood that has lost its bright red color.

Further Activities in Biology

1. Could you make a chart showing the blood vessels as roads, a few scattered cells to which goods are delivered as buildings, and the transportation of goods to and from the cells?

2. Report on the life and work of William Harvey.

3. Report on some of the theories of the circulation of blood before Harvey's time. (See Locy, *Biology and Its Makers.*)

4. Look up and report on blood transfusions.

5. Make a model of a human heart.

PROBLEM 4 *How Are All Our Cells Provided with a Constant Supply of Oxygen?*

Where oxygen enters the blood. The living, working cells need food. The food enters the blood in the villi of the small intestine and is carried to the cells. The cells also need a constant supply of oxygen; respiration goes on in all the cells. Blood brings the oxygen to the cells. Much oxygen is used and there are special organs that make it possible for large amounts of oxygen from the surrounding atmosphere to enter the blood. These organs are the lungs. The lungs are so placed and constructed that an enormous amount of blood comes near a very large quantity of air in a short time.

Passageways to the lungs. If you do EXERCISE 1 and study Figure 225 you will be able to trace air along the air passageways in the head and neck. By doing EXERCISE 2 you will learn how the air is cleansed and warmed on the way to the lungs. Once it has passed through the

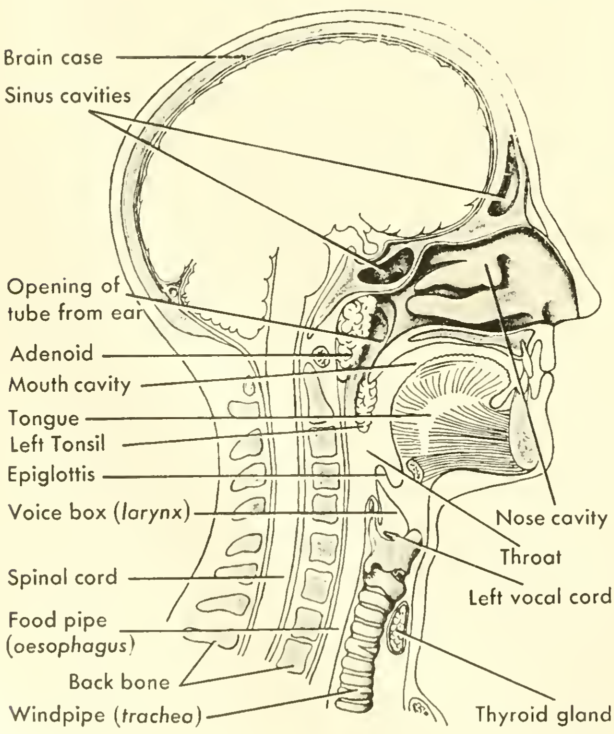


FIG. 225 *Section through head and neck. Name in order all the passages through which the air passes in travelling to the windpipe. What happens to air as it is breathed in through the head and neck?*

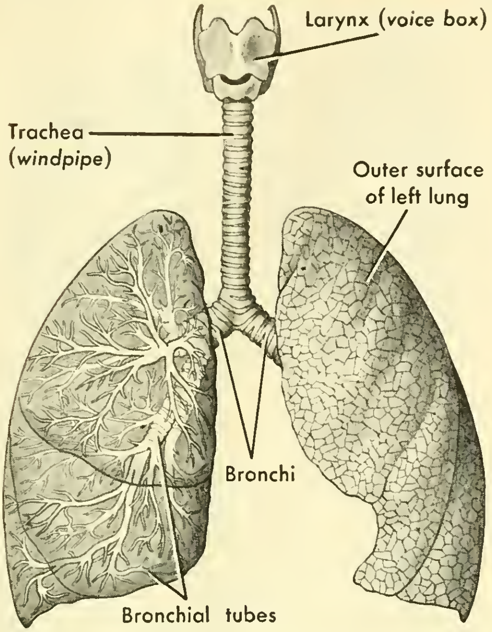


FIG. 226 *The right lung has been cut to show the larger bronchial tubes. See Figure 227 for the smallest bronchial tubes and the air sacs.*

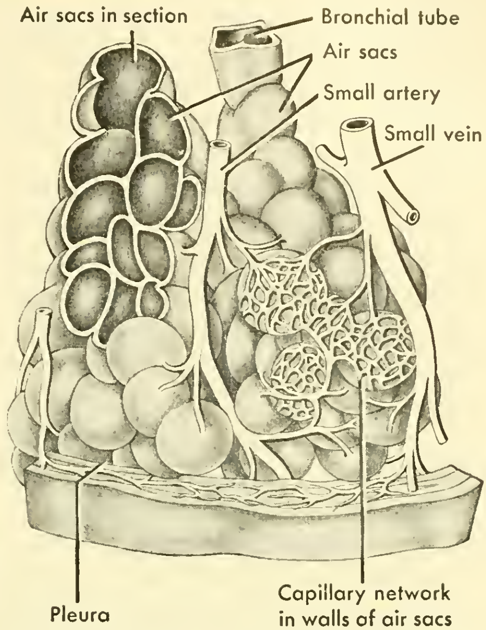


FIG. 227 *A piece of lung highly magnified. There are capillaries in the walls of all the air sacs. Of what importance is this?*

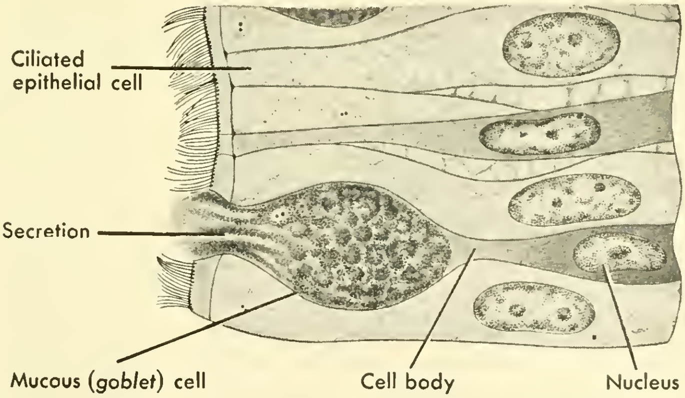


FIG. 228 *Mucous membrane lining the breathing passages. It contains two very different kinds of cells. How does each help in cleansing the air that enters?*

voice box (*larynx* — lar′inks) it enters the windpipe (also called *trachea* — tray′-kee-a). This tube, about one-half inch across, extends down a little more than four inches in an adult of average size. Then it divides into left and right branches (*bronchi* — bron′ky). Each branch enters a lung and divides and subdivides like the branches of a tree.

The windpipe is lined with epithelial cells which have cilia lashing upwards. In its walls lie incomplete hoops of cartilage which keep the windpipe open, allowing free passage of air. They support and protect the tube. The branches also have cartilage support but the amount of cartilage gets less and less as the branches become smaller. The finest branches lack cartilage. Their walls contain, besides the epithelial lining, rings of involuntary muscle. In an attack of asthma these muscles contract; this results in partially shutting off the air supply.

The lungs – a vast membrane. A study of lamb or beef lungs, as described in EXERCISE 3, will help you to understand the structure of lungs. The branch from the windpipe disappears inside of the lung. Here, as you know, it divides into branches, *bronchial tubes*, taking on the appearance of a tree without leaves. The branching is clearly diagramed in Figure 226. The bronchial tubes are not lung tissue. The lung tissue itself is found where the leaves of the tree would be. Each fine twig opens out into an air sac whose walls are made of a single layer of flat cells (epithelium) and a thin layer of elastic tissue. This is the lung tissue. Each sac can fold up into a small space or stretch to a great size. In the walls of each air sac there is a network of capillaries (see Fig. 227).

If the lungs were a simple bag the number of square inches of membrane that could be brought in contact with capillaries would be small. A large house left as an empty shell would have relatively little wall surface inside. If, however, this same building were divided up into apartments the interior wall surface would be increased astonishingly. The lung is built on the same principle. For this reason, the lung membrane has an enormous area. All of the area is in contact with capillaries. Gases are continually diffusing into the capillaries and out of them. Thus the composition of the blood is rapidly changing as it flows through the lungs.

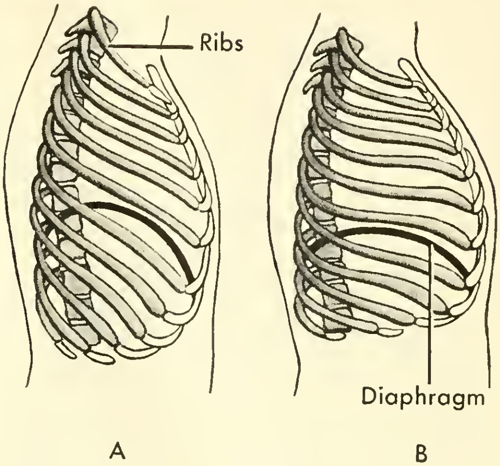


FIG. 229 *Figure* A *shows the chest cavity while you are exhaling. Figure* B *shows it while inhaling. Compare the position of the diaphragm in* A *and* B. *What difference do you note? What difference do you observe in the ribs of the two chest cavities? How do the movements of the diaphragm and ribs change the size of the cavity? Explain why the changes in size cause movement of air into and out of the lungs.*

The importance of elasticity in the lungs. If the lungs were not elastic it would be impossible for you to breathe, that is, to inhale and exhale air. The chest moves regularly every few seconds. It grows larger and smaller, larger and smaller. And so do the lungs. When the chest cavity increases in size the lungs follow suit; when it grows smaller, the lungs also grow smaller. Because the lungs are elastic they can change size with the chest cavity. Some of you probably can enlarge your chest cavity more than others. Try your chest expansion by breathing out and measuring your chest just below the armpits with a tape measure. Then take as deep a breath as you can and again record the size of your chest.

How is the chest cavity changed in size? The experiment you have just performed shows the increase in girth (distance around) of the chest. As you read this take a deep breath. Can you feel the muscular effort involved? The muscles are attached to the ribs. As they contract they force the breast bone up and out in such a way that the cavity becomes larger. You can make a very simple model to demonstrate this movement of the ribs by doing EXERCISE 4.

This is not the only way in which the chest cavity becomes larger. A thick sheet of muscle called the *diaphragm* (dye'a-fram) makes up the lower wall of the chest cavity. This diaphragm completely separates the chest from the abdominal cavity. There are a few large holes in the diaphragm through which the food pipe and some of the main blood vessels pass, but the diaphragm and the tubes are joined so closely that neither air nor liquid can slip between them. Now this sheet of muscle is dome shaped when relaxed (see Fig. 229). As it contracts it flattens. This flattening of the diaphragm makes the chest cavity larger from top to bottom. It occurs at the same time as the raising of the ribs, so that the size of the chest cavity is increased considerably in two directions: from back to front and from top to bottom.

The contraction and flattening of the diaphragm and the contraction of the muscles which raise the ribs and breastbone are what we call breathing movements. With every contraction of these various muscles, you breathe in. With the relaxation of the rib muscles the ribs once more move down and in; and as the diaphragm relaxes, it arches up again. The chest cavity thus becomes smaller. This relaxation of the muscles requires no effort. And as you relax the muscles you breathe out. Take a deep breath again. You can feel the effort of inhaling and the relaxation of exhaling.

How the lungs are filled with air. If you dip the open end of a medicine dropper into water while squeezing the bulb and then let the bulb regain its normal size, water rushes up into the dropper. The water is pushed up into the dropper by the force of the air pressure down on the surface of the water outside the dropper. Since air cannot be seen pushing anything, you may think that the water is "pulled up" into the dropper or that there is a vacuum which the water must fill. But these explanations have been shown by many experiments to be incorrect. The water is between two pressures. There is the normal air pressure on the outside, pushing against the surface of the water in the dish, and there is air pressure on the inside of the dropper. But you have squeezed much of the air out of the dropper and as you relax the bulb the air inside will have little pressure. The outside air pressure is greater and it pushes water into the dropper.

Just as water can be pushed by the pressure of air, so air itself or any gas can be pushed. If you put the open end of the dropper into a smoke cloud you would see the smoke move in just as the water did.

This is exactly what happens when you breathe. While you are not breathing in or out, the pressure of air in the air sacs and the pressure of air outside are equal. Air does not move in or out. But as soon as you increase the size of

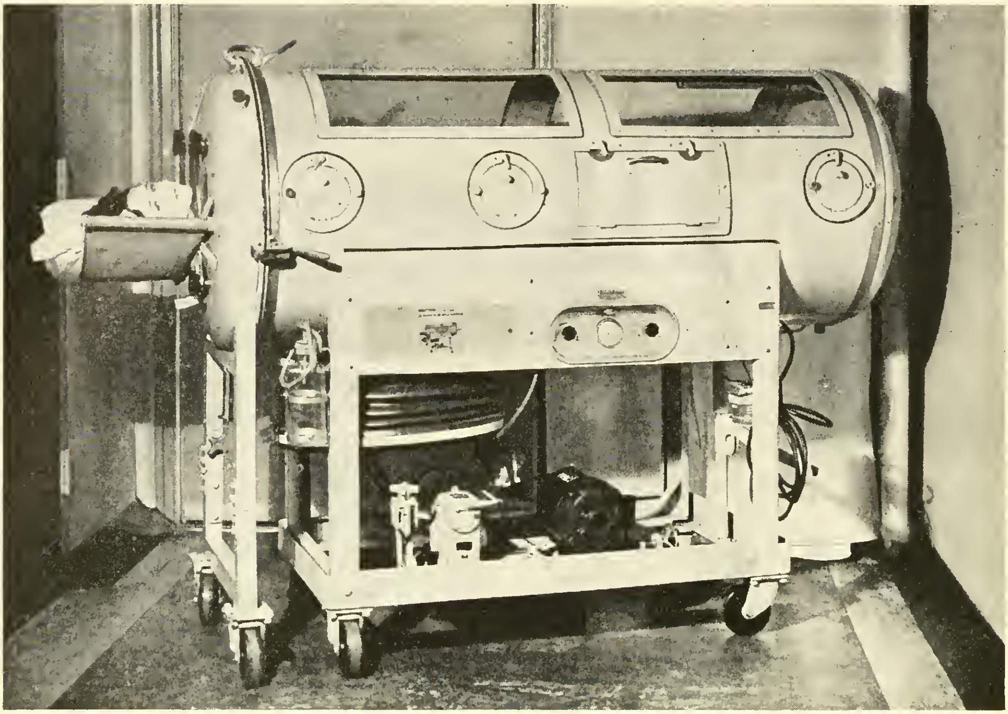


FIG. 230 *An "iron lung." This apparatus is used to produce breathing movements for paralyzed or weak patients. How does it work?* (CHILDREN'S MEDICAL CENTER, BOSTON)

the chest cavity the pressure of air inside the chest cavity becomes less. The pressure of air outside the lungs is greater and air is pushed in. It moves through the nose and mouth passages and through the windpipe and bronchial tubes into the air sacs.

If you then make the chest cavity smaller, the walls press on the air sacs, thus raising the pressure of air inside. Since the air pressure inside is greater than the pressure outside, air moves out of the sacs. It flows through the bronchial tubes and out of the nose and mouth passages. This is exhaling. Under normal conditions we inhale and exhale about 18 times a minute. You can make a model of a chest cavity that can be made to "breathe." See EXERCISE 5.

In poliomyelitis (infantile paralysis) the chest muscles and diaphragm are sometimes paralyzed. An "iron lung" (Fig. 230) is used to maintain the breathing motions. Can you figure out how it works? Be sure to check your reasoning.

During the breathing movements as the lungs fill up with air and rub against the inside wall of the chest cavity there might be friction between these two surfaces. But friction is reduced to a minimum because the lungs are covered and the chest walls are lined with thin, moist, very smooth membranes, called the *pleura*.

Few air sacs are filled when you inhale. Most of the air sacs, particularly those that lie farthest away from the windpipe, neither receive nor lose air during ordinary breathing. A particularly forcible expansion of the chest brings some of them into play, but even this will not send air into the most distant air sacs. In the same way, exhaling never leaves the lungs empty of air. Yet the air in these remote parts mixes slowly to some extent with the air you inhale because the gases within the lungs move about by diffusion.

Changes in the air within the air sacs. You can determine in a crude way how exhaled air differs from inhaled air. Can you devise a simple experiment? If not, you will find suggestions in EXERCISE 6. Scientists have analyzed the air breathed in and the air breathed out. Thus they know what goes on inside. Ordinary air contains about 78 per cent of nitrogen, less than 21 per cent of oxygen, a fraction of 1 per cent of carbon dioxide, and varying amounts of water vapor. Water vapor is not counted in the percentages. The air that comes out of the lungs contains the same per cent of nitrogen but only about 16 per cent of oxygen, 4 per cent of carbon dioxide, and much more water vapor than it had when it went in.

While the heart is beating normally, three and one half to four or more quarts of blood are brought to the lungs each minute. Here the blood flows through capillaries so narrow that the red corpuscles move practically in single file. Each corpuscle is separated from the supply of oxygen by the thin capillary membrane and the thin membrane of the air sac. Each membrane consists of cells only one layer thick. These are excellent conditions for diffusion. Since the blood arriving in the lungs has come from all parts of the body it has recently lost a part of its oxygen supply to the cells and it has acquired an extra amount of carbon dioxide from the cells. Therefore oxygen will diffuse from the air sacs into the capillary; and carbon dioxide will diffuse from the capillary into the air sac. The oxygen that enters combines directly with the hemoglobin. However, there is much more oxygen in the air sacs than the red cells can pick up. For this reason there is much oxygen left in the exhaled air.

Breathing and respiration. As applied to animals, the term respiration means the exchange of gases between an organism and its surroundings. In an organism like man this is a complex process which is most easily described in two parts. You have just read of the entrance of oxygen into the lung capillaries and the passage of carbon dioxide and water vapor out of the lungs. This was called breathing. The oxygen taken in goes to all the cells. Now the movement of oxygen into cells, the oxidation with the release of energy which follows, and the movement of carbon dioxide out of the cell is the second part of respiration, called cellular respiration. Respiration in man, therefore, includes breathing and cellular respiration. Botanists use the term respiration to mean only the oxidation of food in the cells.

What makes the chest muscles work? Regular messages travel along the nerves to the muscles of the ribs and to the diaphragm so that regular contractions take place. Normal breathing is thus an automatic process that goes on during sleep as well as during waking hours. These messages start from a small region at the base of the brain called the breathing

FIG. 231 *The man wearing a vest is using the Shaefer prone pressure method of artificial respiration. At what times is it useful to know how to give artificial respiration?* (AMERICAN RED CROSS)

center. (It is in the part of the brain called the *medulla oblongata.*)

The nerve messages leave the breathing center at a fairly regular rate. Many factors affect the rate at which the nerve messages leave the center. One of these factors is the amount of carbon dioxide in the blood. This factor affects the breathing rate in the following way. When there is an unusual amount of oxidation there is also an unusually large amount of carbon dioxide in the blood. Thus the breathing center is stimulated to send out impulses faster. As a result you breathe faster and deeper and your lungs exhale more air rich in carbon dioxide. Because of this, more and more carbon dioxide diffuses out of the lung capillaries; gradually the concentration of carbon dioxide in the blood is again decreased to normal and you once more breathe more slowly. Determine your normal breathing rate and the rate after moderate exercise. Follow the suggestions in EXERCISE 7. Certain sensations, such as cold due to the sudden chilling of the skin, also change the breathing rate. So do emotions, such as fright or anger.

There is a certain amount of conscious control of breathing. You can decide to take a deep breath or to stop breathing, for example. But you cannot ordinarily prevent it, or, as we say, hold your breath, for more than two minutes.

"Artificial respiration." All cells need a constant supply of oxygen, particularly the brain cells. The damage that results from completely cutting off the oxygen supply from the brain cells for as little as ten minutes can never be repaired. But even after a person's breathing is interfered with for any reason, such as filling the lungs with water (this is what happens in drowning), or with poisonous gases, or as the result of an electric shock, the blood is still delivering oxygen to the individual cells. This continues for some time even though the amount delivered is very much smaller. As long as the heart muscle has enough oxygen to keep contracting the person has a chance to survive. When breathing has been stopped, the small supply of oxygen in the body must be added to as rapidly as possible. We must try to get fresh air into the air sacs by means of "artificial respiration." As more oxygen diffuses from air sacs into blood the body cells gradually begin to work more actively. In time the breathing mechanism again starts up. But all this may take a long time. For this reason artificial respiration must be continued, sometimes for several hours, until the person again begins natural breathing, or until a physician declares the case hopeless.

Artificial respiration may be given without apparatus in one of two ways. The Shaefer prone pressure method is perhaps the better known of these methods. The patient is placed on his stomach with his face turned to one side. The first aider straddles him (see Fig. 231). Pressure is applied to the lower ribs gently but firmly and rhythmically at the rate of 16 times a minute. In another method the patient is placed on his back on a board or stretcher and rocked in a seesaw fashion up and down 16 times a minute. The rocking must be sudden but gentle. The abdominal organs press against the diaphragm regularly and thus reestablish the breathing movements. Everyone should learn to use the Shaefer method of artificial respiration. The Red Cross, the Y.M.C.A., the Y.W.C.A., Boy and Girl Scouts, and various other agencies provide such instruction.

Altitude troubles. Air pressure gets lower the higher you rise above sea level. This affects fliers in two important ways. There is much nitrogen carried in the blood and in the body fluids. This is neither helpful nor harmful under normal circumstances. It is present merely because nitrogen forms 79 per cent of the atmosphere at sea level, and by diffusion it enters the blood. When a flier ascends rapidly to a region where the air pressure and therefore the nitrogen pressure is lower the nitrogen forms bubbles in the blood and in other body fluids. These bubbles cause pain, may cause paralysis and even death. This condition is called the "bends." The formation of bubbles in the blood is similar to the formation of bubbles in a bottle of soda water when the pressure is lowered by removing the cap. "Bends" was known before the days of high flying; deep sea divers and other men who worked under high pressures and later changed too quickly to normal air pressure met the same difficulty. The flier can overcome the bends by inhaling pure oxygen before his flight. In one hour he can rid himself of half the nitrogen in his body, thus preparing himself for his ascent. But often fliers must take off at a moment's notice without such preparation. Some large planes have pressure-sealed cabins that maintain a suitable air pressure no matter how high the plane goes.

Another result of high altitude flying is known as *anoxia* (an′-ox′-ia), which means a lack of sufficient oxygen. Above 10,000 feet the air is so rarefied that the amount of oxygen is too small to provide for sufficient diffusion into the blood. Corpuscles passing through the lungs do not take on their full load. At first this causes a feeling of well-being, so the flier who is climbing in his plane is not aware of his danger, and fails to use his oxygen mask. As he goes higher the lack of oxygen affects his vision and hearing; coordination and judgment become poor; he becomes unconscious. With oxygen masks fliers may now fly at altitudes of well over 40,000 feet.

How did we answer the problem question? The movements of the chest cavity are responsible for the passage of air into and out of the lungs. The muscular diaphragm and the muscles attached to the ribs contract, enlarging the chest cavity. They relax, diminishing the size of the cavity. As a result of this contraction and relaxation air enters and leaves the lungs. The air that enters has a larger percentage of oxygen and a smaller percentage of carbon dioxide than the air that leaves. This is because the air sacs are well fitted for an exchange of gases between the blood and outside air. They have a large surface, their walls are thin and moist and plentifully supplied with capillaries. With blood to transport the oxygen you can see how our cells are provided with a constant supply of oxygen.

Questions

1. Of what use to a man are his lungs?
2. Name in order the openings and passages through which air passes on its way to the lungs. Describe the structure of the windpipe and explain how each part is useful.
3. Explain the relation to one another of bronchus, bronchial tubes, air sacs. Describe the structure of an air sac.
4. When our chest cavity grows larger what happens to the air sacs? Why can they do this?
5. Explain two ways in which you can make your chest cavity larger. Explain how the chest cavity becomes smaller.
6. Explain the connection between air pressure and the filling of a fountain pen. Explain how your lungs become filled with air and how air is moved out of the lungs.
7. To what extent are the air sacs emptied in breathing? To what extent is the air within them changed?
8. How does the composition of the air that leaves the lungs differ from that which enters? Account for the two important changes just given.
9. In what different ways is the term respiration used?
10. What makes the chest muscles work in ordinary quiet breathing? What causes them to move faster after vigorous exercise? What else may cause them to move faster?
11. Describe two methods of giving artificial respiration. Explain the sequence of events within the body when you give artificial respiration.
12. State two possible results of high altitude flying. At about what altitude does anoxia occur? What are its symptoms?

Exercises

1. Through what passages does the air travel in reaching the lungs? Close your mouth and inhale. Where does air enter? The nostrils open into the throat. Put your finger on the neck just under the chin, and speak. What do you feel? What pipe lies in the front of the neck? Does this seem to have hard or soft walls? Compare with Figure 225. What name is given to this portion of the tube? What are the advantages of hard walls? Where does the food pipe lie with reference to the windpipe? In reaching the food pipe food passes over the entrance to the windpipe. Place your fingers on your voice box again and swallow. Describe. While you are doing this, the epiglottis, which you see in the diagram, moves from its upright to a horizontal position. Of what advantage is this in swallowing? What fails to happen when you "choke"? Why can you not speak and swallow at the same instant? When you get a crumb into the top of your voice box, how do you get rid of it? Explain. Examine the diagram. Find the adenoids in the picture. How might a child give evidence of having enlarged adenoids? Why are children with large adenoids sometimes listless and dull in school?

2. Why is it better to breathe through the nasal cavities than through the mouth? Air contains dust which is irritating. On the dust particles are bacteria which may be injurious. Examine the entrance to your nasal cavities. How are they fitted for stopping the entrance of dust? In the upper part are microscopic cilia. Of what use might they be? The upper part of the nasal cavities and the mouth are both lined with mucous membrane. What characteristic of this membrane fits it for catching dust? Considering the width of the nasal cavities and the mouth cavity, which has a better chance of catching dust? Why? In winter when the outside air is cold, which cavity is better fitted for warming up the air on its way into the lungs? Explain. State three reasons why it is better to breathe through the nose than through the mouth.

3. What is the structure of a sheep or beef lung? Which of the structures mentioned in the text can you find in this specimen? What do you observe that has not been mentioned? Feel the outer surface and describe. This smooth membrane is part of the *pleura*. The pleura not only covers the lungs but lines the inside of the chest cavity. Of what use is a smooth membrane here? (In life it is moist.) What kind of tissue makes up this membrane? What do you notice when you feel the windpipe? The substance in the walls is cartilage. How is the cartilage arranged? Of what advantage is the cartilage? Are these lungs collapsed or expanded? If you can, compare the weight of a piece of lung with the weight of a piece of beefsteak of the same size. Explain. Lay a piece of beef lung in a pan of water. Why does it float? What color is the lung? Why? Write up your observations. Compare them with others.

4. How do the ribs move in breathing? A model may be used to show the rib movements. Use a board, one inch by two feet, to represent the

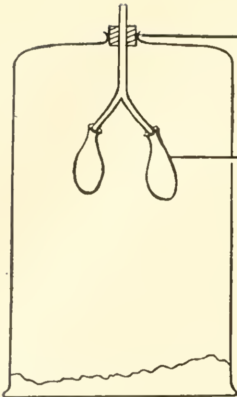


FIG. 232 *A simple model to illustrate breathing. How does this model differ from the chest cavity with its lungs?* (*See* EXERCISE 5.)

backbone. Fasten pieces of stiff wire two inches apart at right angles to this board. Bend the wires until they almost meet in front. The wires are to be connected in front by another strip, representing the breast bone. If the wires are fastened loosely, they can be moved so that they slope downward at an angle. This is the position of the ribs after air has been exhaled. Raise the ribs. What happens to the breast bone? What happens to the size of the cavity? (A simple two-dimensional model may be made by using strips of cardboard and brass fasteners. Try it.)

5. How can you demonstrate the part played by air pressure in breathing? See Figure 232. Attach two rubber balloons to a Y-tube. Push the other end of the tube through a one-hole stopper that has been placed in the neck of a bell jar. The balloons are to hang down in the jar. Cover the large open end of the jar with rubber sheeting. The connection between sheeting and jar must be air tight. Make this model "breathe." Explain fully. What happens?

6. How does exhaled air differ from inhaled air? Before you perform this experiment make sure you know what percentages of oxygen and carbon dioxide are normally present in the air. Blow your breath into a rubber balloon. Notice how much the balloon has expanded. Then permit it to empty itself under the surface of limewater in a jar. Now pump air into the balloon until it is as large as it was before. Empty it into limewater in another jar. Examine both jars. What conclusion do you draw? Now light a candle. Invert a jar over it. Notice how long the candle burns (use a watch). Collect exhaled air in a jar of the same size (over water). Invert this jar over a burning candle. How long does the candle burn? What conclusions do you draw? Prepare a report.

7. What is the effect of exercise on the rate of breathing? How often do you breathe in a minute while sitting quietly? Do setting-up exercises for one minute and then count the number of times you breathe in a minute. Explain. Compare your results with those obtained by others.

FURTHER ACTIVITY IN BIOLOGY

Find out the best method of artificial respiration and demonstrate it to the class. (Consult *Boy Scout Handbook* or *American Red Cross Manual.*)

PROBLEM 5 *How Does the Body Get Rid of Wastes Formed by Cell Activity?*

Wastes formed by living cells. Oxidation goes on in all living cells. Food and oxygen are brought to them by the blood stream. When carbohydrates and fats are oxidized the carbon and hydrogen in them unite with the oxygen, forming carbon dioxide and water. These are waste substances because under normal conditions they are not used again in the body.

When protein (containing carbon, oxygen, hydrogen, nitrogen, sulfur, and phosphorus) is oxidized, other compounds besides water and carbon dioxide are formed. The nitrogen does not unite with oxygen directly; nitrogen is an inactive element and does not easily enter into new combinations. But, in a roundabout way, a compound consisting of carbon, oxygen, hydrogen, and nitrogen is formed. This substance is called *urea* (you-ree′a). Urea, too, is called a waste because it is of no further use to the body. Another nitrogenous waste produced is *uric acid*. There are also "salts" formed that are wastes. All of these are soluble in water.

Cell wastes are removed. You know that the cells in an animal's body lie in a liquid known as lymph. The wastes, which are all soluble, diffuse out of the cells into lymph and capillaries. Directly

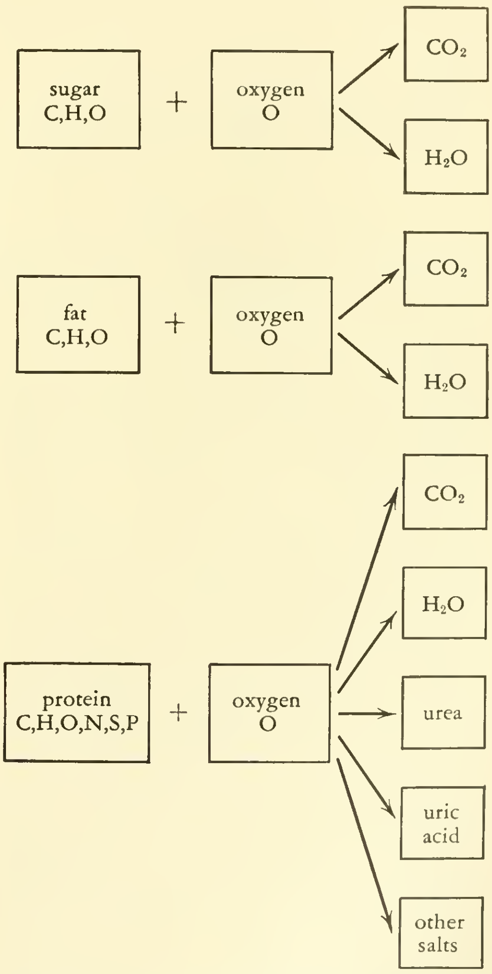


FIG. 233 *The waste products formed when sugar, fat, and protein are oxidized. Which food substance yields the largest number of wastes? What are the five wastes produced by the oxidation of this compound?*

or indirectly the wastes get into the blood stream and become part of the plasma. Once in the blood, the wastes are carried about until they reach some organ which is specially fitted to take them out of the blood circulation and remove them from the body. Such organs are called *excretory* (ex′cre-tor-y) *organs* for they have the power of excretion. In each organ special substances are removed from the blood and passed to the outside of the body. The organs which do this are the lungs, the kidneys, and the skin.

The kidneys — their structure and work. There are two kidneys. Each is a small but extremely important organ. The kidneys are attached to the abdominal wall behind the small intestine just below the diaphragm. There is one on each side of the spinal column. Each kidney is bean-shaped, about four inches long, and dark red in color. Examination of beef or lamb kidneys will give you a very good idea of man's kidney. See EXERCISE 1. In the outer part of each kidney there are about one million microscopic structures which do the work of filtering the waste substances out of the blood. Each is shaped like a ball with a mass of capillaries coiled around it. From it runs a microscopic tube which, after joining other tubes, ends in the cavity of the kidney. The waste substances which enter the kidney from the blood are largely water, urea, uric acid, and some salts. The solution is called *urine.* As the urine flows from the million microscopic tubes it fills up the cavity of the kidney. From this cavity it flows down the *ureters* (you-ree′-ters), leading to the bladder. These ureters can be easily seen in the kidney you may be studying and in the diagram.

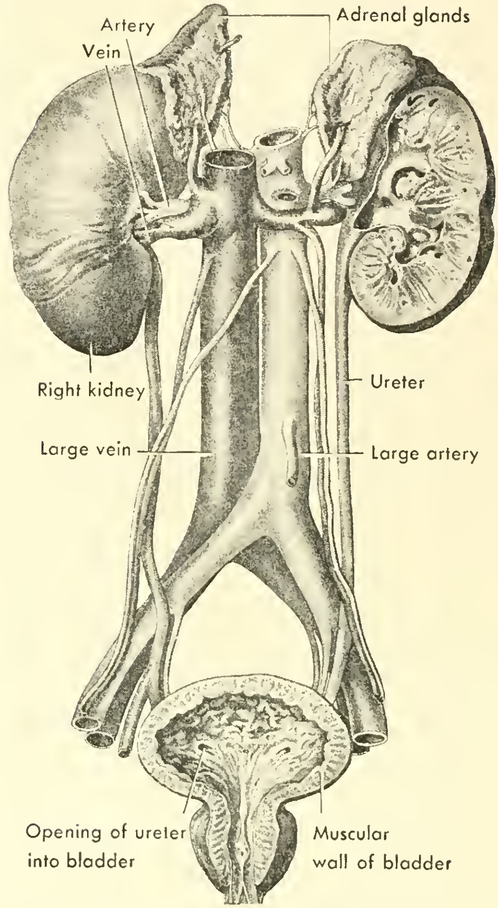


FIG. 234 *The left kidney is cut open to show the cavity where the urine collects. Where does the urine go then? In what organ is it stored? See Figure 235 to learn more about the complex outer portion where wastes diffuse out of the blood and collect in branched tubes.*

The bladder holds the urine until it is passed from the body.

While the wastes, for the most part, are relatively harmless substances in themselves, if they were not removed from the body they would accumulate in the plasma and in the lymph; diffusion out of body cells would be stopped and many of the life processes would thus be interfered with.

FIG. 235 *The branched tubes which carry urine from the outer portion of a sheep's kidney to the kidney cavity.* (WARD'S NATURAL SCIENCE ESTABLISHMENT, INC.)

The skin is also an important organ. The skin is an organ of excretion; it excretes water and small amounts of salts. But this is not what makes it important to the working cells. Its importance lies in the fact that it is active in regulating the body temperature. Protoplasm is a sensitive, highly complex substance. If conditions are varied beyond comparatively small limits, the protoplasm of your body cells will cease to function normally. The skin covering the whole body, under normal conditions keeps the temperature of your cells almost uniform. Do EXERCISE 2 to see whether the body temperature is kept uniform. When you consider the extremes of temperature to which many of us are exposed in various climates, or at different seasons of the year, this is most amazing. Our mouth temperature is about 98.6° F whether we are out in a blizzard or sitting next to the radiator or stove indoors, whether we live at the north pole or at the equator.

The process of oxidation releases heat energy in the body. As more oxidation goes on our temperature would tend to rise. But the skin normally operates so that as the temperature tends to rise it is brought down. On the other hand when there is less oxidation this activity of the skin becomes less. The skin regulates temperature in several ways; much of it is done by the sweat glands.

The sweat glands. If you examine your skin with a magnifying glass you will find it closely dotted with pores. Many of these are the openings of microscopic sweat glands sunk down into your skin. Water leaves them all the time. You can test this by placing a close-fitting, clean, dry vial over the end of one of your fingers.

Each sweat gland consists of a long, narrow tube which is coiled up at its lower end. Around this coiled part is a network of capillaries (Fig. 237). The gland cells receive large quantities of water and a small amount of various salts from the plasma flowing through the capillaries. These wastes diffuse into the gland cavity as sweat. Thus the cavity and duct of each gland become filled with sweat. This overflows onto the skin from each of the many glands. The salts contained in the sweat remain on the skin while the water evaporates, as you can show if you do EXERCISE 3.

The secreting of sweat is a continuous process. Under normal conditions one

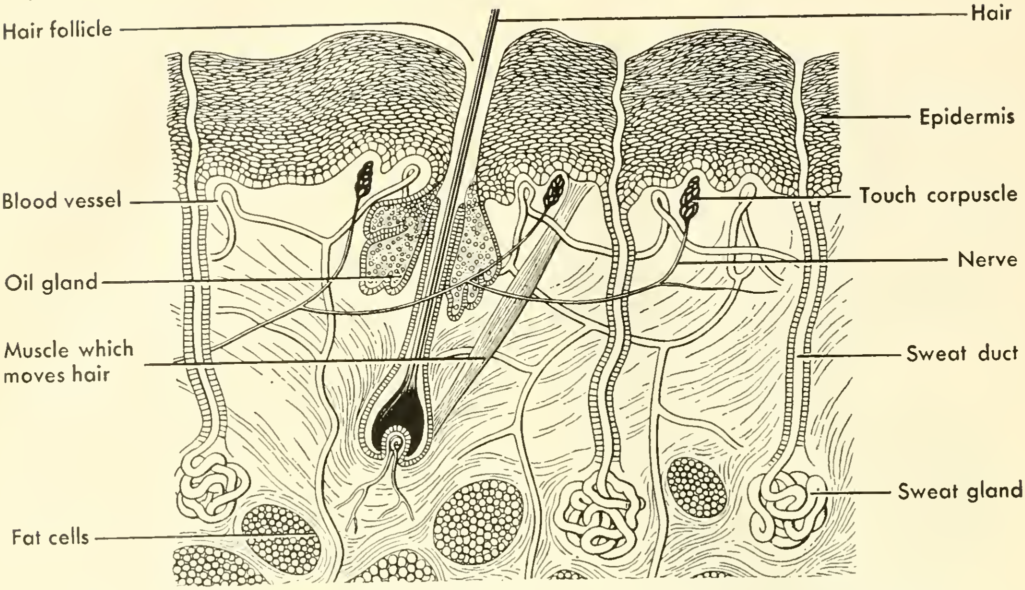


FIG. 236 *Section through skin. In which layer are blood vessels and nerves lacking? Why do outer layers of the epidermis die? What other structures are found below the epidermis? These structures are in a skin layer called the* dermis.

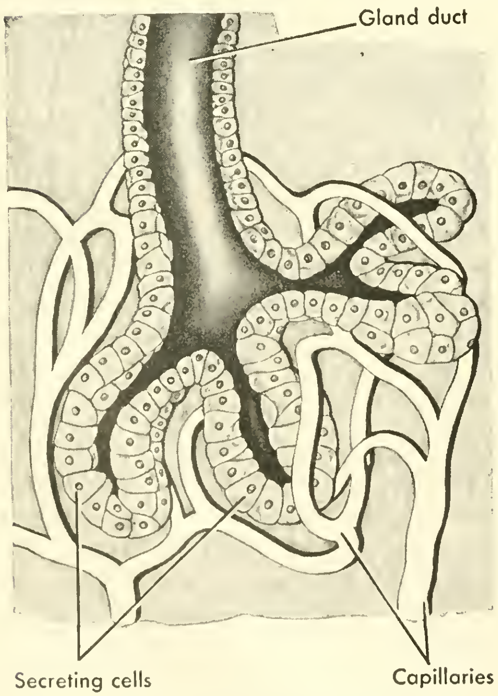


FIG. 237 *A sweat gland highly magnified. Notice the many capillaries near the secreting cells of the gland. How do sweat glands help in regulating body temperature?*

to two pints of water are lost daily in this manner by a healthy body not engaged in exercise. Yet ordinarily you are not conscious of sweat on your skin because it evaporates as quickly as it comes to the top of the duct. You become aware of it only when it pours out more rapidly than it evaporates from the surface. This happens during vigorous exercise or on warm days, particularly in a moist atmosphere when the evaporation of sweat is slow because of the moisture in the air.

A cooling system that regulates itself. Evaporation from any surface cools the surface. If you spread a drop of alcohol on the back of one hand and a drop of water on the back of the other hand, you will notice that the alcohol evaporates first. You will also notice that the spot that was wet with alcohol becomes cooler than the spot that was wet with water. Now perform a more accurate experiment by doing EXERCISE 4. The liquid evaporating from the skin takes heat away from the skin and, of course, from the blood in the capillaries just beneath the surface. Thus the body cools off. When sweat no longer evaporates, your body becomes hot, that is, your body temperature rises. This is sometimes the immediate cause of fever; the sweat glands are not working properly and heat is not lost. But when your body is normal there is constant evaporation of water and constant loss of heat. Moreover, the body automatically regulates or varies the amount of heat lost. Regulation of heat loss is very important to good health. How is it done?

You know from experience that when you are exercising and large amounts of heat are being released in your body, or when the temperature of the air around you is very high, the skin looks red. This is an indication that more blood than usual is in your skin; the capillaries there are filled to capacity. The more blood that passes the cells of the sweat glands, the more chance there is for these cells to take out water and salts. Sweat flows freely. As a result there is much evaporation, and more heat is lost. At the same time some heat is lost directly from the skin by what is called radiation. As the blood begins to cool off your skin looks less red. Evidently less blood is flowing through the skin. As less blood flows past the sweat glands there is less secretion of sweat. The rate of evaporation becomes less, and less heat is lost. All this happens without your planning or thinking about it. The nervous system automatically regulates the size of the small blood vessels in the skin and thus the amount of blood that flows through the vessels. You should be able to apply this information in formulating some good health rules. EXERCISES 5 and 6 will help.

The skin functions in several other ways. EXERCISE 7 will demonstrate one interesting way in which the skin functions. A careful study of the diagram will also teach you much about your skin. You may not think of the skin as an organ because it is not concentrated in one mass. Spread out over the whole surface of the body it measures in a person of average size about one and a half square yards. But it is an organ just as much as the stomach or heart or lungs because it consists of a group of tissues that performs some definite work. The outer tissue of the skin is the *epidermis*. It consists of many layers of cells. The outermost layer of epidermal cells, which is in constant contact with the air, is constantly drying up. As the protoplasm dies these outer cells become hard, thus affording protection to the various tissues underneath. Being dry, the cells tend to rub off, but new ones are being formed continually through the division of the active cells underneath. Wherever these dead cells heap up in unusual amounts a callus is formed.

Under the epidermis lies a much thicker layer called the *dermis*. Both dermis and epidermis are forms of epithelium tissue. In this layer are found structures of various kinds such as the roots of the hairs deep down in the dermis; the tiny bands of muscle attached to the hair which by contracting make the hair stand straight up, and cause what you call "goose pimples"; the oil glands which secrete oil onto the shaft of the hair; the small blood vessels which supply all the living cells and which branch into numerous capillaries around the coil of the sweat glands; and the special sense organs and nerve endings. These are well protected by the epidermis, yet are sufficiently near the surface to provide sensations of touch, heat, cold, and pain.

Ventilation and the skin. For many years it was thought that ventilation of rooms where many people were gathered was important in order to replace the oxygen used and to remove the carbon dioxide breathed out. Now we know that "bad" air affects the skin. You have just read that regulation of body temperature is one of the very important functions of the skin. And you know that this regulation is largely dependent on proper evaporation of moisture from the skin. When large numbers of people are gathered in a small space which has not enough ventilation, the air soon becomes warm and saturated with water vapor. Evaporation slows up; the skin does not have an opportunity to lose heat; and its temperature rises. Experiments on human subjects have shown that the feelings of discomfort, headache, drowsiness, and general restlessness under such conditions are due, at least in large part, to the lack of heat regulation. In air conditioning, therefore, both temperature and humidity are controlled.

The care of the skin. Since the skin is a complex organ and is so important to our well-being, it is important to keep it healthy. Largely because sweat and oil are excreted onto the surface of the skin, much dirt and foreign material tend to collect on it. Soap and warm water are needed to remove this. It is important to keep the pores of the oil glands from clogging with dirt. The clogged pores of oil glands are known as blackheads.

It is important to know that the skin must be protected against excessive sunlight. Some of the cells in the skin contain pigment (coloring matter). Dark skinned people have large amounts of pigment; fair skinned people have small amounts of pigment. Sunlight in moderate doses increases the amount of pigment in most people and the skin tans, thus protecting it against the burn of the sun's ultraviolet rays. In some people the cells do not produce much pigment and the person burns instead of tanning. This may be very serious. But the danger of ultraviolet rays exists even for people who tan.

Under regulation by the Federal Food, Drug, and Cosmetic Act cosmetics are required to be free from poisonous substances. It is well to remember, however, that certain cosmetics, just as certain soaps, may be more or less injurious to your particular skin.

Disorders of the skin. Younger people, particularly those of high school age, sometimes suffer from *acne* (ack'knee) which is another name for pimples. Pimples appear on the face and sometimes on the upper part of the body. The cause may be deep-seated and difficult for a physician to find and remedy. For some unknown reason the oil glands become involved, the secretion remaining in the duct. Then, if bacterial infection sets in, a little red swelling appears. This pimple may disappear in a few days but frequently it breaks open and pus is discharged. The person who suffers from acne should put himself under the care of a competent physician, should understand that the condition in many cases is not the result of neglect or dirt and should remember that in time it will disappear, especially if he stops worrying about it.

Certain germs or molds may infect the skin, causing such diseases as impetigo (im-pet-tie′go) and ringworm. Since the germ or mold is on the surface of the body it is easily transferred to other people; that is, these diseases are very contagious and great care should be taken not to come in contact with the patient or anything he has handled. Often skin eruptions are caused by allergies; you will read about allergies later.

Questions

1. What are the wastes formed in the oxidation of carbohydrates and fats? What are the wastes formed in the oxidation of proteins? Why are more wastes formed when protein is oxidized?
2. Name three organs of excretion. Trace the path of the waste substances from the cell to each excretory organ.
3. Describe the location of the kidneys. What wastes are excreted by the kidney? Wastes are filtered out in the kidney. Where do they go from there?
4. Explain how secretion from the skin may be important to a muscle cell in your arm.
5. Describe a sweat gland.
6. How is the activity of the sweat glands and the amount of sweat increased? Of what advantage is increase of sweating to the body? What may have gone wrong when you have a fever?
7. Why is the skin considered an organ? Name five structures found in the dermis. State four ways in which the skin functions.
8. What makes air "bad air"? How have our ideas changed in regard to the effect of bad air on the body?
9. Why does dirt collect so readily on the skin? What are blackheads? Explain how ultraviolet rays affect people with a fair skin, and those with dark skins.
10. Name and describe the most common skin disorder of people of high school age. How should it be treated? What are two more serious skin disorders? Why are they so contagious?

Exercises

1. What is the structure of a lamb or a beef kidney? Cut the kidney lengthwise in half. Do you see that there is a cavity in the concave portion of the kidney? Use a strong magnifying glass to discover what opens into this cavity. What leads out of the kidney? Is the color of the kidney the same throughout? What do you conclude about the presence of blood?

2. How much variation is there in the temperature of a normal healthy body? Take your temperature after strenuous exercise. If possible take your temperature at some time when the atmosphere is cold and you are feeling chilly. How much difference do you note? How can you explain your observations?

3. What part of sweat remains on the skin? Using an evaporating dish, heat water in which are dissolved small amounts of salts such as are commonly excreted by the human body (sodium chloride and calcium chloride). Continue until all the water has disappeared. What is left? Have you used a control? What is constantly happening on a small scale on the surface of your body? Can you explain why it is desirable to clean the skin with soap and warm water every day?

4. How does evaporation affect the temperature of an object? Use three thermometers with equal temperature readings. Wrap the bulb of each with a small piece of cotton. Either absorbent cotton or cotton cloth will do. Hang up the three thermometers side by side about three inches apart. With a medium dropper put a drop of alcohol on one bulb and a drop of water on another. After two minutes add another drop of alcohol and of water. Leave the third dry. Read the temperatures. Explain the differences in the readings.

5. The answers to all the following questions grow out of your understanding of the paragraph you have just read. Remember that rapid evaporation cools you much more than slow evaporation. (*a*) What might be the danger of going right out after a hot bath on a cold day? Explain. (*Hint*: What effect does heat have on the blood supply to the skin?) (*b*) What is the advantage of a cool shower after a hot bath? (*c*) What might be the danger of sitting in a strong cool breeze after vigorous exercise has made you hot? (*d*) Why is so much more discomfort felt on a warm "muggy" day than on a warm dry day? (*e*) Is an electric fan of any real benefit or does the user merely imagine that it helps him?

6. Summarize your information by formulating as many rules as you can think of for keeping cool on a hot day and keeping warm on a cold day. Give your reason for each.

7. What is an important function of the skin besides regulation of body temperature? As you sit still at your desk, close your eyes and move your hand until it touches something on your desk. What did it touch? How did you know? Examine Figure 236 for some structure which makes it possible for the skin to do this.

Further Activities in Biology

1. How can you measure the percentage of moisture in the air of your room? Construct a wet and dry bulb thermometer. This piece of apparatus consists of two thermometers, one of which has a thoroughly wet piece of cotton cloth wrapped around its bulb. If the air can hold more moisture, water will evaporate from the wet bulb thermometer, and its

temperature will fall. When the wet bulb thermometer stops falling, note its temperature. What is the difference between its reading and the dry bulb reading? With the dry bulb reading and the difference in temperatures, you can find the percentage of moisture (relative humidity) in your room by consulting a relative humidity table.

2. By preparing a large thermometer containing alcohol with a little red ink in it, you can demonstrate to the class the effect of evaporation on the temperature of an object. What else must be done in this experiment?

3. Look up and report on methods of air conditioning.

PROBLEM 6 *What Substances Help Regulate Cell Activities?*

Chemical regulators. It is curious that although our bodies contain dozens of organs, hundreds of tissues, and billions of cells, all parts normally work together. A complex organism remains alive because all its parts work together and all its cell activities go on at a proper rate, sometimes more slowly, sometimes more rapidly. They go on in a balanced way. Why is this so? The nervous system is partly responsible. But much regulating is also done by chemical substances, called hormones.

Hormones, or chemical regulators, affect the rate at which substances are made and broken down in the cells. Through their activities they affect the activities of organs. The rate of heart beat, the width of small arteries or small air tubes, and the secretions of certain glands are all, partially at least, regulated by hormones. You have already read of a hormone, secretin, which regulates the activity of the secreting cells in the pancreas. The effects of some hormones may be very far reaching indeed; they may determine how large or small a person will be when full grown or whether he will be of normal intelligence.

Ductless glands. To have such important effects these hormones must reach the cells in all parts of the body. If this seems difficult, remember that there is one substance, blood, that does get close to all cells. Hormones simply travel in the blood. They diffuse directly into the blood from the glands that produce them. For this reason hormones may be defined as chemical "messengers" or regulators made in one part of the body and producing their effects in another part. The glands which secrete hormones are called *ductless glands* or glands of *internal secretion* as distinguished from glands with ducts such as sweat glands or gastric glands. Another name is *endocrine* (en′-doh-creen) glands. The hormones may be called internal secretions because the secretions go directly from the gland into the blood.

The thyroid gland and its secretion. One of the best known of the ductless glands is the thyroid gland, which lies in the neck just below the voice box (larynx). The gland is about two inches long. See Figure 239. The hormone produced by the thyroid gland is called *thyroxin.* Thyroxin was first extracted from the gland; later its chemical composition was discovered and finally it was made in the laboratory. Thyroxin is a compound containing comparatively large amounts of the element iodine. Iodine gets into the body in the form of chemical compounds that are found both in food and in drinking water.

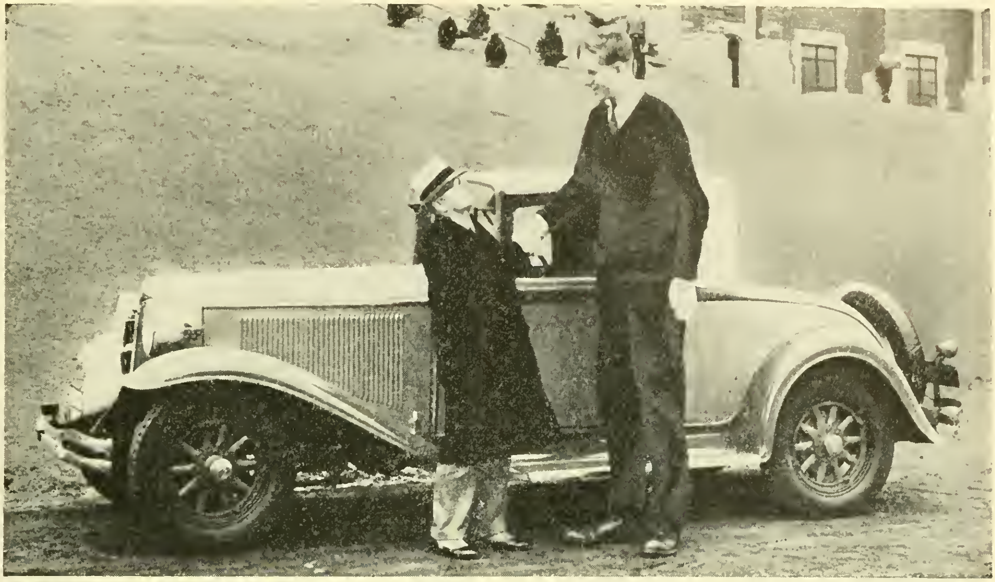


FIG. 238 *Robert Wadlow at the age of 15 shaking hands with a full grown man. Before he died he was 8 feet 7 inches tall and weighed 450 pounds. Study of these pages will provide an explanation.* (ACME)

The effects of thyroxin on the organism have been studied. From experiments on goats, pigs, rabbits, and other mammals we know that if the thyroid gland is removed from a young animal its physical development is interfered with and the reproductive organs do not develop. Its basal metabolism is very much reduced, that is, oxidation is slowed up. Feeding an extract of the thyroid gland to the animal soon after the operation prevents these changes. It is believed that thyroxin acts as a catalyst, speeding up oxidation in all parts of the body.

In the lower vertebrates removing the thyroid has equally striking effects. Tadpoles without a thyroid gland never develop into frogs. They remain as tadpoles and fail to develop reproductive organs. On the other hand, feeding thyroid extract to normal tadpoles has the opposite

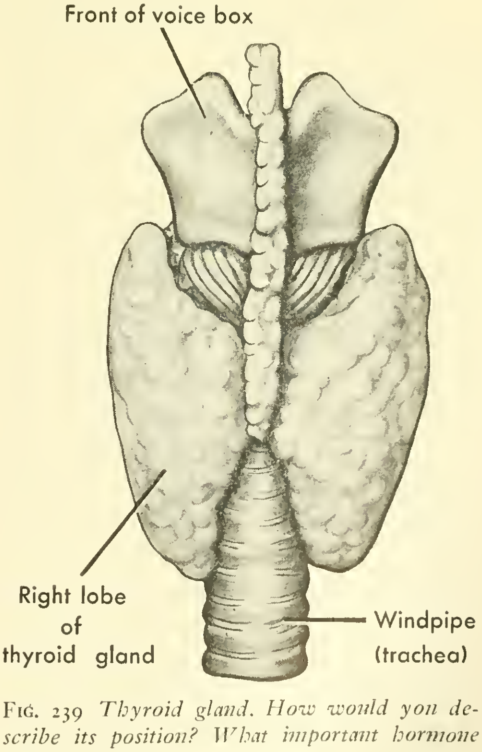


FIG. 239 *Thyroid gland. How would you describe its position? What important hormone does it produce?*

FIG. 240 *The picture on the left shows a woman in whom there was an insufficient secretion of thyroxin later in life. The other picture shows her after treatment with thyroxin. What differences do you note?* (MASSACHUSETTS GENERAL HOSPITAL)

effect. The tadpoles change into adult frogs rapidly without first growing to their full size and the frogs that result are unusually small. This experiment can be performed in the high school laboratory. It requires the daily careful attention of a student. See EXERCISE I.

Too little thyroxin in man. When a child is born with a gland that produces too little thyroxin, that is, when there is a deficiency of thyroxin, the effects noted in experimental animals soon show themselves. The child is undersized and underdeveloped physically and it is, also, mentally deficient. The brain, like the rest of the body, does not develop normally. As in the experimental animal, metabolism is decreased and the child becomes sluggish. This condition has been recognized for a long time, it is known as *cretinism* (cree′ti-nism) and the child is spoken of as a *cretin*. The feeding of thyroid extract helps to bring about normal growth and development. The earlier the treatment is begun the better will be the results.

In some people the thyroid gland begins to secrete less actively in later life, long after the body and the brain have reached their full development. Such people are not mentally defective, although they may be slow-moving and slow-thinking because their basal metabolism is far below normal. Since the rate of oxidation is reduced they tend to become overweight. Very small amounts of thyroid extract will remedy this condition. The extract is so extremely powerful in its effect that only a competent physician should prescribe it.

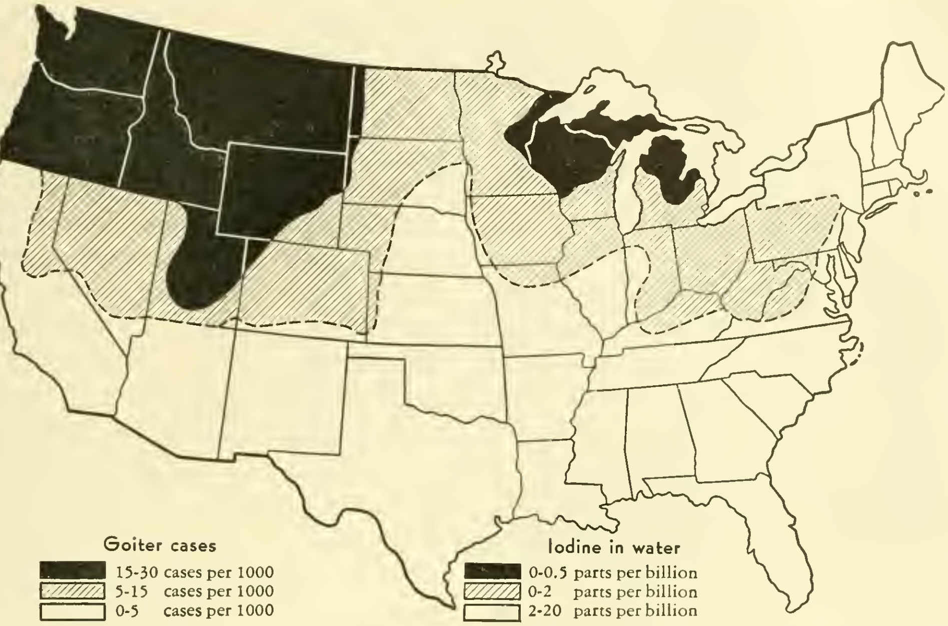


FIG. 241 *Goiter map of the United States showing conditions in 1923. Examine the figures just above. What conclusions can you draw about the cause of simple goiter? Where were cases most common? Where were they least common?*

It may surprise you to learn that an enlarged thyroid gland may mean that the gland is secreting too little thyroxin. You may have noticed that some people have a swelling in the neck in the region of the gland. They have a simple goiter. These goiters may occur when there is too little iodine in the diet. They are thus more common in regions where the amount of iodine salts in drinking water or in near-by farm products is too small. Health officers in such localities sometimes add iodine salts to the drinking water. Sometimes the use of iodized table salt is recommended.

A different type of goiter. In a very different kind of enlarged gland or goiter the gland produces too much thyroxin. With oversecretion the rate of oxidation increases. The person is often restless and easily excited. In more severe cases, the patient loses weight, the temperature is above normal, and the heart beats more quickly than usual. This type of goiter (*exophthalmic goiter*) sometimes causes the eyes to bulge. It may become serious, unless the amount of thyroxin is reduced. This may be done by operating to remove a portion of the gland or to shut off part of the blood supply to the gland. To test your understanding of the last paragraph do EXERCISE 2.

An important discovery. There is a new and interesting treatment for overactivity of the thyroid gland. To understand it you must stop for a moment to examine an important discovery about atoms made in recent years. It has been learned that an element such as iodine, for example, may have atoms of two or more kinds which differ slightly even though they are still atoms of iodine. Such atoms are called *isotopes* (ice′oh-topes). Some isotopes are radioactive, that is, they give off powerful rays like those given off by radium. Some can be made radioactive by a machine known as a cyclotron. Among such isotopes is radioactive iodine; another example is radioactive phosphorus. By chemical action, radioactive atoms can be put into compounds which can then be fed to people or injected into their bodies. The compounds are carried about the body and made use of by one organ or another. Thus the compound containing radioactive iodine is carried to the thyroid gland which uses iodine in the making of its hormone. While the iodine is there the rays it gives off help to relieve the abnormal condition of the gland. Many cases of overactivity have been successfully treated by this method. Later in the book you will read of another isotope useful in the curing of disease.

Isotopes are also being used in animal experimentation to trace the various chemical substances through the body. If the isotope is radioactive it readily shows its presence in the organs. If not, it may be located in the tissues chemically. Such isotopes are called tracers or tagged atoms. Thus isotopes, whether radioactive or not, are of great importance. By their use it is hoped that much more can be learned about the metabolism of the body.

A hormone regulating sugar metabolism. Thyroxin speeds up oxidation of sugar but there is another hormone, called *insulin*, which is also intimately connected with sugar metabolism. Insulin is responsible for keeping the normal amount of sugar in the blood. The presence of a little more or less sugar in the blood may seem unimportant to you but a physician knows that any unbalancing of this sort has far reaching and serious results. Insulin, it is true, also hastens oxidation but let us see how else it affects sugar metabolism. You will remember that when sugar is not oxidized immediately it is changed into the storage product, glycogen. This may happen within muscle cells or in the liver. Now insulin helps in the storage of glycogen. You can see that if the body produces no insulin or too little insulin sugar will accumulate in the blood for two reasons: first, less sugar is used up in oxidation; and second, less sugar is taken out of the blood to be stored as glycogen.

Insulin helps to keep sugar out of the blood in still another way too complicated to explain. In fact, with extreme lack of this hormone tissue proteins begin to break down into sugar and other substances, thus adding to the amount of blood sugar. This condition, where insufficient insulin is produced in the body, is known as *diabetes*. The disease, if unchecked, is dangerous and may lead to death. Diabetes can be recognized by the presence of too much sugar in the blood. From the blood some of the sugar passes into the urine. In fact, until recently the testing of urine for sugar was considered sufficient for detecting diabetes.

The discovery of insulin. As long ago as Roman times diabetes had been given a name and its symptoms described carefully. For centuries it was believed to be a disease of the kidneys, since sugar appears in the urine. Not until the beginning of this century did we learn that

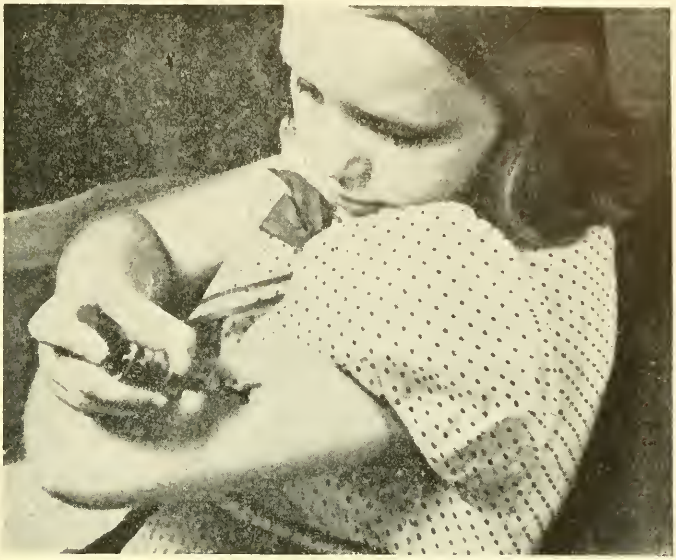


FIG. 242 *This girl has diabetes. She has learned to inject the amount of insulin prescribed by her physician.* (ENCYCLOPAEDIA BRITANNICA FILMS, INC.)

the disease is caused by a lack of insulin and that the insulin has no connection with the kidneys. The various steps in the history of this discovery make an interesting story.

The first step was taken some time before 1850 by the great French physiologist Claude Bernard, a pioneer in experimental biology. Not satisfied with speculation and observation, he performed carefully controlled experiments on animals. By means of some of these experiments he showed that the liver takes part in sugar metabolism. Because of this Bernard suspected that it might be the liver, rather than the kidneys, that was not acting normally in diabetes. But experiments to test the truth of this theory showed it to be false.

Then about 1890 an important discovery was made. Two German investigators were interested in digestion, particularly pancreatic digestion. They had in their laboratory some dogs whose pancreas had been removed. The laboratory helper who cared for the animals, a keen observer though knowing little science, noticed that the urine of the dogs that lacked a pancreas attracted large numbers of flies. He reported this seemingly unimportant observation. The trained scientists, knowing that flies are attracted to sweet liquids, suspected that the excretions might contain sugar. This proved to be true. Therefore they reasoned that the presence of sugar in the urine might have some connection with the loss of the pancreas. This was an entirely new idea. More experiments were performed. It did not take long to prove that a pancreas, and not a kidney, condition caused an oversupply of sugar in the blood and urine.

In the meantime, a biologist named Langerhans had discovered little patches of cells in the pancreas that were different in structure from the rest of the gland. It was suspected that these cells might have something to do with controlling the amount of sugar in the blood. Autopsies (dissection after death) showed that in diabetics many or all of these cells were damaged. The next step was to cut the duct of the pancreas so that its digestive juice could not reach the small intestine. Despite this the animal did not get diabetes. By this time the existence of ductless glands was known, so that it was easy to accept the idea that Langerhans' "islands" of cells are ductless gland cells whose secretions diffuse directly into the blood. It was evident that the pancreas has two different kinds of secreting cells; it is both a gland with a duct and a ductless gland. It makes a digestive juice and secretes an important hormone.

It was not until 1921 that two Canadians, Banting and Best, succeeded in obtaining the hormone from the "islands of Langerhans," in the pancreas of an animal. They called it insulin. They soon discovered ways of injecting insulin into the body of a human being who cannot supply his own. See Figure 242. This account of the discovery of insulin is more or less typical of scientific discoveries. Read the paragraph again and then do EXERCISES 3 and 4.

A hormone valuable in emergencies. Fear, anger, or excitement of any kind stimulates two small glands each of which fits like a small cap on the upper end of a kidney. These are the *adrenal* (ad-ree′nal) glands. The inner portion of the glands secretes the hormone *adrenin* (ad-ren′in). When the body is at rest the blood contains practically no adrenin. When such emotions as fear or great joy are aroused the glands secrete actively and the adrenin acts almost instantaneously. Professor Cannon of Harvard performed a large number of experiments on cats with and without adrenal glands. He found that when an animal is afraid or excited, when it is fleeing or defending itself or attacking an enemy, adrenin brings about changes in the body all of which seem to fit the animal for its emergency. For this reason the adrenal glands are sometimes called the "glands of combat."

What are the changes caused by adrenin? You must look at many parts of the body for your answer. The skin becomes pale, and if the body were transparent, you would see many of the internal organs losing color too, for the blood vessels to all these organs are constricted (made smaller), shutting off much of the blood supply. Furthermore, the adrenin has a direct effect on the involuntary muscle cells. As a result the digestive tract and some of the other abdominal organs largely stop their activities. The heart, on the other hand, beats more forcibly. At the same time the blood vessels to the skeletal muscles and brain are made wider by the adrenin. Because of these changes blood reaches the brain and muscles faster and in larger quantities. The air passages widen, with the result that more oxygen reaches the lungs and the blood stream. The change from glycogen to glucose is speeded up in the liver. All of these changes bring about more oxidation and release of energy where it is needed, in the brain and in the skeletal muscles. At the same time if there is a wound and the blood escapes, adrenin hastens clotting. The body has automatically prepared itself for flight or struggle with the enemy. The animal with fur or feathers, furthermore, shows what we have come to recognize as a sign of fear or rage, the bristling of the fur or the ruffling of the feathers. This is caused by the contraction of the microscopic bands of muscles in the skin. In us, this contraction produces gooseflesh. You may have heard of people performing the most amazing feats of strength in a crisis. Can you now explain what occurred in their bodies?

Physicians make frequent use of the powerful effects of adrenin on the body. In cases of heart failure, it may even be injected directly into the heart in order to stimulate it. Adrenin is also used to help clot blood and to help asthmatics whose breathing tubes are constricted.

Other hormones in the adrenal gland. The outer portion of the adrenal glands, known as the *cortex*, is quite different from the part that secretes adrenin. It produces other hormones which affect the body in many different ways and very profoundly. A hormone (*cortin*) has been extracted. This can be injected into the body when disease of the adrenal glands would otherwise prove fatal.

Ductless glands and circus freaks. The giant and the dwarf, the fat man and the bearded lady in the side shows of the circus are all individuals suffering from an abnormal condition of one ductless gland or another. In these cases the disturbance is of a kind which produces extreme outward changes; many gland disturbances may be just as severe but produce changes which are not visible. Giantism and dwarfism can be directly traced to a disturbance of a small gland which lies at the base of the brain. This is the *pituitary* (pit-two′i-ter-ree) *body*. The gland is about as large as a small pea and is in two parts. The front (anterior) part secretes a hormone which

FIG. 243 *Both men are full grown. Why did the midget stop growing earlier than the man of normal size?* (COPYRIGHT PICTURES, INC.)

speeds up growth of the skeleton as was shown by the following experiment. An extract was made of the gland, and this extract was injected into young rats for a period of five or six months. These rats and their controls were carefully weighed and measured. At the end of this time the injected rats had grown to almost twice their natural size and weight. Giant rats were produced.

In the case of the giant of the circus there is an oversecretion of the pituitary hormone while the child is growing. You may have seen people, too, in whom only certain bones are enlarged, the bones of the face and perhaps of the hands and feet. This condition (known

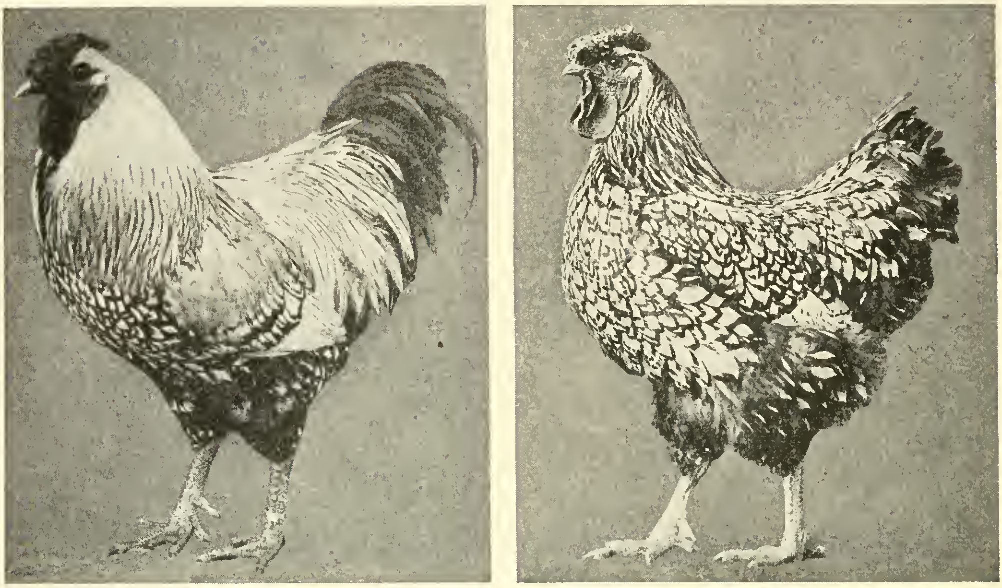


FIG. 244 *The sex glands of this silver-laced Wyandotte rooster (on the left) were removed. As a result he changed into the hen-feathered bird shown on the right. What is the difference in plumage?* (U. S. BUREAU OF ANIMAL INDUSTRY)

as *acromegaly*) is due to oversecretion by the gland later in life. It is sometimes treated by an operation on the gland. With an undersecretion of the hormone in a child, growth of the bones is stopped at an early age; the result is a midget. In cases of undersecretion which are not too severe, extracts of the pituitary gland have been injected but so far without much success.

The pituitary — the "master gland." The anterior portion of the pituitary gland secretes other hormones besides the one which affects growth of the skeleton. These hormones affect the reproductive organs, the thyroid, the outer part of the adrenals, and other ductless glands. That is, the pituitary with its variety of hormones has many important direct and indirect effects. Because of its influence on so many parts of the body it has received the name of the "master gland."

The posterior portion of the pituitary gland also produces several hormones. They affect the body in various ways, one of which is to stimulate the contraction of smooth muscles. You will remember that the walls of the digestive organs contain smooth or involuntary muscle cells. You have no direct control over such muscles. But they "obey" this pituitary hormone which comes to them through the blood. The tiny muscles in the walls of the arteries are also smooth muscles; they too are made to contract more violently by this hormone.

Other ductless glands. It is not difficult to obtain specimens of ductless glands from the butcher. Study them and answer the questions in EXERCISE 5. In close contact with the thyroid are the two much smaller *parathyroids*. The secretion of the parathyroids seems to have something to do with the presence of sufficient calcium salts in the blood. A lack of calcium salts in the blood due to an undersecretion of the parathyroids is dangerous. It causes a certain kind of convulsion or muscle spasm.

The sex organs, of which you will read more in a later unit, secrete hormones into the blood besides performing the function of reproduction. These hormones are responsible for the development of the characteristics that distinguish males from females. See Figure 244.

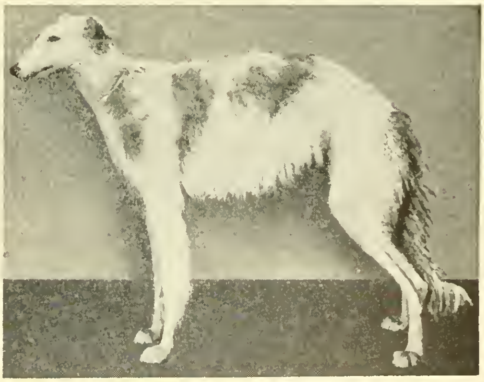
The thymus is often mentioned as a ductless gland. There is no clear-cut evidence, however, that it is a ductless gland. It lies behind the upper part of the breast bone. It is comparatively large in young children and grows smaller with age. Its use in the body is not definitely known.

Year by year new hormones are added to the list of those you have read about. It may well be that as investigation continues other organs may be found to serve as ductless glands. This is a comparatively new field and much research must still be done before scientists can understand how the complex activities of the cells in all parts of the body are regulated. You will find a review table on hormones at the end of this problem.

How a complex animal lives and grows. Let us sum up very briefly the most important points in this unit. The body of a complex animal such as ours has many parts and billions of cells. All the cells are supplied with soluble food and with oxygen. All produce CO_2, H_2O, urea, uric acid, and other salts in the process of oxidation. The blood and lymph bring the needed substances to the cells and

BULLDOG

BLOODHOUND



RUSSIAN WOLFHOUND

FIG. 245 *Certain differences between dogs may be caused by differences in the activities of ductless glands. Can you state what abnormal gland condition might have produced each of the three breeds of dogs shown above? Do you know another breed in which you might suspect ductless glands to have played a part?* (AMERICAN MUSEUM OF NATURAL HISTORY) carry the others away. So every cell is kept alive.

Some organs do special jobs. In the intestine blood takes on foods besides the wastes. In kidneys, lungs, and skin, blood loses water. You can most readily review the activities of some of the important organs of the body by examining the following table. The first line of the table shows what goes on *in every organ all the time*. The part below shows what goes on over and above all this in certain organs.

The blood, as you see, not only provides for the continued life of each individual cell (first part of table), but by reaching every organ, it connects all parts of the body. Because of the blood, an organism acts as a single unit rather than as a collection of organs. But there is further provision for making the parts of the body work together, for making the cell activities go on at a proper rate and in a balanced way. This is done by the hormones, the secretions of ductless glands. The hormones under normal conditions do much to regulate the processes of growth and development and help to keep this complex body working efficiently.

While the hormones help in the regulating of body processes, you will learn in the next unit that the nervous system plays an extremely important part in this regulation. Our bodies are, indeed, complex machines!

Activities of Some of the Important Organs

ORGAN	ORGAN RECEIVES FROM BLOOD	ORGAN SUPPLIES TO BLOOD
Every organ in the body	All soluble food substances Oxygen	Wastes formed in oxidation (CO_2, H_2O, urea, uric acid. and other salts)

Besides what is shown above, the organs named below receive and supply the following:

Small Intestine	Special substances for making digestive juices	Large quantities of all digested food substances
Lungs	CO_2 and H_2O (these are exhaled)	Oxygen
Kidneys	H_2O, urea, uric acid, other salts (excreted as urine)	
Skin	H_2O, a few salts (excreted as sweat); substances used to make oil	
Ductless glands	Special food substances used in making hormones	Hormones
Liver	Sugar (made into glycogen); worn-out red corpuscles; excess amino acids	At times, sugar from glycogen; urea from breaking down of excess amino acids

Questions

1. What do chemical regulators do for the body? Give examples of their effects.

2. Where are hormones made? Where do they do their work? Give three names for glands that secrete hormones. How do they differ from other glands?

3. Locate the thyroid gland. What are the results of removing the thyroid gland in an experimental animal? What name is given to the hormone secreted by the thyroid gland? What is known about its composition?

4. What is cretinism? How does it show itself? What effect does thyroid deficiency have in people who are fully developed? What external symptom might make you suspect thyroid deficiency? What often prevents its occurrence? How can it be treated?

5. What are the effects of, and what is the treatment for, oversecretion of thyroxin?

6. What is meant by an isotope? Name a radioactive isotope and tell how it can be used.

7. In which ductless gland is insulin made? What disease is caused by its deficiency? "Insulin keeps sugar out of the blood." In what ways does it do this?

8. What important contributions did Claude Bernard make to science? What chance observation led to the discovery of the cause of diabetes? What are two entirely distinct activities of the pancreas?

9. What are the "glands of combat"? Where are they located? State five ways in which adrenin prepares the body for an emergency.

10. Of what further importance are the adrenal glands?

11. Which gland is functioning abnormally when giants or dwarfs develop? Where is it located?

12. Which is the "master gland"? How did it get its name? Explain the effect of the hormone secreted by the posterior part of the pituitary gland.

13. Name two other important ductless glands and state what effect each has on the body.

14. Sum up briefly what every living cell takes from and adds to the blood in every organ of the body and what special organs take from the blood and give to it. In what respect is our body more than a collection of organs?

Exercises

1. How does the feeding of extracts of thyroid gland affect the development of tadpoles? Place a *very minute* amount of thyroid extract in an aquarium containing tadpoles. Change the water each day before adding fresh thyroid extract. Observe and record what changes take place in the tadpoles. What control will you use in this experiment?

2. Answer the following questions: (*a*) Because one kind of goiter occurs almost entirely in regions where the drinking water lacks iodine, is it reasonable to conclude that this goiter is caused by lack of iodine? Suppose that someone advanced the idea that this type of goiter was caused by bacteria. How might you find out which hypothesis is correct? (*b*) Some types of pills which claim to reduce weight have been found to contain relatively large amounts of thyroxin. Would these pills accomplish what they claim to do? Explain. Would it be wise to take such pills without a physician's advice? Explain. (*c*) Explain why shutting off the blood supply from the thyroid gland would help in the case of an overactive gland.

3. Do you understand scientific method? The account of the discovery of insulin is more or less typical of all important scientific discoveries. Read the paragraph again carefully. How many centuries did it take before there was much real progress in solving this problem? Why did it take so long? Do you think that the laboratory helper was using any of the methods of science? Explain. Why were the scientists able to make use of this accidental discovery? From what you have just learned, sum up as many of the elements of scientific method as possible. Then list the qualities which a good scientist must possess, and in each case refer to a definite incident.

4. What truth is there in the statement: "Experimentation speeds up a hundredfold the acquisition of knowledge"? What is there peculiar to an experiment that enables a scientist to get at the truth more quickly?

5. Study of ductless glands. It is not difficult to obtain specimens of some of the ductless glands from your butcher. Which glands did you obtain? From which part of the animal did they come? What is the size and shape of each? Handle the glands. How does gland tissue differ from muscle tissue? What is the color? Why are large amounts of blood necessary to the gland cells?

Further Activities in Biology

1. Look up the story of the discovery of secretin. Report to the class.

2. Much has been written about the effect of the endocrine glands upon personality. Look up and report to the class on this topic. Be very critical of this work.

3. Plan other experiments like Exercise 1. Consult your teacher before attempting them.

PROBLEM 6. *Hormones Help Regulate Cell Activities*

In UNIT V you will consider these problems:

PROBLEM 1. What Are the Simplest Forms of Behavior in Animals?

PROBLEM 2. What Makes Complex Behavior Possible in Many-celled Animals?

PROBLEM 3. How Does the Behavior of Complex Animals Differ from That of Simpler Forms?

PROBLEM 4. How Do Plants Respond to Their Environment?

UNIT V WHY LIVING THINGS BEHAVE AS THEY DO

FIG. 246 *All that could be written about the behavior of this boy while he is popping corn would fill a large volume. What facts about his behavior could you state?* (THREE LIONS)

PROBLEM 1 *What Are the Simplest Forms of Behavior in Animals?*

The meaning of "behavior." To the biologist behavior does not mean good or bad conduct. It means the sum total of all an organism does in the course of its life. Stumbling as you stub your toe, opening your umbrella in the rain, deciding to walk to the river for a swim, feeling happy over an unexpected school holiday, waking when the alarm rings, going to sleep and dreaming, listening to the radio, all these things and many more make up your behavior. In this unit we will study the behavior of organisms.

Environment and sense organs. As you cross a city street the honking of an automobile horn may reach your ears. You turn your head and see a red car coming toward you. It passes you and you feel the heat of the exhaust on your skin; the fumes strike your nose. One sense organ after another has received something from the environment: your ears, your eyes, special cells in your skin and in your nose. Because of the way they function the sense organs are called *receptors.*

Anything that excites a receptor is called a *stimulus* (plural stimuli – stim′-you-lie). Light rays are a stimulus to the eyes; sound waves are the stimulus received by the ears. Each receptor is so made that it picks up a different kind of stimulus from the environment. It is because of your receptors that you become aware of the environment.

Stimuli call forth responses. If you are crossing the street absent-mindedly, you may get the loud blast of an automobile horn close to your ear. You start; that is, certain muscles in your body contract violently and you move as a result. In your kitchen you may carelessly brush your hand against the hot oven; almost instantaneously you jerk the hand away from the stove. This, too, is the result of muscular contraction. In both instances a stimulus was received that aroused some part of you to action. In both instances there was a muscular contraction. This contraction of the muscles and the resulting bodily movement was your *response* to the stimulus. The muscles which contract are called *effectors,* as distinguished from receptors which receive the stimulus. If the automobile that blows a horn close to your ear touches you and knocks you down, falling is not your response to the stimulus. Can you explain how this differs from a true response to a stimulus?

Responses are not always muscular contractions. A sharp cinder in the eye (stimulus) causes two visible responses: blinking of the eyelid, which is due to a muscular contraction, and increased secretion of the tear gland. In this case there are two quite different effectors. Many responses to a stimulus are not visible. In the case of the automobile approaching you the hearing of the horn is itself a response; recognizing the noise as a horn is another response; the feeling of pain and the feeling of fright which follow are also responses; and there are many other possible responses. Sometimes a response follows upon a stimulus immediately; at other times it may be delayed a long time.

Unlearned responses in all animals. In you, as in all other animals, there are responses that are inborn or unlearned. The sucking movements made by a baby's mouth when its lips come in contact with any object and the clasping movements made by the baby's fingers when they touch your finger or a stick are inborn responses made by all babies. Unexpectedly touching a hot stove, provided the stove is hot enough, will always cause the hand to be jerked away. This, too, is inborn and unlearned. The same response is made by you and by me and by a very young child. An act of this kind, which is a simple direct response to a stimulus and which is inborn and unlearned, is called a *reflex act* or simply a *reflex*. Starting at the sound of a loud noise, blinking when a cinder enters the eye, and the secreting by the tear gland at this time are also reflex acts.

There are many reflexes in us and in all other animals which occur internally and which are therefore not noticed. When food reaches the top of the food pipe a ring of muscle contracts; by the contraction and relaxation of this muscle the food is pushed to the stomach. Each muscular contraction is a response to a stimulus and is a true reflex. When the food reaches the stomach another reflex is started. This time the response is made by gland cells, that is, gastric juice is secreted. You can demonstrate some of your own reflexes by doing EXERCISES 1, 2, and 3.

How much of the animal's behavior is reflex? You will learn that many animals perform some acts which are not reflexes. But, in general, the less complex an animal is, the greater is the proportion of its reflex acts. In the simpler vertebrates, such as the fish, amphibians, reptiles, and even birds, almost all behavior is inborn and unlearned (reflex). Very few acts seem to be learned during the lifetime of the individual. In more complex vertebrates, such as mammals, there is a greater proportion of learned behavior. Much of man's behavior is learned, as you will see. The mammals most nearly like man, such as the apes, have a greater amount of learned behavior than the mammals that are less like man. But no other animals can learn nearly as much as man can.

As far as we know, among invertebrates behavior seems to be largely, if not entirely, unlearned behavior. The elaborate routine performed by spiders, by ants in their nests, by bees in their hives, by wasps in nest building, and by beavers in making dams is unlearned. Without study we might be led to believe that much of this behavior is learned and carefully thought out. It is not. Let us examine some of the behavior of several animals more closely.

Instinctive behavior. The spider spins its web in a most elaborate design; if you have ever read a description of how it is done you will know how complicated the process is. You are obliged to struggle over even an explanation of how it is done. How could the spider learn to do it? If a young spider which has never seen a web is placed by itself, it will in time spin a web like the one spun by its parents. If it is raised with spiders of another species which use a different design it does not imitate what goes on around it; it spins the kind its parents spun. This is pretty good evidence that the spider did not learn how to spin its web.

FIG. 248 *A wasp's nest is built by a succession of reflex acts. How can we know that the wasp's behavior is instinctive, not learned?* (AMERICAN MUSEUM OF NATURAL HISTORY)

Web spinning is obviously unlearned, but it is more than a simple reflex. It seems to be the product of a reflex act followed by a second reflex of a slightly different kind and a third and so on until the web is completed. When the first thread has been spun, it serves as a new stimulus and the second step is performed. This provides a different stimulus and the third reflex is set off. The spider's reflexes go on in regular order. We can use the term *instinctive behavior* for such a chain or series of reflexes. Each act of the instinctive behavior is an inborn and unlearned response. The animal acts according to a pattern with which it seems to have been born.

Instinctive behavior requires no intelligence. It is clear that instinctive behavior is unlearned. Furthermore, experiments furnish evidence that animals do not show thought or intelligence in instinctive behavior. Wells, Huxley, and Wells in their book *The Science of Life* tell of an interesting experiment which shows that intelligence does not enter into instinctive behavior. The bush turkey hatches from an egg laid at the bottom of a heap of decaying plant material. After breaking through the shell, the young bird wriggles up and out at the top of the heap. Then it shakes itself and runs off, seemingly to find protection. It is doing the correct thing. But is it doing the correct thing because it is using thought and intelligence? The answer is given by the following observations. The young bird was caught and again placed at the bottom of the pile from which it had just wriggled. It stayed there without a struggle. It was born with a pattern of behavior for wriggling upward as it left the shell, and it did that. But there is no pattern for doing this a second time. If the baby bush turkey in the experiment had not been rescued, it might have remained under the pile of decaying material. It was not using intelligence when it pushed its way out the first time, it was just performing an inborn, unlearned act. Because of this and other similar obser-

FIG. 249 *Well constructed dams like this one can be built by beavers that have never seen a dam. As you may already know, beavers build houses in the ponds made by dams like this. In the fall they gather and store food which is used during the winter. How can you explain their activities?* (NATIONAL PARK SERVICE)

FIG. 250 *Young quail in a nest on the ground, photographed from above. Where is the head of each bird? What advantage is there in this position? Did the young birds think up this good device for protecting themselves?* (GEHR)

vations we know that much of what seems, at first glance, to be intelligent behavior in lower animals requires no intelligence.

The misuse of words. Some technical terms used by scientists and defined in this book are often used carelessly in everyday speech. In the biology classroom you must learn to use exactly the words so frequently misused in ordinary conversation. For example, people may say, "He *instinctively* defended the good name of his high school." Now you know that the action was not an instinct, as instinct is defined above. The action was not inborn. When a skillful automobile driver makes a quick move that prevents an accident, some people say, "His reflexes are wonderful." Of course, it is not his reflexes that are wonderful, for the skilled driver was not born with the ability to drive his car. In a later problem we will read why and how he avoided an accident.

Behavior in the simplest animals. The simple response to a stimulus described in you and other animals occurs in protozoa, too. Professor H. S. Jennings, who spent many hours studying the behavior of protozoa and other simple forms, relates how he once watched a large ameba pursue a smaller one back and forth across the slide. After a long chase the pursuer began to pinch off a small piece of its prey (see *A* in Fig. 251). It succeeded in pinching off the piece and began to engulf it as it would engulf any particle of food (see *B* of Fig. 251). But the small piece of ameba was alive and active, and by sending out pseudopods, it flowed away from its captor (see C of Fig. 251). Again it was chased and engulfed. Again it escaped. This time the large ameba stopped chasing the smaller one. But do not think that it gave up "in despair" for, as far as we know, neither the large ameba nor the small one was in any way conscious of what it was doing. The small ameba was not "afraid" of its pursuer, nor did it "try" to escape or plan its actions. The behavior of both amebae was typical of that of any protozoan at all times. The small ameba was a food stimulus to the larger one; the larger one responded by sending out pseudopods in the direction of the stimulus. The small ameba was also responding to a stimulus; its response was the forming of pseudopods in the opposite direction. Both were performing reflex acts. Neither showed intelligence any more than the spider in building its web, or the bush turkey in wriggling out into the open. You can study reflexes in protozoa by doing EXERCISES 4, 5, and 6.

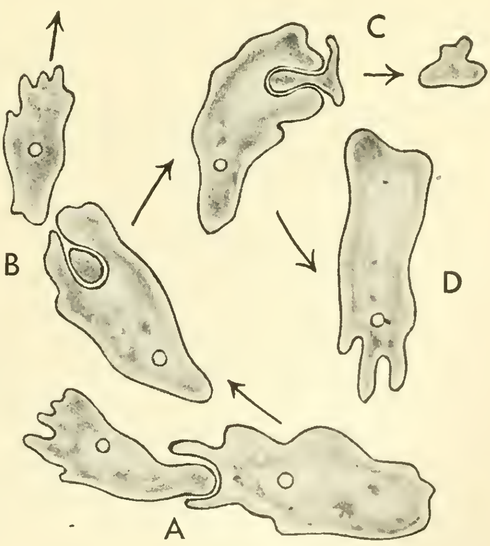


FIG. 251 *Responses in two amebae. Is this behavior intelligent or reflex?*

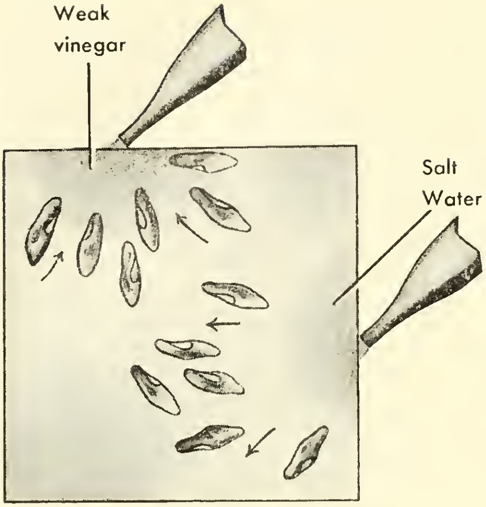


Fig. 252 *How do paramecia respond to salt water and weak vinegar?*

Protozoa respond to many other stimuli. When a paramecium, in the course of its swimming, meets some solid object other than food, it reverses its direction. It is responding to a mechanical stimulus. A change in the intensity of light or in its color also acts as a stimulus to a paramecium; so does a change of temperature, or a change in the chemical composition of the water. Food is a chemical stimulus. And paramecium reacts to electrical stimuli as well.

Why protozoa seem to show intelligence. If you have ever watched the responses of protozoa you have perhaps wondered at their intelligence. The organism is almost always performing acts which are useful to it. But if it has no intelligence why does it make such correct responses? It is because organisms making responses unfavorable to themselves quickly die and leave no offspring. They survive only if their protoplasm makes useful responses. It is for this reason that all protozoa capable of continued existence will always seem to show intelligence. Now review this problem by doing Exercise 7.

Questions

1. What does the biologist mean by *behavior?*
2. Name four places in the human body where sense organs are found. What is a receptor?
3. What is an effector? Name some stimuli and the responses made to them by the human body.
4. Define a reflex. Give two examples of human reflexes that you have seen occur. Describe two internal reflexes.
5. In which group of organisms do reflexes make up a larger proportion of the behavior, vertebrates or invertebrates? Defend your answer.
6. How does an instinctive act differ from a reflex act? Describe an instinctive act performed by some animal. How do you know that instinctive acts are unlearned?
7. Describe an experiment which illustrates that an instinctive act is not an intelligent act.
8. How are the words "instinctively" and "reflex" often misused? Explain why the words are incorrect when used in that way.

9. Describe a case of reflex behavior in an ameba. Name five stimuli that can cause a response in a paramecium.
10. Why do the responses of paramecia seem to be intelligent?
11. Make four or five short statements to sum up this problem.

Exercises

1. Why is the knee jerk an example of a simple human reflex? Let someone gently tap your knee just below the kneecap when your legs are crossed. What happens? Can you keep from jerking your leg when the knee is tapped? Explain.

2. In a fairly dark room, examine the pupil of a student's eye. Then direct the beam of a flashlight into it. Explain what happens.

3. What type of behavior is displayed by the secretion of saliva? This experiment will be especially successful before lunch or late in the afternoon. Display some tempting portion of food or talk about food. What happens? What receptors are stimulated? Which effectors respond?

4. (*a*) How do paramecia respond to various chemicals? You should have a rich paramecium culture for all these experiments. See directions, page 69. Find a paramecium which has come to rest near some food particles. Run a drop of blue fountain-pen ink slowly under the cover glass. Observe the surface of the animal closely. What do you see? How do these structures differ from the cilia? Under natural conditions the trichocysts are used for protection. What is the stimulus? What is the response? Is the behavior you have just seen useful or harmful to the organism? (*b*) Now run a drop of red ink under the cover of a second slide. What do you observe? Do all foreign chemicals seem to produce the same response? What objections might be raised to drawing conclusions from what you observe? Explain fully.

5. If you have a microprojector, project some paramecia on the screen and run a weak electric current through the water. What is the response of the paramecia? If other protozoa are available find out whether they respond in the same way.

6. Can you devise an experiment to show the response of protozoa to light? Try it and record your observations. Discuss the experiment with the class.

7. Discuss the following: (*a*) If you create a current in the water and the paramecia are pulled along by the current, is their movement a reflex act? Why or why not? (*b*) Although in instinctive behavior an animal generally responds "correctly" to its environment, under what circumstances may this type of behavior not be useful to the animal? (*c*) Cite some instinctive behavior that is injurious or fatal to an animal. Why has the species not died off as a result of this instinct? (*d*) How could you determine whether a particular act is an unlearned reflex or an act which depends on intelligence?

Further Activities in Biology

1. Can you think of any human reflexes that you could demonstrate to your classmates?

2. Study the instinctive behavior of some animals you can watch closely — perhaps ants, bees, spiders, caterpillars making cocoons, birds, and so forth.

3. If you have seen the response of a protozoan to light, it would be interesting to discover whether certain rays call forth more of a response than others. You may use prisms or photographic filters to obtain the light rays you wish to test.

4. Do paramecia respond to gravity? Plan an experiment to find out. (*Hint:* Use a long, narrow tube.) Can you devise a control? Discuss this with your classmates.

5. What would paramecia do if two stimuli with opposite effects were applied at the same time? Light and gravity might be tested. Present your results to the class.

6. Using a U-tube and one or two dry cells, devise an experiment to test the response of Paramecium to an electric current. What is your control? Explain.

PROBLEM 2 *What Makes Complex Behavior Possible in Many-celled Animals?*

Properties of protoplasm. All animals consist of protoplasm, and protoplasm has several properties which make it different from lifeless matter. One of these properties is *irritability*, the ability to respond to stimuli. It is believed that protoplasm has the property of irritability because it is so complex physically and chemically. Changes in the environment may easily cause changes within it. The physical and chemical changes that take place in the structure of living matter are the direct cause of the responses which the animal makes.

When you see streaming in the ameba or lashing of cilia in the paramecium, the protoplasm is exhibiting another of its properties — *contractility*. The single-celled protozoan can perform reflex acts because it has these two properties, but for you or any other complex animal to perform a reflex act requires more than simple irritability and contractility. In animals that consist of many parts there is a nervous system which is useful in making the many parts of the animal work together. Reflex acts, as well as all learned acts, in complex animals are possible because of the nervous system. Let us study this important system.

The nervous system. You know what happens when someone accidentally puts his outstretched hand into a flame. He pulls his hand out of the flame. But he also feels pain and probably has a sudden fright together with a rapid heart beat, a catching of the breath, and perhaps a tight feeling about the abdomen. How does it happen that so many organs respond to the one stimulus?

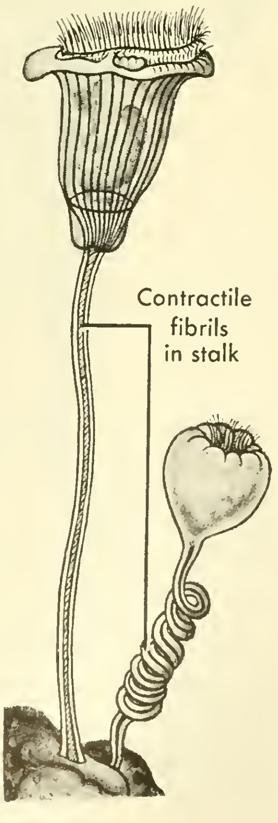


FIG. 253 *Vorticella, a tiny one-celled animal, is attached by a contractile stalk. One Vorticella has just been touched by a glass rod. How did it respond? What two properties of its protoplasm make this possible?*

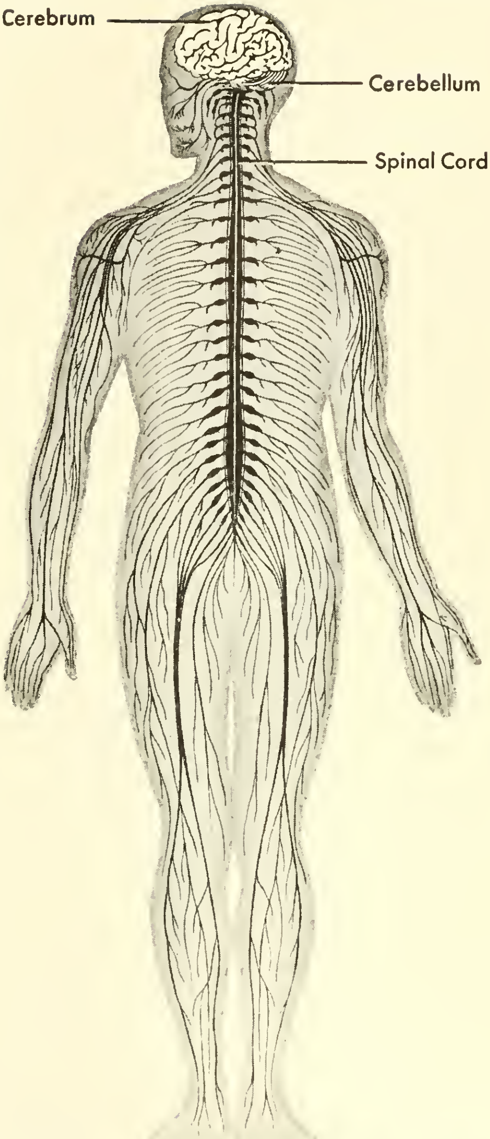


FIG. 254 *The central nervous system of man. Only the largest nerves are shown. About how many nerves arise from the spinal cord? Notice how the nerves branch into all body parts.*

There is a complex nervous system in you which makes your billions of cells work together, making you one organism instead of a group of independent cells. This nervous system consists of two parts, the *central nervous system* and the *autonomic nervous system*. The autonomic system is often called the involuntary nervous system. The two systems of nerves work together closely. The autonomic nervous system controls the internal responses, such as the contractions of the heart and digestive tube, secretion by digestive glands, and many others. You are seldom aware of these responses. You will learn more about the autonomic nervous system and its activities later in this problem. Let us study the central nervous system first.

Nerves and nerve centers. The nerve centers of the central nervous system are the *brain* and its continuation, the *spinal cord*. Attached to these are the nerves which look like white cords stretching all through the body. Study of Figure 254 shows that, while nerves are found in every part of the body, they do not interlace or form a network. All the nerves are attached to the brain or spinal cord. If you traced any nerve in the figure from its farthest point in any part of the body you would always end up in the brain or spinal cord. That is why they are called the nerve centers.

When a receptor is stimulated, a "message" or *impulse* travels along a nerve to the nerve center. If the response to this stimulus is a muscular contraction, it means that another impulse goes out along a nerve to the muscles, which then contract. An impulse never goes from the receptor directly to the muscle. Our central nervous system is somewhat like a telephone system with a central office. Ordinarily, you communicate with a friend through the central office, not directly.

Protection of the nerve centers. The nerve centers of the central nervous system are well protected in man by bony coverings and by membranes. Covering the brain and spinal cord are membranes called the *meninges* (men-in'jees). A liquid between the membranes and in brain cavities acts as a shock absorber. Outside the membranes of the brain is a *cranium* or skull made of bones tightly joined. Outside the cranium is the scalp. If your school has a human skeleton examine the skull. If not, you can learn a great deal about your own skull by examining the skull of a cat or dog.

The spinal cord is almost as well protected as the brain. Besides the membranes and the liquid, the cord is protected by the spinal column or backbone. The backbone is not one bone but a series of small bones, the vertebrae (ver'-teh-bree), which are held together by ligaments. The column is sometimes called the vertebral (ver'teh-bral) column. Because the bones composing it are not rigidly joined to each other, the backbone is flexible. The spinal cord ends about three quarters of the way down the spinal column. All of this will be clearer to you if you do EXERCISES 1 and 2.

The brain and spinal cord. The human brain consists of several regions, three of which are easily distinguished: the *cerebrum* (ser'e-brum), the *cerebèllum* (ser-e-bel'lum), and the *medulla* (med-dull'a). The cerebrum is by far the largest part of the human brain; it lies directly under the top of the skull. The cerebellum is tucked in under the back of the cerebrum next to the medulla. The medulla or brain stem looks like a

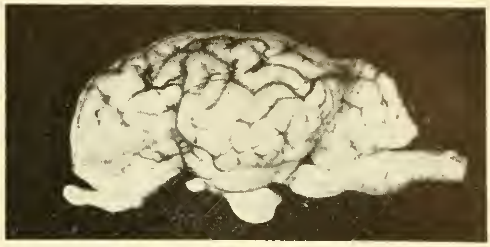


FIG. 255 *A sheep's brain. The front end (left) is the cerebrum. What are the other two parts? The spinal cord is attached at the right.* (WARD'S NATURAL SCIENCE ESTABLISHMENT, INC.)

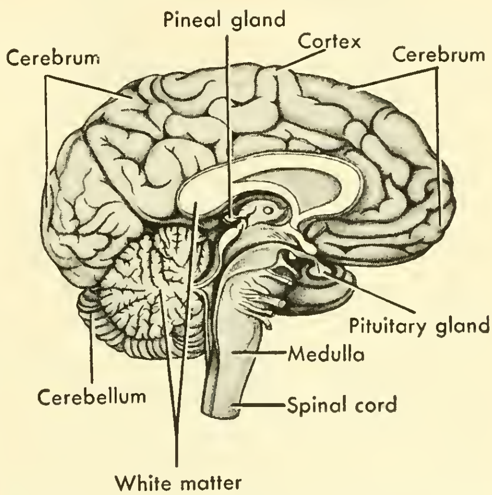


FIG. 256 *A section through the middle of the human brain. Compare it with the brain of the sheep. Which of the three regions of the brain have convolutions?*

widened out spinal cord; in fact, one might consider the cord as an extension of the brain. This shows clearly in Figure 256. You will find it helpful to study a sheep's brain, which is somewhat like our brain in structure (EXERCISE 3).

The cerebrum has a right and a left half. There is a deep cut (fissure) between the two halves that almost completely separates them. If you cut all the way down through the brain between these halves you will discover in the very inside a small cavity filled with fluid (cerebrospinal fluid). The brain substance around the cavity is whitish in color. Outside of the white matter lies the region of the "gray matter" of the brain, better known as the *cortex*. In all the mammals the cortex is in folds or ridges known as *convolutions* (kon-voh-lew'shuns). If this cortex were spread out smoothly, it would cover an astonishingly large surface.

The cerebellum, like the cerebrum, has white matter inside, surrounded by gray matter. In the medulla, however, the gray matter is mixed irregularly with the white matter. In the spinal cord the gray matter forms a column inside the white matter. This column of gray matter looks, in cross section, much like an "H" or a butterfly with wings spread out.

Activities of the cerebrum. Through study of diseased and accidentally injured brains, we have learned much about how the various parts of the brain work. Experiments with animals, too, have contributed much information, for there is good reason to believe that the different parts of the brain work much the same in all vertebrates. Let us see what has been learned by experiments with pigeons. In one common type of experiment parts of the bird's brain are removed, one after the other, and the behavior of the bird is studied after it has recovered from each operation. When the cerebrum is removed the bird seems, at first glance, to act like a normal bird: it can still hop and move its wings; it can still peck at food and swallow. But closer observation shows that unless its bill comes into contact with food the bird will not eat; it does not see or recognize the food. It fails to initiate any actions. Only the original, inborn behavior (reflex), remains unchanged.

Let us see what this shows about the cerebrum. The bird failed to see or recognize food. Evidently, while the eye is the receptor, it is the cerebrum which interprets the impulses that come from the eye. Various other experiments all lead to the conclusion that sensations depend on the sense organs and the cerebral cortex combined. The part of the cortex receiving impulses from the sense organs is called the *sensory* region. One part of the human cortex is used in sight, the part lying in the back of the head. Another part, the region on the side above the inner ear, is used in hearing. Other parts of the cortex are used in smelling and tasting. Our sensations are all dependent upon something that happens in the cerebral cortex after it has received impulses from the receptors.

Secondly, while the bird retained its inborn reflexes, such as pecking at its food once the food touched the bill, it is clear that initiation of impulses occurs in the cerebrum. Here lie centers which control the contraction of voluntary muscles all over the body. These centers are called *motor* areas because the activity here results in motion. Impulses from the motor areas do not go to the various muscle cells directly but are relayed through other parts of the brain. Furthermore we have learned from these and other experiments and observations on human beings that memory, thought, learning, will, and the emotions are associated with the cerebrum. The well-developed cerebrum, such as is found in

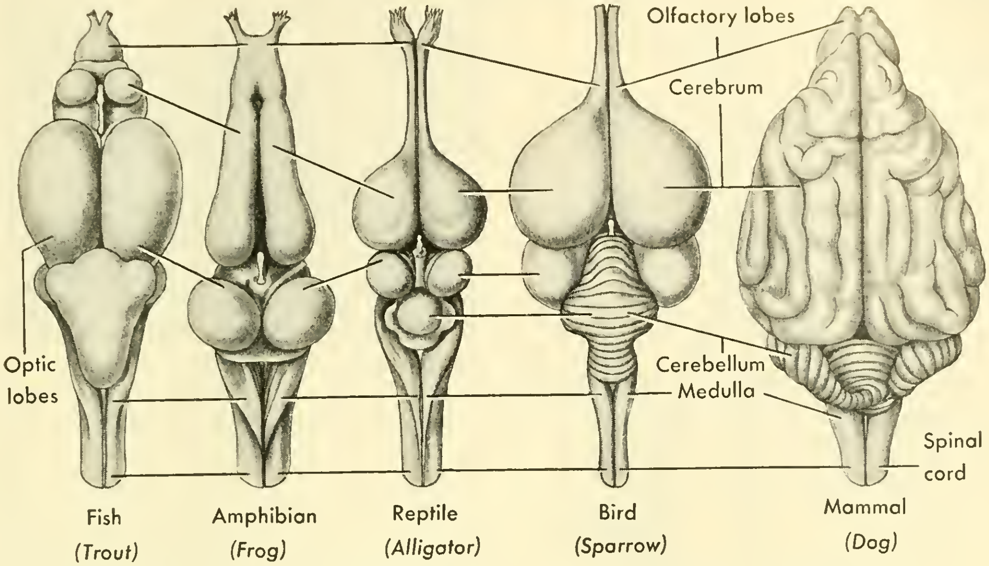


FIG. 257 *Which parts do you find in all five brains? Which part is not visible in the dog's brain? Is there any similarity in the general plan of these brains? Compare the dog's brain with that of the sheep shown in Figure 255.*

man, is evidently a very busy portion of the brain.

Activities of the cerebellum and medulla. If both cerebrum and cerebellum are removed, the pigeon can still move the muscles of its legs and wings but perfect control of these parts seems to have been lost. The bird stumbles and staggers and falls over on its side. Each muscle can contract but it can no longer work in cooperation with the others. This and similar experiments provide evidence that the cerebellum is needed for proper teamwork or *coordination*, as it is called, between the muscles of the body. Without the cerebellum the animal cannot behave as a unit. Since there are more than two hundred muscles in a vertebrate's body, the coordinating of muscular movements is important.

But even in the absence of a cerebellum the pigeon can continue to live if it is fed and protected. Its heart beats regularly, it breathes, it still digests its food, and if you touch its foot it still responds by contracting the muscles of the leg. Evidently neither cerebrum nor cerebellum controls these activities. But when now the lowest portion of the brain, the medulla, is removed, the results are different. The heart stops beating, breathing ceases, and the pigeon dies. There can be little doubt that circulation, breathing, and other internal activities depend on the medulla.

The brains of other animals. While experimentation with birds gives us considerable insight into brain activities you must not get the impression that the bird's brain is just like man's brain in structure. Study Figure 257 in which there are drawings of the brain of a fish, a frog, an alligator, a sparrow, and a dog. These animals represent the five classes

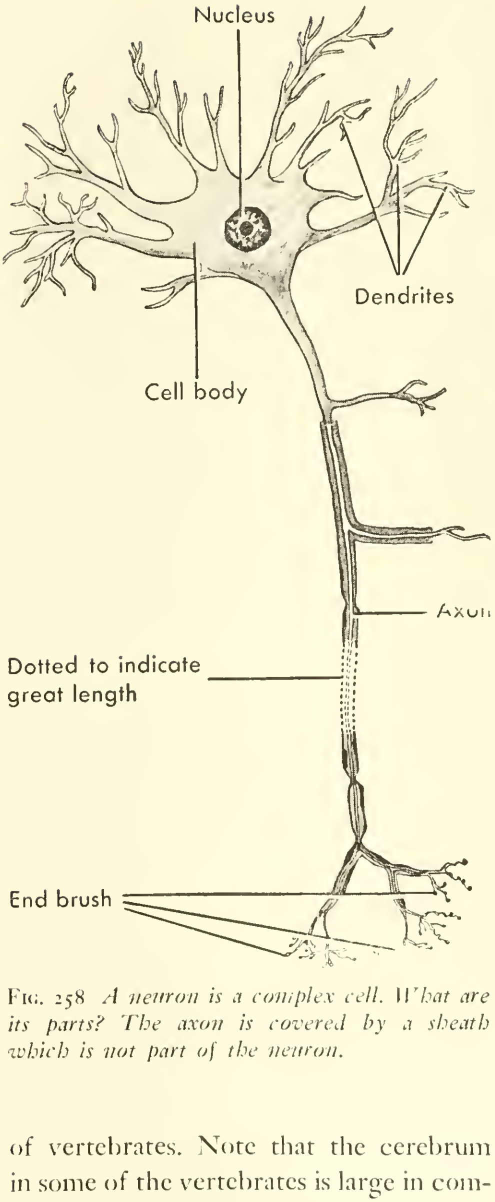


FIG. 258 *A neuron is a complex cell. What are its parts? The axon is covered by a sheath which is not part of the neuron.*

FIG. 259 *Chimpanzee eating. What would you judge about the size and appearance of its cerebrum?* (NEW YORK ZOOLOGICAL SOCIETY)

of vertebrates. Note that the cerebrum in some of the vertebrates is large in comparison with the rest of the brain; in other vertebrates it is comparatively small. Since you know something of the activities of the cerebrum, which animals would you predict to be most intelligent, judging from the appearance of the brain? Does your prediction fit what you know of the animal's behavior? Comparison of the brain of the sheep (Fig. 255) with the diagram of the human brain again shows a difference in size of cerebrum. In fact, the more nearly the cerebral cortex of an animal approaches that of man in size and complexity, the more nearly does the animal's behavior resemble man's. You can test your understanding by doing EXERCISE 4.

Cells of the nervous system. Microscopic study of the gray matter of the brain and cord shows that it is made up largely of nerve cells, or *neurons* (new′-rons). The neuron is the unit of structure of the nervous system. There are several different kinds of neurons. We shall now study one kind. See Figure 258. This neuron consists of a cell body drawn out into two kinds of projections. One of these is the *axon*, the other the *dendrite*. Each cell is likely to have two or more dendrites and the dendrites are usually thickly branched, close to the cell body. The name "dendrite" comes from the Greek word meaning tree. The axon is single and is unbranched or only slightly branched. However, at its extreme end it is subdivided into the end brush or terminal branches. Axons, and sometimes dendrites, too, may be very long compared to their width. Though they are very thin projections from a microscopic cell, and therefore invisible, some axons or dendrites are two feet or more in length. Impulses travel into the cell body by way of a dendrite and out of a cell body by way of an axon.

Cell bodies of neurons are quite variable in shape and size. They have a conspicuous nucleus, but the neurons of man lose their power of multiplication soon after birth. The protoplasm in the cell body, axon, and dendrites has the same properties as all other protoplasm but it has one property, irritability, developed to a very high degree. The neuron is able to transmit impulses through the body with great speed.

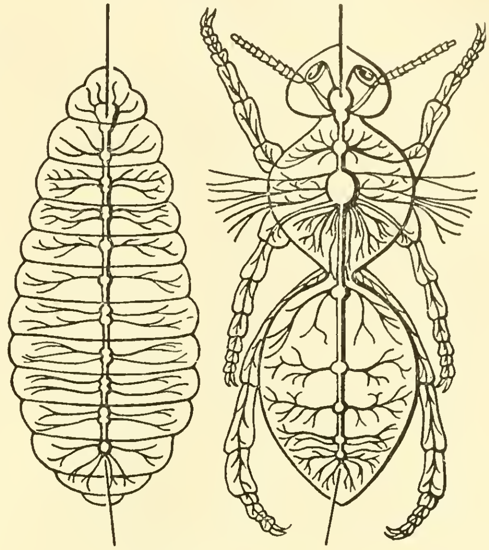


FIG. 260 *Chains of ganglia in the honeybee larva and adult. They are found along the ventral side. Insects have no true brain or cord.*

Cell bodies outside the brain and cord. You have just read that the cell bodies of neurons lie in the gray matter of the brain and cord. Some cell bodies of neurons, however, lie outside of these centers. They form small groups called *ganglia* (gan'glee-a). The singular is *ganglion.* These ganglia are found in definite regions, either near the spinal cord or close to the internal organs. Those close to the organs are part of the autonomic system. You will read about them later. The nervous system of insects consists of chains of ganglia from which the nerves extend. See Figure 260.

Relation of nerves to nerve cells. If you again refer to Figure 254 you will be reminded that all the nerves originate (are attached to) in the brain or cord. There are roughly forty pairs of nerves. By separating into finer and finer branches these nerves reach all the cells of the body. A nerve is nothing more than a bundle of axons with a covering. An axon is therefore often spoken of as a nerve fiber. Even a very fine branch of a nerve is a bundle of axons, not a single axon. A large nerve consists of many thousands of axons, or nerve fibers. Most axons have a covering or sheath. This sheath is glistening white.

A nerve fiber gets food through its cell body. If a fiber is cut, the portion which is detached from the cell body soon dies. The portion attached to the cell body may grow out. In other words, the cell body with its nucleus is the only portion of a neuron in which there can be renewed growth. In this way a whole nerve could grow again or *regenerate,* but regeneration of human nerves does not occur commonly.

The nerve impulse. In most of our nerve fibers an impulse travels at the rate of about 75 yards per second, about as fast as a bullet shot from a revolver. After the passage of the impulse the nerve fiber must rest for a tiny fraction of a second before it can carry a second impulse. It is possible to measure the amount of heat released, the amount of oxygen used, and the amount of carbon dioxide produced by nerves. All these increase while the nerve carries an impulse. While the details are not fully understood, it is known that electrical energy is somehow involved in the passage of an impulse. The electrical currents have been measured.

When a nerve impulse starts in a neuron it travels away from the cell body along the axon to the end brush. There it starts up similar impulses in the dendrites of other neurons close to the end brush. The dendrites carry the impulse into the cell body. In this way impulses may be relayed from neuron to neuron until they reach effectors. The region including end brush and dendrites, where the transfer of a nerve impulse from one neuron to the next takes place, is called a *synapse* (sin′aps). The method of transfer is not completely understood. But it is known that the synapse always slows up the passage of an impulse. Sometimes an impulse does not get across the synapse at all.

Neurons may connect with many others. Since the end brush may be very much branched, an impulse from one cell may be sent to the dendrites of several different neurons. This is true of

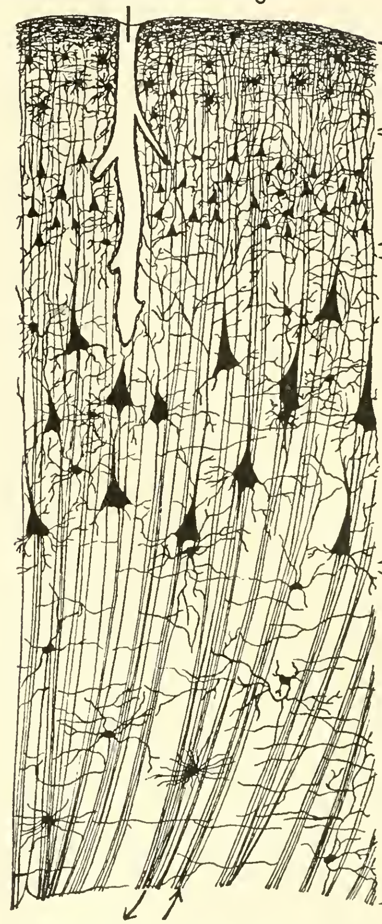


FIG. 261 *A greatly magnified section through the cerebral cortex of man's brain. Only a few of the neurons of this complex tissue are shown. Many synapses are shown.* (*See Figure 262.*)

cell *A* in the diagram, Figure 263. The dendrites of one cell may also come in contact with the end brushes belonging to many different neurons. This is true of the dendrites in cell *C*. The diagram should help you to realize how in a region like the cortex of the cerebrum where the neurons lie close together very many connections are possible. At one time, an impulse may take one path; at another time it may travel to other neu-

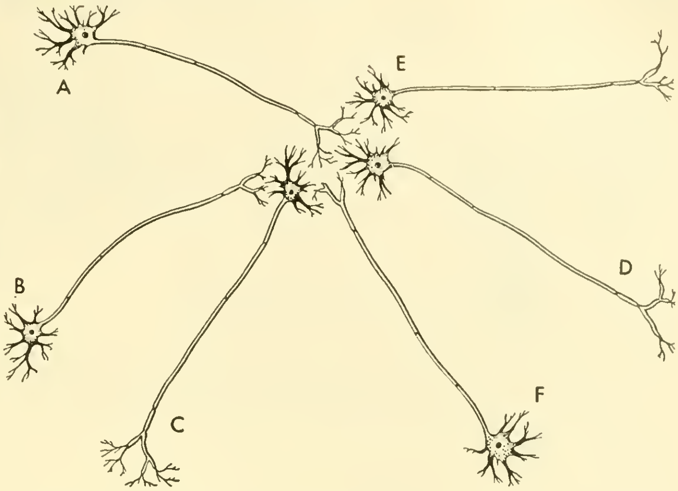


Fig. 263 (above) *To which cells may cell* A *send impulses? From which cells may the dendrites of cell* C *receive impulses?*

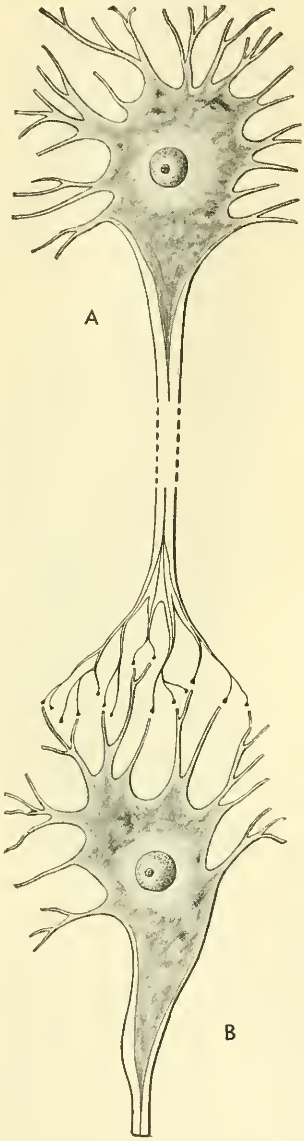


Fig. 262 (left) *An impulse can pass from* A *to* B *across a synapse. Cell* A *is shortened (see the dotted lines). Cell* B *is incomplete. Copy this diagram. Complete cell* B *and show how the impulse would get into another cell,* C, *beyond* B.

rons along a different route. The response may be different if a different route is taken by the impulse.

The reflex arc. Now let us trace an impulse from receptor to effector. In a reflex, under normal conditions, the impulse always takes the same path and only a few neurons are involved. Let us take as an example your inborn response to the touching of a hot stove. A receptor in your skin is stimulated by heat, and an impulse travels from receptor to neuron. This happens to be one of the neurons whose cell body lies in a ganglion outside of the spinal cord. This neuron, too, is different in structure from the neuron we studied above. Instead of having short, widely branched dendrites it has a long-drawn-out dendrite extending all the way from your finger tip to the cell body which lies in a ganglion, just outside of the cord about on a level with your arm. The impulse travels along this long dendrite into the cell body. From the cell body the impulse continues along the outgoing axon. This axon enters the gray matter of the cord (showing in cross section as an imperfect "H"). Here the axon ends in an end brush. The impulse travels from the brush into the dendrites of a second cell and out along its axon. This axon extends from the cord along the arm and ends in an end brush. This end brush connects, not with

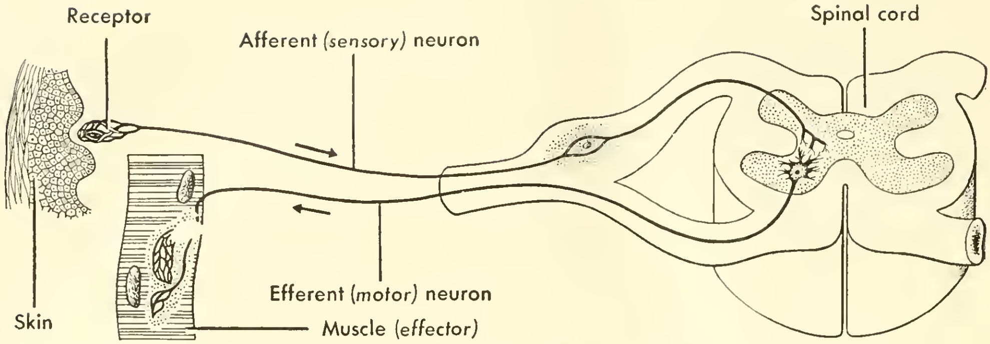


FIG. 264 *The simplest type of reflex arc. No intermediary neuron is shown. Note that the cell body of the afferent neuron lies outside of the cord (in a ganglion). It is different from the neurons you have seen before. It has one very long dendrite. Where are its ends?*

another nerve cell, but with a muscle cell in the arm. The muscle cell is the effector. When the impulse reaches it the muscle cell contracts. In this reflex act, there were used, first, a receptor; second, a transmitter, or nerve cell which carries the impulse to the nerve center (spinal cord); third, another transmitter which carries the impulse out of the nerve center (spinal cord); and, fourth, an effector which receives the impulse, and acts. The first neuron, which carries the impulse inward to the cord, is called the *afferent*, or *sensory*, neuron. Afferent means leading into. The second neuron, which carries the impulse out of the cord, is called an *efferent*, or *motor*, neuron. To help you understand what you have read do EXERCISE 5.

This description and the diagram are oversimplified. What is shown happening in *one* receptor and in single neurons happens in a group of receptors and neurons lying side by side. Therefore all the muscle cells in the muscle contract. And the diagram is oversimplified in another respect. In reality there are probably several neurons lying in the cord between the afferent and efferent neurons. These relay the impulse from the afferent neuron to the efferent neuron. Such neurons are called *intermediary* neurons. But there is little relaying; in other words, there are few synapses and that, no doubt, is one reason why this impulse travels with great speed. You pull your hand away almost instantaneously.

Now in all of us the impulse takes this path and it always takes the same path unless some of the cells have been destroyed. But, you will say, "I pull my hand away because the stove feels hot." That is not true. When the impulse takes the path we have just described you could not have felt anything. No sensations arise from impulses to the cord. You have learned that you feel, you see, and you hear because the cells of the cerebrum receive impulses.

Becoming conscious of the heat. Evidently there must be an impulse reaching the cortex of your cerebrum or you would never be aware of "hot stove." How might this impulse reach the brain? When the impulse from the finger tip reaches the cord it jumps across the syn-

FIG. 265 *The autonomic nervous system. Can you find plexuses? Where? There are two parallel chains of ganglia like the one shown here.*

apse not only to the efferent neuron but also to another neuron whose axon extends all the way up through the cord to the cerebrum. About the time the one impulse reaches the muscle the other one reaches a neuron in the cerebrum. You become conscious of heat while you are pulling your hand away.

A frog can be used to demonstrate that a reflex goes through the spinal cord without the use of the brain. By a simple operation the brain of the frog can be completely cut off from the cord. When the skin on one side is irritated with acid, the foot is raised and brushed against the body just as it would be in a normal frog. Evidently, the brain is not needed for this reflex act.

The autonomic nervous system. You will remember that the nervous system is in two parts: the central and the autonomic nervous system. The most important fact about the autonomic system is that it controls such bodily actions as heartbeat, flow of digestive juices, secretion from other glands, peristalsis, and changing the size of arteries. The actions the autonomic system controls are involuntary. We do not decide on such action. We cannot, for instance, change the rate of heartbeat or flow of gastric juice at will. Notice that the autonomic system controls glands, smooth or involuntary muscle, and heart muscle; the central nervous system controls striated or voluntary muscle.

The autonomic nervous system consists of many nerves and ganglia. There are two chains of ganglia near but outside the spinal column along the whole length of the body cavity. These ganglia are connected to the nearby brain and spinal cord by nerves. Near, or attached to, or within the walls of each of the organs controlled by the autonomic system there are networks of nerves called *plexuses.* Such plexuses include ganglia as well as nerves.

The autonomic nervous system and the central nervous system together control the activities of muscles and glands, enabling them to work together. It is because of this that the body acts as a unit.

Receptors are important. Although we cannot see, hear, taste, smell, or feel without the cortex of the brain, neither could we do these things if we did not have receptors. There are taste buds on the tongue and special nerve endings for smelling in the nose. Scattered in the skin are tiny structures which receive stimuli of pressure, touch, and cold; separate ones receive each of these stimuli. There are also bare nerve endings which when stimulated by a variety of stimuli give rise to pain. You can learn much about these receptors by doing EXERCISES 6, 7, 8, 9, and 10. The skin is not equally sensitive in all parts of the body; the receptors and nerve endings are more concentrated in certain parts. For example, the skin is more sensitive to touch and to pressure on the finger tips than on the back. The lips are more sensitive to pain than are the palms of the hand.

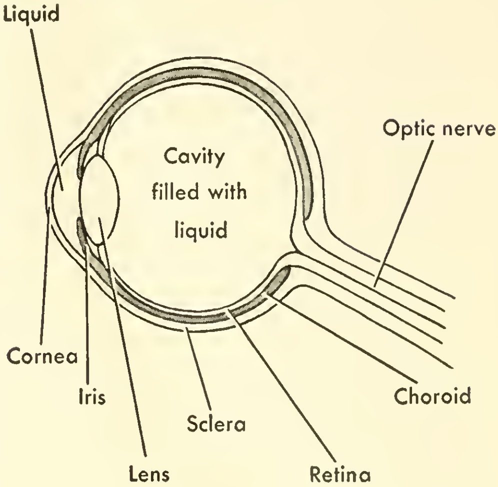


FIG. 266 *A simplified diagram showing the parts of the eyeball. What are the three coats? Through what must a ray of light pass before it reaches the retina?*

Up to this point you have thought of receptors as being structures near the surface of the body which bring your body into relation with the environment. But there are receptors inside the body, too. For instance, there are receptors in the stomach wall. When the empty stomach contracts these are stimulated. Through them you get the sensation of hunger. Nerve endings, perhaps in the throat or other parts of the body, when they lack sufficient water, are responsible for the sensation of thirst. There also are many other internal receptors. All receptors are important because they help keep the body as a whole informed of the internal and external environment.

The eye. We must study the eye so that we may know how to care for it. The eyeball is almost spherical with a lens suspended in it near the front. It is a very complicated organ which has highly sensitive receptors which are stimulated by light. These receptors lie in the *retina* (ret'i-na), the layer which lines most of the eyeball. The receptors in the retina connect with the nerve to the brain. Outside the retina is the second coat (choroid). It is complete except for a small opening directly in front of the lens. This opening is the *pupil.* A small portion of the choroid coat can be seen as the colored part of the eye (iris). By changes in size this portion regulates the size of the pupil, admitting more or less light to the lens. The third coat (the sclera) is tougher than the other two. It completely surrounds the eyeball. The part that covers the iris and lens is transparent. It is called the *cornea.*

Light rays pass through the transparent covering, then through the pupil, and thus strike the lens. The lens directs the rays to the retina. Thus an image is formed on the sensitive cells of the retina. The lens becomes flatter or more rounded in forming an image on the retina. Figure 267 shows how focusing is

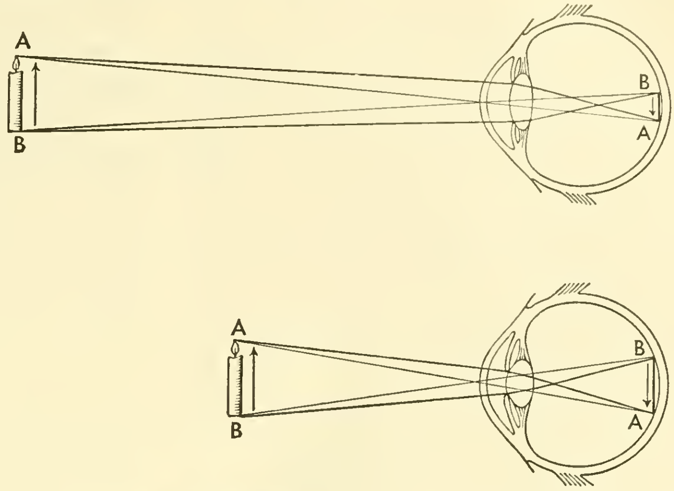


Fig. 267 *As an object (candle) is brought closer to your eye the shape of the lens changes. How? Compare the two figures. If this change did not occur the image would be blurred because it would not be focused on the retina.*

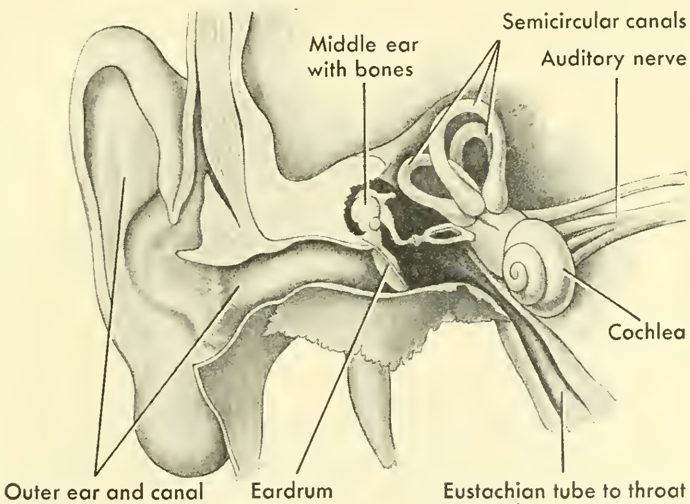


Fig. 268 *The parts of the human ear. Find the outer ear, middle ear, and inner ear. What names are given to the bones in the middle ear? By what passageway is the ear connected with the throat?*

done. With age the ability to change the shape of the lens is nearly lost by many people. The condition is farsightedness and it can be corrected by wearing glasses.

When the eyeball, instead of being spherical, is elongated or shortened, the image does not fall directly on the retina. Vision is then blurred. These faults can also be corrected by wearing glasses. If you do Exercise 11 you will understand the reason.

The ear. If you examine Figure 268 you will see that there is an outer ear and canal, a middle ear, and an inner ear. The inner ear contains the receptors used in hearing. They lie within a spiral passageway through one of the bones of the skull. The spiral passage makes several turns like the turns in a snail shell. For this reason it is called the *cochlea* (kok'lee-a). The spiral canal is filled with a liquid and within part of its length lie the receptors which are in contact with the *auditory* (hearing) nerve. Sound waves pass through the outer ear and canal and hit the eardrum at the entrance to the middle ear. The vibrations are passed along the very small bones known as the *hammer*, *anvil*, and *stirrup* which stretch across the middle ear. Then the vibrations reach the tiny membrane at the entrance to the snail shell. These vibrations set up waves in the liquid which fills the spiral passage (cochlea). The waves wash over sensitive receptors, stimulating them. Thus sound stimuli are received in the inner ear and sent by the auditory nerve to the cortex of the cerebrum. Do EXERCISE 12; what you learn may prove to be useful.

The inner ear which picks up sound stimuli is important to us in still another way. Part of the inner ear opens into a bony structure consisting of three arches which lie almost at right angles to one another. They, too, are filled with liquid and lined with a membrane containing sensitive cells attached to nerve endings. As the head moves and turns, first some, then others of these cells are stimulated by the liquid. Thus man's brain is kept informed of the position of these arches (*semicircular canals*), making it possible for a human being to know the position of his body and keep his balance.

QUESTIONS

1. Name two properties of protoplasm which enable an animal to perform a reflex act.
2. The two parts of the nervous system work together closely. What are they? What does each do?
3. Name the nerve centers. How are the nerves related to the nerve centers?
4. Name in order, starting on the outside, all the structures that protect the brain. Why is the spinal column strong and flexible?
5. Name the three main regions of the brain. What is the arrangement of gray and white matter in the cerebrum? In the cerebellum? In the medulla? In the cord?
6. In what two ways have we learned about the activities of each region of the brain? Name the chief activities of the cerebrum.
7. What are the activities of the cerebellum and medulla? Define coordination.
8. When you examine the brain of fish, frog, reptile, bird, dog, and man what differences do you note in the cerebrum?
9. What is the unit of structure of the nervous system? Name and describe the parts of a neuron. Which property of protoplasm is highly developed in a neuron?
10. Where do the cell bodies of most neurons lie? Where else are they found?

11. What is the relation of nerves to nerve cells? Of axons to nerves?
12. How fast does a nerve impulse travel? What changes take place in a fiber as an impulse travels along it? How are impulses relayed from neuron to neuron? What is a synapse? Why does the number of synapses affect the speed of an impulse?
13. What is the result of having neurons closely packed in the gray matter?
14. Trace the path of the impulse in a simple reflex using the terms receptor, dendrite, cell body, axon, afferent neuron, gray matter of cord, efferent neuron, muscle.
15. Explain how you become conscious of heat when you accidentally touch a hot stove.
16. What kind of muscles are controlled by the autonomic nervous system? In which parts of the body are such muscles found? Describe the structure of the autonomic nervous system.
17. Name three kinds of receptors found in the skin. What sensations do we get through internal receptors?
18. What lines the back of the eyeball? With what does it connect? What name is given to the opening into the eyeball? What lies directly behind this opening? Which part regulates its size? What is the result of having an eyeball which is shorter than normal? Longer than normal?
19. Explain how sound waves travel to the receptors from the time they hit the drum at the entrance to the middle ear. Of what importance is the inner ear besides receiving sound stimuli?

Exercises

1. How does the skull protect the brain? Examine the skull of a human being, of a dog, of a cat. What is the advantage in having the skull rounded on top? How many different bones do you see? How are they joined together? Note where the brain stem leaves the skull.

2. How does the spinal column protect the spinal cord? Examine two or three vertebrae from the backbone of some mammal, or if possible a human backbone. Fit the vertebrae on top of each other. In the living organism, what keeps the separate bones together? Why is the backbone flexible? Using a pencil, show the position of the spinal cord. Where do the nerves pass through the spinal column? Examine the surface of a vertebra at the point where it touches the next. In the living organism there is a pad of cartilage between every two vertebrae. Of what use is it?

3. What is the structure of the brain of a mammal? If possible, obtain a fresh sheep's brain. Notice the thin coverings over the brain. They are called *meninges* (men-in'jees). Compare with the picture of the human brain (or, better, with a model) and distinguish cerebrum, cerebellum, and medulla. Compare the number of ridges in the sheep's brain with those in our brain. Feel the brain; which tissues seem to be lacking? Cut

the brain lengthwise from top to bottom. Find the cortex and the white matter. Draw a single diagram of this section.

4. Answer the following questions: (*a*) Is a person with a large brain necessarily more intelligent than one with a small brain? Why or why not? (*b*) What device can you think of for illustrating that the convolutions must increase the amount of cortex in a brain? (*c*) Why is an injury to the base of the skull particularly dangerous? (*d*) What would be the result of destroying the part of the brain in which the nerves from the eyes end?

5. Study the diagram of the reflex arc. Draw separately (*a*) the receptor, (*b*) the afferent neuron, (*c*) the efferent neuron, and (*d*) the effector. Make a second drawing in which you put these parts together so as to make a reflex arc. When you have read further you can add neurons to show how you become conscious of the hot stove.

6. Are there separate receptors for "hot" and "cold" in man? Mark out a one inch square on the forearm of a blindfolded student. Slightly heat a needle; cool another in ice water. Using the blunt end, touch nearby points within the marked area with the hot and cold needles. Put a dot on a sheet of paper to correspond to the points at which warmth is felt and a cross to indicate where the needle felt cold. Do the dots and crosses fall on the same spots? Repeat this experiment, using other students. Are the receptor maps exactly alike?

7. In what parts of the tongue are the taste buds sensitive to substances that are sour, bitter, sweet, or salt? Blindfold a student. Test various parts of his tongue with sugar, salt, quinine, and lemon juice. Have him rinse his mouth after each test. Record your results. Repeat with several other students. Draw a diagram of the tongue and indicate the sensitivity of each part to the four substances.

8. How could you show that you smell rather than taste most substances? Try it and report.

9. Do foods have the same flavor if you are blindfolded? Try it and report.

10. Are touch receptors evenly distributed over the body? Blindfold a student. Your results will be better if he does not know what you are going to do. Keep accurate records. Touch his forearm lightly with the points of two dissecting needles or other fine-pointed instruments, the points being about three eighths inch apart. Does he feel two points or one point? Moving the points of the needle closer together or farther apart, test various parts of the hand and forearm. For several places find the greatest distance at which he thinks the two needles are one. What was the shortest distance between the points at which he could feel both? What would this indicate? Now repeat the operations on the palm, fingers, back of the hand, cheek, forehead, and so on. Where are touch receptors closest together? Repeat the entire experiment using different subjects. Why is this necessary? What are your conclusions?

11. How do nearsighted and farsighted persons see? Copy the upper diagram in Figure 267, which illustrates how the light rays from a candle are thrown on the retina. Leaving the image where it is, erase the back of the eyeball and draw a long eyeball instead of a spherical one. Where does the image fall with relation to the retina? A nearsighted person has eyeballs like this. Why does he not see objects clearly when held at the normal distance from the eye? A farsighted person has eyeballs that are too short so that the image falls back of the retina. Draw this condition.

12. Answer these questions: (*a*) Examine the diagram of the ear. Why may ear trouble follow a sore throat or a cold in the head? (*b*) What advice would you give if an insect crawled into the outer ear? What would stop its passage? If it should be a stinging insect what treatment would be most likely to make it use its sting? Some insects move toward the light; what might you try?

Further Activities in Biology

1. Prepare a simple model to show afferent, efferent, and intermediary neurons. Use strings of different colors.

2. Dissect out the brain, spinal cord, and large nerves of a large frog. This takes skill and patience because the organs are soft and easily damaged. Ask your teacher what instruments to use for cutting bone, or try several to find which works best.

3. It might interest you to learn about the sense organs of some of the lower animals. Do the following: (*a*) Is the earthworm equally sensitive to light at both ends? What experiment would you use to determine this? (*b*) Devise an experiment to find out how an earthworm responds to the vibration of a nearby blow. (*c*) Put a splint that has been dipped in xylol near an earthworm. What do you observe? Find out if all parts of the body are equally sensitive to smell. (*d*) Look up and report on color perception in bees.

PROBLEM 3 *How Does the Behavior of Complex Animals Differ from That of Simpler Forms?*

The nervous system and behavior. You now know that the behavior of a species of animal depends in many ways on the kind of nervous system it has. Some animals have complex brains made up of billions of neurons with enormous numbers of connections through end brushes and dendrites; their behavior is complex. If the brain is simple in structure, the behavior is simple.

But no one has been able to explain what goes on in the neurons of human beings. No one has been able to say what changes take place in man's neurons when he thinks or remembers something that happened a year ago or feels sorry for someone. We are fairly sure that neurons are involved in these forms of behavior but we don't know how.

In spite of our ignorance of the part played by neurons a great deal has been learned about human behavior by observation and experiment. Some of the important ideas developed by *psychologists* (sy-kol′o-jists), people who are students of human behavior, will be presented here.

Our behavior is extraordinarily complex. The behavior of a simple animal is difficult to understand. The behavior of an animal with a brain is almost too complex to describe, let alone explain. There are so many stimuli being received, so many responses being made, so many neurons taking part all at the same time, that describing each act as a separate act gives quite the wrong picture. In describing your behavior at this moment one might say that you are reading this page. But what a false impression that would give of what is really going on in you! In the first place that one act of reading involves a great many other acts: contracting many eye muscles to move your eyes across the page, probably holding down of the page by the muscles of your arm, perhaps the holding of a pencil, seeing the letters, interpreting the words, understanding the meaning. And there are dozens of other responses that you are giving at this moment that have no direct connection with your reading. You are contracting muscles which keep your body in an upright position, you are performing all the internal reflexes, such as breathing, heartbeat, and digestion. You may be hearing a truck rattling outside the window, feel a breeze on your face, smell the food being prepared in the kitchen, feel a twinge in an aching tooth, and so on indefinitely. There is no limit to the complexity of the behavior in a higher animal.

FIG. 269 *Is driving a tractor a reflex act? What are some of the reflexes that are going on in this boy? What stimuli is he receiving that call forth other responses?*

Each act, too, is generally not clean cut like a reflex act, in which receptor, transmitter, and effector can be located and named. In a reflex one can trace stimulus to response. In acts which are not inborn a stimulus may cause one response in you now, a different one ten minutes later. Hearing your neighbor's radio may serve as a stimulus to turn on your radio. At some other time it may serve as a stimulus to get up and close the window. The response cannot be surely predicted. A response to a stimulus may be so long delayed that it is difficult to describe just what the stimulus really was. When you closed your book and picked up a tennis racket, the stimulus may have been received hours earlier when you heard the words, "Meet me at four o'clock!" On the other hand, the stimulus may have been recent. Perhaps you read the word "court" in your book, or your eye happened to fall on the racket in the corner, or you heard the bounce of a ball or smelled honeysuckle which covers the stopnets on the court. Any one of these stimuli may have changed your behavior, making you close your book and pick up your racket. You may not even have been conscious of the stimulus.

Learning. The word "learning" may suggest memorizing a lesson. It includes also learning of many facts without formal study. You learn the names of your classmates, you learn that a knife cuts, that woolen clothes are warm, how one make of car differs from another, and countless other things of which you are not even aware. This is one kind of learning.

We shall use the word learning in a much broader sense. In learning we not only store up facts, but we learn to respond to new stimuli, we learn to make new responses. All of the large number of

FIG. 270 *Learning includes much that is not written in textbooks. Many neurons are brought into action while this young lady learns to skate.* (PRESS ASSOCIATION)

activities of your life which are not simple reflexes or instinctive acts are learned acts; they are dependent on learning. They make up the greater part of your behavior.

Let us study some of your learned behavior more closely. You must remember that much of this behavior is not yet understood, that the discussion must be short in this book, and that the little you learn now is just a small step on the road toward more complete understanding of the behavior of human beings.

The conditioned response. Let us examine first a simple form of learning found in many animals and in very young babies. You know that the presence of food in the mouth stimulates the secretion of saliva. This response is inborn; it is a true reflex. As the baby grows older it learns to recognize the odor or sight of certain foods. After a while the odor or sight of these foods calls forth the secretion of saliva long before the food reaches the mouth. A new stimulus (obtained through the eyes or nose) now calls forth an act that at first was a response to another stimulus. Since the act is now a response to a different stimulus it is called a learned or acquired response. It is also called a *conditioned response*. Sometimes it is called a *conditioned reflex* but since by definition a reflex is unlearned, it seems confusing to use such contradictory words together. This conditioned response is one example of simple learned behavior, behavior that is not reflex.

Pavlov's experiments. More than half a century ago Pavlov, the great Russian physiologist, became interested in such learned responses and determined to study them experimentally in animals. You have read in an earlier chapter how, by placing food in the dog's mouth and ringing a bell at the same time, after a number of repetitions, secretion of saliva took place at the sound of the bell, without the presence of food. Pavlov substituted the ringing of a bell for the normal

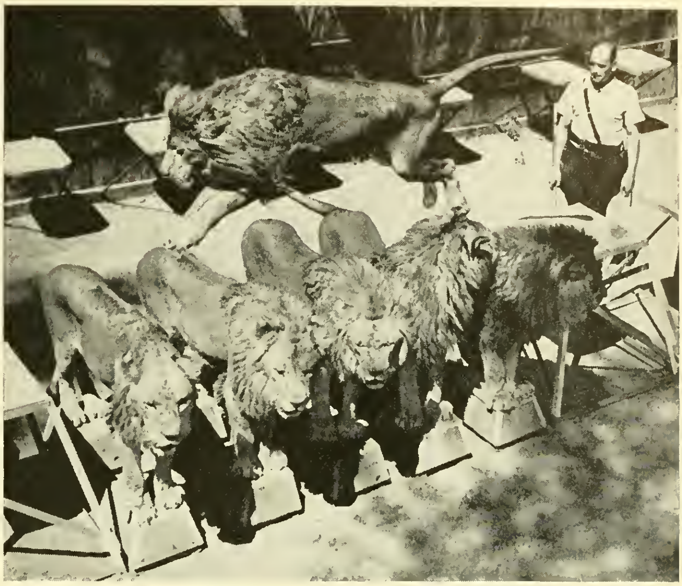


FIG. 271 *What reflexes are used as the basis for training animals such as these to perform?* (ACME)

food stimulus and the dogs secreted saliva. Pavlov called it a conditioned reflex; we prefer to call it a conditioned response. A conditioned response is unlearned as readily as it is learned. Thus it is clearly different from a reflex in two ways: it is learned, while a reflex is inborn; and it may be unlearned or lost, while a reflex is rarely lost unless cells are injured.

Conditioned responses are common. The conditioned response is one of the simplest of the learned acts. It often accounts for the training of an animal. To teach your dog to respond to your call, you hold out some desired food and whistle or call at the same time. The smell of the food is the stimulus and he comes. But as he smells the food he hears your call; two stimuli attach themselves to the response. Soon you can drop the food stimulus and the call alone will serve to make the dog come to you. As a rule conditioning such as this does not wear off, probably, because the dog finds a reward in coming to you even if he gets no food. Some animals make the substitution quickly; they learn easily. Others need more frequent repetition. If possible do EXERCISE 1.

A baby, too, acquires conditioned responses. At a very early age the baby's mouth goes through sucking movements at the sight of the bottle or the sound of the mother's footsteps or any other sounds associated with the usual feeding. Can you think of other conditioned responses in the child? Conditioning in the child is easy up to about the age of four. But there are situations in which even an adult may be conditioned.

Other kinds of learned responses. There are many learned responses which are not conditioned responses. As a child you learned to do many things which now seem so natural to you that you may not realize that they are learned responses; you have forgotten how difficult it was to learn them. Learning to hold a spoon and feed yourself is one of

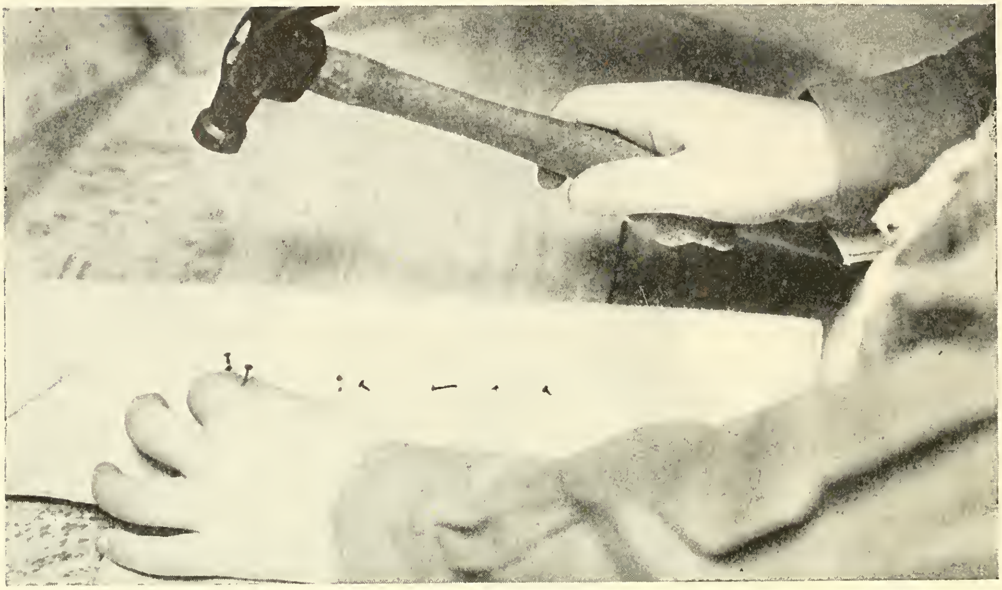


FIG. 272 *Humans learn by trial and error. This youngster probably hammered his fingers in the beginning, but with repetition, such wasted motions become less frequent. Why is this not a conditioned response?* (38TH ANNUAL REPORT, SUPT. OF SCHOOLS, NEW YORK CITY)

these. Learning to open a door is another. Learning to dress yourself, to skate, and to ride a bicycle became problems at various stages of your growth. There were countless responses for you to learn. Most of them were not conditioned responses built on our inborn reflexes. How did you learn them? Again let us turn to animal experimentation to find the answer. In the less complex animals behavior is less complex and for that reason more easily studied.

A fish learns by "trial and error." In one experiment some shade-loving fish were kept in an aquarium which was half in the sun and half in the shade. They usually gathered at the darkened end, especially since this was the end at which they were fed. One day they were gently forced to the sunny end of the tank and kept there by a glass partition placed across the aquarium. This partition contained a small hole just large enough for a fish to pass through. As you would expect, the fish swam back and forth along the glass until, by accident, one struck the opening; it darted through. The fish was quickly rewarded by getting food and by being in the shade. Up to this point the behavior of the fish was reflex behavior; it succeeded because of good luck. But when the experiment was repeated many times with this same fish it got to the hole with fewer and fewer wasted motions and therefore in a shorter time. The fish modified its behavior; it learned. It learned after many repetitions in the course of what is sometimes called "trial and error."

Other examples of trial and error. Many similar experiments in learning have been performed with a large variety of animals. Chickens have been frequently used and rats perhaps most often. Even earthworms have been experimented with. Boxes have been constructed with a maze, a confusing network of paths, only one of which leads to food at the end. Animals have been put into such a maze and observations made of their attempts to reach food. The first success was accidental. With repetition an animal will learn to find its way in a shorter and shorter time. In one experiment the following figures were obtained. On the first attempt it took a rat 28 minutes, the next time 11, then 12, 4, $4\frac{1}{2}$, 5, 5, $2\frac{1}{4}$, $2\frac{1}{4}$, 2, and so on until after about the thirtieth time it ran through its maze to the exit in less than half a minute. Between the tenth and thirtieth performances there were again several slight ups and downs; on the seventeenth try, for instance, it took the rat 3 minutes, but on the whole the rat made better and better scores. The rat was learning. Experimenting with rats in a simple maze is not difficult.

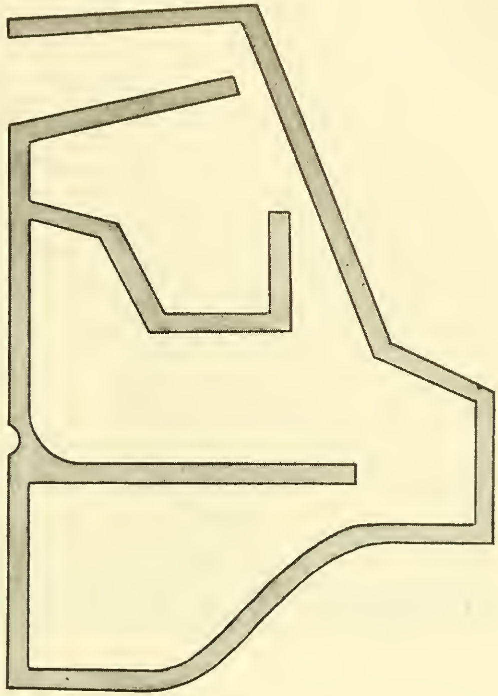


FIG. 273 *Professor E. L. Thorndike tested chicks in this maze. At first the chicks fluttered about wildly and ran back and forth until they got out. After many trials the chicks learned to find the correct exit with almost no errors.* (THORNDIKE)

Professor Thorndike observed the behavior of cats, not in a maze, but in a "puzzle box." This is a box made of slats too close together for the cat to squeeze through and closed with a door which can be opened from the inside by means of a lever. A hungry cat was placed inside. Food was placed outside the door. After trying to get through the bars the cat moved about and clawed the sides until by accident it pressed on the lever (trial and error). The first time it took 160 seconds. On successive trials these scores in seconds were made: 40, 85, 22, 32, 10, 21, 12, 12, 18, 12, 10, 8, 11, 8, and 8. The cat was learning to do what at first it accomplished by accident. You could arrange these figures in such a way that they would mean more at a glance. See EXERCISE 2.

You, too, have learned by trial and error and after many repetitions; you did so in learning to feed yourself, to dress yourself, and in the many other activities you learned as a child. You can observe yourself while solving a problem by trial and error if you do the Chinese ring puzzle. See EXERCISE 3. Or try your success in tracing your way through a maze with a pencil point. See EXERCISE 4.

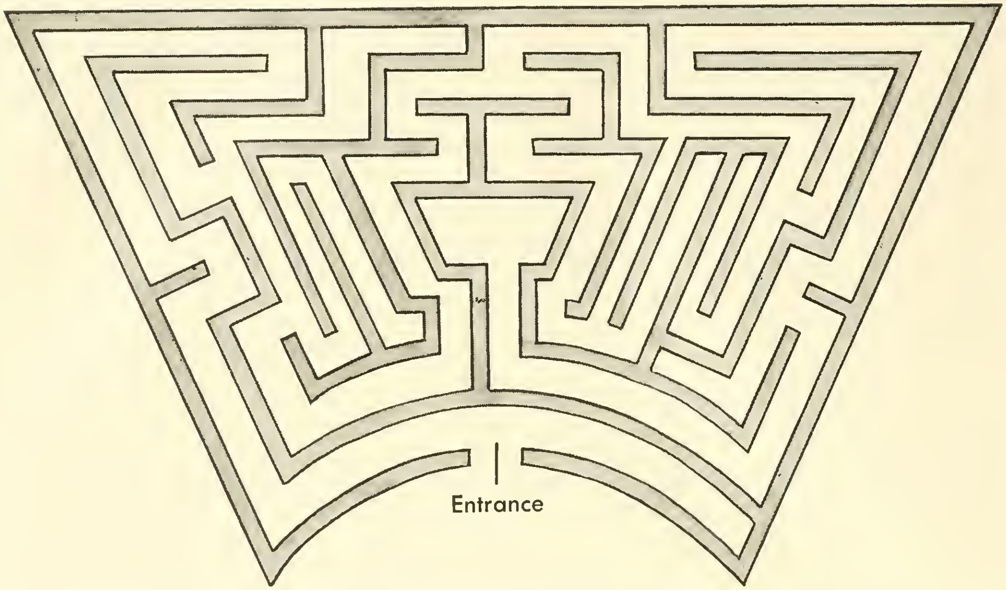


FIG. 274 *In the Hampton Court Palace gardens in England a maze was constructed by planting a hedge in an elaborate design.*

Habits. If you look back to the figures which showed the rat's success in finding its way through a maze on successive days you will see that it accomplished its task faster on the second day than on the first. We say that it had begun to "learn," whatever that may mean. After several days it had learned its way still better. In other words there are all degrees of learning. When an animal has repeated an act often enough and particularly if it has met with reward, the learning becomes complete. The act then appears almost like a reflex. Yet it is not a reflex, because, as you know, a reflex is inborn, not learned. This kind of completely learned act is called a *habit.* The fish that rises to the surface of the tank every morning at eight o'clock because you have made a practice of feeding it at that time has learned completely to respond in a certain way; it has developed a habit.

Habits and reflexes compared. A habit may become so firmly established that it is performed with as much regularity and with almost as much speed as a reflex. That is, it becomes automatic; you do not think about it. In this respect, it is like a reflex act. But it differs from a true reflex in that a reflex is inborn and requires no learning; a habit is learned. The man who through a quick response avoids an accident in his car has acquired habits; he has learned certain actions so perfectly that he can respond with great speed.

There is another great difference between habits and reflexes: reflex or instinctive behavior in a certain species of animal is identical in all members of the species, for these animals are born with a complete pattern for reflexes laid down in their nervous system. But the habits of one animal may or may not be like

FIG. 275 *Has this boy learned how to thread a needle? Has it become habitual? What makes you think so?* (38TH ANNUAL REPORT, SUPT. OF SCHOOLS, NEW YORK CITY)

those of its sisters and brothers; the habits, which are learned during the lifetime of the animal, will depend, of course, on the particular surroundings in which the animal lives.

It is impossible and useless for you to try to label each automatic act as either a reflex or a habit. Very frequently when an act is a complicated one a part of it may be learned and another part may be reflex. One overlaps the other.

Habits are of help to you. In the first years of your life you were so busy acquiring habits that you have never been as busy since. You learned to move one leg after the other without holding on and without even so much as thinking about legs. There were many random motions and many unsuccessful attempts before you completely learned to walk with ease. There was trial and error and after many repetitions there was success. You learned to use a spoon, even a fork, without having the food fall off. You learned to move certain muscles in your tongue and in your jaws, in a particular way, so that you could say hundreds of different words. If you had been left in the jungle, away from other humans, you would no doubt have learned to make many strange noises but you would never have uttered a real word. Speech is not inborn. Speech is learned by imitation through frequent trials and repetitions until it becomes automatic. You learned to grasp a pencil and draw pictures which no one but you could recognize. At last you learned to form letters so easily that now there are no false motions and you can think about what ought to be put down next while your fingers go right on moving. All of these things and a hundred others that you do daily are habits.

These habits are very helpful to you. The child who has completely learned to tie his own shoelaces without fumbling can tie up his shoe in a very much shorter time than when he first attempted it. Speed is acquired. Furthermore, the laces stay tied; accuracy or efficiency is developed. After the shoelaces have been tied a few hundred times, the necessary nerve connections are made so easily that the child need not even keep his eyes on the job; he can tie the laces while watching the kitten chase its tail. When an act has become habitual you can perform it and another act at the same time.

Necessary conditions for habit formation. There must be frequent repetition. Obviously you must not let exceptions occur, for that means making a new start each time. Yet repetition at frequent short intervals is not the only condition necessary for complete learning or forming habits. Surely you have discovered that the more deliberately and the more eagerly you go about learning anything the more successful you will be. But what makes you eager? It is the knowledge that there will be a reward at the end. In the learning of other animals the reward is often food. For you the reward may be the feeling of success, the surpassing of others, or the thrill of accomplishment. Also the reward for you may be long delayed and yet serve as an incentive. In other animals it must be immediate.

Anything unpleasant serves as the opposite of a reward. It teaches an animal to avoid something. An earthworm, put into a maze where it has a choice of paths, learns to avoid a certain path if it always gets an electric shock along this course. For the child it may be merely a look of disapproval on the parent's face which keeps the child from learning certain actions. To review the paragraphs on habits do EXERCISE 5.

Breaking habits. Probably you have several habits that are of no use to you. You learn responses so easily, that is, you acquire habits so readily that sometimes you become perfect in activities without becoming aware of it. These activities may be useless or even harmful. Have you such habits? Breaking yourself of a habit may prove to be very difficult. Merely determining to break yourself of a habit may meet with little success. Many habits are so completely automatic that often you are no longer conscious of practicing them. Or, you may be conscious of the habit and it may give you satisfaction; in that case you are torn between the desire to break the habit and to keep it. The best way to break a habit seems to be to attempt to substitute another less objectionable habit for the original one. EXERCISE 6 will help you become aware of some of your own habits.

Acts involving thought or reasoning. The sum total of our learned behavior is more than the many conditioned responses and innumerable habits and skills which we have learned through trial and error. Human beings especially have many activities of a still different nature. A cat in a puzzle box solves its problem of escape by trial and error. A baby would do the same. But you under similar conditions would not resort to trial and error. You would find an easier way of getting out of a puzzle box. You would begin by looking about you. You would know, without trying, that the slats are too close together to permit you to squeeze through. In the meantime you would be receiving many stimuli. On one side of the box you would see a door. You now see a lever on the door. You would, therefore, try the lever and free yourself. You might have to try the lever several times before it worked (trial and error), but through observation and reasoning you would figure out how to release yourself.

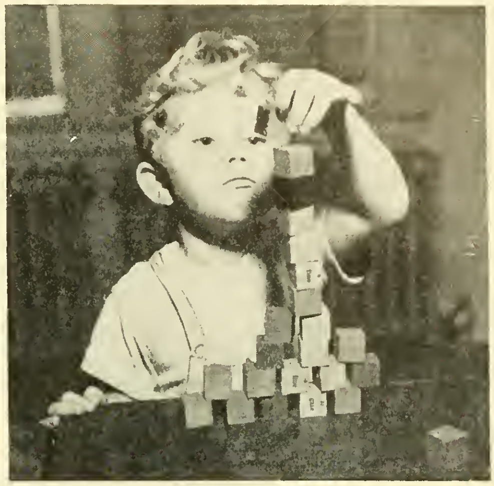


FIG. 276 *What reasoning has gone into this simple activity?* (38TH ANNUAL REPORT, SUPT. OF SCHOOLS, NEW YORK CITY)

Experience needed for reasoning. If you have done something or observed something and stored it up in your memory you have had a certain experience. The more you do and observe and store up the more experiences you will have had. You have learned the size of the space needed for your body to pass through. You have seen doors before and you have stored up memories of doors, their appearance, and their use. You have had experiences with levers before and you remembered them. It is obvious that the more experiences you have had and the better you can store up these experiences the more readily you can solve, by reasoning, any problem you meet.

Reasoning in other animals. To some extent the cat and other mammals, too, store up memories and draw on these at some future time. Have you seen evidences of this? They may solve simple problems in ways other than by trial and error. Apes certainly do so, as the following experiment demonstrates. A particularly intelligent chimpanzee was used for the experiment. Two bamboo rods of different thicknesses, so that one could be fitted into the other, were placed in the chimp's cage. A banana was laid outside of the cage at such a distance that it could not be reached with either rod. The animal began by reaching for the fruit with the longer stick. After several unsuccessful attempts he gave up. Later while playing with the two rods in the back of the cage he accidentally fitted the smaller into the larger. At once he jumped up, went to the front of the cage and reached for the fruit with the jointed stick he had just made. The sticks accidentally fell apart so he again fitted one within the other. This time he secured the banana. Once having fashioned his new tool (accidentally, the first time), he associated the tool with the banana which he had tried to reach some time before. He immediately recognized the use to which he could put the jointed stick. Because of his ability to make this association, he solved his problem of getting the banana.

FIG. 277 *This chimpanzee has learned that he will get food by pulling on the rope. The food is placed in a carrier attached to the other end of the rope.* (DR. ROBERT YERKES, YALE UNIVERSITY)

In other experiments carried on at Yale University, chimps have shown an astonishing ability to learn and reason. Chimpanzees were taught to get their own food at "chimpomats." They use poker chips of different sizes and colors in place of coins. They soon learn to distinguish between their different "coins" and to hoard the more valuable ones. When poker chips are distributed, even after the chimpanzees have been well fed and while not in sight of the chimpomat, they will fight for the most valuable "coins." It is clear that experiences are stored and associations made.

Tools that help in reasoning. You have stored up an incredible number of experiences in your memory, far more than any other animal; you have a much larger cerebrum. But you have another advantage. Men have developed certain tools which all other animals lack, tools which aid them in getting experiences. They have developed speech and writing. Because of speech and writing you can learn from others what you cannot experience directly yourself; and you can learn in minutes or hours what otherwise would take years or a lifetime of experience to learn. Thus you can store up countless experiences and draw on them to help you reason. Therefore, much of your behavior as you grow up is of the kind which involves reasoning, rather than trial and error.

Behavior and emotions. In describing the unlearned and learned responses of man and certain other vertebrates we have scarcely referred to one very important part of behavior. You all know the feelings of anger, joy, sorrow, amusement, hope, fear, surprise, love, and hate. All of you have experienced these feelings or *emotions,* although you may find yourself unable to define any of them. Emotions play a very large part in your life. They determine a great many of your responses. Some of them may produce striking physical changes in your heartbeat, breathing, secretion of digestive juices, peristaltic contractions, and contractions of skeletal muscles. You read earlier that anger causes the adrenal glands to secrete more actively, bringing about changes in many parts of the body. This is also true of some other emotions.

Other vertebrates, evidently, have emotions too. In apes and in men the feelings or emotions are shown in the facial expression, but dogs and cats also make clear to us how they feel. If you have ever watched goats or lambs you know how they kick up their heels in play. Even fish can show anger, as displayed by the behavior of the Siamese fighting fish. But to what extent, if any, invertebrates have emotions is difficult for us to determine. Perhaps a true brain is needed for emotional behavior. The less developed the brain, the less emotional behavior is shown. Experiments with animals indicate that the emotions are controlled by the lower centers of the brain and by the autonomic nervous system.

FIG. 278 *What emotion is this little girl expressing in her face and her whole body?* (EVA LUOMA)

Emotions and growing up. A very young baby seems to have only three emotions: fear, anger, and pleasure, and they are called forth by a very limited number of stimuli. Patting or rocking calls forth pleasure; restraining its muscular movements arouses anger; and a loud noise or being dropped causes fear. As the baby develops, the variety of emotions increases and the number of stimuli which may arouse these emotions is increased enormously and with great rapidity. In someone of your age the stimuli could not be listed, for they are countless and they are somewhat different in each person and different in any one person at different times. And the variety of emotions you may experience would take a long time to list. Try it by doing EXERCISE 7.

Our emotions may play us all kinds of tricks; we often come to associate them with quite unrelated objects or circumstances. For example, a young child given its first taste of carrots may feel "pleasure." But as he eats, an unexpected noise may frighten him. Fear may thus become associated with the food and thereafter carrots will be unwelcome. Can you give other examples of an emotion which attaches itself to the wrong stimulus?

As you grow older and your experience with different situations and different people broadens, you will tend to be better able to meet new situations and new people calmly. Growing up means development of emotional balance as well as increase in ability to think straight.

Behavior in man. Your behavior includes a large variety of responses. Some of these are inborn responses or reflexes, largely internal reflexes, on which life depends. Some are habits, the acts that you have learned to perform quickly and efficiently through long practice and repetition. Somewhat like them, but far fewer in number, are your conditioned responses; these are changed reflexes, in which new stimuli call forth old responses. But these responses make up only a small part of your behavior. Most of your responses are learned responses which involve thought and reasoning and emotions. It is such behavior which makes it possible for men to conquer disease, to design buildings and bridges, and to build up a United Nations organization.

This makes a complex story in which all but the simplest acts are hard to describe and almost impossible to explain biologically. Psychology is a recent and one of the most fascinating fields of biological study which attempts to explain our behavior. Much progress is now being made in the science of psychology.

Questions

1. How does man's behavior compare with that of a fish? Why?
2. Give an idea of the complexity of your behavior at the present moment. List some of the stimuli which might cause a response such as opening the window.
3. Show how learning means much more than memorizing a lesson.
4. Give an example of a conditioned response in a baby. Why is the name "conditioned response" better than "conditioned reflex"?
5. State two ways in which a conditioned response differs from a reflex. Whose name do you associate with conditioned responses?
6. Explain how conditioned responses are made use of in training animals.
7. Name some responses, other than conditioned responses, which have been learned by you.
8. How does a fish learn by trial and error?
9. Give two other examples of trial and error learning in animals. Cite figures to show that there was learning in these acts.
10. Define the term habit. Give an example of a habit acquired by some animal.
11. In what respect does a habit resemble a reflex? How does it differ from a reflex?
12. Name five habits that all of us have acquired. Give three reasons why it is a help to us to make certain acts habitual.
13. Name four conditions that are necessary for acquiring habits.
14. What is the best way to break a habit? Why is it so difficult?
15. Tell how your behavior in a puzzle box would differ from that of a cat.

16. What is meant by experience? Explain how experience would help you in a puzzle box.
17. Give an example of reasoning by a chimpanzee.
18. What tools used by man and no other animals help him gain experience?
19. Name six or eight emotions you have experienced. How can they affect you physically? How do they affect your responses? Discuss emotions in other animals.
20. How do a young baby's emotions compare with yours in (*a*) variety, and (*b*) in the number of stimuli which may arouse them? Why is it necessary to learn to control the emotions?
21. Name and define the different kinds of responses you make. What makes up the largest part of your behavior?

Exercises

1. (*a*) If you have ever had a pet, describe how you trained or conditioned it. (*b*) Give an example of a conditioned response in a child.

2. Using the figures given for the experiments with rats and cats, draw a learning curve on cross-ruled paper for each of these animals. Can you suggest reasons why the animals did not improve steadily?

3. What type of learning do you display in solving a puzzle, such as the Chinese ring puzzle? Time yourself. Describe the method by which you solved the puzzle. How long did it take your classmates? What method did they use? How long does it take the second time? You can vary this experiment by placing a mirror on a table with a sheet of paper in front of it. Draw a star or a horse by watching your pencil in the mirror. Don't look at your hand. Time yourself. Do it a second, third, and fourth time, keeping a record of the time.

4. Make several copies of the maze (Fig. 274). Keeping the diagram covered and exposing only as much as you need to see to continue, trace the path to the center with a pencil line. Time yourself carefully. Keep a record. How long does it take you the second time? The third time?

5. Answer these questions: (*a*) Why is it that a good pianist does not have to think of where to place his fingers when playing a composition? (*b*) A pieceworker in a factory earned $12.00 the first and second weeks; $13.00 the third; $14.50 the fourth; and $16.00 the fifth. Compare this record with the trial and error figures for the rat. What difference do you note? Why should there be this difference?

6. (*a*) Make a list of fifteen activities that have become habitual to you. State about each whether the habit is helpful to you, harmful, or unimportant. (*b*) Name one or two bad habits that you have acquired. Outline exactly how you may break yourself of a bad habit.

7. List some of the feelings or emotions you have experienced. Then group them together into classes. For example, pleasure and joy can be grouped together. Which of all the emotions do you find the strongest?

Further Activities in Biology

1. How can you establish a conditioned response in white rats? Train white rats to come for food at some special signal. What will you do to make the rats lose this conditioned reflex? Try it. Keep a record.

2. Devise an experiment to show the "trial and error" method of learning by a cat or dog or some other pet. (*Hint:* Use a puzzle box from which the animal can escape by pushing one side.)

3. Determine to what extent the presence of food at the end of a maze will affect the time in which the animal learns to get out of the maze.

4. Report on various methods of aiding one's memory. You may try some of these methods to see if they actually do help you to memorize better.

PROBLEM 4 *How Do Plants Respond to Their Environment?*

A common response in plants. Surely you have noticed that some plants placed near a window turn the broad side of their leaves toward the light. The turning may take a few days or sometimes only a few hours. Light is the stimulus; the response is bending of the stem in the direction of the source of the light or the bending or twisting of the leaf stalk. By doing EXERCISES 1 and 2 you can determine how both roots and stems respond to light. When the response is the turning of the organism or some part of the organism toward or away from the source of the stimulus, the behavior is called a *tropism* (troh′pism). The word means "turning." When the stimulus is light, the tropism is called *phototropism* (fo-tot′row-pism), or light turning. The stem and leaf stalks, since they turn toward the light, are said to show *positive phototropism.* See Figure 279. The turning of a part away from the light is *negative phototropism.*

In some animals, too, there are reflexes which can be called tropisms. That is, the animals turn toward or away from the source of a stimulus. You have seen moths fly directly into the light. Is this positive or negative phototropism? Protozoa, also, make some reflex responses that are tropisms.

Other tropisms. It is very easy for you to discover the effect of gravity on the parts of a plant by doing EXERCISE 3. Gravity is a stimulus to which plants are sensitive but to which most animals do not respond. The main root of a plant turns down toward the center of the earth, the main stem grows away from it. The root is therefore said to have positive *geotropism* (jee-ot′ro-pism), earth turning, and the stem is said to have negative geotropism. See Figure 281.

Mechanical stimuli also cause striking tropisms in some plants. The grapevine, the pea plant, and others which grow tall and have stems without much wood have sensitive stemlike structures known as *tendrils.* The tendrils grow toward any

FIG. 279 *Where was the source of light to which these nasturtium plants responded? How did they respond?* (BLAKISTON)

FIG. 281 (above) *A young sunflower plant was blown down by the wind. The tip of the stem continued to grow. Can you give two possible reasons why it grew up?* (SCHNEIDER AND SCHWARTZ)

FIG. 280 (left) *Squash tendrils attached to a dead pine stem. After its tip has caught on an object the tendril tightens up in a corkscrew.* (SCHNEIDER AND SCHWARTZ)

solid object with which they come in contact and wind themselves about the support in tight coils. In this way they hold the plant up. This is called positive *thigmotropism*, which means the turning toward an object that is touched. The stems of a number of plants twine around objects. Pole beans and morning glories are good examples. This is also thigmotropism. See Figure 280.

Chemical substances may act as the stimulus which causes some part of a plant to turn. The unequal distribution of water, minerals, gases, or other substances in the neighborhood of the plant may result in *chemotropism*. One very common example of this is the response of most roots to water. This special kind of chemotropism is known as *hydrotropism*. As you can see, plant protoplasm is sensitive to a variety of stimuli. Try EXERCISE 4.

Not all responses of plants are tropisms. Light — its intensity, the kind of light rays — the relative length of periods of light and darkness, temperature, gravity, water, the presence of other chemical substances, and, to a lesser degree, electricity and other stimuli bring about responses in plants. The responses are not always tropisms. For example, some flowers close at night. They respond to a stimulus, but it is not a turning toward or away from the source of a stimulus as you can see in Figure 282. If tulips are available it will be interesting for you to try the effects of temperature on opening and closing of the petals. See EXERCISE 5.

Why plant responses are slow. You can jerk your hand away from a hot stove very rapidly because you have

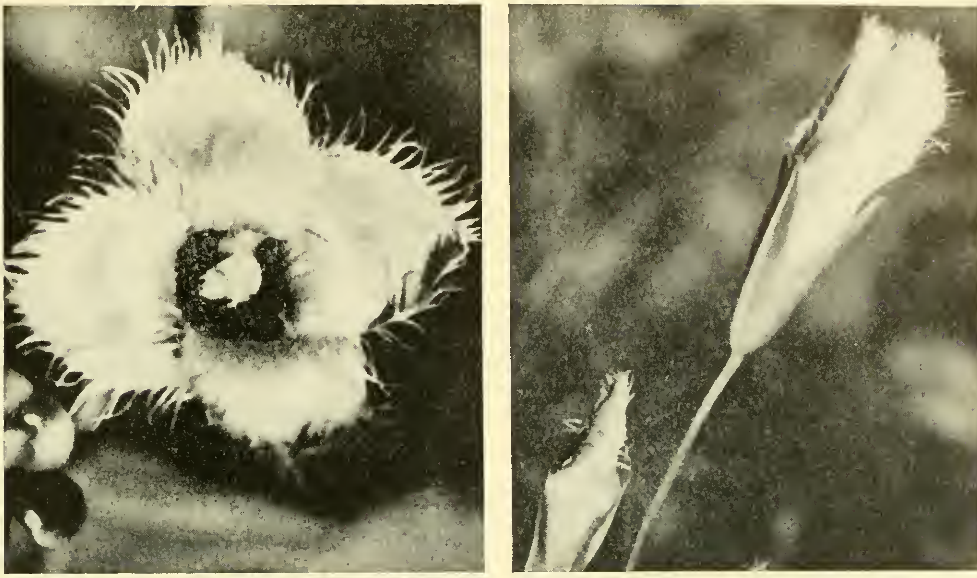


FIG. 282 *Fringed gentians in the daytime* (left) *and at night* (right). *What might be the stimulus that causes this response?* (GEHR)

muscles which contract. These bend your arm and pull it away. Secondly, even though the receptors are far from the effectors, the response is fast because impulses travel with great speed in the nerves. Plants have no special receptor cells; they have no nerves; and they have no muscles. It is not surprising that their responses are slow. How is it that their parts move or bend at all without muscle tissue?

Unequal growth produces bending. Most bending and turning in plants is caused by unequal growth. If cells on one side of an upright stem grow faster than those on the opposite side the stem must bend in the direction where there is less growth. It has been found that young leaves and stem tips form a "growth" hormone (auxin — awk′sin) in the presence of light. This is transported downward from the leaf or the stem tips and gathers mostly on the shaded side of the stem. Whether the hormone causes changes in the cell wall or the protoplasm is not known. It is known that in certain concentrations it causes cell enlargement and, since it gathers on the shaded side of the stem, the cells there become enlarged, bending the stem toward the light. Bending occurs in the growing region of a stem, the portion just back of the tip. Would you be interested in working with growth hormones? See EXERCISE 6.

Gravity also has an effect on the distribution of auxin. In a horizontal stem gravity causes auxin to gather mostly on the lower side. Because of this the tip of a horizontal stem will bend upward. See Figure 281. In horizontal roots auxin also gathers on the lower side. In roots, however, the hormone collects in concentrations high enough to slow up or inhibit the enlargement of cells. When the lower cells of a horizontal root grow more slowly than the upper ones the root bends down.

In all these examples, since the response depends on cell growth, it is slow but lasting. The part of the stem or root which has once bent does not bend back. You must remember that only a short region at the tip of a root or stem, the youngest part, can lengthen by cell enlargement and cell division. When, therefore, the direction of the stimulus is changed, the part which is at the moment the youngest part will respond. In that way, by frequently changing the source of the stimulus, it is possible to make a stem or root grow zigzag. How would you perform an experiment to produce a zigzag stem?

The discovery of auxin has had important results. Since the discovery of the growth hormone, auxin, there has been much research along these lines. The Boyce Thompson Institute for Plant Research at Yonkers, New York, has taken a leading part in this work. A variety of compounds, similar to auxin in chemical composition, have been made in the laboratory. They, too, seem to act as growth hormones, producing the most startling effects on plants. Certain of these cause the growth of roots on stems or leaves at the point where they are placed. This discovery can be made practical use of by people who raise plants. By using "artificial auxins" it is possible, too, to prevent apples from falling before fully ripe and to raise seedless tomatoes and certain other fruits (see p. 450).

A faster method of response. In some plants the bending response depends on a different mechanism which works more rapidly. The sensitive plant (*Mimosa*) is a good example. The plant has compound leaves. At the point of attachment of each leaf and leaflet in the sensitive plant is a little swelling. The cells within this swollen portion are stretched to capacity with cell sap. They are said to be turgid. This makes them stiff in the same way that a very full hot water bag is stiff. Because they are firm these turgid cells help to support the leaf. Certain stimulations cause their cell membranes to change in such a way that the cells lose water and become soft. As a result they no longer act as a support and the leaf droops. The stimulus may be either touch (a mechanical stimulus), heat, or certain gases. It may be applied at the tip of one of the leaflets, causing the turgid cells in every part of the plant to lose their turgidity within a minute or two. It is possible that the impulse travels along strands of protoplasm which connect the cells. After a short time the cells in the swellings again become turgid; the leaves recover and unfold again. To study turgor try EXERCISE 7.

Unusual plant behavior. The behavior of the sensitive plant is unusual. Certain other plants also have unusual and interesting behavior. Among them are some of the so-called insect-eating plants which catch, digest, and absorb small insects. You need not go to strange foreign lands to find them. The little sundew is often seen along the edges of ponds in many parts of the United States, and its relative, Venus's-flytrap, is not uncommon in sandy bogs in North and South Carolina. The leaf of the sundew has sticky hairs which fold over and entangle the small insect which touches

FIG. 283 *Mimosa, or Sensitive Plant. When the photograph at the left was taken, the plant had been undisturbed for several hours. The whole plant was slightly jarred and, after a few minutes, again photographed. Which parts responded to the stimulus? How is the response made?* (GENERAL BIOLOGICAL SUPPLY)

them. See Figure 284. The pitcher plant, common in many swamps, is also an insect-eating plant but it merely traps insects without directly responding to their touch. Once the insect is caught all these plants secrete juices which digest the prey.

Animal and plant behavior. Animals and plants have little in common in their behavior. This is to be expected since their structure is so different. But they have one thing in common. They are living, that is, they consist of protoplasm which is irritable. Therefore, they all respond to stimuli in the environment, even though the stimuli may be very different.

Plants, in general, have a large variety of tropisms. Parts of the plant turn toward or away from a variety of stimuli such as light, gravity, water, and chemicals. Certain plants, such as the tulip in its "sleep" movements, the insect-eating plants, and some others have responses other than tropisms, but these are the exceptions. Plants have nothing like a nervous system nor even nerve cells. Plant responses are slow because movements toward or away from the source of a stimulus are by unequal growth on opposite sides of the stem or root, or by changes in turgidity of cells. When it is a matter of growth, it takes hours (or days) for the response to become evident. The growth hormones, or auxins, play a part in such movements.

As you can see, behavior in plants is far simpler than behavior in all but the simplest animals. Since plants lack a nervous system, and lack even nerve cells, they cannot have the variety of responses shown by animals. Nor can they show any but very simple behavior.

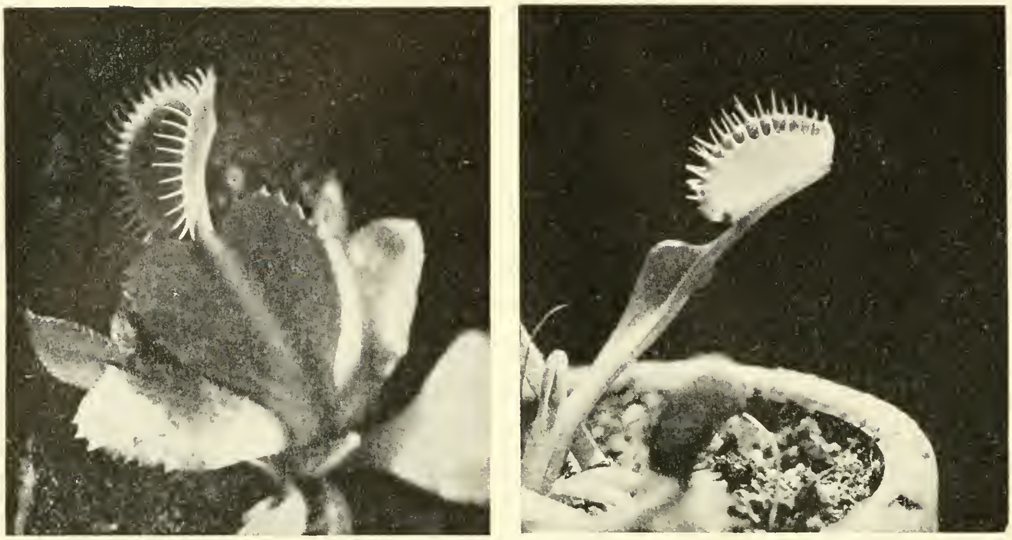


FIG. 284 *Two views of a Venus's-flytrap leaf. When an insect touches the short hairs on this leaf, the leaf quickly folds up as though it were hinged in the middle. Thus the insect is trapped. Juices are then secreted and the insect is slowly digested and gradually absorbed. The "insect-eating" plants, like animals, can use meat as part of their food. They do not depend upon this source, however.* (HUGH SPENCER)

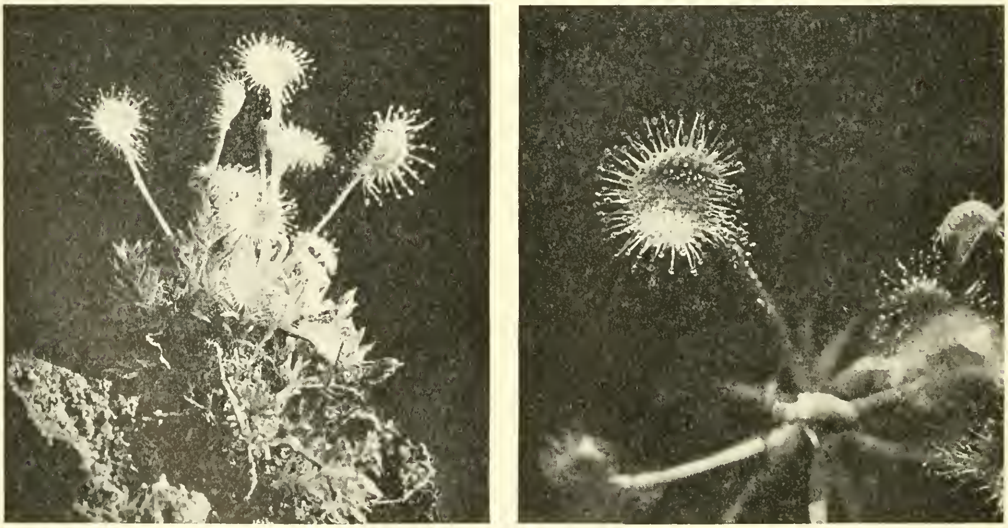


FIG. 285 *Sundew. The whole plant at left and a close-up of one of the leaves at right. Perhaps at some time you have found these sundew plants in a bog or at a botanical garden greenhouse. Do you see that the leaves are covered with tiny hairs, each with a drop of liquid at its tip? The photograph cannot show how these drops of sticky liquid glisten in the sunlight. Insects attracted to these leaves alight on them and are caught by the sticky substance. The tiny hairs soon respond by folding down over the prey, entangling it. Digestive juices are then secreted by the leaf, and after a time the insect is digested and absorbed.* (HUGH SPENCER)

Questions

1. Define tropism. What is meant by negative and positive phototropism? Give an example of an animal tropism.
2. Name other kinds of plant tropisms and the stimulus in each case.
3. Name seven environmental factors which may cause bending, turning, or twisting responses in plants. Name a response which is not a tropism.
4. Why are plant responses slower than animal responses?
5. How does light affect the location of the growth hormones in stems? How does gravity affect its distribution in stems? Explain how unequal growth causes bending of a stem or root.
6. What are some of the uses of auxin?
7. What else besides unequal growth enables parts of plants to turn or bend? Give an example. Define turgid.
8. Name three insect-eating plants. Explain how two of them catch small insects. What becomes of the insects?
9. Why is it that both animals and plants respond to their environment? Sum up the differences between plant and animal behavior.

Exercises

1. To demonstrate bending toward the light, positive phototropism. Obtain two similar small boxes with sliding or hinged covers. Stand the boxes on end with the door facing you. Cut a window in the top of one. In the other, cut a window of the same size on one side about halfway up. Place moist sawdust at the bottom of each box. Plant some young pea seedlings in each. Close the cover and permit the boxes to stand in a warm room. Keep seedlings moist. Observe after some days. Record your observations, and explain.

2. How do roots respond to light? Cover a tumbler of water with gauze. Suspend several mustard seedlings with straight roots from one to two inches long on the gauze so that the roots are wholly in water. Place a wooden box with a narrow window along one side over the tumbler. Examine after some days. Describe. Does this experiment need a control? Why or why not? What kind of phototropism is shown by mustard roots?

3. How can you show the positive geotropism of roots and the negative geotropism of stems? Line a jar with heavy, wet blotting paper, making sure that the light is excluded. Cut a sheet of cork so that it can stand up in the jar. Cover the cork with wet blotting paper. Pin pea seedlings to the cork, making sure that the pins go through the cotyledons and that the peas do not touch the cork. Pin the seedlings so that the tiny roots and stems point in several different directions. Cover the jar with a sheet of glass, lined with wet blotting paper. Keep the blotting

paper moist by adding water when needed. Examine the seedlings regularly for several days. What happens to the roots? to the stems? Is there a control? Can any other stimuli have affected these plants? How can the results be explained?

4. Can you suggest the method of an experiment to find out whether or not roots have positive hydrotropism?

5. How does the tulip blossom respond to changes in temperature? Place a tulip blossom standing in a glass of water in an ice box. After half an hour or more place it in a warm room. What do you see? In what respects is the method of this experiment faulty? Why can you not draw conclusions from what you have seen? What should you do to make this experiment valid?

6. Working with synthetic growth hormones. Use young tomato plants or any other young rapidly growing plants. Indol-butyric acid, indol-acetic acid, or naphthalene-acetic acid are growth substances which may be used. They may be obtained from biological supply houses. Prepare a mixture of about 0.1–0.25 grams of hormone to 50 grams of lanolin. Separate the plants into two groups, one group to be the control. To one group apply small amounts of the lanolin mixture to a small area on the side of the stem facing the light. Watch both groups of plants for a week or more. What do you observe? When you write up your notes describe exactly what you did and what happened; diagrams may help. What have you learned about the action of these synthetic growth hormones?

7. Cut some slices of raw potato about one eighth of an inch in thickness. Allow them to lie exposed to the air for two hours and feel them. Explain. Draw a cell as it must look in the potato slices now. Draw the same cell as it must have looked when you started the experiment. Why do stems and leaves of some plants need little supporting tissue to keep upright?

Further Activities in Biology

1. Do plants respond to artificial light as they do to sunlight? Perform an experiment to find out.

2. By filtering out some of the rays of light you could find out whether a plant is more sensitive to some rays than to others.

3. Time the speed with which a sensitive plant responds to a stimulus. Use a watch with a second hand. Gently stroke the lower midrib of one leaf and watch closely for the first sign of response in that leaf. How long does it take before some other leaf responds? Measure the distance the message traveled in that time.

4. The study of the effect of growth hormones on plant cells has had important practical consequences. Commercial preparations of 2-4-D can be obtained in local hardware stores. Spray the preparation on the weedy area of a lawn (follow directions). Describe the effects of the chemical.

PROBLEM 4. *How Plants Respond to Stimuli*

In UNIT VI you will consider these problems:

PROBLEM 1. How Are Our Bodies Protected against Microorganisms?

PROBLEM 2. What Have Scientists Learned about Conquering Some Common Diseases?

PROBLEM 3. (Optional) How Have Recent Discoveries Changed Some of Our Ideas about Disease?

PROBLEM 4. How Do We Attempt to Stop the Spread of Disease?

PROBLEM 5. How May We Achieve Better Health for All?

UNIT VI CONSTANT CARE IS NEEDED FOR MAINTAINING OUR HEALTH

FIG. 286 *The National 4-H Club health champions selected at Chicago in 1947. Most of us can be just as healthy as these young people are. There is much that we can do for ourselves to keep or get healthy. In addition to what we can do, there is much that must be done by the city, the state, and the federal government. Do you know what part each plays?* (NATIONAL COMMITTEE ON BOYS AND GIRLS CLUB WORK)

PROBLEM 1 *How Are Our Bodies Protected Against Microorganisms?*

Disease. Without troubling ourselves about an exact definition of the word disease, we can think of a disease as a condition in which all or some part of the body is not working properly. Earlier you studied certain diseases, such as diabetes, which occur when the ductless glands do not work normally. These can be called *metabolic* diseases. In the discussion of diet you read of *deficiency* diseases, such as scurvy and rickets, which occur when the diet does not contain enough of the necessary vitamins. Another type of disease, *organic* disease, is caused by the actual change of some organ in such a way as to prevent it from working well. Such diseases are heart disease or kidney disease.

This unit, however, is concerned with a different type and a very common type of disease in man. It deals with the diseases caused by other living organisms which make their home in or on man's body.

Parasites. Organisms that make their home in or on some other organism and that obtain their food directly from it are called *parasites;* their type of food-getting is called parasitism.

There are many parasites that may affect us. Some are fairly large, such as the various kinds of worms that live inside us, but most parasites are microscopic. The microscopic parasites may be protozoa (animals) or they may be plants such as moldlike forms and bacteria. Ringworm, for example, is caused by a moldlike plant and so, also, is athlete's foot. Malaria is caused by a protozoan. But parasitic protozoa and moldlike forms are comparatively rare. By far the largest number of microscopic parasites are bacteria.

Since the organism in or on which a parasite lives is called the *host*, we can say that man is the host of many types of bacterial parasites. Those that cause disease in their host are called *pathogenic* (path-oh-jen′ik), a word that means "producing suffering." Microscopic organisms that cause disease are popularly called *germs.*

Although there are many kinds of bacteria that live as parasites in or on man and other living things, not all bacteria are parasites. Far from it. The majority live on dead plant or animal matter or on food. Such bacteria cannot be called parasites. You will read about these in a later unit.

Characteristics of bacteria. Bacteria (singular *bacterium*) are single-celled organisms. The cell is usually very tiny, much smaller than most plant or animal tissue cells. Bacteria have a firm cell wall and for this and certain other reasons

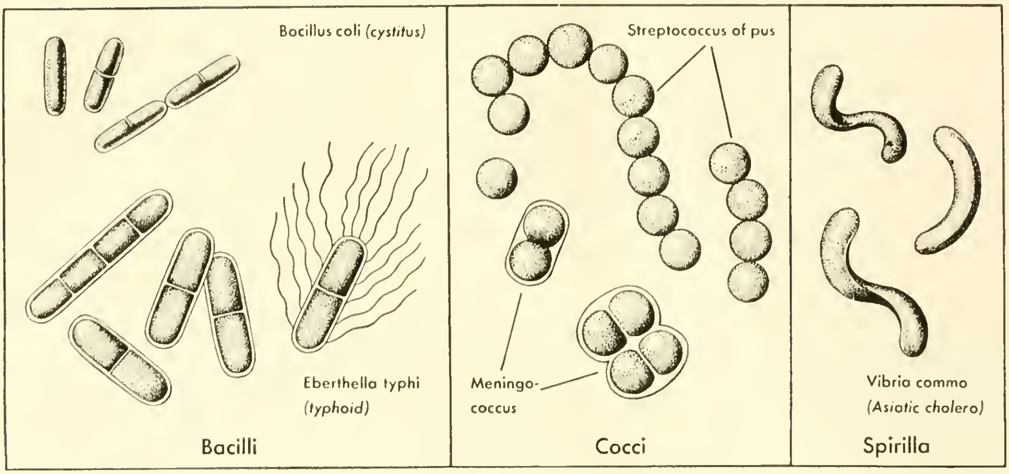


FIG. 287 (above) *According to shape bacteria are called bacilli, cocci (cock'sye) and spirilla. How do these differ in shape? Some bacteria hang together in chains or in small groups.*

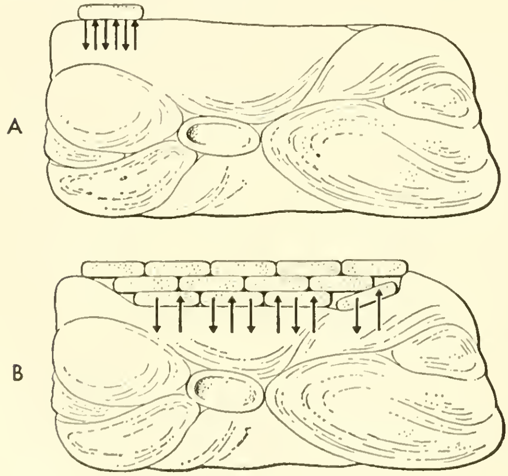


FIG. 288 (left) *This illustrates what may happen when a bacterium settles on a piece of meat. Arrows indicate that something is leaving and something is entering the bacterium. Can you explain what? Drawing B represents the same piece of meat some time later. What has happened to the bacterium and to the meat? What would be the last chapter of this story?*

they are considered plants. They have no nucleus but do have chromatin granules scattered through the cytoplasm. Some bacteria can move by means of long hairlike projections (*flagella*) but most bacteria cannot carry on locomotion. Drawings of several kinds of bacteria may be seen in Figure 287, magnified about 3000 times. Because they all lack chlorophyll they are classified as fungi along with mushrooms, molds, and yeasts. Like other living cells they secrete enzymes, digest, assimilate, release energy which they use, and reproduce.

The study of bacteria. The study of bacteria, *bacteriology*, includes observation of the growth of bacteria in the laboratory, their effect on other organisms, and their appearance under the microscope. Bacteriology is a young science because methods of raising bacteria, microscopes good enough to see them, and special methods of making them visible under the microscope were not discovered until after the middle of the last century.

Present methods make *culturing* (raising) most kinds of bacteria easy. In the

FIG. 289 *Typhoid bacteria. Only a few bacteria are shown. The wavy lines are flagella.* (GENERAL BIOLOGICAL SUPPLY)

laboratory, bacteria are raised on a *culture medium.* One kind of medium is a broth containing proper food materials, such as beef extract and peptones. Many kinds of bacteria will grow and reproduce in this medium if they are kept at a suitable temperature. *Incubators* can provide a suitable temperature. By doing EXERCISE 1 you will learn how to prepare a culture medium for raising many kinds of bacteria. To raise pathogenic bacteria, it is sometimes necessary to use a special culture medium that contains some substance taken from the tissue of the host.

To be useful for study a culture medium must be free from bacteria. In other words, it must be *sterile.* Since bacteria are present practically everywhere, a bacteriologist must provide for getting rid of all bacteria which may find their way into the culture medium. He *sterilizes* everything used in the preparation. He uses very high temperatures for sterilization. An object to be sterilized may be passed through a flame or exposed to steam under pressure.

Solid media are also used. An especially useful device was developed by a famous German bacteriologist, Robert Koch (1843–1910). The difficulty with liquid culture media is that in them the different kinds of bacteria are all mixed together. It is impossible to study a single kind because the different kinds cannot be separated from one another. To get around this difficulty, Koch mixed gelatin with the broth. Now in place of gelatin we often use agar, a substance obtained from certain seaweeds. Agar, like gelatin, is liquid while it is hot but becomes solid when it cools. To provide a large surface for bacteria to grow on, the culture medium, while still liquid, is poured into a flat glass dish known as a Petri dish, where it hardens. Sometimes it is poured into a test tube which is kept in a slanting position while the medium hardens. This is called an agar slant. Your teacher may be able to show you examples of both. See EXERCISE 2. Since the culture medium is solid the bacteria do not mix. They increase in number and soon there is a huge number of them in one spot. This mass of bacteria is called a *colony.* All the bacteria in a colony are of the same type since they all came from a single cell. You can raise colonies yourself. See EXERCISE 3.

If a bacteriologist wishes to study one kind he can raise this kind. He touches a sterile needle to a colony of the kind he wishes to study. When the needle is then touched to a fresh agar slant, a new colony of the same kind will form because some bacteria have been "transplanted." In this way it is easy to start *pure cultures*, that is, cultures containing only one kind of bacterium.

Identifying bacteria. Some bacteria can be identified merely from the appearance of the colony. Some colonies are smooth, others are rough; some are white, others have a distinct color such as yellow or red. Generally one cannot determine the exact kind of bacteria by the appearance of the colony. Examining bacteria through a microscope helps somewhat in identifying them. But even after microscopes had been improved to magnify 1000 times or more, it was still difficult to see bacteria because they were so transparent and so tiny. Koch and other bacteriologists discovered chemicals that dyed or stained the bacteria but did not stain other cells. This was of great value because staining made it possible to see and identify bacteria in body tissues.

If you have a school laboratory, it will be possible to prepare a pure culture and to stain bacteria, as described in EXERCISES 4 and 5. If you have dishes of nutrient agar, you can easily test for the presence of bacteria in air, in water, and on objects outside the body. See EXERCISES 6 and 7.

Favorable and unfavorable conditions for growth. Bacteria will grow and reproduce only if kept moist and at a proper temperature. Like other organisms that lack chlorophyll, they depend on manufactured food. By doing EXERCISE 8 you can determine for yourself to what extent external conditions affect the

FIG. 290 *How many colonies of bacteria can you find on this agar plate? How many bacteria were introduced?* (BROOKLYN BOTANIC GARDEN)

growth of bacteria. In general, bacteria are not killed by low temperatures but they fail to reproduce unless the temperature is favorable. Bacteria have been known to survive at temperatures below the freezing point. Very high temperatures, on the contrary, kill bacteria. The temperature must be extremely high to kill all kinds. Even boiling does not kill all species; some have been known to survive five hours of boiling. This is possible because in some species the cell may secrete a very resistant wall around itself; it is then called a *spore*. Fortunately for us, very few pathogenic bacteria form spores. Bacteria in the spore form can be killed by heating them in steam at great pressure. This method is used in the home when a pressure cooker is employed in preserving fruits or vegetables. Before pressure sterilization was invented objects were sterilized by heating them in ordinary steam for an hour three days in succession. Although slow, this method was successful because after the first or second steaming the spores became ordinary bacterial cells and were killed in the next heating.

Bacteria, like all other cells, are also destroyed by strong chemicals. Such substances are known as *disinfectants*. When strong enough, disinfectants kill even the spores. The chemicals known as *antiseptics* do not as a rule kill bacteria; they produce conditions which are unfavorable so that the bacteria do not increase in numbers. They are also less injurious to tissue cells. For this reason antiseptics are used on cuts and wounds.

Lack of moisture is another unfavorable condition. Dryness prevents the bacteria from getting food, growing, and reproducing; in general it does not kill them.

How bacteria enter the body. Bacteria constantly surround the animal. How do they enter? They never enter by themselves. They are always brought in, sometimes attached to particles of dust or to some food, sometimes floating in a liquid. All kinds of bacteria enter in this way, pathogenic as well as harmless ones. If the conditions are favorable to the bacteria, they multiply; if not, they die. But the right conditions for entering and multiplying in the body are not usually present.

The body is protected in a number of ways against the entrance of bacteria. The openings into the body, such as the nose and mouth, have a sticky coating of mucus which catches the particles of dust and the bacteria which may be attached. Cilia on the epithelial cells lining some of the air passages sweep these particles out of the body. Those bacteria that are swallowed and reach the stomach come in contact with juice containing hydrochloric acid and are usually killed.

Covering the outside of the body is the skin, through which bacteria cannot pass. To be sure, sometimes there are breaks in the skin; these may be very small, but tiny as they may be they present a wide gateway to bacteria. The skin may be pierced by an animal, even a small insect, which may introduce microorganisms when it stings. Once past the barrier of the skin the invading bacteria may enter the other tissues where there is moisture, food, and a suitable temperature for growth.

The second line of defense. The first line of defense is composed of the skin and the devices, such as hairs in the nose, cilia, tears, and moist membranes, that catch bacteria-laden dust particles and carry them away from the tissues. The second line of defense exists within the body itself. You read earlier about the phagocytes that gather at the point of infection and how pus is formed. With certain acute infections large numbers of phagocytes and other types of white corpuscles appear in the blood. Phagocytes may also engulf and digest animal parasites and foreign particles of all sorts.

There are other cells in the body that engulf bacteria just as the phagocytes do. These cells are scattered about in organs and tissues, among them the liver, spleen, lungs, and bone marrow. Those that are found in the general connective tissue of the body are particularly active. These go to the place of infection together with the phagocytes. To recall what you learned about white corpuscles, do EXERCISE 9.

Another body defense. Pathogenic bacteria most often injure their host because their protoplasm is poisonous to the host. Sometimes the injury is the result of poisonous substances that go out of the bacterial cell. These poisonous substances made by bacteria are called *toxins.* Each kind of bacterium produces a special kind of toxin. We say that toxins are specific.

The presence of toxins in the body causes it to produce substances which make the toxins harmless. The substances that make toxins harmless are called *antitoxins.* The body cells that produce antitoxins release them into the blood; the antitoxins are thus carried throughout the body. Antitoxins are also specific in action, that is, an antitoxin neutralizes a special toxin and has no effect on any other toxin. We may compare it to a key which fits only one lock. Thus diphtheria antitoxin neutralizes only diphtheria toxin; it does not affect tetanus toxin. You will read more about antitoxin in the next problem.

But antitoxins are by no means the only protective substances in our blood. We make *opsonins*, which are substances that act on bacteria in such a way that phagocytes can more easily devour them; *lysins,* which dissolve bacteria; and *agglutinins*, which cause bacteria to gather in clumps.

Immunity to disease. The antitoxins, opsonins, lysins, and agglutinins are called *antibodies.* Now do EXERCISE 10. In general, antibodies are made only after the germ enters; they are not naturally present in the blood as are the phagocytes. Also, the antibodies are not living cells.

When an animal has produced antibodies in combating a special bacterium the animal is said to have acquired *immunity* to that disease. This immunity may last a very short time, as in influenza, or for many years, as in whooping cough, scarlet fever, and generally in smallpox. People in China and India, four thousand years ago, deliberately exposed their children to smallpox whenever there was a particularly mild epidemic, knowing that they would not get smallpox a second time. See EXERCISE 11.

Sometimes it happens that an individual or even a whole species has *natural immunity* to a disease. Apparently the entering germ does not meet suitable conditions in the host; the germ dies and does no harm. For example, man has natural immunity to distemper, a deadly disease of dogs. Now try EXERCISE 12.

QUESTIONS

1. Give a simple definition of disease and name four types of diseases.
2. Define parasite and host. Define parasitism. What kinds of plants and animals may be parasites?
3. Describe bacteria as to size, structure, and shape. What activities do they carry on?
4. To raise bacteria what food and temperature conditions are necessary? What does a bacteriologist mean by sterilizing? How does he do it?

5. What is the advantage of a solid culture medium? By whom was this method devised? How is a pure culture made?
6. In what different ways are bacteria identified? In order to identify them microscopically what is necessary?
7. What is a bacterial spore? Describe the effect of extreme heat, extreme cold, dryness, and chemicals on bacteria. Make exact, not general, statements in your answer. Distinguish between antiseptics and disinfectants.
8. By what *method* do bacteria enter the body? By what *routes* do they enter?
9. What is the body's first line of defense? What is the second line? Describe the structure and work of phagocytes. Where would you look for cells that engulf bacteria?
10. Define toxin and antitoxin. What is meant by saying an antitoxin is specific? Name and describe the action of three other substances besides antitoxin which act against bacteria or their products.
11. Explain how the body acquires immunity. Why are phagocytes not listed among the antibodies? Name some antibodies and tell what each does. Discuss the length of time that acquired immunity may last. How has this information been made use of for many centuries? What other kind of immunity is there besides acquired immunity? Explain.

Exercises

1. How may bacteria be raised in a liquid culture medium? Heat together in a saucepan 250 cc (a glass) of water, $2\frac{1}{2}$ grams of salt, $2\frac{1}{2}$ grams of peptone and $2\frac{1}{2}$ grams of Liebig's beef extract. Filter into test tubes, filling them about $\frac{1}{3}$ full. Close each test tube by stuffing a wad of cotton into the mouth. Stand the test tubes in boiling water for a minute. Put a very small amount of material scraped from the inside of your mouth into each of several tubes. Close them again. Place the tubes in a warm place for several days. What do you notice? What may account for the change in the broth? How could you find out?

2. How may nutrient agar be prepared? Heat together the ingredients mentioned in Exercise 1 (using four times as much of each) and add 10 grams of agar. Put in baking soda until red litmus paper is turned blue by the mixture. When the agar is dissolved, filter the mixture through thick absorbent cotton lining a funnel. Warm the cotton and funnel before they are used. Why? Allow the filtered substance to flow into a glass flask. Plug the mouth of the flask with a wad of sterile absorbent cotton. Why is the plug used? Why is a cotton plug used instead of a rubber stopper? If you wish to use this nutrient agar for studying special kinds of bacteria or if you wish to keep it, what must you do to the agar in the flask? Why? If you wish to pour the agar into Petri dishes, what should you do to the Petri dishes in advance? Use 10 to 15 dishes. When you are ready to transfer the sterile agar into sterile Petri dishes, you

must heat the flask to liquefy the agar mixture and then pour it in such a way that as few bacteria as possible will have a chance to enter during the pouring. What precautions would you suggest? Consult with your teacher to make sure that you have thought of all possible precautions. Some of the medium may be poured into sterile test tubes laid on a table at an angle of about 30°.

3. What can be learned about bacteria grown on agar plates? Pour a very little (10–15 drops) broth containing bacteria into a sterile agar plate and tilt to spread the liquid well over the surface. Close the Petri dish and set it aside in a warm place (about 80° F). Examine every morning and evening. How long does it take before you see bacteria on the agar? Why can the bacteria now be seen? Each colony contains millions of bacteria. What does this indicate about their rate of reproduction? What are some of the differences among the colonies? Of what use might a knowledge of these differences be to bacteriologists?

4. *Demonstration.* To show how to make a pure culture of bacteria. Pure cultures are grown best on agar *slants.* Pour some sterile agar into a sterile test tube and plug it with a wad of absorbent cotton. Then place the test tube in a tilted position at an angle of about 30 degrees until the agar hardens. In one of your exposed Petri dishes you will no doubt find a colony of a striking color. Transfer bacteria from this colony. Before transferring the bacteria to the slant, what must you be careful to do with the needle you employ? Would you recommend heat or disinfectants? Why? Holding the needle in the flame until it is red hot and then allowing it to cool for a moment before applying it to the colony of bacteria will prove successful. Why is a test tube better than a Petri dish for making a pure culture?

5. *Demonstration.* To show how staining helps in the study of bacteria. On each of two slides smear a small drop of the broth containing bacteria. Permit the slides to dry. Then pass them through a flame rapidly three times with the side that contains the bacteria uppermost. Cover the material on one slide with some dye like methylene blue or gentian violet and allow it to stand for two minutes. Wash the dye off with water and examine the slide under the oil immersion lens of the microscope. Compare the unstained slide with the stained one. What do you note?

6. Where are bacteria found? Expose a number of sterile Petri dishes containing sterile agar to the air in your classroom, in the school corridor and playground, and in other places for several minutes. In other dishes, place various objects, such as chalk dust, floor dust, food, and saliva. Label each of the dishes and put them away in a warm place for a few days. What do you find? Can you be sure that the bacteria came from the various objects or places to which the Petri dishes had been exposed?

7. Devise and perform an experiment to find out the relative number of bacteria in your classroom and in a room in your home. What will you need for your experiment?

8. Do external conditions affect the growth of bacteria? Devise and perform an experiment to discover the effect of different temperatures (ice box, close to a furnace, room temperature, etc.) on growth of bacteria. Will you need a control? Does boiling kill bacteria? How could you find out? Are you sure your method is a good one? Devise and perform an experiment to find the effect of drying on the growth of bacteria.

9. What do you remember about the blood? Answer these questions: (*a*) Can red corpuscles serve as scavengers? Why or why not? (*b*) When a doctor wishes to know whether there is an internal infection he examines a drop of blood under the microscope. What is he looking for? How will he make his decision?

10. Can you explain how a scientist would perform an experiment to discover whether an antibody is specific? (He would use rabbits or guinea pigs, probably.) Give all the steps in order. Would he need a control?

11. Do you think the people of India and China were wise to expose their children to disease when a mild form occurred? Explain. Explain why you would or would not recommend this to your family.

12. Make an outline summary of this problem.

Further Activities in Biology

1. If you can obtain pus material from a small pimple, smear a bit of it on a slide and allow it to dry. Then pass the slide through a flame quickly once or twice. (Do not bring the material in direct contact with the flame.) Now cover the dried pus with a dye such as methylene blue, and allow it to stand for two or three minutes. Wash the dye off in running water; examine the slide under the high power of the microscope. You should be able to see phagocytes with engulfed bacteria.

2. Read about Eli Metchnikoff and his discovery of phagocytes. (*Microbe Hunters* by Paul De Kruif.)

PROBLEM 2 *What Have Scientists Learned About Conquering Some Common Diseases?*

The germ theory of disease. You are so accustomed to the idea that germs cause certain diseases that it is difficult for you to realize that man has not always known this. At the time when the early settlers came to this country, medical students were still being taught that disease was caused by some unusual position of the planets! In the days of George Washington men had no suspicion that diphtheria and pneumonia and other diseases were caused by living microorganisms. It was a century ago, within the memory of your great-grandfather, that an Italian scientist took the first step toward the discovery of the *germ theory of disease* — the theory that certain diseases, those now known as *infectious* diseases, are caused by definite microorganisms. He noticed that all silkworms which were affected by a disease common at the time were hosts to a very small parasitic fungus. There were no exceptions, so he concluded that the fungus was the cause of the disease.

As time went on other discoveries of this kind were made; for example, some unimportant skin diseases of man were shown to be caused by fungi of one kind or another.

About 1875, suspecting the part played by bacteria in disease, Koch directed his

FIG. 291 *One African tribe treats all aches and pains by bleeding the patient. The "doctor" makes a cut over the affected part. He then places a goat horn over the cut and sucks the air from the horn. These people know nothing of the germ theory of disease. When was the germ theory established?* (CHICAGO NATURAL HISTORY MUSEUM)

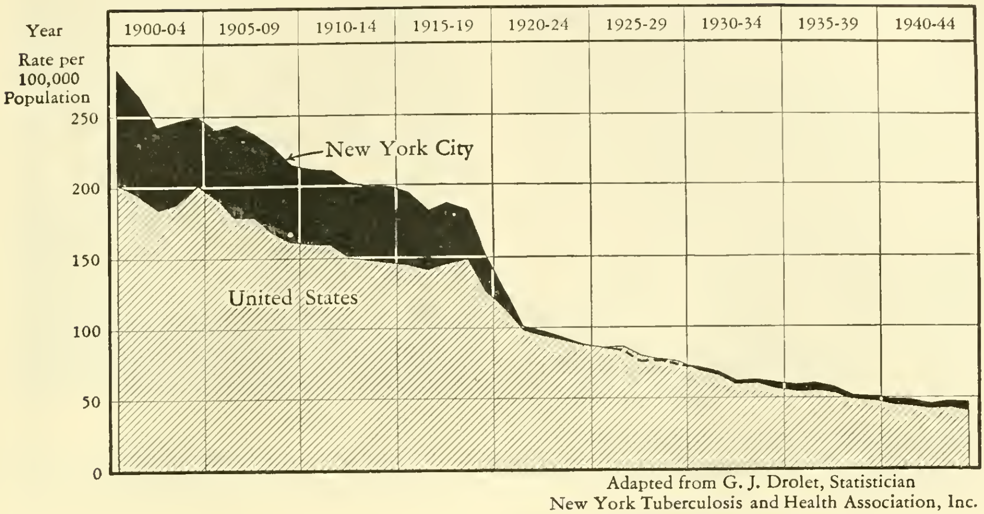


FIG. 292 *A graph showing the tuberculosis death rates in New York City and in the United States as a whole from 1900 to 1944. Compare the death rates in 1900 and 1944. What has been done to cause the change in rate of death from tuberculosis? Now compare the death rate in New York City with the rate in the country as a whole. What might be the explanation of this difference in rates?*

energies to finding a germ that might cause anthrax. Anthrax, a common disease of sheep and cattle, was responsible for a great loss of money. It was known to affect man also. Another bacteriologist had declared that a specific germ caused the disease, but he had not produced convincing evidence. To check this belief, Koch and others working in bacteriological laboratories in various countries spent years in patient investigation and experimentation. Koch finally succeeded in finding the bacillus and proving that it and it alone caused anthrax. Gradually enough evidence was collected to convince those who studied disease that each of the common infectious diseases is caused by some definite organism. Thus the germ theory of disease was established.

Another important discovery. Some years after his discovery of the anthrax germ Koch found the cause of tuberculosis. His seemingly unimportant work on staining brought him success. He was able to develop a special method which stained one species of bacterium only. Other species of the same shape and general appearance did not take the stain. The one which took the stain appeared regularly on his slides when he examined the tissues of animals that had died of tuberculosis. His newly-developed method of distinguishing species of bacteria by staining enabled him to single out the germ which caused tuberculosis.

Tuberculosis was well named the "great white plague," for this disease took an enormous toll of lives. It probably reached its peak when the industrial revolution brought the growth of towns and small cities, and when people began to work long hours in crowded factories. In 1780 in England, 1100 out of every 100,000 people died of tuberculosis; in 1930 the total death rate of all disease was only very slightly more than that. Figure 292 is a chart of the death rate from tuberculosis in New York City and in the whole United States. This chart should be studied carefully. See EXERCISE 1. While tuberculosis can affect any organ, the most common form is lung or pulmonary tuberculosis. Since the germs of pulmonary tuberculosis are easily spread by coughing, and since infected people are generally not confined to their beds, the disease can spread rapidly. Koch's discovery of the germ was of great importance. When the cause of the disease became known, measures could be taken to stop its spread. There is now a widespread campaign to teach people how to prevent tuberculosis.

Doctors can now detect the disease in the early stages by chest x-rays. When people have these x-rays taken frequently as part of a regular medical checkup, the death rate from tuberculosis will be reduced still further because in its early stages tuberculosis is relatively easy to cure.

Koch's four postulates. Koch always found a certain type of bacterium in animals suffering from tuberculosis, but this was not enough to convince him that the bacterium caused the disease; perhaps it merely accompanied the disease. He felt that four steps must be successfully taken before one could say that a disease is caused by a specific germ. The four steps are often spoken of as *Koch's postulates*. See the next column. Do the four postulates provide evidence for the germ theory of disease? See EXERCISES 2 and 3.

Koch's Postulates

To prove that a disease is caused by a germ:

1. The germ must be found in every organism that has the disease.
2. The germ must be grown in pure culture so that it can be definitely identified.
3. When the germs grown in the laboratory are injected into healthy animals, these animals must show all symptoms of the disease.
4. The germ must be recovered from the sick animals and must be identified as the original germ.

Koch did all this before announcing that he had found the cause of tuberculosis. As you read further, however, you will see that it is not always possible to take these four steps. In fact, we must even modify our understanding of the germ theory of disease to some extent because of recent discoveries.

The early contributions of Louis Pasteur. As a rule a scientist can work out every step of a problem only with direct or indirect help from others. Had Koch failed to read the scientific journals of his day, had other bacteriologists not taken an interest in his work and discussed it with him, the germ theory of disease could not have been established. There were many men in many countries working along these same lines at this time. Among them was Louis Pasteur (1822–1895), who shares with Koch the credit for giving to the world the germ theory of disease.

Louis Pasteur discovered that specific microorganisms changed grape juice to

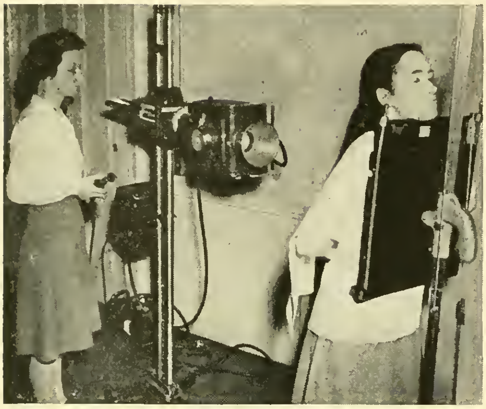


FIG. 293 *If chest x-rays were taken of all people periodically, lung tuberculosis would be detected and could be reduced.* (BOSTON TUBERCULOSIS ASSOCIATION)

FIG. 294 *A Board of Health worker examining Petri dishes. Which step might this be in deciding that a disease is caused by a specific germ?* (NEW YORK CITY BOARD OF HEALTH)

wine, wine to vinegar, and caused milk to sour. These are all chemical changes. In the making of beers and wines yeast plants partially oxidize sugar, producing alcohol and carbon dioxide. This incomplete oxidation is called fermentation. Bacteria also carry on fermentation or incomplete oxidation when they sour milk by producing lactic acid and when they spoil or sour wines by changing alcohol into acetic acid.

This work of Pasteur was of great practical importance to the wine industry because methods were soon found to prevent the growth of bacteria that caused the spoiling of wines. It was of even greater importance in quite a different way. Our understanding of fermentation paved the way for the germ theory of disease. Pasteur was soon convinced that disease bacteria could bring about changes in the body in the same way that they could change liquids in a flask.

Pasteur turns to the study of disease. Convinced of the truth of the germ theory of disease, Pasteur devoted his attention to the study of immunity of animals to disease. With the help of his assistants he raised pathogenic bacteria of many kinds in his laboratory. Among others, he raised pure cultures of the bacteria which caused cholera (coll'er-a) in chickens. One day he discovered, largely by accident, that when he kept these cultures for some time the bacteria seemed to become weaker. He came to this conclusion because he noticed that when such cultures were injected into healthy birds they did not die, although they became ill. When he *inoculated* (in-oc'you-lated) these same birds, after their recovery, with a fresh culture of cholera germs, they did not contract the disease. Why not cultivate such weakened germs in large numbers and make a practice of inoculating healthy birds with them? If an epidemic of chicken cholera should occur these birds could then, perhaps, resist the disease. Pasteur tried this and it worked. When the next cholera epidemic came, none of the inoculated birds fell ill; they seemed to be immune or not *susceptible* (suss-sep′ti-ble) to the disease. In those days the various antibodies had not yet been recognized, but Pasteur knew that in some way the animal must be responding to the bacteria.

Could he make animals immune to other diseases? Pasteur turned his attention to anthrax. He decided to try to weaken the germs in a new way, by subjecting them to a high temperature (108° F) for some days; this proved successful. When he injected such germs into healthy sheep, the animals contracted anthrax, but in a mild form. When the sheep had recovered entirely from that attack, he inoculated them with the most virulent (strongest) anthrax germs he could find. Most of the animals had become completely immune to the disease; just a few had a slight attack of anthrax. Since the tissues of the sheep had been active in making antibodies we say that the sheep had developed *active immunity* against anthrax.

Scientists were so skeptical that Pasteur was obliged to give a public demonstration of his work. Even then there were many who refused to believe that by giving a disease one could prevent the development of that disease later on.

Pasteur inoculates against rabies. Having been so successful in immunizing animals against two diseases, Pasteur attempted to apply the same principle to hydrophobia, or *rabies* (ray′bees). Formerly, rabies was a common disease among dogs and from them it frequently spread to human beings and some other animals. It was always fatal. After much experimentation, Pasteur succeeded in weakening the organism which caused rabies although he never was able to see it. It is believed now to be one of the *filterable viruses* (vy′rus-es), one of the organisms too small to be seen with the ordinary microscope. Pasteur suspected that the organism settled in the spinal cord and brain. So he cut out the spinal cord of a rabbit which had died of rabies. By drying the spinal cord he successfully weakened the virus. When he injected this weakened virus into dogs, starting with the weakest virus (material that had been dried the longest time) and using stronger doses with each inoculation he found that the dogs became immune to rabies.

Although the experiments had all been successful and the theory underlying them seemed sound, Pasteur still hesitated to try out his weakened virus on human beings. One day he was obliged to do so. A nine-year-old boy who had been bitten by a mad dog was brought to his laboratory. The parents pleaded with Pasteur to use his treatment on the child. Still Pasteur hesitated, for this case was different from those he had experimented with before. In his laboratory dogs had been inoculated with the virus before they had been bitten by a rabid animal. Now he was asked to inject virus into the child which had already been bitten. Knowing that the disease comes on very slowly, sometimes many weeks after the bite, he thought that possibly the inoculations could take effect in time to save the child. Knowing too that without treatment the child could not possibly recover, Pasteur finally yielded to the persuasion of the parents. After fourteen days of treatment the child left the hospital; rabies never developed.

This boy was the first human being to be saved from rabies. It is now common practice to inoculate those who have been bitten by a dog unless the dog can be examined and is declared free from rabies.

Immunity to smallpox. If you have ever had a smallpox vaccination that "took" you will remember the intense itching in that spot. You were having a very mild attack of the disease. In a true case of smallpox the patient has spots all over his body that itch and get sore; frequently deep pits or pocks are left when the sores heal. You have rarely or never seen people with faces disfigured with pock marks because in the United States and in many other countries smallpox has been almost wiped out. Yet, up to about 1800 there were not many persons in Europe who escaped it. And even today the disease exists in virulent form in some parts of the world, particularly in southern China and India.

It is to Edward Jenner (1749–1823), an English physician, that we owe thanks for our ability to control smallpox. In about 1790 Jenner followed up some interesting observations and tests that had been made by farmers. Cows suffered from cowpox, a disease that resembled smallpox. The dairymaids that milked the diseased cows frequently came down with a mild disease something like smallpox. Now people had noticed that dairymaids who had had this disease did not get true smallpox, even though everyone else on the farm fell ill. Jenner, following the methods of a few courageous men who had tried this before, scraped some of the material from one of the sores or pustules of a cow that was suffering from cowpox and rubbed it into a scratch on a boy's arm. The boy became only mildly ill and he was later shown to be immune to smallpox, even when directly exposed to it. Jenner said he *vaccinated* the boy because he took material from a *vaccus*, the Latin word for cattle. And the material he used was called *vaccine* (vak'seen).

Vaccination became fashionable in England. The practice spread to France and Germany. Jenner was honored and feted by kings and adored by all the people, in spite of the fact that in his day severe illness often resulted from vaccination. Can you answer the questions in EXERCISE 4?

Why we should be vaccinated. Particularly in the 18th century and again in the 19th century smallpox epidemics were widespread and severe. No one, or almost no one, is naturally immune to smallpox. Yet, in 1942 in the whole United States there were only 89 cases of the disease and fewer than 10 deaths. The chief reason for the decline is that vaccination against smallpox has become almost universal in a great many countries. It is only when people become careless about regular vaccination that the disease may reappear in a community and then spread rapidly. The state of Pennsylvania had justly prided itself on its good smallpox record. Some years ago the number of smallpox cases suddenly rose. Why? A woman from another state had visited in Pennsylvania and was mildly ill with a disease not diagnosed until later. From her there originated 63 cases of smallpox in the state, another one in Maryland, and one in New Jersey. All 65 could be traced to this one woman, and all these 65 people, it was discovered later, had never been vaccinated or had not been vaccinated for a long time. The immunity obtained through successful vaccination may last only twelve months or it may last for many years.

The few unvaccinated people in a community such as you and I live in are relatively safe because all the rest of us have been vaccinated. Vaccination is not the haphazard process it was in Jenner's day. The vaccine is most carefully prepared. Calves are carefully cared for and tested to make sure they are free from tuberculosis and other diseases; then they are inoculated with cowpox virus. As the disease develops, a large amount of material is taken from the pustules of the calf; this contains a virus closely related to the smallpox virus. It is later purified in the laboratory and tried out on experimental animals to test it for purity and strength. Throughout, it is handled with the greatest care so that when a doctor scratches vaccine into your body, he is certain that he is not introducing germs of other diseases with the vaccine. Why are some people opposed to vaccination? See EXERCISE 5.

The work of Jenner and Pasteur. Jenner vaccinated against smallpox long before the germ theory of disease had been established. He did not know about the existence of bacteria or filterable viruses; he could know nothing about the weakening of bacteria and virus. He did not understand why or how vaccination prevented smallpox. Therefore the same method could not be applied to other diseases. On the other hand, Pasteur's work served as the foundation for many further discoveries because it was based on accurate information. Actually Pasteur saved very few lives through his immunization against rabies, since rabies was never a widespread disease in man; but since his discovery of immunization pointed the way to the prevention of many other diseases, it has been said about Pasteur that "he saved more lives than Napoleon took in all his wars." Do EXERCISE 6.

Typhoid fever and immunization. Typhoid fever is an infectious disease caused by a germ that enters the body with food or drink. After the germ is swallowed, it settles in the digestive tract causing a severe general illness and often damaging the intestine. During the course

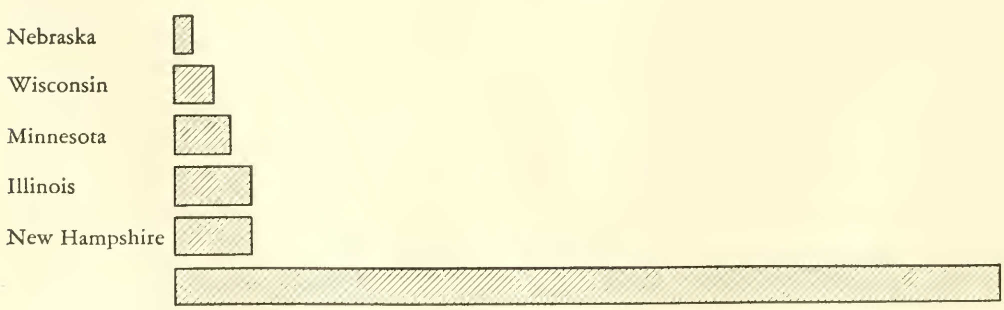


FIG. 295 *A graph based on the number of cases of typhoid (and the related disease, paratyphoid) in five states with an excellent record and in the one state which had the worst record. (Based on reports in 1944–1945.) What health practices reduce the number of typhoid cases? (See pages 326 and 343–348.)*

FIG. 296 *A stage in the preparation of typhus vaccine. Of what advantage is it to use eggs instead of an animal in the preparation of vaccine?* (WIDE WORLD)

of the disease the germs pass out with the excretions so that they are eventually found wherever the sewage goes, in the soil or in streams and lakes. In a later problem you will discover how one case of typhoid fever in a community might sometimes start an epidemic. Immunity can be given by inoculation with dead typhoid germs. The dead bacteria stimulate the tissues to make antibodies. Because immunity lasts only a few years the inoculation, or "vaccination" as it is sometimes loosely called, must be repeated if one is to be continuously protected. Ever since the first World War, everyone in the United States armed forces has been immunized against typhoid. Civilians, too, are frequently immunized if there is any likelihood of their being exposed to the germ. This has very much decreased the number of cases.

Immunization against other diseases. Measles, like rabies, is caused by a filterable virus. Doctors have now succeeded in making a vaccine from measles virus cultured on fertile hen's eggs. Many children have already been made actively immune to measles with this vaccine. Active immunity can be given to children against scarlet fever and whooping cough, also. Even though these vaccines do not always result in complete immunity they at least protect the child from a serious case of the disease.

A vaccine against tuberculosis has also been given experimentally by the United States Public Health Service to 100,000 or more people. The vaccine which was used (called BCG) was originally made in France. Other vaccines have been used but no one can yet say that any of these vaccines will provide complete protection against tuberculosis.

Influenza vaccines are being experimented with and used. And experiments are being carried on with immunization against bubonic plague. Bubonic plague we think is the disease that was called the Black Death and that swept over the whole of Europe in the Middle Ages.

Passive acquired immunity. In typhoid fever, smallpox, rabies, and the other diseases just mentioned, the animal acquires active immunity by the formation of antibodies in its tissues. Late in the last century, another important discovery was made in the fight against diseases. In 1892 a pupil of Koch, a German physician by the name of Emil von Behring, gave successful inoculations against diphtheria. His method was different from that developed by Pasteur, and his object was to find a cure rather than a prevention.

Diphtheria germs enter through the nose or mouth and settle in the throat. Here they produce a painful swelling. The toxins they excrete are carried through the body, causing high fever and distressing symptoms. Emil von Behring knew that the diphtheria germ produces a toxin that enters the blood stream. The tissue cells produce an antitoxin which acts against, or neutralizes, the toxin. Knowing this, Behring decided that some other animal could be made to do the work of producing the antitoxin. This could then be transferred into the human body ready-made and ready for action. His reasoning proved to be correct. Behring raised diphtheria germs in pure culture and injected some into a healthy horse. He was using Pasteur's method of building up active immunity. Later he took the antibodies from the horse and injected them into a person. By this method, the human body can be fully armed against diphtheria within a few hours. Behring used the treatment mostly to cure children after they showed symptoms of the disease; but he also injected the antibodies into a child that had been exposed to the disease but had not yet been taken ill. He found that the antibodies could be used both as a cure and as a preventive.

If used as a cure it is extremely important that the antitoxin be given as soon as the diagnosis is made and that a competent physician be called to make a diagnosis if diphtheria is suspected. When the antibodies are given as a preventive, the person acquires *passive immunity*. It is called passive because the person's cells remain inactive. Such passive immunity is obtained immediately but lasts only two or three weeks.

How antitoxin is prepared. A pure culture of the germs is made in broth; toxins accumulate in the broth. The bacteria are filtered out, and the toxin is collected. It is treated with various chemicals to weaken it. It is then called *toxoid*. This toxoid is injected into a horse. A small amount of toxoid is used for the first inoculations. Then toxin is used. Every five or six days, over a period of several months, the horse is inoc-

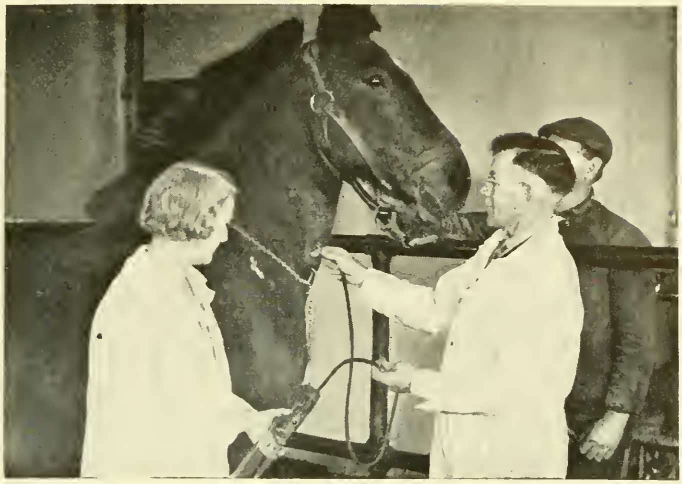


FIG. 297 *Bleeding a horse for antitoxin. Why is this horse able to supply antitoxin?* (NEW YORK CITY BOARD OF HEALTH)

ulated, each time with a stronger dose. In this way the horse never develops the disease, but its body produces large amounts of diphtheria antitoxin. This is carried in the plasma.

Bleeding the horse, clotting the blood, refining and preparing the serum with its contained antibodies, testing it out on a laboratory animal, and finally bottling it are the steps in a long and costly process, for all these operations must be performed with the greatest care and accuracy.

Active immunization against diphtheria. When Behring's antitoxin is used as a treatment against the disease which has already set in, it prevents many deaths (see Fig. 298). When it is used to immunize, it has far less value because the immunity lasts only a few weeks; the injected antitoxins quickly disappear from the blood. In an attempt to wipe out diphtheria as completely as smallpox has been wiped out, scientists set themselves the task of developing an active immunization. Dr. Bela Schick, a Hungarian physician now living in the United States, succeeded in this. He injected some diphtheria toxin into the arm of a healthy person. For safety he gave some antitoxin with the toxin. The mixture is called "toxin-antitoxin." Schick started with a weak dose and gave the cells time to make some antitoxin. Then he gave a second stronger inoculation and after a while a third. Nowadays toxoid, a weakened toxin, is injected instead of toxin-antitoxin. It has been found that one to three injections are needed to give a child active immunity for life.

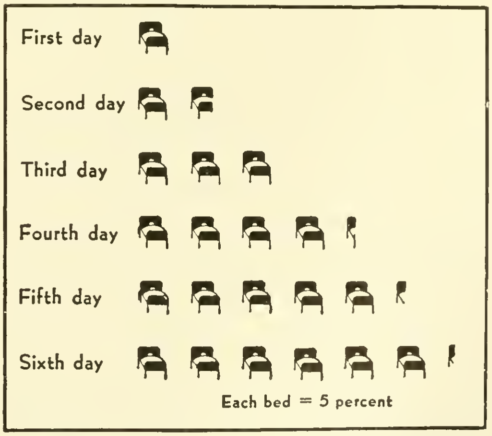


FIG. 298 *Compare the percentage of deaths from diphtheria when antitoxin is given the first day with the percentage of deaths when it is given on the sixth day.* (SAUNDERS)

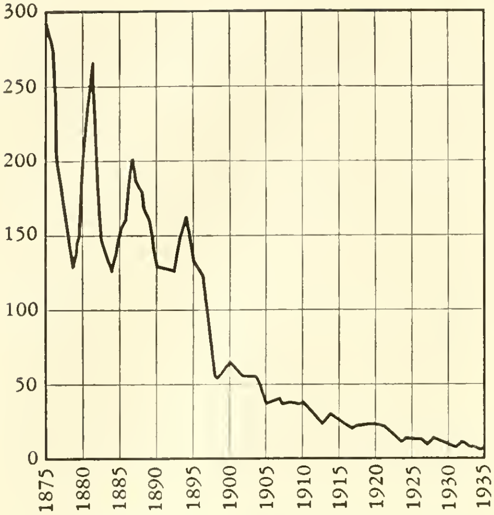


Fig. 299 *Death rate from diphtheria per 100,000 people in New York City. Compare the rates of 1882 with 1935. Since which year has there been a steady decrease? Why?* (SAUNDERS)

Fig. 300 *The bacillus that causes tetanus (lockjaw) forms a spore at one end of the cell. Of what importance is this fact?* (AMERICAN MUSEUM OF NATURAL HISTORY)

Testing for susceptibility to diphtheria. Some children seem to have a natural immunity to diphtheria. In this respect it is different from smallpox to which none of us seems to be naturally immune. Doctor Schick wanted to avoid unnecessary immunization. He therefore devised a simple test now known as the "Schick test." By means of this, the susceptible children can be discovered.

A very small amount of toxin is injected into the skin of the arm. After about twenty-four hours a doctor can tell from the appearance of the skin in the region near the injection whether or not the person is naturally immune. If a peculiar red region appears, the results are "positive," that is, the child is susceptible, and the doctor recommends immunization with toxoid. If the results are negative, immunization is not necessary. Immunization is a safe and cheap insurance against diphtheria. And at the same time it helps to protect others in the community. When every child is tested for susceptibility and then immunized if necessary, there will be less diphtheria.

Antitoxin against lockjaw. Until recently lockjaw or *tetanus* (tet'an-us), like rabies, meant certain death. Unlike most other pathogenic bacteria, the germ that causes the disease can form a spore. In this form it can live for a long time without the warmth and food of the animal's body. Tetanus spores may rest in the soil; they are common in soil which has been long under cultivation, particularly if it has been fertilized with horse manure. How do tetanus spores get into the soil? The germ lives in the horse and some other animals. Having entered through the mouth, it can live and reproduce in the digestive tract without giving any symptoms of the disease or doing any harm to the animal. The germs leave the animal's body in large numbers with the excretions. Once out of the body they form spores in the soil. Other horses, in grazing, swallow some of the spores. Thus the germs, by multiplying in one horse after another, become plentiful in certain soils.

When any soil, or an object that has been in contact with the soil, gets into a wound there is a chance that tetanus spores will enter with it. When the germs enter through a break in the skin they become dangerous, especially if it is a "puncture wound," one which is deep and admits little air. Then the germs multiply and form strong toxins which spread through the system, reach the brain, and cause severe contraction of the muscles (lockjaw). Fortunately, antitoxin against tetanus toxin is available. As in diphtheria, if antitoxin is given promptly, the toxin is neutralized and kept from spreading. Antitoxin used for treatment is supplied by horses and is prepared in much the same way as diphtheria antitoxin. See EXERCISE 7. In all accidents and especially in those which involve deep wounds, it is wise to have a prompt inoculation with tetanus antitoxin.

Recently, it has become possible to provide lasting immunity against tetanus by the use of a toxoid. After injection, the body builds up an active immunity that lasts for several years. Physicians now often give babies injections against diphtheria and tetanus at the same time.

"Borrowing" antibodies. Diphtheria and tetanus are the only common diseases against which there are true antitoxins. But we borrow other kinds of antibodies against a good many kinds of diseases. For treating measles, scarlet fever, certain types of pneumonia, and various other diseases doctors use immune serum taken from some person or animal who has had the disease. The serum is used as a treatment. It is given after the person has acquired the disease. You will easily see that this treatment is different from the active immunization described above.

Blood poisoning following operations. Long before Pasteur's work on immunization was perfected and long before physicians made a practice of immunizing against disease, equally important work was being done along other lines — the control of blood poisoning due to bacterial infection which usually followed operations. As always, when progress is being made in science, there are many investigators working on the same problem. Toward the close of the last century there were two scientists whose names stand out particularly in connection with the study of blood poisoning — the Hungarian doctor Ignaz Semmelweis and Sir Joseph Lister (1827–1912), a Scotch surgeon.

Up to about 1860 physicians used hot tar or red hot irons to prevent infection after an amputation. They attempted abdominal operations only when it was unavoidable, for in such operations blood poisoning almost always followed.

The discovery that germs could cause disease led some physicians and surgeons to suspect that the blood poisoning which accompanied so many operations might also be caused by bacteria. Lister tried a strong disinfectant, carbolic acid, a substance that he knew killed bacteria in a culture. He dipped his hands and instruments in this before he went to the operating table; he sprayed the body of the patient with it during the operation; then he covered the wound with gauze soaked in carbolic acid. Success was immediate; wounds did not develop pus, and the number of deaths after operation decreased considerably.

But Lister was not wholly satisfied with the method, because the carbolic acid which so successfully killed the bacteria also injured the tissue cells and wounds healed slowly, sometimes not at all. Lister then tried the following: instead of sterilizing the wound after the bacteria had settled in it, he tried to make it impossible for bacteria ever to get in. He got rid of bacteria on his instruments by sterilizing them in boiling water, and he operated in a room which was as nearly sterile as he could make it. Instead of soaking the wound in disinfectant, the skin was made sterile before the operation was begun. In other words, Lister developed what is called *aseptic* surgery instead of *antiseptic* surgery. Thereafter, surgical wounds usually healed rapidly, and bacterial infection following an operation became the exception instead of the rule. In the thirty odd years since Lister's death, many improvements have been made in the construction of the operating room and in methods of keeping germs from wounds during and following operations. We owe a great debt of gratitude to men like Lister and Semmelweis, but these discoveries would not have been possible had it not been for the painstaking work of Robert Koch and Louis Pasteur and their many co-workers. All these men together developed and established the germ theory of disease. See whether you can answer the questions in EXERCISE 8.

The use of drugs. In the early days of history diseases were often treated with herbs. Some of these or their extracts, called drugs, are still in use to give temporary relief from pain or fever or other symptoms of disease. But after the discovery of the germ theory of disease, physicians attempted to combat the germ and its products rather than to try to treat the symptoms with drugs.

Before 1910 about the only chemicals used against bacteria in the body were antiseptics on wounds and quinine which, taken internally, seemed to interfere with the growth of the microorganism causing malaria. Then in 1910 Ehrlich discovered "606," a specific chemical which worked against the syphilis organism. This opened up a new field of research and within the last ten or fifteen years the chemical treatment of disease has grown rapidly.

Venereal diseases. One of the most dangerous of the communicable diseases and one of the most widespread is syphilis. The disease comes on slowly. Its first symptom is usually a harmless looking sore which heals. The disease spreads slowly, ending eventually in the nervous system. Thanks to Paul Ehrlich (1852–1915), and many research workers since his death, it is possible to cure most cases of the disease by use of chemicals containing arsenic and bismuth. More recently, penicillin has been found effective in curing many cases. If treatment is begun soon enough, most cases of syphilis can be cured. The number of deaths from syphilis in the United States has been very much reduced.

The disease may be spread from one parent to the other and thus to the un-

FIG. 301 *Colonies of one of the molds that produce penicillin. Commercially the mold is cultured in huge vats or tanks.* (PRESS ASSOCIATION INC.)

born child. The death of some babies before or after birth is caused by syphilis in the mother. For this reason, many of our states require a doctor's statement certifying freedom from syphilis before issuing a marriage license. The Wassermann test for detecting syphilis is a simple test. In states that require no certificate many people have themselves tested and, if necessary, treated when marriage is contemplated.

Gonorrhea (gon-o-ree′ah) is the second of the venereal (ven-ee′ree-al) diseases, that is, diseases spread commonly through the sex organs. Blindness in babies is one of the dangers of gonorrhea.

The sulfa drugs. In 1932 a patent was issued in Germany on a chemical produced in the laboratory and used with almost magic effect on the deadly streptococcus germ. Although the German scientists kept the chemical composition a secret, French scientists almost immediately learned the composition of the substance that brought about the miraculous cures. It was *sulfanilamide.* One after another, other *sulfa compounds,* such as sulfadiazine, sulfapyridine, and sulfathiazole, were developed. The sulfa drugs were discovered just in time to save countless lives. During World War II less than 4 per cent of wounds became infected. During World War I the percentage was much higher. In earlier wars infection was almost the rule.

The sulfa drugs are far better than ordinary antiseptics in treating wounds. Antiseptics which are effective against bacteria are more or less injurious to the neighboring tissue cells. This is not true of sulfa drugs, which prevent the growth of bacteria or kill them probably by interfering with their nutrition. Sulfa drugs should not be used except under the direction of a physician.

The sulfa drugs have a great variety of uses: in pneumonia, instead of the sera which are prepared with great difficulty and expense; in surgery, against infection; against the streptococcus causing sore throats; and recently even against a virus in a widespread eye infection (trachoma).

More recently sulfa drugs combined with iodine have been used successfully to prevent infection by the sporeformers, tetanus and anthrax germs. Sulfa drugs alone have no effect on these.

Penicillin. *Penicillin* (pen-i-sill′in) is another drug that is used against wound infections. It is extracted from a mold. Recently it has been made in small amounts by chemists in the laboratory. You have no doubt seen a blue-green mold growing on cheese or other foods. Several relatives of this blue-green mold produce the substance which is extracted and used as the drug, penicillin. Other molds, too, have been found to yield substances that stop the growth of bacteria. As time goes on, you may hear more of *streptomycin*, and other compounds that can be used to interfere with the growth of germs in the human body. Streptomycin is produced by bacteria that live in the soil. Drugs such as these, obtained from living organisms, are called antibiotics (anti-by-ot′ticks).

The conquest of disease. The story of man's attempts to conquer disease is a long and exciting one. When Koch and Pasteur proved that some diseases were caused by bacteria, they opened up a new approach to the problem of preventing and curing disease. Pasteur and others showed that it was possible to prevent disease by inoculation with weakened germs. Later the use of antitoxins for the cure of diphtheria and tetanus was discovered. Other immune sera were used. Still more recently tests for susceptibility were found.

Then discoveries took a new turn. Beginning with Ehrlich's discovery of a chemical that could cure syphilis, a whole series of chemical compounds has come into use. Some, the sulfa drugs, were produced by the chemist; others, penicillin and streptomycin, have been extracted from living organisms. They have opened up new possibilities in the prevention and cure of disease. To help you sum up part of this problem do EXERCISE 9.

When these improved methods of combating disease are made available to all people, we may expect healthier, happier, more useful citizens.

QUESTIONS

1. State what is meant by the germ theory of disease. How old is the theory? Which germ was first definitely associated with a human disease?
2. What connection is there between the industrial revolution and tuberculosis? Why did Koch's discovery of the germ help to reduce the death rate of tuberculosis?

3. State Koch's four postulates.
4. With what problems did Pasteur concern himself in his early years? What is meant by fermentation? How did this work lead him to the belief in the germ theory of disease?
5. To what important problem did Pasteur turn once the germ theory was established? Explain how chickens were made immune to chicken cholera. What must be done to germs if they are to be used for giving active immunity? How were the germs treated in each of the two diseases, chicken cholera and anthrax?
6. What is probably the cause of rabies? How does it enter? Where does it seem to settle in the body? Describe how the material used for inoculation is prepared. Why can it prevent the disease if used to inoculate?
7. What is one reason why smallpox was so widespread before 1800? What material did Jenner use to prevent smallpox and why did he call the process vaccination?
8. To what extent has smallpox been stamped out in the United States and Europe? Why? What precautions are taken in the preparation and use of vaccine to make it safe?
9. Why is Pasteur sometimes said to have saved more lives than Napoleon took?
10. How do typhoid germs enter and leave the body? Why is it important that we all know these facts? State exactly what effect inoculation against typhoid has had.
11. Against which three children's diseases have doctors recently perfected a method of giving active immunity?
12. How does von Behring's inoculation against diphtheria differ radically from the various vaccinations described above? Why is the horse said to have active immunity, the person passive immunity? Did von Behring give antitoxin mostly as a preventive or as a cure? Why is it better for the one than the other? In what year does the chart show a very great and a permanent drop in the death rate from diphtheria? Explain.
13. Give all the steps in the preparation of diphtheria antitoxin and give the reason for each step.
14. Why did doctors look for an active immunization against diphtheria? Who discovered this? How was it originally given? How has the method been changed recently?
15. How can a physician determine whether you are susceptible or immune to diphtheria? Of what advantage is this?
16. In what important respect does the tetanus germ differ from all other common germs? Why is this important to us? How does the tetanus germ enter the body? Explain why tetanus germs are likely to be found in the soil. How are tetanus toxoid and tetanus antitoxin used?
17. What is immune serum? For which diseases is it used? Does it give active or passive immunity?

18. What were the contributions of Semmelweis and Lister? What did they owe to Pasteur? Explain the difference between Lister's antiseptic surgery and aseptic surgery. Which is practiced now?
19. What great advance in the use of specific drugs has medicine made within the last ten or fifteen years? In what respect are the chemicals now used different in their effects from the herbs used formerly?
20. How does Ehrlich's treatment for syphilis differ from the other methods of treating disease?
21. For what conditions are sulfa drugs used?
22. How are penicillin and streptomycin obtained? how used?
23. Sum up the contents of this problem briefly by explaining: germ theory of disease, active and passive immunity, and the use of chemicals.

Exercises

1. How well can you interpret a graph? How many people per 100,000 died of tuberculosis in the United States in 1900? How many died of tuberculosis in New York City in that year? How did the two death rates compare in per cent? How did they compare in per cent in 1944? When was the United States death rate reduced to one half of that of 1900? When was it reduced to about one fourth of the 1900 death rate? Can you suggest reasons why the death rate in New York City should have been so much higher in the early years? Can you give reasons why the death rate in 1944 in the United States should be so very much smaller than in 1900? Are you sure that the reasons you give are the correct ones? Why or why not?

2. Why were scientists slow to accept the germ theory of disease? If the germ theory were a totally new theory to you, would you be convinced of it after a demonstration such as described in the text? If not, why not? Which of the steps, if any, would you be willing to omit?

3. Answer the following questions: (*a*) You read that all silkworms attacked by a disease were hosts of a parasitic fungus. Are you justified, therefore, in concluding that the fungus is the cause of the disease? Why or why not? (*b*) What qualities of a great scientist did Robert Koch have?

4. Can you explain why in Jenner's day severe illness frequently resulted from vaccination? When did Jenner live? State the precautions which physicians now take to avoid trouble.

5. Antivaccinationists use arguments such as these: "The health records of a large city in which vaccination of school children is required show that in the years from 1930–1935 not one case of smallpox occurred, but there were three deaths following vaccination." How would you answer this and explain the facts? "Vaccine is made from material taken from a calf and scratched into human tissues. This is unclean and unsafe." How

would you answer? Can you find any other arguments used by antivaccinationists?

6. (*a*) Considering the work done by both men why do you suppose that Pasteur has become so famous while Koch is little known to many people? (*b*) Note the dates of Jenner's and Pasteur's immunizations. Why is Jenner given so much less credit than Pasteur?

7. How is tetanus antitoxin prepared? List all the steps that must be taken if the antitoxin is to be safe for use.

8. (*a*) In what ways are Lister's and Pasteur's ideas applied in the home today? (*b*) List the steps you would take to prevent infection in a wound. Give a reason for each step. (*c*) A friend of yours has just returned from the hospital after an appendicitis operation. List as many scientists, past and present, as you can who contributed to his safe recovery. Explain.

9. Copy and complete the following table. Do not write in this book.

	ACTIVE IMMUNIZATION	PASSIVE IMMUNIZATION
(a) Practiced first by whom?		
(b) Date		
(c) Disease in which first used		
(d) Other diseases in which used		
(e) Advantage of each over the other type		
(f) Disadvantage of each		
(g) How is material prepared for inoculation?		

Further Activities in Biology

1. Make a report to the class on early theories of disease.

2. Report on the life and work of Robert Koch, Pasteur, Lister, and Jenner. Have your class secretary write to the Metropolitan Life Insurance Company, New York City, for biographies of scientists.

3. Report to your class on Edward Livingston Trudeau and his treatment for tuberculosis.

4. Visit a hospital laboratory to find out what hospitals do in the fight against disease.

5. Report on the antivaccination movement in the United States. If possible, quote arguments used by antivaccinationists to see whether they have good scientific reasons for their statements.

6. Prepare a book of clippings describing recent discoveries in the field of infectious disease.

7. Consult the Readers' Guide in the library for references to recent articles on sulfa drugs, penicillin, and other antibiotics.

PROBLEM 3 *How Have Recent Discoveries Changed Some of Our Ideas About Disease?*

Advances in the germ theory. At one time it looked as though knowledge of the germ theory of disease and of active and passive immunization would make it possible to conquer every infectious disease fairly soon. Unfortunately, later research showed that facts were not so simple as had been believed. For example, while it has long been known that pneumonia is caused by a spherical germ (pneumococcus — new-mo-cock′us), further study showed about 32 different strains of this germ. They all look alike under the microscope and they all cause the same general type of disease which the doctor calls pneumonia but they differ in their activities. And the treatment that may help against one strain may not help against another. Physicians now speak of Type I, Type II, and Type III pneumonia germs. What was once called Type IV is known to be a group of about 29 strains. And what is more, some kinds of pneumonia are caused by other bacteria as well as by viruses.

The different strains of a germ differ in their effect on the patient. One strain may be weak or nonvirulent; another may be very virulent. They may even grow differently on nutrient agar. In the case of typhoid and some other germs, the virulent strain forms smooth, round colonies. The weak strain forms rough colonies. The difference is so marked that bacteriologists have come to speak of *S* and *R* strains.

The different strains of a germ often change. In one experiment a harmless germ found in drinking water was injected into an animal in the laboratory. Later, when it was recovered from the animal, it had become virulent. In another case, nonvirulent Type I pneumonia germs were injected into mice together with dead Type II germs. The germs later found in the mice were a virulent Type I strain! Evidently, we are still far from having solved all the problems of infectious disease.

Learning more about antibodies. Bacteriologists are now attempting to discover the chemical nature of various antibodies. They hope to be able to manufacture antibodies in a test tube, instead of merely relying on an animal's body to manufacture them. A beginning has been made at the California Institute of Technology. The Type III pneumonia germ has a coating which contains a special kind of sugar. When this sugar is added to one of the proteins of blood plasma, heated, and then slowly cooled, the protein changes into a new protein which acts as an antibody. While this antibody has not yet been used in disease prevention, this is a most important discovery.

Equally startling experiments have been performed at the Rockefeller Institute for Medical Research in New York. A vaccine against pneumonia was made chemically in a test tube. The substances used were white of egg (a protein called albumen) and sawdust, which contains the carbohydrate cellulose. This new vaccine has been used on animals and proved to be as effective on them as the vaccine made of dead pneumonia germs. To sum up what you have read do Exercise 1.

A new field – viruses. Though the existence of viruses has been known for about 50 years, we know comparatively little about them. But this much is certain. They are so extremely minute that they can pass through porcelain or stone filters. That is why they are often spoken of as "filterable viruses." It has been estimated that the smaller ones among them would have to be magnified a thousand times or more to be the size of a typhoid germ. The electron microscope has enabled us to see images of viruses.

Some viruses seem to be very resistant to cold. Influenza virus has been kept for several months packed in dry ice at a temperature of –108° F, and when after this treatment it was diluted one to a million it was still virulent enough to kill experimental animals.

Viruses are so intimately associated with the living cell that they cannot exist away from it. That is, we cannot raise viruses on nutrient agar. They will grow only on living tissue cells. Keeping tissue cells alive outside the body is a fairly recent discovery. It was early in this

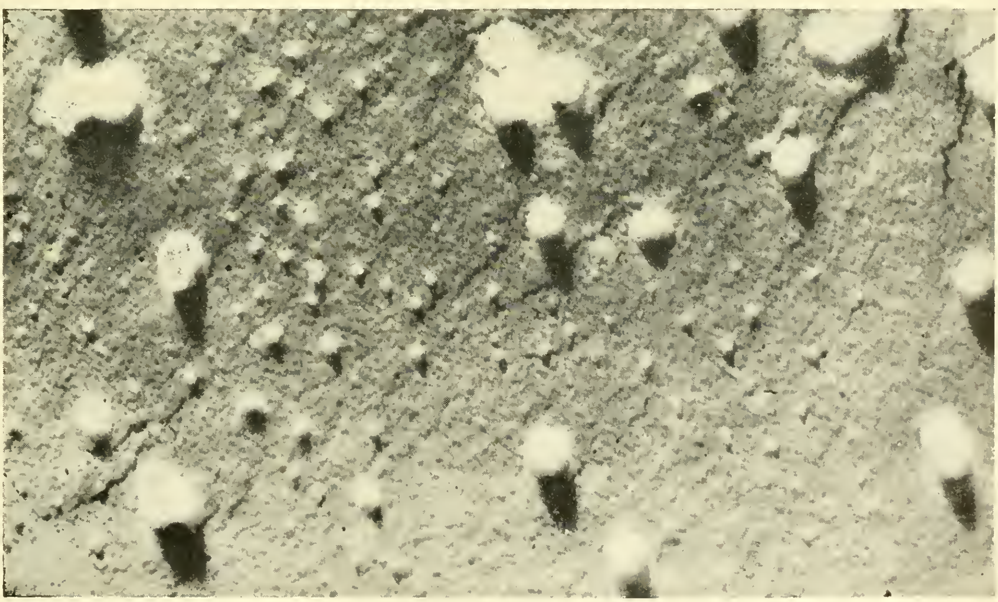


Fig. 302 *Influenza virus photographed with an electron microscope. (See page 11 for a picture of an electron microscope.) The white spheres which look like balls of cotton are the virus particles. They are magnified about 60,000 times. In what ways are these virus particles different from bacteria? Why are viruses difficult to study? What are some of the other diseases caused by viruses?* (R. C. WILLIAMS AND R. W. WYCOFF)

century that Dr. Ross Harrison discovered the technique of raising tissues outside of the human body. Now, tissues of many kinds can be raised. Once tissue culture had been perfected, experiments with viruses made great strides.

Is a virus living? Scientists do not all agree on the answer to this question. The virus causing a disease (mosaic disease) in the tobacco plant was separated from the plant by Dr. W. M. Stanley, one of our Nobel prize winners. He proved that the virus, when purified, formed protein crystals, apparently nonliving, although it grew and reproduced in the plant. But many scientists still think a virus is alive, because under favorable conditions it multiplies, as living things do, and keeps its power of infecting organisms. Smallpox virus has been grown on a tissue culture, a very tiny amount transferred to a second culture, and so on, eleven different times. At the end of the eleventh transfer there was 50,000 times as much virus as there was at the beginning of the experiment. We cannot yet be certain whether or not some of the viruses are living or lifeless. If you are especially interested, you will enjoy reading more about viruses in some college bacteriology textbook.

Little progress in conquering virus diseases. More than 70 diseases attacking man and other animals are known to be caused by viruses. Among the common ones besides smallpox are chickenpox, poliomyelitis (infantile paralysis), epidemic influenza, mumps, measles, "parrot fever" (psittacosis), yellow fever, and some very ordinary ailments, such as the common cold and fever blisters.

It is interesting to note that a virus disease, smallpox, was the first disease against which successful active immunization was practiced. Jenner did not know anything about either bacteria or viruses. Pasteur showed how to immunize against a second virus disease, rabies. Since then relatively little progress has been made in developing immunization against diseases caused by viruses, although there is now a vaccine against two other virus diseases: influenza, a contagious disease found all over the world; and yellow fever, a serious disease of the tropics transmitted by mosquitoes. In many countries viruses are being raised and experiments are being carried on. Scientists believe they know the reasons for many of their failures. Success, therefore, may be just around the corner. You can summarize all that you have read about viruses by doing Exercise 2.

A discovery which seemed promising. At the Pasteur Institute in Paris, a Frenchman, D'Herelle (De-rell′), found something small enough to pass through a porcelain filter that preyed on and destroyed larger bacteria. He called it *bacteriophage* (back-teer′iy-o-faj), bacteria devouring. Sometime before this an English scientist (Twort) had noticed that in harmless colonies of bacteria there were transparent, glassy spots where the bacteria were disappearing from the agar. Whatever it was that did this could be transferred to other colonies. He published his findings but did not attempt an explanation. But D'Herelle continued his studies and found bacteriophage widely distributed. It is plentiful in sewage. Therefore D'Herelle filtered the sewage and collected the bacteriophage. He hoped that it would kill the bacteria

FIG. 303 *A college bacteriology laboratory. Here students learn much more about bacteria than can be learned in a high school course. Which parts of their equipment do you recognize?* (UNIVERSITY OF MASSACHUSETTS)

which cause intestinal diseases, such as typhoid and dysentery. Sometimes it did, sometimes it did not, bring about improvement in the patient. D'Herelle hoped that bacteriophage might be spread from person to person in certain epidemics to kill the bacteria. Animal experiments, however, showed that the bacteriophage was of no help in preventing the spread of disease.

As with virus, there is still dispute about whether bacteriophage is a living organism or a lifeless protein. Whatever the answer may be, at present it looks as though bacteriophage will not be as important in conquering disease as was once hoped by a few scientists.

The future. No one can predict what developments will occur in the near future in the prevention and the cure of infectious diseases. But there are so many promising possibilities for the production of new vaccines and of satisfactory antibodies, of chemical drugs and of antibiotics that we can hope much pain and suffering will be spared us. This is a great and growing field for scientists; it is a field of great service to mankind as well as a field of exciting scientific warfare against deadly germs.

QUESTIONS

1. What is now known about pneumonia and its cause? Give an example of how germs change in virulence.
2. Describe two chemical experiments which show how important chemistry is to the bacteriologist.

3. What is a filterable virus? Give two reasons why little progress could be made in virus study until recently.
4. Why do some bacteriologists believe a virus to be alive; others, lifeless?
5. Name some common diseases caused by a virus. Against which four virus diseases has a vaccine been developed?
6. What is a bacteriophage? Where is it found? How useful has bacteriophage proved itself to be in conquering disease?
7. What can you say about the future of bacteriology?

Exercises

1. This recent work is so technical that you can do no experimentation in connection with it. Instead, make sure that you understand what you have read on advances in the germ theory of disease by summarizing the facts in two columns headed "Startling Facts about Strains of the Same Species of Bacterium," and "Startling Facts about Chemically Prepared Substances Used as Antibodies and Vaccines."

2. Sum up your understanding of a virus in a table under the following headings: Characteristics of a Virus; Reasons for Believing a Virus Is a Living Thing; Reasons for Believing That It Is Not Living; Diseases Caused by a Virus; Virus Diseases against Which We Have Vaccines.

Further Activities in Biology

1. You will find rather difficult but interesting reading in Frederick Eberson's *The Microbe's Challenge*, Jaques Cattell Press, 1941. Report to the class on some topic such as viruses or bacteriophage.

2. Look through the recent files of the *Science News Letter* for information on viruses.

PROBLEM 4 *How Do We Attempt to Stop the Spread of Disease?*

Epidemics of former times. It was not uncommon formerly for epidemics to sweep over Europe and Asia. In the fourteenth century bubonic plague, spoken of as the Black Death, spread over Europe, Asia, and Africa, killing probably as many as 60,000,000 people. In the fifteenth century came an epidemic of smallpox; in the nineteenth century, cholera; and in the twentieth century, influenza. Even in the early days, whether men believed devils, evil spirits, or the stars caused disease, they feared contact with the sick for they had observed that contact brought disease. They fled to escape and in fleeing they spread the germs even farther. Nowadays we know better; instead of running away, we make sure that those who are sick from a communicable disease are separated from the well. We *isolate* the patient who has a communicable disease.

Community action is necessary. The habit of collecting figures about things that happen is a useful one. Some people make a profession of collecting and studying such figures, or *statistics*. The recording of statistics about disease and death was begun in various countries in the first half of the last century. The statistics were interesting to those who examined them thoughtfully. Long before men knew about the role of bacteria in disease, they realized that overcrowding and filth went hand in hand with communicable disease. These conditions cannot be controlled to any great extent by any one individual. They can be remedied only by the members of the community working together.

Ordering lepers to wear a bell or to clothe themselves so that they could be recognized was one of the first examples of community action. A later step was the establishment of *quarantine* (kwar′-un-teen) — the isolation, not only of the sick, but of those suspected of possibly being sick. In the Middle Ages, the Italian city of Venice kept vessels arriving from the East at anchor outside the port for forty days. If no case of plague developed, they were permitted to dock. The word quarantine (meaning 40) comes from this practice.

But little progress in stopping the spread of disease could be made before the germ theory of disease was accepted. To prevent communicable diseases from spreading, we must know how the germ enters the body, through what channels germs leave the sick person and where and how long they will live in various environments outside the body. It is necessary to have this kind of information if a community is to prevent the spread of disease through control of the environment. Such control of the environment by health officers or boards

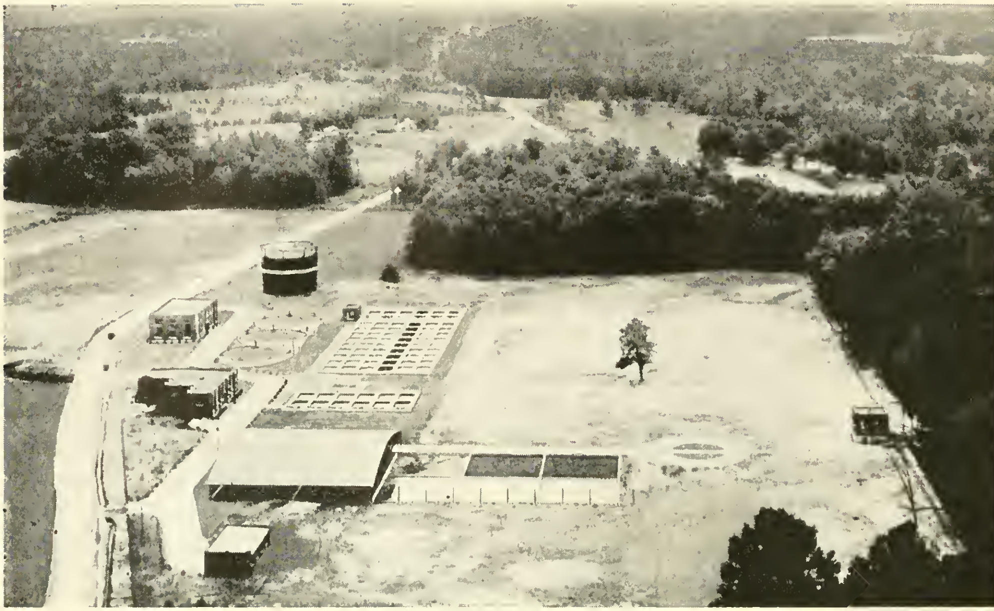


FIG. 304 *Many cities dispose of their sewage in plants like this (Durham, North Carolina). Why do not the health officials let sewage flow into streams or into the ocean?*

of health is called *sanitation*. Health laws in regard to quarantine, insect control, the disposal of sewage, the treatment of drinking water, and the handling of food sold to the public must be made and enforced. Each state has its health department, and each city or town has an active medical officer or board of health for this purpose. Still further protection is given all of us by the U.S. Public Health Service with the Surgeon General at its head. No doubt you can think of a good many duties of a board of health. Could your class divide itself into committees and assign to each committee the preparation of a report on one or more functions of the board of health of your community? See EXERCISE 1.

Safeguarding the water supply. Some germs, such as those causing typhoid fever, cholera, and dysentery, are taken into the body with food or drink; they multiply in the digestive tract and leave the body with the solid wastes. Mixed with particles of decaying matter, the typhoid germ can live in water for weeks or even months. This is unusual, for most disease bacteria die soon after leaving the tissues and fluids of the animal's body. Though they are not spore-formers, typhoid germs may survive even the freezing of water. It is important, therefore, that sewage be carefully disposed of so that the germs cannot enter streams or wells or get into food supplies. Water or food that contains disease germs is said to be *polluted* (pol-loot′ed).

There are two ways in which a community must protect itself against the water-borne diseases. First it must dispose of its sewage either by allowing it to flow into large bodies of water where it does not pollute the drinking water, or

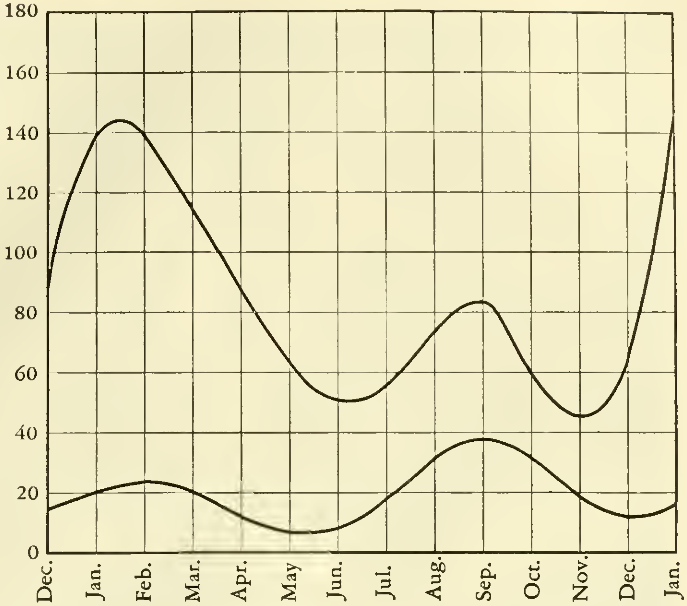


FIG. 305 *Each curve shows the death rate from typhoid per 100,000 people in Albany, New York, during each month of the year. The upper curve shows the number before the drinking water was filtered; the lower, after filtration. What was the highest rate before filtration? What was the highest rate after filtration? What besides filtration helps in conquering typhoid?* (SAUNDERS)

by treating it with chemicals. Second, the community must safeguard its drinking water. Water free from all pollution is difficult for a city to obtain. Some cities, such as New York, Boston, and Los Angeles, construct huge reservoirs many miles away. The water in the streams and lakes of the watershed (the region supplying the reservoir) is guarded against pollution. Before it enters the large pipes that carry it to the city, it is aerated (mixed with air), and otherwise cleaned. Other cities follow a different practice. They collect the available water, even if possibly polluted, and then purify it by passing it through huge sand filters and treating it with chemicals, like chlorine, which kill the microorganisms. Partly because of measures such as these and partly also because of widespread immunization, typhoid fever has become rare in the United States and most of Europe. Study Figure 305 to see what effect filtration of water had on the number of typhoid cases in Albany, New York, years ago. Try EXERCISES 2 and 3.

Safeguarding the milk supply. In the milking of cows and the later handling of milk, a person who has germs in his body may transfer them to the milk. The bacteria may live and reproduce there. Serious epidemics of septic sore throat and other diseases have been started in this way. Then, too, if the cow has tuberculosis, undulant fever, or another of the diseases which attack both man and cattle, these germs may be in the milk. For this reason, at one time people drank boiled milk. But it was found that boiling changes the taste of milk and makes it unsuitable for babies. The problem was solved by the pasteurization of all milk sold to the public. It is required in most communities. The process was named in Pasteur's honor since he treated wines and beer in a similar way to keep them from spoiling. When milk is pasteurized, it is first heated to a temperature of about 150° F for about half an

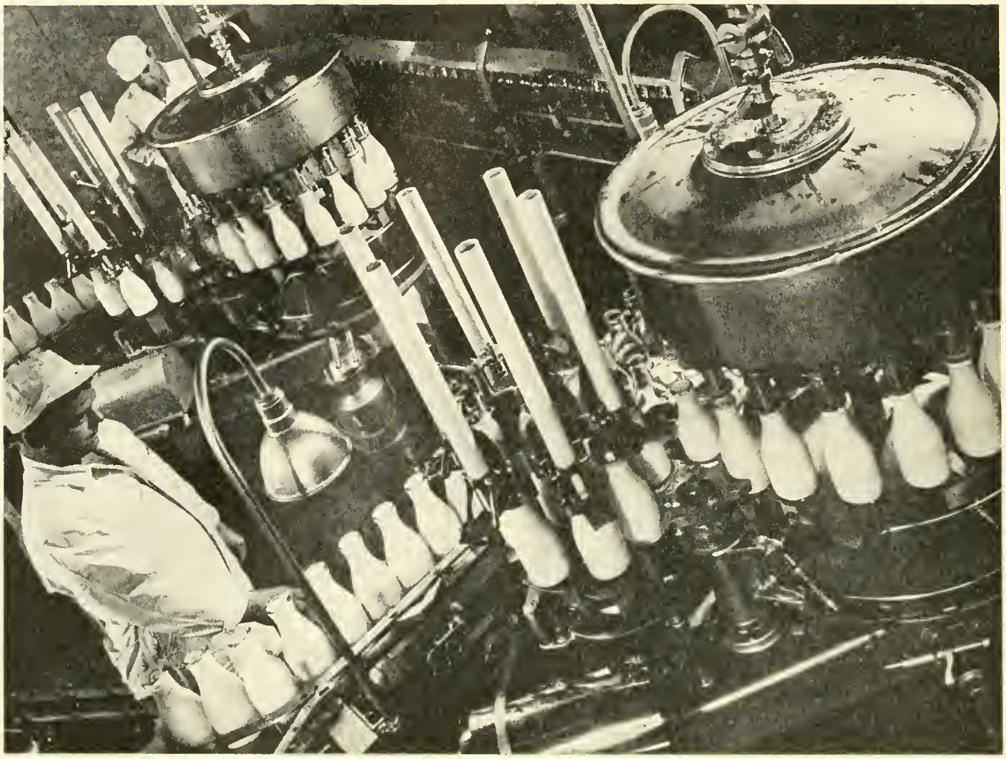


FIG. 306 *The milk bottles are filled when they are under the tanks and capped by the machine holding the paper tubes. What is the advantage of filling and capping milk bottles by machine?* (NATIONAL DAIRY COUNCIL)

hour. This is far from the boiling point, and the milk is not changed to a great extent. The temperature is sufficient, however, to kill the pathogenic bacteria that may have entered by accident. Pasteurization also kills some of the other bacteria which are found in huge numbers in even the cleanest milk. You can see how plentiful bacteria are in milk by placing a few drops on nutrient agar. See EXERCISE 4. Many of the bacteria in milk are of the kind that cause souring. The moderate temperature of pasteurization does not kill them; it merely stops their growth. Therefore, the milk should be iced immediately after it has been heated and should be kept cold. In recent years a simple test has been devised to show whether milk has been heated sufficiently to free it of pathogenic bacteria. Raw milk contains an enzyme (phosphatase) which is easy to test for and which is destroyed by the amount of heat which should be applied during pasteurization. If a sample of pasteurized milk still shows the presence of this enzyme, it is clear that insufficient heat was used in the pasteurization.

In large cities, officers of the board of health regularly inspect the pasteurizing plants. Dairy farms are also inspected to make sure that all rules for the proper keeping of cows and handling of milk are obeyed. In spite of this inspection,

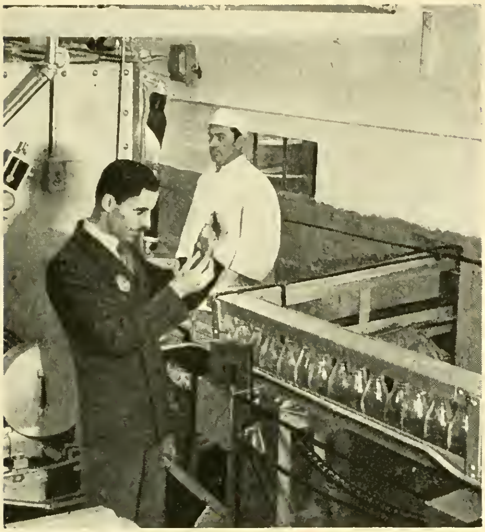


FIG. 307 *A Board of Health inspector making a test in a milk plant. What kinds of tests does he make? How may an inspector's work affect your health even if you do not drink milk?* (NEW YORK CITY BOARD OF HEALTH)

FIG. 308 *In most large cities some food is sold from push carts. Not all are as clean as this one. What can you learn from this picture about the care of food in stores or at home?* (AMERICAN MUSEUM OF NATURAL HISTORY)

however, it is dangerous to drink raw milk unless it is especially certified to be free of disease germs. Such milk is marked "certified" milk.

Carriers. Most pathogenic germs cannot live outside the animal's body for more than a few hours. It was believed that quarantine and isolation of patients should, therefore, stop the occurrence of a disease such as diphtheria. Then it was discovered that a patient may keep germs in his throat for some time after he is well and up and about. He becomes a *carrier*. And what is worse you or I, right now, may be carriers of diphtheria germs though we have, perhaps, never had the disease. We know there are carriers of diphtheria, scarlet fever, and typhoid. It is possible that poliomyelitis (infantile paralysis) and a score of other diseases may sometimes be spread by carriers.

The person who is known to become a carrier after recovery from a disease such as typhoid is registered by the health officer and forbidden to work at jobs that involve the handling of food. Rarely does anything go wrong when such precautions are taken. In a recent small outbreak of typhoid in one of our large cities a number of cases appeared in close succession within one small district. Health officers speedily traced all the cases to one registered carrier and an unfortunate leak in the plumbing of the house in which the carrier lived. In the basement of the house fruit was being sold.

The carrier who has never been sick with the disease is frequently not detected. Since there are always some undetected carriers, health officers must consider all possible ways in which germs may be passed from person to person, and must take steps to prevent such transfer.

Precautions against the spread of germs. The health laws of many communities require that special types of drinking fountains be installed; that paper towels be supplied in public washrooms; that food and drink may be sold only in licensed establishments that meet high standards of cleanliness; and that those who have certain diseases be quarantined. Other laws require that foods which are eaten cooked be protected not only from dust on which bacteria ride, but from flies which may be carrying germs on their feet. The common housefly was once called the typhoid fly because of the important role it played in carrying typhoid germs from excretions to food. For this reason food is protected by being packaged or kept under cover.

Shellfish that grow in polluted waters near large cities are often eaten raw and they may also spread typhoid or other intestinal diseases. Oyster and clam beds in many states are frequently inspected to prevent possible infection. Bacteria and particularly larger parasites may be carried in meat from diseased animals. There is federal inspection of slaughter houses to ensure us protection.

Recent measures for health protection. A large variety of germs can be spread from the respiratory organs, clinging to the tiny droplets of moisture expelled in ordinary speaking and particularly in coughing and sneezing. Since there are likely to be a number of carriers in every gathering of well people, the air may contain large numbers of pathogenic germs. Recently ultra-violet lamps have been installed in some public gathering places to kill germs in the air. This practice has met with considerable success and is likely to be further extended. Mist sprays containing disinfectants are also being used with success in large meeting places.

Carriers other than man. Insects are important carriers of disease germs. Some, like the housefly, spread germs that stick to their feet; these are not true carriers. But numerous other insects that bite get germs of one special kind from the blood of a sick person and transfer them to the next well person they bite. In some of these cases the germ may live in the insect for a considerable time. Fleas are carriers of the germs of bubonic plague from one rat or ground squirrel to another or from one of these animals to man. When the rat or squirrel dies of the disease, all the fleas leave the body carrying virulent germs with them. Extermination of all rats and ground squirrels with their fleas would be the best preventive measure. But this is probably impossible. In most communities there are very many more rats than there are people. Poisoning and trapping gives some immediate relief but as soon as it is discontinued the rat population increases rapidly again. To get rid of rats it is necessary to tear down all old buildings and replace them with completely ratproof buildings. Since killing all rats is so difficult, health authorities have used other methods to keep bubonic plague in check. They try to prevent infected rats from entering our country from ships that come from plague-infested parts of the world. The hawsers (heavy ropes) that hold ships to their piers are equipped

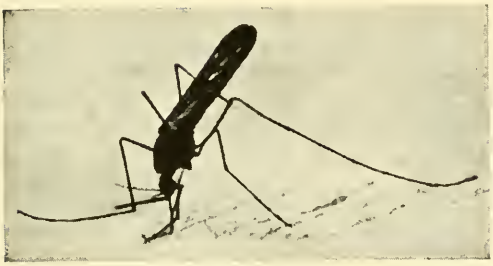


FIG. 309 *The malaria-carrying mosquito (Anopheles) sucking blood. It "stands on its head" when biting. The common mosquito (Culex) holds its body parallel to the surface of the skin.* (SCIENCE SERVICE)

with rat guards, big metal plates, that make it impossible for a rat to leave the ship by way of the rope.

The list of insect carriers is a large one. To name but a few: the body louse carries typhus germs; some mosquitoes carry yellow fever germs; a species of fly native in Africa (tsetse fly) carries the germs of African sleeping sickness. But the mosquito which transmits malaria does the greatest damage.

The importance of malaria. Malaria is common in warm climates, especially in swampy regions where mosquitoes breed. In our southern states there are about 4,000,000 cases every year. Although few of them result in death, the loss in working time due to the disease is very great. Malaria probably costs the country as much as 500 million dollars a year. Worse than that, it brings misery to millions of persons. In the tropics malaria is often fatal; it probably causes the death of a million people yearly in India and Pakistan alone. The medical department of our army rated it as the most important of all diseases during World War II. In the early part of the war in the South Pacific about one out of every ten men became ill with malaria. But a well organized attack on the disease soon cut down the number of cases to one per five hundred men. Malaria leaves no immunity and each patient becomes a carrier for several years.

An age-long mystery is solved. Malaria means "bad air," and damp night air was once considered especially "bad." The reason for this is obvious, now that we know that malaria is spread by the mosquito. Mosquitoes breed in stagnant or slowly flowing water. They are numerous where the ground is swampy and the air is damp. Thirty known species of mosquitoes can transmit malaria and most of them live in the tropics or in the South Temperate Zone. Many belong to the genus *Anopheles* (an-of'el-ees). You learned how to recognize this mosquito.

The organism carried by the mosquito and causing malaria is a protozoan. It spends part of its life in the red corpuscles of man, the rest in the body of the mosquito. Many men contributed their share to the story of the cause and transmissión of malaria. In 1880 Alphonse Laveran, a French army surgeon in Algeria, described the parasite which he found in the blood of malaria patients. Italian investigators saw the parasite too. How it got there, no one knew, so this discovery by itself was not of great importance.

About fifteen years later an Englishman, Dr. Patrick Manson, suggested that mosquitoes might transmit the parasite to man. He had shown that the mosquito transmits another tropical disease, and it had been known for centuries that malaria occurs in regions where mosquitoes breed. Acting on this suggestion, a British army surgeon in India, Dr. Ronald

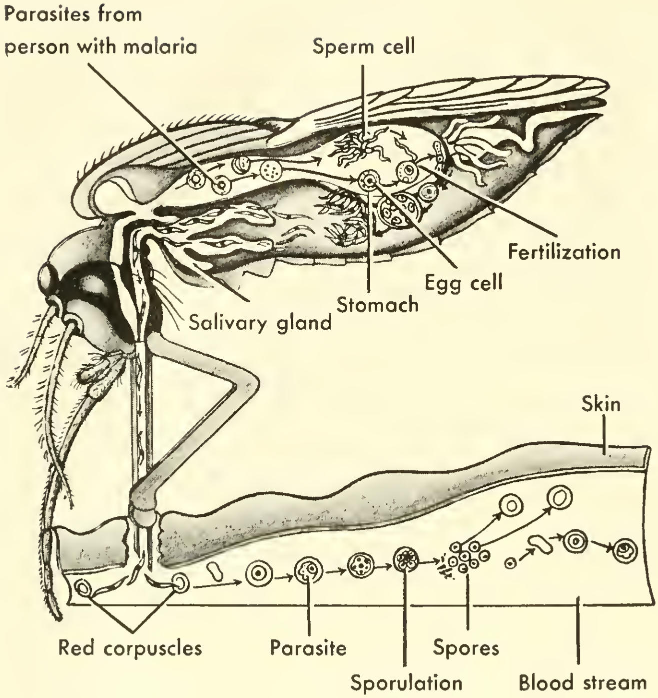


FIG. 310 *A mosquito introducing the malarial protozoan. What changes take place in the parasite in the human blood? When you read the second part of the life history of this parasite, study the mosquito. This mosquito had previously sucked up parasites from a malaria patient. What changes do these parasites undergo in the stomach of the mosquito? When these changes have taken place, the mosquito infects the next person it bites.*

Ross, examined great numbers of mosquitoes in trying to find the parasites. After two years of patient search he discovered in the Anopheles mosquito some protozoa which he believed might be those of human malaria.

These laboratory demonstrations, however, were still not proof of the connection between malaria and mosquitoes. It remained for the London School of Tropical Medicine and for a number of Italian scientists to perform experiments which proved that we get malaria through the bite of a mosquito carrying the particular protozoan and, furthermore, that we can get it in no other way but this. See EXERCISE 5. Could you write out the plans for controlled experiments which would definitely establish the connection between mosquitoes and malaria? See EXERCISE 6.

The malaria protozoan's life story — first chapter. The protozoan leads a complicated life, half of it in the blood of man and the other half in the stomach of the female mosquito. It is never found in the male mosquito. When an infected female mosquito (an Anopheles in this part of the world) bites and introduces a protozoan, the protozoan soon glides into a red blood corpuscle. Being a parasite, it feeds on the corpuscle and grows rapidly. After a day or two it has grown so much that it may completely fill the corpuscle. It now looks much like a tiny ameba with streaming protoplasm. Then the nucleus divides a number of times, a little cytoplasm surrounds each nucleus, and twelve or more small spores are formed. The membrane of what was once the corpuscle now bursts, releasing the spores and accumulated toxins into the blood stream. It is the toxin that produces the characteristic chills followed by fever. Each spore now repeats the cycle; it glides into a new corpuscle, feeds, grows, reproduces; then the corpuscle bursts. When this happens a number of times, a great many of the corpuscles are destroyed. As a result the infected person looks pale and anemic (lacking hemoglobin). He will feel tired because oxygen is not being circulated properly for oxidation. If he does not receive drugs, such as quinine or atabrine, death may follow.

The malaria protozoan's life story — second chapter. In the meantime other Anopheles mosquitoes are likely to have bitten the person with malaria. As a mosquito bites, it sucks up some of the blood and swallows it. If there are many parasites in the body it is likely that the mosquito will suck up some of them. When the parasites get to their new surroundings in the mosquito's stomach they lose their pseudopods and take on a spherical form; then they develop into two types, male and female. Some remain spherical; these are the females. Some develop small whiplike projections, each of which has a nucleus and is really a cell; these are the males. In Figure 311 there are drawings of a male cell piercing a female cell and fusing with it. The fused cell bores its way into the wall of the mosquito's stomach. Then it divides many times. The new protozoa, produced by division, grow. As they occupy more space they push out a kind of pocket, a large swelling on the outer wall of the stomach. Examine Figure 310 again. After some time this pocket bursts, and many of the protozoa are released

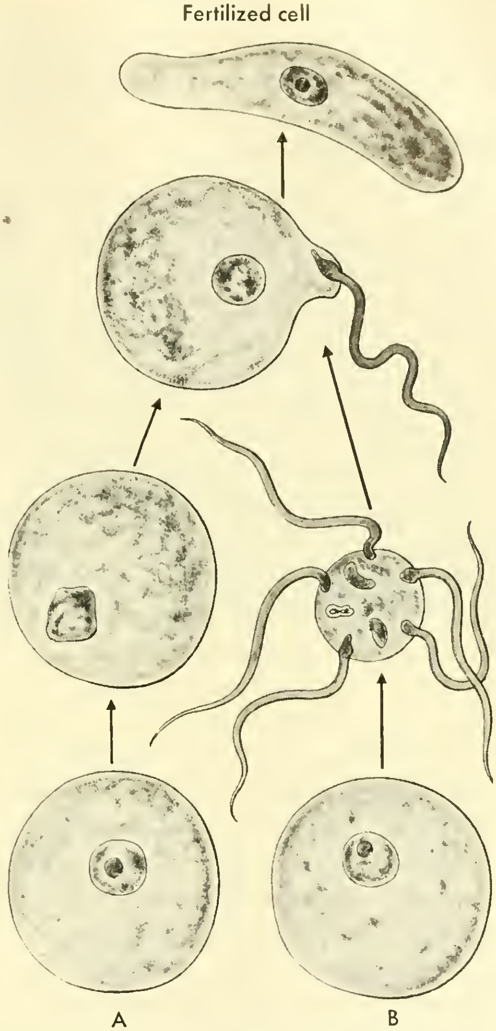


Fig. 311 *How the protozoan changes in the mosquito's stomach. Does* A *change into male or female? Where are the two cells shown fusing?*

into the body cavity of the insect. From here they travel to the salivary glands. The next time the mosquito bites a person some of the parasites will enter with the bite. Do Exercises 7 and 8.

Mosquitoes and yellow fever. "Yellow Jack" or yellow fever was a great scourge in the tropics until man learned to fight not the cause but the carrier. It

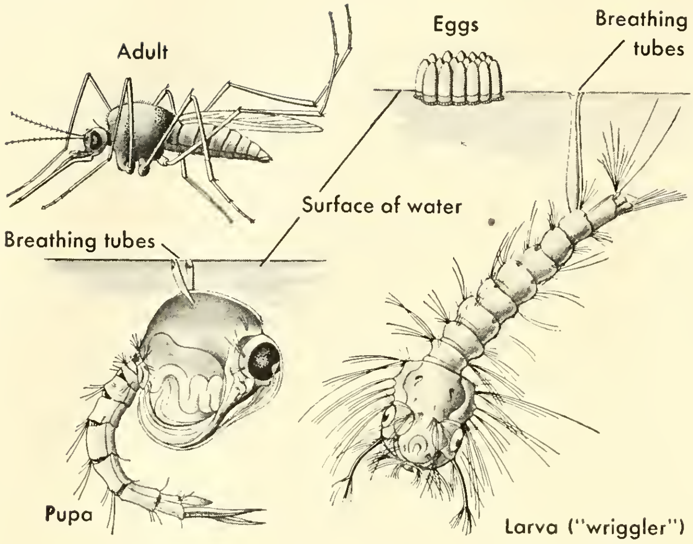


FIG. 312 *The life history of the common mosquito (Culex). All mosquitoes develop in much the same way. How can such information help in the control of mosquitoes?*

was long suspected that the disease was carried by mosquitoes, but since no trace of the microorganism could be found in either man or mosquito, the theory at first was not taken very seriously. We now know why the cause could not be found; a virus causes the disease. After long study and much unsatisfactory experimentation with mosquitoes, carefully controlled experiments performed by Dr. Walter Reed and others brought results.

When a call went out from the United States Army for volunteers for these experiments a private, John R. Kissinger, was the first to allow himself to be bitten by yellow fever mosquitoes which had sucked the blood of a yellow fever patient. In later experiments John J. Moran also allowed infected mosquitoes to bite him. Both men came down with bad cases of yellow fever, suffered horribly for days but finally recovered. Kissinger paid more heavily for his sacrifice for he never fully regained his health. In the meantime three other men of the hospital staff had volunteered for the other part of the experiment. They slept for twenty nights in a screened hut, using the bedding and belongings of patients, some of whom had just died of yellow fever. They had the best of the bargain for, as events proved, the organism causing yellow fever cannot enter the body except through the bite of a mosquito.

These were the first of the experiments which later definitely proved that only yellow fever mosquitoes can carry the virus from one person to another. Once this had been established, it was clear that the way to keep yellow fever from spreading is to destroy the mosquitoes.

Mosquito extermination. Evidently mosquitoes in many parts of the world are not only a nuisance but a menace to health. The problem of mosquito extermination is, therefore, a pressing one. Mosquitoes lay their eggs on still or slowly moving water. The eggs hatch into tiny larvae called wrigglers. In time these develop into active pupae which also live in the water. Both larvae and

FIG. 313 *This old creek is being straightened and made deeper. How will this affect mosquito breeding?*

pupae breathe through tubes which come in contact with the air at the surface of the water. See Figure 312. This is their undoing. For by spreading the thinnest film of kerosene or other oil over the surface of the water we can cut off their air supply and kill them before they develop into adults. Sometimes it is easier and more effective to fill in or drain the stagnant pools. Sometimes it is more convenient to stock the waters with small fish that feed on the larvae and pupae.

How successful have we been? When the life history of the mosquito became known it seemed a relatively easy matter to exterminate them. In the early years of this century General Gorgas of the United States Army began systematically to exterminate the yellow fever mosquito in Havana, Cuba. There the mosquitoes laid eggs in water barrels or other water containers. These were cleaned up or kept covered. The problem, therefore, seemed not too difficult. Other communities followed Havana's example, and it was believed for a time that yellow fever was being conquered. These hopes, however, were soon destroyed, for it was discovered that various species of jungle mosquitoes are carriers of the virus and that many species of monkeys can and do become infected. Mosquitoes bite monkeys as well as man and transfer the virus readily from monkey to monkey or from monkey to man. The task of wiping out mosquitoes in all the jungles of the tropics is more than man can tackle; yellow fever is far from being conquered.

Malaria, too, for a time seemed to be under control. Our success in building the Panama canal was due as much to our war against mosquitoes as to our engineering skill. Draining of marshes, screening of houses, and isolation of the human carrier were measures that proved successful; but they could be carried out only in a relatively small area. There are still great areas where mosquitoes are plentiful and we are far from having wiped out mosquito-borne diseases even in our own country.

The larger parasites. There are many important diseases that have been barely mentioned in the preceding pages. These are the diseases caused by worms of various sorts. These larger parasites damage the body in quite a different way from germs. We do not develop immunity to such diseases. All we can do is to attempt to keep the parasites from entering the body and to fight them with drugs.

Hookworm disease. In many parts of the world, where the climate is suitably warm, large numbers of people have hookworm disease. There are probably as many as two million persons suffering from hookworm in the United States. The worms do not kill their host. They cause anemia which makes the host feel continually tired. Before measures were taken to stop the spread of hookworm a large proportion of the population of certain states was infected with the worm.

The hookworm belongs to the group of roundworms. It is like a tiny white thread, scarcely visible to the naked eye (1/25 of an inch in length). It spends part of its life in the soil and enters its host by boring through the skin of the foot. Children are therefore most likely to become infected because they often go barefoot. Once in the body, the hookworm enters the veins, is swept to the heart, and from there to the lungs. Again it bores. And this time it enters the air passages of the lung. In boring from the veins into the lung it damages lung tissue, thus making the host more susceptible to tuberculosis. From the windpipe it passes into the alimentary canal where it spends the rest of its life and where it does great harm. The worm attaches itself to the wall of the intestine and feeds upon the blood. It secretes a substance which keeps blood from clotting. In this way the worm has a steady flow of food. Since the blood fails to clot, the host is constantly losing blood even when the worm is not feeding. It is this loss of blood which causes anemia. As the parasites develop they reproduce in large numbers. The eggs pass out of the intestines with the excretions and get into the soil. Here each egg changes into a larva which may find its way again into another human host.

Drugs have been discovered which kill the hookworm in the host. Sanitary precautions can be taken to keep the larvae out of the soil. Also, shoes can be provided for people who cannot afford to buy them. Spreading education and establishing a higher standard of living are the best ways of getting rid of the hookworm. Try EXERCISE 9.

Trichinosis. Trichinosis (trick-i-noh′-sis) is a disease of men and pigs caused by a relative of the hookworm. Men get the disease by eating infected pork which is raw or not thoroughly cooked. Once the worms get into the intestines of man they find favorable conditions and develop rapidly. They reproduce, a

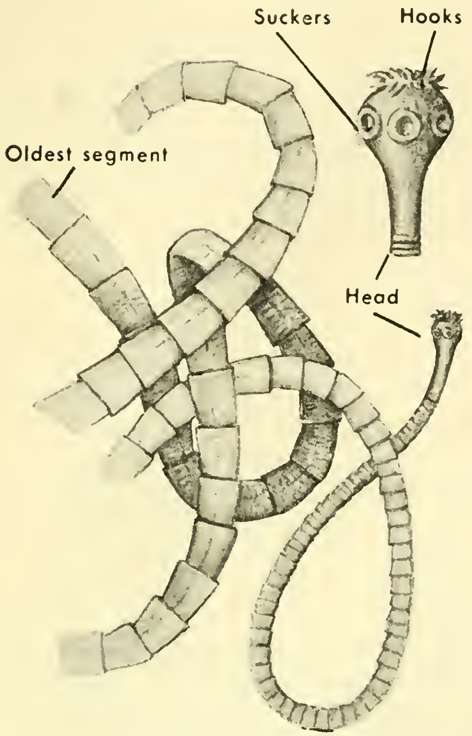


FIG. 314 *The tapeworm is an ugly-looking visitor. It is easy to get rid of, however. How does it cling to its host?*

mature worm being responsible for about 10,000 young. They burrow and find their way into the muscles, particularly the muscles of the diaphragm, tongue, and eyes. Here they come to rest, causing great pain and fever. There is no known cure for trichinosis. In this country there is federal inspection of meat sent from one state to another, but in general there is little inspection for this parasite. Fortunately, the young worm in the pork dies if kept in cold storage for several weeks. But our only real safety lies in very thorough cooking of pork and pork products. The pig seems to get the worm mostly from eating infected pork scraps in garbage.

The tapeworm. The parasite of which you have probably heard most often is the tapeworm, one of the flatworms. There are many species which can live in man. The tapeworm has a larval stage which lives in the flesh of various animals, most frequently the pig, sometimes in beef. Freshwater fish also have been known to transmit one species of tapeworm to man. The larva, having entered the human body, fastens itself to the wall of the intestine by means of the hooks and suckers on its head. See Figure 314. There it stays, absorbing the digested foods by which it is surrounded. It grows and as it grows it produces more and more segments filled to bursting with eggs ready to hatch into new larvae. These segments break off and leave the body with the excretions. If the parasites are then eaten by a pig, they bore through its intestinal tract into the muscles. From this infected pig they may in time again reach man. While in man's digestive tract, the worm uses up the food needed by the host. This may be a considerable amount of food, for the tapeworm is large; it may grow to a length of twenty feet. Tapeworms do only slight damage to the intestinal wall, and a person may live for some time without even being aware of the parasite. They are easy to get rid of with drugs. To keep from getting a tapeworm, you should see that pork and beef are thoroughly cooked. Community help is needed in providing for education and proper meat inspection.

A new science. The scientific study of epidemics (epidemiology) is a new science. In laboratories in London, New York, and elsewhere, research workers are trying to answer many puzzling questions through experiments. They are beginning to arrive at answers by studying the spread of experimentally started epidemics among mice and other animals raised in the laboratory. This kind of study promises to give results. But in this new science, as in all science, progress is far more rapid when planning and research is centralized in properly equipped laboratories. It will be worthwhile for you to summarize what you have learned from the study of this problem by doing EXERCISE 10.

QUESTIONS

1. Why were epidemics more common and more severe formerly than now?
2. Which factors of the environment have long been known to increase communicable diseases? What was needed before this connection could be definitely established? What is meant by sanitation? Who is responsible for proper sanitation in the Federal government? Who in the local community? How does quarantine differ from isolation? What two facts must be known about a germ before the spread of a communicable disease can be stopped?
3. Name three diseases that may be spread by a polluted water supply. In what ways does a community protect itself against such disease? Name two methods by which a community can obtain pure water.
4. Give several reasons why milk may contain dangerous pathogenic germs. Explain how milk is treated in pasteurization and what effect this has on the germs it contains.
5. What is a carrier? In which two ways may you become a carrier?
6. By what four or five methods can a medical officer help to keep germs from passing from a carrier (or diseased person) to a well person? Discuss the danger of raw shellfish, uncovered food, flies, meat which has not been inspected.
7. How can the community protect itself against germs of respiratory diseases?
8. What is the carrier in these diseases: bubonic plague, typhus, yellow fever, African sleeping sickness, malaria? To which group of animals do all these carriers belong? Explain how bubonic plague is spread and how we keep it from entering our country.
9. Give facts and figures to show the importance of malaria.
10. Explain how the cause of malaria was discovered by the combined work of Laveran, Manson, and Ross. How was the connection between the malaria mosquito and the protozoan definitely established?
11. What are the two hosts of the malaria protozoan? Describe its life history in the human host and explain how it affects the host.
12. Describe the protozoan's life history in the mosquito.
13. What is the cause and what is the carrier of yellow fever? Describe the experiments which proved this to be true.

14. Describe the four stages in the life history of the mosquito. What are three methods of exterminating mosquitoes?
15. Explain why mosquito extermination has not proved as successful in stamping out yellow fever as was at first hoped.
16. Besides the microorganisms, what other group of organisms cause disease? What are the two ways of fighting these diseases?
17. Describe the appearance of the hookworm. Tell how it enters the body, by what route it travels through the body, and what harm it does. How is it spread to the next victim? What measures are being taken in our country to stop the disease?
18. How do we get trichinosis? Where in us does the worm settle? How may the disease be avoided?
19. Describe the appearance and habits of the tapeworm. In which animals do the larval (young) stages of the tapeworm live? How does the worm leave the host?
20. Why can we hope soon to know more about the spread of disease and about epidemics?

Exercises

1. What are some of the functions of a health department? List as many of the functions as you can think of. Glancing through paragraph titles in this problem may suggest some that have not occurred to you. Reports prepared by different individuals or committees can then be read to the whole class.

2. (*a*) Why does drinking water carry the germs of intestinal diseases but rarely carry diphtheria germs? (*b*) Towns sometimes pipe sewage to the ocean near oyster beds. Explain why this is dangerous to the health of persons both in the town and in other places.

3. (*a*) How could there have been any cases of typhoid in Albany after the water was filtered? (*b*) How can you explain the fact that oysters, celery, lettuce, and ice cream may sometimes be the means of spreading the germs of typhoid fever? (*c*) Since typhoid germs cannot form spores what advice was probably given the people of Albany before the water was filtered?

4. Using a sterile dropper, dilute a little pasteurized milk with about 10 times the amount of sterile distilled water in a sterile test tube. Shake well. Spread several drops over the surface of a sterile Petri dish containing nutrient agar. Using a second Petri dish, repeat, using milk that was opened for use a day or two ago. Put several drops of distilled water on a third as a further control. Place the dishes in a warm place. Examine after 48 hours. Take careful notes. What have you learned?

5. Scientific discoveries are often the work of many workers. Show how the discovery of the cause of malaria was international. Discuss two other examples of scientific discoveries that were built on the work of others.

6. You now know that (*a*) malaria is caused by a protozoan carried by mosquitoes, and (*b*) mosquitoes breed in swamps. Outline the experiments that must have been performed to prove that malaria can be acquired only by the bite of a mosquito and not by "bad air."

7. Study the diagram, Figure 310. It shows a mosquito injecting a parasite into the human blood. How did this mosquito get parasites into its body in the first place? Under what conditions would it not have injected parasites? We speak of the mosquito as the carrier. If the mosquito could tell the story how would the story differ?

8. The mosquito's life is short. How does the protozoan profit by spending part of its life in man? How does the protozoan profit by using the mosquito as the second host?

9. Draw an outline diagram of the human body, indicating the chief organs. By the use of arrows, show on your drawing the parts through which the hookworm parasite passes.

10. List in a column the following common practices of a health department: isolation, control of water supply, sewage disposal, pasteurization of milk, food protection, food inspection, control of carriers, restaurant inspection, mosquito extermination, rat extermination, public education. Next to each, write the name of the disease (from the list given below) which should be controlled by this method. Remember that some diseases must be controlled in several ways. Bubonic plague, typhoid fever, diphtheria, malaria, cholera, tuberculosis, yellow fever, hookworm disease, smallpox, septic sore throat, trichinosis.

Further Activities in Biology

1. Visit a large food market. Report on the precautions that are taken in the handling of food. Can you suggest any practicable improvements?

2. Visit a large milk distributing plant in your city. Note particularly the steps taken to prevent contamination of the milk. If you live in the country, visit a farm that supplies milk to your neighborhood. What precautions do they take to keep the milk pure?

3. Are you sure that the water supply in your home is pure? What are the possible sources of contamination? Investigate and report.

4. How is sewage disposed of in your community? Is it likely to contaminate the water supply? The bathing beaches?

5. Capture a housefly and let it walk across a sterile agar plate. Put the plate away in a warm place for a few days. What do you discover?

6. You will find Surgeon General Gorgas' account of his work in Cuba interesting reading. And if you can get a copy of the *Scientific Monthly* for the year 1915 published by the American Association for the Advancement of Science, read *The Inside History of a Great Medical Discovery* by A. Agramonte. Read also Defoe's *The History of the Plague.* Prepare a report to be read in class on Zinsser's *Rats, Lice and History.*

PROBLEM 5 *How May We Achieve Better Health for All?*

The average length of life. It is believed that in the 16th century the average length of life in Europe was only about 19 years. By referring to Figure 315 you can see that ever since then there has been a gradual increase in average length of life. Of course, in the 16th century a great many people lived to be much older than 19 years. A very large number died in infancy and in childhood, which brought the average down to such a low figure.

The first large-scale steps taken to lengthen life were in the direction of improving the environment. You read of them in the last problem. Then in this century came the startling advances in bacteriology; these resulted in a sensational reduction of deaths from infectious diseases. And besides all this the gradual raising of the standard of living, higher wages, better food, better housing, more leisure, and greater security are helping to cut down the death rate.

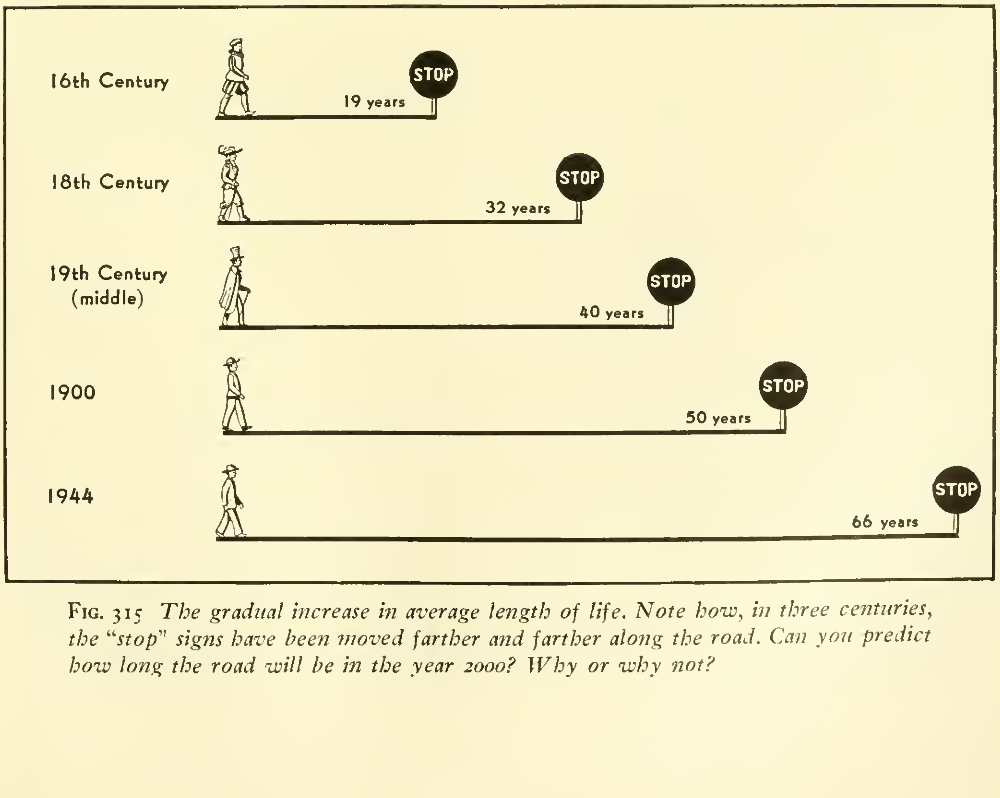


FIG. 315 *The gradual increase in average length of life. Note how, in three centuries, the "stop" signs have been moved farther and farther along the road. Can you predict how long the road will be in the year 2000? Why or why not?*

But we cannot expect to cut down the annual death rate indefinitely by doing more of the same and doing it better. New problems have arisen. Let us see what these are.

The most frequent causes of death. As you examine Figure 316, it may startle you to see that heart and other circulatory ailments and cancer have a far higher death rate than any other disease. You will notice that far more people die of *organic* diseases than of bacterial diseases. Fifty years ago organic diseases caused a much lower percentage of deaths. In those days fewer people lived to middle age; they died before there was likelihood of their developing an organic disease such as cancer or heart or kidney disease, which usually strike in old or middle age.

Is cancer on the increase? You have just read one reason why cancer seems to be on the increase. Then, too, we hear more about cancer now because so much has been learned about the disease that it is now recognized where formerly it was not correctly diagnosed. And people are no longer afraid or ashamed to speak of it, so, of course, we hear more about it. Many people today are wise enough to consult a physician when their suspicions are first aroused. This will result in many more cures, since many forms of cancer can be cured if treatments are begun early.

What is cancer? Cancer was a mysterious disease before the days of good microscopes and tissue cultures. When a person develops a cancer it means that some tissue cells in a part of the body grow and multiply without stopping, forming a lump or tumor. But you must not get the idea that all lumps or tumors are cancers; far from it. Many, perhaps most, are growths that are not dangerous because they remain in one spot and can

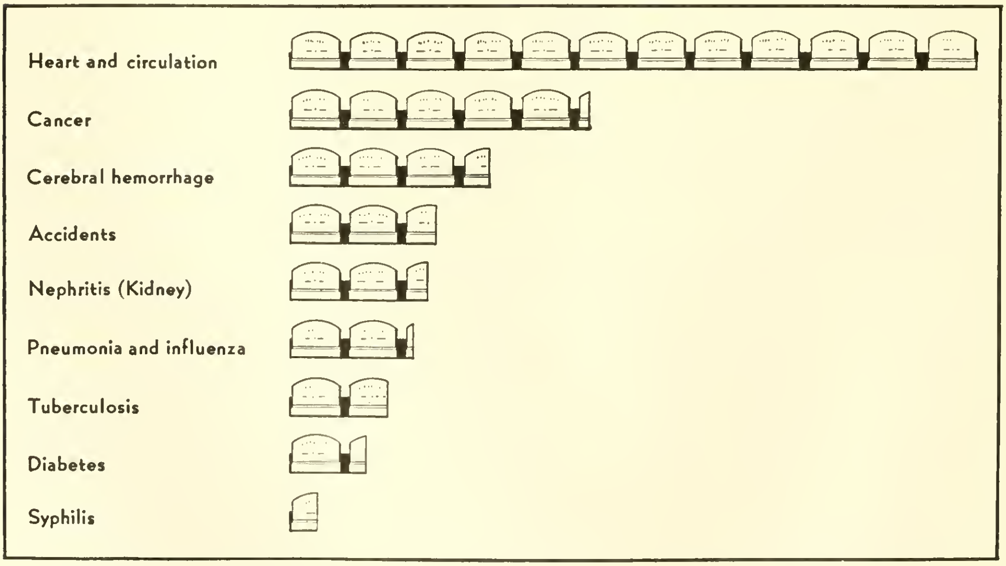


FIG. 316 *Causes of death among the Metropolitan Life Insurance Company policy holders during 1945. Each tombstone represents 20 deaths for every 100,000 people.*

be easily removed. A cancer is a growth that starts in one place and spreads to other parts of the body, where other growths develop. It does this because some of the cells of the original growth break off and are carried about the body by blood or lymph. Once it has spread far there is not much to be done about it. This is why an early diagnosis and early treatment are so important.

The abnormal growth of cells may occur in any organ or any tissue. No one really knows why certain cells run wild in this way. Cancer seems not to be caused by a germ or virus; it is not, therefore, a communicable disease. Furthermore, we know that the tendency to form cancer in man is so indirectly inherited that heredity of cancer need not be a source of worry to any person.* In recent years considerable evidence has been accumulating that cancer may be in some way connected with vitamins, hormones, or enzymes in the body.

When and where we should be on the alert. Sometimes the lack of definite symptoms in the early stages causes cancer to be overlooked by the patient. But lumps or unusual bleeding should always be looked on with suspicion. So should moles on the skin be watched, especially when they tend to grow. It is not safe for you to treat moles except under the direction of a competent physician. Cancers of the skin are not uncommon but fortunately are not serious if treated the correct way. Cancer of the lip seems to be brought on sometimes by excessive smoking; in fact, there is evidence that continued irritation of any kind in one region may start up the growth and multiplication of the tissue cells. In certain industries, the workers, unless properly protected, seem to be affected by irritating substances. This is true of people who work with dyes, tar, luminous paint, or a variety of other substances.

Treatment of cancer. Surgery, in which the cancerous tissues are removed, is commonly used for certain kinds of cancer. Other kinds may be treated with x-rays which, in the proper dosage, kill the cancerous cells but not the healthy ones. Radium, which gives off rays similar to x-rays, can be used to treat some internal cancers by placing it in a capsule near the cancer cells. The giving off of rays is called radioactivity. Recently it has become possible to make radioactive such ordinary nonradioactive elements as phosphorus and calcium. Radioactive phosphorus has been used for some kinds of skin cancer and radioactive calcium has been tried in healing cancer of bone. Much research is now being done, and well-trained young men and women are needed to carry on the work. Education, too, is an important part of the fight against cancer. People must be persuaded to have a regular physical check-up once a year and in this all of us can help and all of us must assume responsibility.

Circulatory diseases. Diseases of the circulatory organs cause even more deaths than cancer. As many people reach middle age, the heart muscle begins to weaken. The weakening may be very slow and if so, less strenuous exercise to prevent overwork of the heart is all that is needed.

* Little, C. C. *The Fight on Cancer.* Public Affairs pamphlet, 1941.

Sometimes the valves fail to close tightly. Leaking valves indirectly cause the heart to work harder than normally and vigorous exercise then strains it unduly. Scarlet fever, rheumatic fever, and other infectious diseases sometimes leave the heart in a weakened condition. This condition may be outgrown when the disease occurs in childhood.

Accidents. Look again at the table on page 360. Accidents must be classed as one of the principal causes of death. In general they occur in and about the home. Automobiles come next as the cause of accidents. Accidents suffered by men and women in industry are less common and yet, all too common. The number of such accidents has been much reduced and can be still further reduced when employers and labor unions join in demanding and using every possible safety device.

Among children of school age accidents cause more than one fourth of all deaths. The five principal causes of death from disease among children in this country are influenza, pneumonia, rheumatic fever, tuberculosis, and appendicitis. All five of these combined take fewer lives than accidents. Most accidents are avoidable; many of them are the result of carelessness of one kind or another. See EXERCISE 1.

Appendicitis. Appendicitis, or inflammation of the appendix, is caused by bacteria but it is not a disease which you can catch from someone else. Bacteria attack the wall of the appendix, thus causing it to swell. As the inflammation increases there is pain, usually but not always in the region of the appendix (lower right abdominal region). Any abdominal pain, therefore, especially if it occurs repeatedly, may be an indication of appendicitis. This is particularly true of young people of high school age, in whom appendicitis is most likely to occur.

Rest and ice packs are the best treatment. Hot pads and laxatives must be avoided. A doctor should be consulted if the pain lasts for more than a few hours. The physician may then take a blood count, for with any serious infection the white blood cells increase two- or threefold very rapidly. He may recommend an operation. Waiting too long may result in the bursting of the appendix and the spreading of the infection to the lining of the abdominal cavity (*peritonitis*). If attacks are frequent even though mild an "interval" operation may be advisable to prevent a more serious attack and to keep pus from being added to the blood. A serious attack could almost always be avoided if everyone knew the common symptoms and knew what not to do.

Better health is needed. Our life expectancy has increased to an astonishing degree in the last fifty years. There is still much to be done about keeping all of us in good health at all times. Among nine million men examined for the armed forces during World War II, 43 out of every 100 were found physically or mentally unfit. Reasons for rejection are indicated in Figure 318.

Figures from industry, too, show a great deal of absence due to illness. The United States Public Health Service reports that during the year 1943 the number of eight-day absences among men because of illness and accidents which

DEDICATED: TO THE SAFE AND HAPPY FAMILY

Check "Yes" or "No"	*Yes*	*No*
Have all small rugs been tacked down or "skid-proofed," and stair coverings securely fastened?	☐	☐
Are windows safely screened or barred to prevent children from falling through?	☐	☐
Do you carry loads so large you can't see what is ahead of you?	☐	☐
Do you ALWAYS use something strong and steady like a firm stepladder instead of a box when reaching for high places?	☐	☐
Do you wipe up spilled liquids or grease right away?	☐	☐
Do the smokers of your family smoke in bed or when dozing in a chair?	☐	☐
When using the oven or broiler, do you stand to one side to light the burners?	☐	☐
Are inflammables like benzene, naphtha and gasoline used and kept in your home?	☐	☐
Do you keep matches in a covered metal container where children cannot reach them?	☐	☐
Are poisons like lye, insect sprays and disinfectants kept high on shelves where children cannot reach them?	☐	☐
Do you always read the label on a box or bottle before using the contents?	☐	☐
Do you keep knives in a wall rack or in a special place in a drawer where they may not expose you to cuts?	☐	☐
Would you touch an electric switch or appliance when any part of the body is wet?	☐	☐
Do you keep electric cords in good repair – throwing away those that cannot be fixed?	☐	☐
Is it safe to put a young baby to sleep in a bed with a pillow and without pinning the covers securely?	☐	☐
Are objects and toys small enough to be swallowed, safe playthings for young children?	☐	☐
Is a window kept opened slightly while a gas or kerosene heater is in use?	☐	☐
Are boxes and objects placed on shelves so that they will not fall off?	☐	☐
Do you know the location of the nearest fire alarm box, and the correct way to call the Fire Department?	☐	☐

FIG. 317 *The Board of Education of New York City, together with the Greater New York Safety Council, Inc. and the Safety Bureau of the Police Department, issues this blank to all school children. Of how many careless practices are you guilty?*

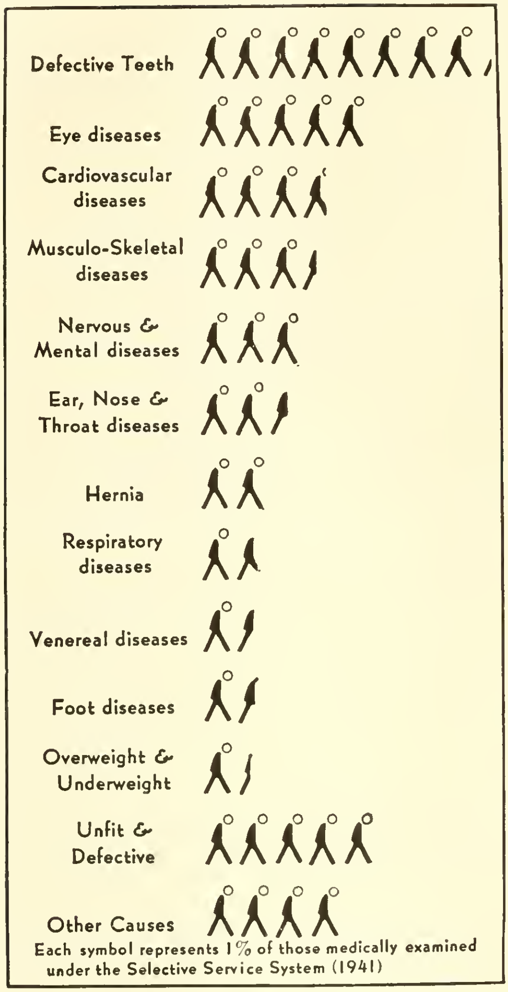


FIG. 318 *Causes of rejection of draftees during World War II. How many causes for rejection are indicated? What caused the most rejections?*

occurred while off the job, was 138 per 1000. Reducing the amount of illness is a major problem for public health agencies. It is a major problem, too, for each one of us.

Other ailments. *Malnutrition* due to the lack of sufficient vitamins, minerals, or other food compounds is still far too common even among people who can afford the very best food. Malnutrition makes the body susceptible to diseases and is the cause of much discomfort and lack of vigor.

The tonsils, the teeth, and the sinuses (cavities in the bones of the head) may all be infected by bacteria. Pus is formed at these infected spots and both toxins and bacteria may spread from that point through the body. Sinusitis, or infection of the membranes lining the cavities, is difficult to cure. But infected tonsils can be removed and teeth with infected roots can be treated or pulled.

Colds are responsible for the greatest loss of time by workers. The common cold is caused by one of many viruses. Since it seems to be almost impossible to avoid coming in contact with these viruses we must depend on building up sufficient resistance to them. Cold vaccines thus far have proved of little help in preventing colds.

We hear a great deal these days about *allergies*. You may be allergic to any one of a large number of substances. That means that you are unusually sensitive to that substance. An allergy may cause running of the nose, watering of the eyes, a cough, a skin rash, an itch, diarrhea, asthma, or some other reaction which usually comes on rapidly. It may be mild and pass off quickly or be very violent and lasting. Sometimes an allergy becomes less troublesome as the person gets older.

Hay fever is the result of an allergy. It is caused by plant pollen. The plant responsible for the worst form of hay fever is ragweed, which begins to produce its pollen about the middle of August. Ragweed is common along roads, around cultivated fields, and in city lots in many

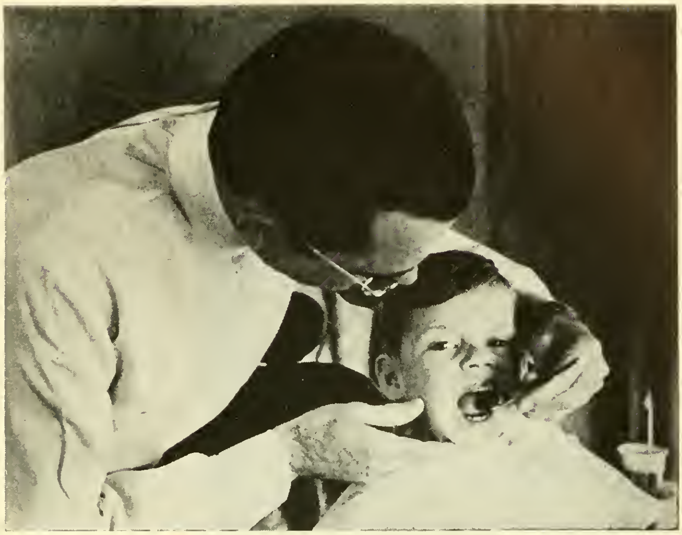


FIG. 319 *A dentist is checking this boy's teeth. An infected tooth may often have consequences more serious than a toothache. Why?* (HYGEIA)

FIG. 320 *This patient is being tested to discover the cause of her allergy. What might be in the many bottles in the background? The doctor can later judge from the appearance of the skin to which substance she is allergic.* (PARKE, DAVIS AND CO.)

parts of the country. People may be allergic to the pollen of many plants. In the early spring it is usually the pollen of blooming trees, especially oak, elm, maple, birch, or hickory. In midsummer it is the pollen of grasses, such as timothy, red top, and others.

Foods cause allergies, and dust is frequently a cause. Other causes are feathers, fur of animals, and almost any substance which can be blown about in minute particles. By scratching small amounts of the suspected substance into the skin and watching the spot, doctors may succeed in discovering the cause of the allergy. Sometimes a doctor may inject the substance in increasing doses to help cure the trouble. Drugs also have been developed recently to relieve the symptoms of some allergies.

Tobacco and health. Professor Raymond Pearl of Johns Hopkins University some years ago gathered figures on the length of life of hundreds of heavy smokers, about an equal number of nonsmokers, and a somewhat larger number of

FIG. 321 *Common ragweed. How may this plant harm you?* (HUGH SPENCER)

moderate smokers. He discovered that a slightly smaller number of heavy smokers might be expected to reach the age of thirty-five than of the moderate smokers and nonsmokers. The difference in life expectancy is even more apparent at forty, and a considerably larger number of nonsmokers and moderate smokers than heavy smokers may expect to reach the age of sixty. He stated his conclusions in moderate and general terms: shortening of life seems to be associated with the smoking of tobacco and the amount of shortening increases with the amount of tobacco used. He did not say that moderate smoking makes people die at an earlier age. Scientists are not prepared to state just how or to what degree the normal body is affected by continued but moderate smoking.

The first effect of tobacco is to stimulate slightly. Taken in large amounts it has a number of marked effects. It contains a substance known as *nicotine*. When this is injected directly into the veins it is a very powerful poison. Inhaling fumes from a cigarette smoked to the end can put into your system 1 to 2 milligrams of nicotine. The fatal dose is 60 to 120 milligrams. Nicotine in a certain concentration in the blood causes an increase in blood pressure, a quickening of the heart beat, and an immediate drop in the temperature of the finger tips.

You probably know that people with serious circulatory diseases, with allergies, sinus trouble, or throat irritations are generally advised not to smoke. Athletes while in training may not smoke; smoking seems to make them short-winded. All these facts should make us think twice before we allow ourselves to acquire a habit which certainly cannot improve our health and which may at some time be injurious. It is easy to keep from acquiring the habit since there is never an immediate desire to smoke after the first trial.

Alcohol. It has been estimated that in the United States there are at least 70 million people who drink alcohol. Of these it is believed that there are about 2 million who sometimes drink to excess and at least half a million who are chronic alcoholics, that is, men and women who are unable to keep themselves from drinking to excess. Evidently, the problem of alcohol is a very important social problem. It was for this reason that the American Association for the Advancement of Science some years ago appointed a Commission to study all phases of the problem. The detailed findings cannot be given here. But this much seems to be clear: alcoholism often is a symptom or product of mental illness. The cause for the strong desire to drink is different in each individual and is not merely the result of moderate drinking. It has also been clearly shown that a chronic alcoholic, to be cured, must refrain from all drinking. Do EXERCISE 2.

Alcohol is absorbed from the stomach very quickly, particularly when the stomach is empty. As it circulates, a larger percentage is absorbed by brain tissue than by other tissues. It acts as an anaesthetic or depressant. It is not a stimulant except for a very short time immediately after being taken. Like other anaesthetics, it acts first on the centers which control thought and emotion. This is why those who drink have the mistaken idea that it acts as a stimulant. In time as more alcohol reaches the brain it affects the lower centers which control such vital activities as breathing. How much is needed to bring about marked changes in these various centers varies with the individual and even varies in the same individual at different times.

Now that the complexity of human behavior is better understood scientists are far more cautious about stating the effect of alcohol on behavior. But it has been demonstrated clearly that there is a relation between the use of alcohol and automobile accidents. The amount of alcohol in the blood of two groups of drivers was measured. One group included men who were not in accidents; the other group was made up of those who were responsible for accidents. In the nonaccident group very few of the drivers had alcohol in the blood. Alcohol was present in the blood of very many of those in the accident group.

Because of these investigations many communities suspend or cancel the driving license if a driver in an accident is shown to have been drinking. Good citizens who drive automobiles will, for their own safety as well as for the safety of others, refrain from driving an automobile after taking alcohol.

Mental health. Mental health is far more difficult to define or observe than physical health. When we observe the normal activities of a boy or girl of sound mental health we discover that his daily living includes work that must be done (school work, household duties), physical play (usually out of doors), a hobby, meeting with friends, engaging in family life in a home, occasional parties or outings, and also some "blues" or periods of boredom and mild unhappiness. This young person is clearly a happy person generally, with a feeling of increasing satisfaction in growing up. Such a person is able to accept the occasional defeats that everyone experiences without suffering from a continued feeling of depression. Together with this ability there goes a growing feeling of independence of thought and action, combined with a readiness to accept increasing responsibility.

It is not possible in a page or two to tell how one can achieve sound mental health. But a few simple rules for the individual will be useful to you.

1. Several times each week play out of doors at some game that you like and that brings you together with boys or girls of your own age.

2. Try out hobbies or learn about them until you can choose one of your own from which you get satisfaction. If

possible find a hobby that includes other persons, both boys and girls.

3. Develop friendships with boys and girls. Your joy in friendship will be great if you are thoughtful and generous and understanding with your friends.

4. Do your school work to the best of your ability; work hard at it so that you can get the satisfaction of knowing that you are doing your best in your most important job.

5. Try yourself out in a new field or in new tasks of increasing difficulty. You may fail from time to time but with each success you will have a new sense of power, of independence, and of maturity. This will help you achieve mental health.

Mental illness. An expert on mental illness is called a *psychiatrist* (sy-kye'a-trist). He is a physician, an M.D. You should distinguish between a psychiatrist and a psychologist. A psychologist is interested in the workings of the mind and in behavior in general. Psychologists are not physicians and, therefore, cannot treat mental illness, nor are they qualified, in general, to discover mental illness. There is much misunderstanding about mental illness; let us attempt to clear up some of it.

People frequently use the word *insanity* to describe severe mental illness. Since there are several kinds of severe mental illness psychiatrists prefer not to use the word insanity because it is not definite enough. Besides, most mental illness is not severe, and insanity is altogether the wrong word for such conditions. Psychiatrists believe a great deal of mental illness is a result of emotional disturbance and they use the word neurosis to describe it.

Of course, the only sensible action to take if you or any member of your family seems to suffer from an emotional disturbance that is long continued is to visit a psychiatrist for diagnosis. Since this is an illness it needs medical attention. Sensible people no longer have the foolish attitude that mental illness is something to be ashamed of. No one is ashamed of having heart disease or appendicitis; no informed person, nowadays, is ashamed of having a mental illness.

You have probably heard people comment on the fact that someone is insane because he inherited insanity from one of his parents or grandparents. When you study heredity you will understand that heredity is so complex that such statements cannot be accurate.

Common worries of young people. It is quite common for young people to be concerned about their mental health. Usually, their concern is unfounded. Well-informed parents, teachers and pastors can do much to relieve this anxiety. The "bull session" in which boys or girls exchange confidences often serves a useful purpose in convincing them that their "difficulties" are normal and usual. They can often learn, also, how other people have overcome these difficulties.

It is quite common also for young people to worry unnecessarily about daydreaming. All of us daydream, especially when we are young. There are times when it is particularly satisfying to think of ourselves as most handsome, bright, charming, rich, and successful. We may think of ourselves as great heroes or as saints suffering great wrongs. We often do so after we have failed in

FIG. 322 *New York Hospital, New York City. Here people are treated for mental and physical illnesses in comfortable, pleasant surroundings.* (THE SOCIETY OF THE NEW YORK HOSPITAL)

some respect or received a rebuff. In general, daydreaming is undesirable only when it interferes with the activities necessary to successful living.

Often young people are sensitive about variations in physical structure, being too short or too tall, too stout or too thin. They fail to realize that they are quite normal even though they are not "average." The normal has so wide a range that you may assume that you are normal.

It is important to remember that mental illness is like physical illness, in that only a qualified specialist can diagnose or treat it. For this reason you must never hesitate to consult a psychiatrist for diagnosis and advice. But, in general, you need not worry about your mental health; most people are mentally healthy.

Education and health. Public education both in and out of school has helped improve the health of many thousands of people. People have been taught the dangers of syphilis and gonorrhea; they have learned to use only pasteurized or specially certified milk and how to exclude bacteria. Education has been of particular help in lowering the death rate of infants. Mothers now generally seek medical advice before the baby is born and obtain advice on infant care. In Cincinnati, for example, the death rate of infants per 1000 births at the beginning of this century varied from 155–200. Since 1940 the figure is 25–50 per 1000 births. The United States compares favorably with other countries in saving infant lives, but it does not stand first. More improvement is needed.

Health a social problem. The statement that health is a social problem means that no single individual is capable of maintaining good health without the aid of all other individuals. The organisms that cause disease know of no community, state, or national boundaries, especially in these days of rapid and extensive travel. Thus health has become a national and international problem. Every state and all large cities have health organizations. The United States has a Public Health Service and the United Nations organization has the World Health Organization to serve as a center of information on world medical development and as a center for research. See Exercise 3.

There is another important way in which health is a social problem. It has long been known that poverty and bad health go together. The disease rate is far higher among low income groups than among high income groups. In 1934 in 10 states, for the age group of 25–44, the number of cases of illness per 1000 in the various types of occupations was as follows:

Professionals	28.6
Clerks	67.6
Skilled workers	69
Unskilled workers	193.5

It was believed by many people that both the poverty and the bad health were the result of bad heredity. But studies made in the United States after 1929 showed that illness increased whenever income fell below a certain level. In general, poor housing, poor food, inadequate clothing, and worry produced illness. Evidently a long-range attack on the social problem of poverty is necessary before the problems of illness and disease can be solved.

Questions

1. How has the average length of life changed in the last three hundred years? In the last half century? State three factors that produced this change.
2. What are the three most frequent causes of death today?
3. Why does the cancer rate seem to have risen in recent years? Why do we hear so much more about cancer now than formerly?
4. What is cancer? How does cancer differ from the less harmful types of tumors? Is it communicable? Is it hereditary?
5. What are some of the symptoms that may indicate the presence of cancer? What are some of the factors that may cause cancer to develop?
6. What is a recent treatment for skin cancer? In what three other ways is cancer treated? How may each one of us help in the war against cancer?
7. In what two respects may the heart be deficient?
8. What is the relative importance of accidents and disease as a cause of death? State a half dozen or more important safety rules.

9. What is appendicitis? What is the only safe thing to do for abdominal pain? Why is a burst appendix so dangerous?
10. Why is inadequate health a major problem for the city, state, and nation?
11. Name and describe four "minor" but important ailments.
12. State some important facts about the use of tobacco. Describe the effects of nicotine. What are the objections to the use of tobacco by young men and women?
13. Of what importance is the alcohol problem? What effects is alcohol definitely known to have? What relation has been found between the use of alcohol and automobile accidents?
14. What are the normal activities of the young person who has good mental health? Can you name other similar activities? State five rules for maintaining sound mental health.
15. What word is used to describe a great many cases of mental illness? What change in attitude is there toward mental illnesses?
16. What is recommended for young people who are concerned about their mental health? To what extent is there reason for their worries?
17. Explain how education has helped to promote good health. What agencies assist in this education?
18. Why is the health of any individual really a social problem? How do we know that poverty produces ill health?

Exercises

1. Divide the class into committees to study accidents and their causes. Separate committees might study automobile accidents, playground accidents, accidents at home, accidents in the school shop, etc. Your study can be summarized by listing your recommendations for avoiding accidents.

2. Find out all you can about Alcoholics Anonymous, an organization devoted to helping chronic alcoholics. Report your findings to the class.

3. Divide the class into committees to find out and report on the activities of the various organizations that are engaged in public health education. What kind of teaching does each do?

In UNIT VII you will consider these problems:

PROBLEM 1. What Makes Possible the Continued Existence of Plants and Animals?

PROBLEM 2. What Are Our Relationships to Other Organisms?

PROBLEM 3. How Do We Try to Solve Our Insect Problems?

PROBLEM 4. Why Must We Practice Conservation?

UNIT VII HOW LIVING THINGS AFFECT ONE ANOTHER

FIG. 323 *Trout fishing in Colorado. This photograph shows one of the relationships of man to other animals. Can you think of some of the relationships of the trout to other animals and plants in the stream and alongside it? What might man do, besides fishing, to change some of these relationships?* (AULTMAN STUDIO)

PROBLEM 1 *What Makes Possible the Continued Existence of Plants and Animals?*

Food chains. When you study the activities of organisms, you find that living things affect one another constantly. In one way or another all kinds of organisms become the food of other organisms, either while they are alive or after their death. Lions eat antelopes; antelopes eat green plants. A hawk may eat a kingbird which had eaten ladybird beetles which had fed on scale insects which got their food by sucking the cell contents from an orange tree. These are examples of what may be called food chains.

Similar food chains exist in the sea. In the surface waters of the ocean there are microscopic green plants known as diatoms. They are present in countless numbers. Darting through the same waters are water fleas and tiny crustacea which eat the diatoms. The small water fleas serve as food for shrimp or small fish, which in turn make good eating for the hungry herring or the mackerel. These are caught and eaten by men.

The organisms at the beginning of the food chain are usually smaller but much more numerous than those at the end. While ten shrimp may make a good meal for a herring, it takes many more water fleas to feed even one shrimp, and countless diatoms to feed one water flea. Furthermore, the food chain, whether it has few or many links, has a green plant at the beginning, for green plants are the only organisms that manufacture food. This must be true of every food chain. Animals do not manufacture food; they only consume it. Try now to do EXERCISE 1.

Special relationships. In many food chains an animal that is larger or fiercer preys on a smaller animal, but sometimes a smaller organism fastens itself to a larger one and feeds on its living tissues. You have read before that this relationship is called parasitism. The parasite feeds on the host. You know that man is a host to many kinds of animal and plant parasites, such as worms, protozoa, the fungi which cause athlete's foot and ringworm, and many species of bacteria. All animals are hosts to a variety of parasites. Plants, too, are hosts to many kinds of bacteria and molds or even to larger plants. See Figure 324. Parasitism is a very common relationship. Sometimes the parasite lives within the host over a long period of time, but sometimes it kills its host quickly; by so doing the parasite ends its own food supply and dies of starvation unless it can move to another host. To see some parasites that may be found in various organs of animals, do EXERCISE 2.

FIG. 324 *A plant parasite, dodder, on goldenrod. Special roots enter the host. How can dodder live without making chlorophyll?* (BLAKISTON)

FIG. 325 *The Indian pipe is a saprophytic seed plant. It does not make chlorophyll. Most saprophytes belong to the group called fungi.* (HUGH SPENCER)

There is another special relationship between organisms. Some plants live on dead organisms, getting their food from the dead tissue cells. They are called *saprophytes* (sap′-row-fites). Saprophytes are always plants, usually fungi of some sort, either bacteria, yeasts, molds, or mushrooms. A few seed plants are saprophytes. See Figure 325. These saprophytes lack chlorophyll and, therefore, are unable to manufacture food as green plants do. Their method of nutrition is called *saprophytism* (sap′-row-fight-ism).

A relationship of benefit to both organisms. Certain protozoa spend their lives within the intestine of the termite; they need the food and the conditions supplied by the digestive tract of the termite. But they are not parasites. They aid the termite by digesting the wood on which it has fed. If the protozoa are removed, the termite dies of starvation in the midst of plenty. Certain species of bacteria live within the intestine of the horse, helping it by digesting part of the food the horse eats. Such a relationship of mutual helpfulness between the members of two species is called *symbiosis* (sim-bi-oh′sis). Two plants may live together, too, each aiding the other. A lichen (Figure 326) is really two plants, an alga and a fungus living in partnership. The alga makes the food used by both. The fungus helps hold the water needed by the alga for photosynthesis and by both organisms for growth.

Symbiosis is less common than parasitism. Sometimes, however, it is difficult

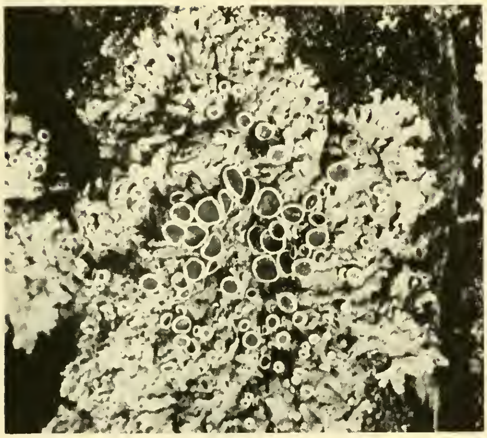


FIG. 326 *A common gray-green lichen, which grows flat on a rock. This lichen is a partnership between a fungus and an alga. What does each contribute to the other?* (HUGH SPENCER)

to determine whether a relationship is one of parasitism or symbiosis. If materials are available you will enjoy EXERCISE 3.

Food chains continue through the ages. Whether or not animals or plants live in special relationships of symbiosis or parasitism, they form a link in some food chain. A particular food chain in a given area may be broken but other relationships establish themselves; life has continued throughout the ages and still goes on. All food chains start with the manufacture of food in green plants. But can plants continue to exist? It would seem that they could because the compounds used by plants in food manufacture are probably as plentiful now as they were millions of years ago. We have every reason to believe that they will continue to be as plentiful.

Now the way to make a limited supply of anything last indefinitely is to keep it in constant circulation. By using it over and over again you can make a very little go a long way. This is true of money circulated from one person to the next. We keep our silver dollars in constant circulation. If someone kept them tied up we would soon run short of silver dollars. The same thing is true of the compounds used by plants. These compounds kept in constant circulation contain carbon, hydrogen, oxygen, nitrogen, and the other elements found in protoplasm. Let us see how these elements are kept in circulation.

How oxygen and hydrogen are kept in circulation. Whether they are green plants, nongreen plants, or animals, all living things use oxygen in respiration. In spite of this, oxygen does not disappear from the earth because oxygen is released when green plants produce sugar from carbon dioxide and water. The same oxygen is used over and over again.

Hydrogen is one element in water. In photosynthesis water is used and the hydrogen becomes tied up in sugar. This sugar, as you will recall, is used in making other sugars, starches, fats, and proteins. These compounds may be oxidized in the plant or may be eaten by animals and oxidized there. In either case they are changed into carbon dioxide and water. Thus hydrogen is used over and over. EXERCISE 4 will help you in reviewing these ideas.

How carbon is kept in circulation. You know that green plants use carbon dioxide in the making of sugars. From these they make starches, fats, proteins, cellulose, and other carbon compounds. If the plant is eaten by an animal, some of these compounds become part of the animal's body by assimilation, although most of the food which the animal eats is oxidized. Oxidation in both the plant and

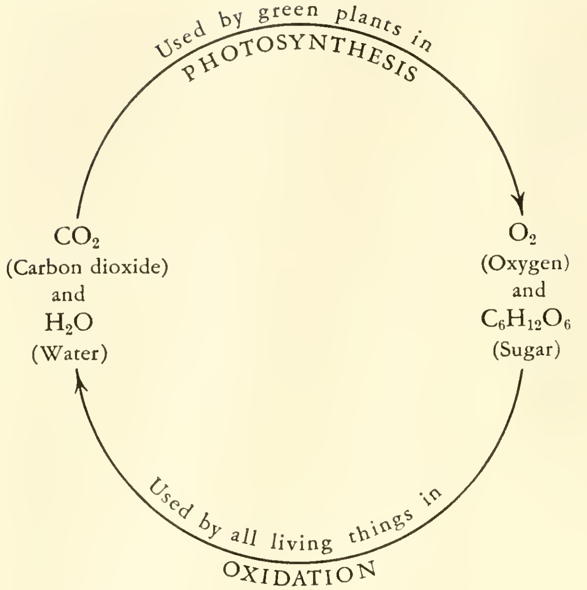


Fig. 327 *This diagram shows how hydrogen, oxygen, and carbon are kept in circulation by living things. Note that the carbon and hydrogen occur as compounds, not as elements. What two processes keep these elements in circulation? The amounts of oxygen, carbon dioxide, and water on the earth are affected by many other processes, in which living things do not play any part. Can you find out what they are?*

the animal produces carbon dioxide. Thus carbon dioxide is returned to the air which surrounds us.

Most plants, however, are not eaten by animals, and animals do not oxidize all the carbon compounds that they eat. This carbon does not remain "frozen" in the plants or animals. It, too, gets back into circulation when the organisms die. The organisms then decay. Various fungi and bacteria cause this decay. They oxidize the carbon to carbon dioxide.

Because of the organisms that cause decay, our planet is not piled deep with the dead bodies of plants and animals in which carbon is locked. And because of these bacteria, the same carbon atoms can be used again and again, thus never becoming exhausted. Try Exercise 5.

Of course, some carbon atoms are taken out of circulation for a fairly long period of time. For example, coal is carbon that was made from the trunks, leaves, and roots of plants many millions of years ago. By burning coal we put this carbon back into circulation.

The circulation of nitrogen. The circulation of nitrogen is somewhat more complicated. Green plants get nitrogen from simple compounds in the soil that contain nitrogen. Most plants can use only nitrates as a source of nitrogen. Others can also use ammonium compounds. Both types of compounds contain nitrogen. In the plant the nitrogen becomes a part of proteins. If the plant is eaten by an animal, some of the plant protein is changed into animal protein. Some is oxidized and nitrogenous material is returned to the soil in urea and other wastes eliminated by the animal. These wastes contain nitrogen in a form not usable by plants. Only a small proportion, however, of plant proteins are ever eaten by animals; they and the nitrogen they contain remain locked up in plants, sometimes for a long time. Thus nitrogen is continually being taken from

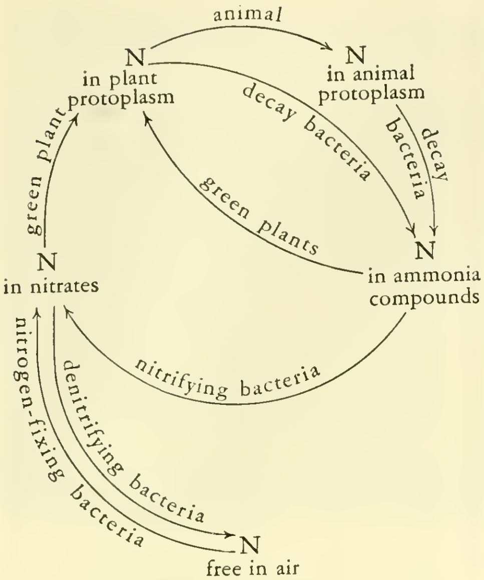


FIG. 328 *Find "N in nitrates" on the left and trace an atom of nitrogen through one complete cycle. Which organisms are involved in this cycle? How is free N produced?*

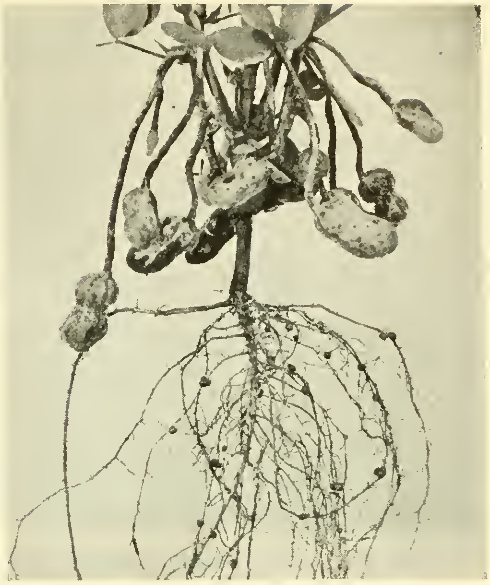


FIG. 329 *Roots and base of peanut plant. Nitrogen-fixing bacteria live in the nodules. How are legumes such as the peanut related to the nitrogen cycle?* (BROOKLYN BOTANIC GARDEN)

the soil and kept in plant proteins, in animal proteins, and in the nitrogenous wastes of animals. In all these forms nitrogen is useless to plants.

The nitrogen, however, is not locked up forever. The ammonium compounds and nitrates needed by green plants are restored to the soil by several groups of bacteria and larger fungi. One group is the decay organisms which form ammonia from the proteins and urea. The sharp odor from a decaying pile of compost or of manure is that of ammonia. Some of the ammonium compounds are used directly by green plants but large quantities of them are built up by another group of bacteria into nitrates. The *nitrifying* (ny'tri-fy-ing) bacteria do this. A careful study of Figure 328 will help you understand how nitrogen is kept in circulation.

Complications in the nitrogen cycle. Side by side with the nitrifying bacteria which build up nitrates in the soil are other species of bacteria known as *denitrifying* bacteria. Some of the denitrifying bacteria again break down some of the nitrates into ammonium compounds and others break down nitrates completely and form nitrogen gas, which then becomes a part of the air. The element nitrogen cannot be used by green plants in food-making, so nitrogen thus released is temporarily lost to green plants and thus to animals. This loss of nitrogen would be serious were it not for still another group of bacteria. These are the *nitrogen-fixing* bacteria of the soil. These bacteria use the gaseous nitrogen of the air and produce plant proteins, which may be changed to nitrates by the decay and nitrifying bacteria. Some of

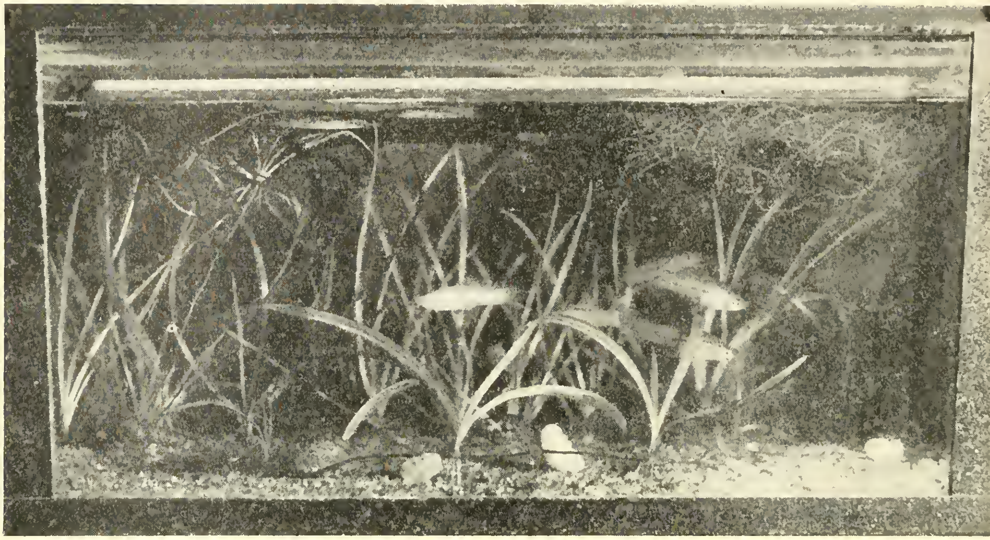


FIG. 330 *A balanced aquarium is a tiny world of living things. What kinds of animals do you see? What substances do they get from the plants? What substances do the plants get from the animals?* (SCHNEIDER)

the nitrogen-fixing bacteria live independently in the soil; others live in nodules (little growths) on the roots of certain plants, such as bean plants, pea plants, clover, alfalfa, and other members of the legume family. This is why planting clover or alfalfa or soybeans in a field helps to improve the field and produce a better crop of some other plant the next year. See Figures 328 and 329.

Nitrogen compounds are also added to the soil in another way – by the electric discharge called lightning. During thunderstorms quite a large quantity of nitrogen in the air is combined with oxygen. The compound is washed by rain into the soil where nitrates are formed.

By lightning and by the action of the nitrogen-fixing and nitrifying bacteria the supply of nitrates in the soil is kept rather constant under natural conditions. Now do EXERCISE 6.

The balanced aquarium. You can imitate in the laboratory, in a limited way, the conditions that occur on the whole earth, and thus you can review briefly what you have read. An aquarium is used for this purpose. In order that the aquarium may imitate conditions on the earth, which lies in space, it is necessary to isolate the aquarium, that is, to seal it. If now you set up an aquarium with green water plants, a few fish, and a few snails and seal it, you will find that the plants remain alive and so do the fish and the snails. You know the reasons for this. The animals and plants produce carbon dioxide by oxidizing food; as a result the green plants will have enough carbon dioxide for photosynthesis in which both sugar and oxygen are produced. The fish and snails will then have enough oxygen for their oxidation. If the proper fish are chosen they and the snails will eat the plants, thus making sure that the plants will not overcrowd the aquarium. In this way, too, the fish and snails get food. The fish and snails in the meantime excrete wastes containing nitrogen and other mineral elements. Then the bacteria, which are always present, change these wastes to nitrates and other mineral compounds. When just the proper number of green plants, fish, snails, and bacteria are included, the plants and animals will live for a long period of time without the addition or removal of anything. It is said then to be a *balanced aquarium*. In a balanced aquarium each important element is kept in circulation. In the same way on our planet the important elements are kept in circulation through the activities of bacteria, green plants, and animals. Thus the continued existence of all living things is made possible. See EXERCISE 7.

QUESTIONS

1. Give three examples of food chains. How do the organisms at and near the beginning of a food chain differ from those at or near the end?

2. Define parasite and saprophyte. Name some animals and some plants that live as parasites in or on you. Give examples of saprophytes.

3. How does symbiosis differ from parasitism? Give examples.

4. Which are the only animals in a food chain that do not eat other animals? Why have the earth materials used by plants not been exhausted up to this time? What important elements are present in the earth materials used by plants?

5. Explain how the oxygen supply on the earth depends on photosynthesis and oxidation. Explain how the element hydrogen in water may pass from plants to animals and back again to plants.

6. Describe a carbon cycle. What group of organisms is active in preventing carbon from being tied up indefinitely in the bodies of plants and animals? In what form has some carbon been kept out of circulation millions of years?

7. How does the plant use nitrates taken from the soil? How do the bacteria of decay enter into the nitrogen cycle? By what organisms are the simple ammonium compounds built up into nitrates again?

8. Contrast the work of denitrifying and nitrifying bacteria. In what form must nitrogen be to be of use to plants?

9. Describe the work of nitrogen-fixing bacteria. Where are they found? Explain how thunderstorms affect the nitrogen cycle.

10. Summarize briefly how the continued existence of plants and animals is made possible. Explain how a balanced aquarium imitates these conditions at least to a limited degree.

Exercises

1. Give other examples of food chains.

2. *Demonstration.* The frog and the butterfish are the victims of many parasites. Examine liver, lungs, and intestinal canal of a freshly killed frog or the teased out muscle of a butterfish for parasites. Describe what you find.

3. *Demonstration.* If green hydras are available they can be studied under the microscope. What makes the hydra green? What kind of relationship does this illustrate?

4. Draw an oxygen and hydrogen cycle without consulting the book. Or draw a different type of oxygen cycle.

5. (*a*) Draw a circle and by writing words and drawing pictures on it show how carbon may go from the air through the seeds of plants into a bird, and back again into the air. This is called a *carbon cycle.* (*b*) Show how carbon goes from the air into grass and into a pig where large amounts are stored.

6. (*a*) If you bought an old farm and the land was poor, what kinds of crops would you plant first? (*b*) Explain how the same bacteria of decay may be useful in one place and harmful in another.

7. Suppose a sealed balanced aquarium contained green plants, a small goldfish, a snail, decay bacteria, and nitrifying bacteria. Explain how the aquarium might remain in balance for many months. Be sure to use the carbon and oxygen cycle in your explanation. What might happen if the aquarium were to be placed in light that was too dim?

Further Activities in Biology

1. Are bacteria more numerous in sand or in humus (the dark top soil)? If you have Petri dishes, you can find out.

2. Start and maintain a balanced aquarium. Turtox leaflets should be of help.

3. If you draw well you could make interesting and original charts to illustrate the carbon, oxygen, and nitrogen cycles.

4. If you live near a farming section, find out what the farmers are doing to keep the necessary soil compounds from becoming exhausted.

5. Read up and report about commercial, large-scale nitrogen fixation.

6. Cut open and examine a nodule on a fresh leguminous plant. Use a microscope.

PROBLEM 2 *What Are Our Relationships to Other Organisms?*

The web of life. We have seen that living things are interdependent. Animals and nongreen plants could not live without the food made by green plants. Green plants continue to exist because of the organisms which bring about decay. So complicated are these interrelationships that one biologist has called the tangle the "web of life." And this web of life becomes even more complicated because of the relationships of organisms to all parts of their physical environment. This relationship of organisms to all parts of their environment, including other organisms, is a special field of biology called *ecology* (ee-kol'o-gee).

Relationships in small areas change constantly. If you look at any fairly small area of the earth, you soon discover that the numbers of individuals of a particular species constantly change. Sometimes the change is like a pendulum swinging in one direction and back again. In some years the northern woods are crowded with rabbits. As a result the lynx, which feeds on rabbits, begins to prosper. More of its offspring find food and survive, so that soon large numbers of lynxes feel the pinch of hunger. Some die of starvation and those that survive reproduce less plentifully. This gives rabbits an opportunity to increase again. The pendulum swings back and the cycle, in time, is repeated. In reality, in the tangled web of life, each swing of the rabbit-lynx pendulum affects many other organisms; these changes have not been described.

Changes of a different nature may also occur. About sixty years ago a farmer moved away from his farm in southern Ohio. Because the hilly farm was very poor, no one could be found even to try to raise crops on it and it was abandoned. Today, on one hillside field which was once a farm there is a grove of pine trees. First, there were weeds and grasses; then scattered shrubs and brambles which grew from seeds blown by the wind or carried by birds. Pine seeds, also, were blown in from a nearby grove. These seedlings grew more slowly but eventually grew taller than the other plants in the field. Some pines grew taller than others and, eventually, those in the shade, along with the shrubs and brambles, were killed by starvation because there was too little light for photosynthesis. The kinds of birds, small animals, and insects changed with the changing plants.

One could give many examples of changes in animal and plant populations. You may have noticed some examples yourselves. Ecologists through careful recording of facts can now predict approximately when some species will

FIG. 331 *Sheep are among our most useful animals. How are they useful to us? How may a large flock such as this change the environment?* (U. S. FOREST SERVICE)

increase or decrease. The changes take place without any interference from man. They are the results of changes that are brought about by the organisms themselves.

Man's relationships differ. Our population increases out of all proportion to that of other organisms. In recent years it has grown at the rate of 25,000,000 persons a year. This affects our relationships with other organisms. We destroy organisms and the pendulum does not swing back as in the rabbit-lynx relationship. Thus, problems are created for us, as you will read later in this unit. Our relationships, too, are complex and very numerous. We are not only a link in a food chain, but we make use of innumerable organisms in countless other ways.

Our use of animals. We are dependent on animals in many ways even in this age of machines. We use animals and their products for food. We make leather from skins; we use furs; we get wool for clothing and feathers or down for pillows and comforters; and we use hooves and horns to make glue. For ages we have used animals as beasts of burden. The list is long: horses, donkeys, oxen, dogs, elephants, llamas, camels, and others. But there is still another important use of animals: modern use of animals for the purpose of experimentation. The guinea pigs, white rats and mice, monkeys, dogs, and cats used by biologists and physicians have saved many millions of human lives.

And not least is the value of bees and other insects in cross-pollinating flowers. Without this many seeds would fail to develop, many plant species would become extinct. You can add to this list by doing EXERCISE 1.

Man and higher plants. Everything we eat unless it is animal food or salt comes from plants. We may eat the root, the stem, the leaves, the flower or the fruit with its seeds as vegetables. We use the seeds of certain plants such as wheat, rice, oats, barley, corn, and others as cereals or grains. They are concentrated foods containing little water and much nourish-

FIG. 332 *Fruits of the cotton plant. Three have burst open showing where the cotton grows. Why is cotton an important crop plant?* (U. S. DEPARTMENT OF AGRICULTURE)

ment. Some of them are rich in proteins and much cheaper than meats or fish. Plants also supply us with such minor foods as spices, sugar, tea, coffee, flavoring, and substances for making beer and other alcoholic liquors. Before reading further do EXERCISE 2.

The other uses of plants are many and important. Much of our clothing is made from cotton. From trees we obtain lumber, wood pulp for the manufacture of paper, firewood to heat homes and for cooking, and the raw materials for many manufactured products. One of the most important of these is rubber. From the forests we obtain also turpentine, rosin, tar, tannin for tanning leather, cork, and many other products. And from the forest trees that lived millions of years ago we get our coal. Some stems have fibers that are used for weaving linen (flax) or for making rope (jute, hemp, and others). Some supply us with drugs; quinine, for example, is extracted from the bark of the cinchona tree originally found in Peru. (You will find *The Fever Bark Tree* by M. L. Duran-Reynals interesting reading.)

How we use microorganisms. We think so often of microorganisms as causes of disease that we tend to forget how useful some of them are. You read in the last Problem of the bacteria and molds that restore nitrates to the soil and are useful in the carbon cycle. You have already learned that yeasts ferment sugar, changing sugar to alcohol and carbon dioxide. In breadmaking the carbon dioxide raises the dough, making the bread light. A special kind of yeast is used in this process. Other kinds of yeasts are used to produce alcohol. See EXERCISES 3 and 4. Some kinds are used in the brewing of beer where grains are acted on by yeasts; others in the fermenting of grapes to produce wines. Recently, too, yeasts have come into use for their vitamin content, and certain kinds of yeasts have been developed that contain very large percentages of protein, providing essential proteins at a smaller cost than meat.

Among other microorganisms that we use are the bacteria that give flavor to food, especially meat. Almost all meat is tough. One method of making it tender is to let it "hang" for a while. Frequently,

FIG. 333 *"Wheels" of Swiss cheese in a curing room. The distinctive holes and the distinctive flavor are due to bacteria.* (KRAFT FOODS COMPANY)

the tenderizing is done by bacteria which also give the meat a pleasant flavor. If the hanging is allowed to continue too long, we say the meat goes bad or decays. Some cheeses are the product of bacterial action on milk. Other cheeses are produced by the action of molds. Whether cheeses are made from cream, whole milk, or skim milk, particular microorganisms do the work.

Bacteria are also used in changing alcohol to vinegar, and in numerous other industries. Flax, jute, hemp, and other fibrous plants are "retted" (rotted) in water through bacterial action to separate fibers from the rest of the plant.

How do microorganisms harm us? You have already studied something of our relationship as hosts to the parasites called disease germs. Other microorganisms harm us in less spectacular but quite important ways. Curiously some of them are the same organisms that at times are helpful.

The bacteria and molds that make meat tender and that flavor cheese make both the meat and the milk unfit for food by decaying it, if their growth is not stopped soon enough. The decay microorganisms, which are helpful in changing dead plants into humus, are harmful when they decay wharf pilings, building timbers, and telephone poles. Yeasts which are very useful to us are also harmful when they spoil fruit.

We have long worked on the problem of keeping foods from decay. The Indians smoked and dried meats and fish. For hundreds of years meat which was to be used on long ocean voyages was packed in barrels of brine (strong salt water). And early in the seventeenth century Francis Bacon, long before bacteria were known, proved that cold preserves food. For a long time, too, vinegar, spices, and sugar have been used. If sufficiently concentrated, all act as mild antiseptics and preserve food. Sometimes

FIG. 334 *These tall stalks of mullein, a common weed, compete with tree seedlings at the edge of a forest. Why do we think of them as weeds?* (BROOKLYN BOTANIC GARDEN)

chemical preservatives such as benzoate of soda are used commercially. To protect us against the use of harmful chemicals the Food, Drug, and Cosmetic Act was passed. Heat is used in pasteurization and in canning. Extreme heat kills bacteria. If applied while food is in an airtight can, there will be no further bacterial action.

While we have learned much about food preservation, you know that there is a constant struggle to keep our foods from spoiling. We struggle, also, for the preservation of other articles. Against the decay of wood we use paint and such disinfectants as creosote. None of the methods thus far discovered is perfectly satisfactory and all take time and cost money. To review this paragraph do EXERCISE 5.

Weeds are harmful to us. Our desire to raise only the plants we choose makes us regard some plants as weeds. You probably know the ragweeds, tarweeds, bindweeds, tumbleweeds, thistles, and many other weeds. Why do we call them weeds?

A weed is best defined as a plant that is not wanted or a plant that is out of place. A corn plant is a weed if it is growing in a field of wheat. In general a weed is a plant that is prolific (reproduces in large numbers) and that is well fitted to grow in many environments. For these reasons weeds are so common in gardens and fields. Weeds may be edible and usable. Milkweed and purslane, two very common weeds in many parts of the country, are sometimes eaten. Since plants that are not wanted take useful minerals from the soil, they can cause serious financial loss to the farmer. The farmer spends large sums of money in labor and time to destroy the weeds that interfere with his desired crops. Do EXERCISE 6 to find out why the unwanted plants we call weeds are so common.

FIG. 335 *Smut is one of the parasites of corn. These balls each contain billions of spores.* (U. S. DEPARTMENT OF AGRICULTURE)

FIG. 336 *A white pine infected with blister rust. How can this disease be controlled?* (U. S. FOREST SERVICE)

Parasites on plants are harmful to us. Plants as well as animals are subject to disease. Their parasites are commonly viruses and molds; but they may be bacteria, roundworms, and insect larvae. Corn is frequently attacked by a fungus known as corn smut. You may have seen corn ears that consisted partly of a sooty black mass. Such a mass may also appear on the corn tassel or the stem. The black mass is a mass of spores which are very small and long-lived. They are easily blown about by wind. When one of the spores alights on a tender young part of a growing corn plant it begins to form threads (hyphae) which grow into the tissues of the corn plant, using the food made by the host. The threads in time produce a large mass which becomes black as spores are formed. The smut does little harm to the plant unless it appears in the ear, but this is where it frequently forms. Control of corn smut is very difficult.

Rusts are parasitic fungi that have caused great damage to plants. The white pine blister rust, which was brought to the United States from Europe in the early part of this century, killed many white pine trees throughout New England. The rust must spend part of its life in a second host, a wild gooseberry or currant bush. Spores are formed in the berry bush. These, when released, infect the pine. The spores formed there must find their way back to the gooseberry or currant. To save the pines, it is necessary to destroy wild gooseberry and currant plants.

Another serious fungus disease, called the Dutch elm disease, threatens to destroy the American elm trees so commonly planted along streets in many cities for shade and decoration. The fun-

FIG. 337 *A single tugboat cutting off the sun's rays. Which organisms might be affected by this smoke?* (SHERMAN)

gus kills the tree by killing the phloem tissues in the bark of the trunk and roots. This fungus was discovered in Holland in 1919. No one knows how it got there. In 1930 it was first reported in this country. It is believed that the fungus and two species of bark beetle which carry the fungus from tree to tree entered on logs imported from France. They spread rapidly. It is common for organisms that are imported to spread with great rapidity. The reason for this is clear. In their original environment there are usually natural enemies which keep the organism in check. When organisms are imported into a new environment there may be no natural enemies present, so they increase more rapidly than before.

Plant diseases are very common. Specialists all over the world are engaged in studying them, looking for both cause and cure. You can readily see that they are of great importance when they destroy plants that are valuable to us.

Civilization changes our relationships. As you have seen, our relationships to other living things are complex and far reaching. As civilization progresses we enter into new and different relationships with animals and plants. We domesticate some animals and cultivate some plants. As we travel from continent to continent we carry animals and plants with us. We cut down forests and plow the prairies. Where your city or town now stands there once was a forest or plain. Not only has the vegetation been destroyed but the birds and other animals that once lived there have moved away or died. Rats and roaches, on the other hand, have increased in numbers. In every city there are likely to be more rats than people. Wastes from our factories and sewage from our cities flow into streams and kill the plants that are the food of fish. A century ago the Hudson river and the Illinois river below Chicago were well stocked with fish. We are constantly changing our relationships with other organisms. Thus we create problems. You will read how we attempt to solve these problems.

QUESTIONS

1. Give some examples of interdependence. Define ecology.
2. Show how the relationships of animals and plants may change.
3. How do our relationships differ?

4. List the different ways in which other animals are useful to us.
5. Name various kinds of complex plants that are useful to us and state in which ways they are used.
6. Explain the use of yeast to us. Explain how bacteria and molds are used in flavoring foods and in other industries.
7. Besides causing disease, how are microorganisms harmful to us? List the ways we use to preserve foods and other materials against bacteria of decay.
8. What is a weed? Explain how weeds may cause a serious financial loss.
9. What kinds of organisms cause plant diseases? Describe each of three plant diseases, naming the plants affected. Why do imported organisms often spread rapidly?
10. Give examples of changes in our relationships which result from our civilization.

Exercises

1. Make your own list of the ways in which we use animals. Make the list specific; it can easily be made much longer than the list in the book.

2. Prepare a list of plants used by man and compare it with the list in the text. Perhaps members of the class can pool their lists.

3. If you have not already observed the process of fermentation add a pinch of yeast cake (from the grocery store) to a dilute solution of molasses or sugar in water. *Do not cork.* Why? After 12 or 24 hours taste and smell the mixture. What do you notice? Explain.

4. What is the gas produced in the mixture of sugar and yeast? A flask containing a yeast mixture four or five hours old should be closed with a one-hole rubber stopper. Lead a delivery tube through the hole in the stopper into a vial of limewater, making sure that the lower end of the tube is below the surface of the limewater. What do you see after about an hour? Explain.

5. Carefully study the labels on a variety of cans, jars, and bottles of food. State what you find.

6. Study five common weeds. What is there about the roots, the stems, the leaves, the fruits, or the seeds that makes them so hard to get rid of?

Further Activities in Biology

1. If you have a flower or a vegetable garden identify the worst weed offenders. Do your observations agree with those of your classmates?

2. Look through your list of titles of Farmer's Bulletins published by the United States Department of Agriculture and other bulletins and write for those that apply to this problem. Report to the class.

3. Posters giving information on plant diseases are sometimes displayed in post offices or other public places. Study these and report to the class. If you can draw well you might make some posters of your own.

PROBLEM 3 *How Do We Try to Solve Our Insect Problems?*

In what ways are insects harmful to us? There are more than 600,000 species of insects. A surprisingly large number of them affect us directly or indirectly. Some live as parasites on us and other animals. Some of them carry disease germs; they spread disease among domestic animals as well as among men. Some carry diseases such as blights and wilts from plant to plant, causing great losses in crops.

Some insects attack trees in the forest, along the roadside, or on city streets. They may strip them clean of foliage or destroy the wood or bark. The tree may die slowly or rapidly, depending on where the insect settles and on what it eats. The insects that attack trees probably cost us not less than 150 million dollars every year in the United States alone.

Some insects may destroy the wooden framework of our houses, the carpets on our floors, the paper on our walls, and the clothes in our closets. The losses caused in these ways are relatively small yet far from unimportant. But the insects that are of the greatest importance to us are those that attack our crops: plants standing in the field, and grains that have been gathered and stored.

We make an insect problem for ourselves. When farms were only a few patches surrounded by forest or prairie, insect damage was usually slight because natural enemies kept the population down. Now vast fields consisting of many thousands of acres are planted to a single crop. The nesting places of natural enemies are thus destroyed, and harmful insects often increase alarmingly. The history of the cotton boll weevil is an illustration. In Mexico, where cotton plants were raised in small patches here and there, this insect remained under control. But the southern farmers of the United States planted thousands of acres of their land to cotton, and the boll weevil which had migrated northward flourished and multiplied enormously. Each year more cotton was planted and the boll weevil pest grew worse. The large crops enabled the weevil to increase in number rapidly. This was especially true because its natural enemies were absent. Farmers thus create a problem which must be solved through ingenuity and at enormous costs.

Who suffers from the damage done by insects? Many species of insects do us grave damage by injuring our crops. The full extent of this damage is rarely appreciated by people who live in cities. And many city people fail to realize that

Fig. 338 *Many kinds of insects injure trees. A piece of bark has been raised to show the tunnels of the pine beetle. The eggs are laid in them. Why does this tunneling injure the tree?* (U. S. FOREST SERVICE)

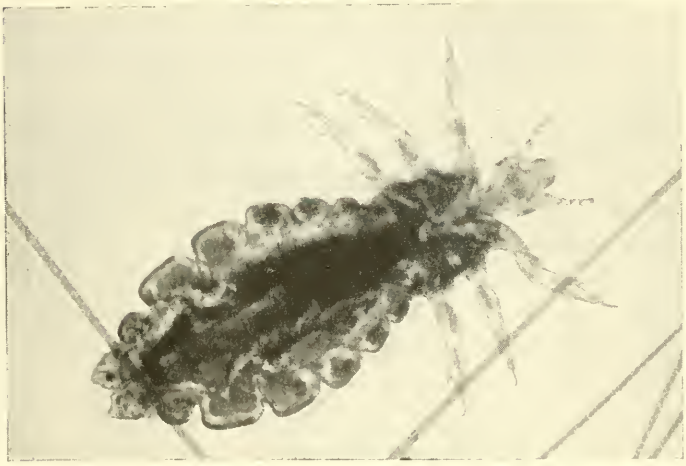


Fig. 339 *The human head louse. The lines are human hairs. Closely related species attack dogs, goats, and other animals, and do much harm.* (U. S. BUREAU OF ENTOMOLOGY)

Fig. 340 *The boll weevil lays its eggs in a cottonboll. See text, page 389.* (U. S. BUREAU OF ENTOMOLOGY)

such insects are as important to them as to the farmer. No matter where we live we all pay higher prices for many kinds of foods because of insect damage.

Most farmers know how this comes about. The city boy or girl ought to know, too, so that the farmer's problem may be understood by all. The farmer raises potatoes for sale in the market. He puts in a certain amount of labor on this acre of potatoes and spends money for fertilizer, farm implements, and so on. If the Colorado potato beetle injures

FIG. 341 *Larvae and adults of the Colorado potato beetle. How do such insects injure potatoes underground?* (U. S. DEPARTMENT OF AGRICULTURE)

his plants and reduces the size of the crop, the farmer receives less money per acre. Not only is the size of the crop reduced but the farmer has had added expense. He has been forced to buy chemicals and has had to devote much time and energy to fighting the insects in order that he might save at least some of his crop. The total cost of raising potatoes is therefore much greater because of the insect pests. The farmer receives a smaller profit and we all pay higher prices. Insects that destroy our crops in the United States cost us billions of dollars every year. The problem is so serious that one famous student of insects, Dr. L. O. Howard, in a book called *The Insect Menace*, considered whether or not the insects might defeat us in the long run.

What is our only hope of keeping insects down? Insects are so well adapted to all kinds of environments that they come into competition with us at every turn. Our one advantage over them is our brain. There are scientists all over the world devoting their lives to the study of insect problems. This branch of biology is called entomology (en-toe-mol'o-jee). Our government has established a Bureau of Entomology and Plant Quarantine at Washington as part of the Department of Agriculture. Dr. L. O. Howard was at one time chief of this bureau. He became interested in this work as a very young boy and began contributing original and important observations while still at school. Assisting in the work of the Bureau of Entomology are the Agricultural Experiment Stations in the various states. Insect control is one of their important functions.

In order to learn how to control a particular species of insect, a very thorough study must be made of its whole life history and its habits. We must know such things as which food it eats, how it obtains its food, exactly where and when its eggs are laid, and exactly where the young spend their lives before they become adults. We must also know its relations to other animals, particularly its natural enemies. Begin by reviewing what you have learned about insects by

FIG. 342 *Damage to corn, done by the larvae of the European corn borer. It does even greater damage in weakening the stalks.* (U. S. BUREAU OF ENTOMOLOGY)

FIG. 343 *Caterpillars of the gypsy moth moving up a tree. What stops their progress? How do gypsy moth caterpillars harm trees?* (U. S. DEPARTMENT OF AGRICULTURE)

doing EXERCISES 1 and 2. Then let us see how this information is being put to practical use.

How we fight the European corn borer. The European corn borer, which has been in our country for only about twenty-five years, has spread through many states. It causes much damage in moist years, usually less damage in dry years. The small moths are good fliers and they spread rapidly. The moth lays its eggs on the leaves of the corn or on some of the commonest weeds. The small larvae feed on the outside of the plant for a few days and then enter the ear (Figure 342) or the stalk within which they spend the winter. It is unusual for larvae to live through the winter; in most insects it is the pupa which winters over. These larvae spin cocoons and soon after come out as adults. You can see that one method of control might be that of destroying the stalks after harvest but before the moths emerge in the spring. This is only partially successful because it has not been possible to destroy all the cornstalks and the weeds which may contain larvae. To find out about the most harmful insects in your neighborhood do EXERCISE 3.

Catching the chinch bug and the gypsy moth. The chinch bug is a tiny insect with sucking mouth parts. It is less than a quarter of an inch long, yet it multi-

FIG. 344 *One nest of tent caterpillars may eat all the leaves from a small tree. The caterpillars return to their nest at night. At that time they can be destroyed by burning the nest.* (GENERAL BIOLOGICAL SUPPLY HOUSE)

plies with such rapidity that in some years it causes losses in the grain fields of the Mississippi and Missouri valleys that amount to millions of dollars. The eggs are laid in the ground or on the young stems of grains or wild grasses. After five or six weeks the bugs are full-grown and by this time their feeding ground is pretty well exhausted. Then they migrate in vast hordes. Though they have wings they march on foot to a neighboring field. They move forward blindly so that millions can often be trapped in ditches filled with kerosene. This is only one of several ways in which the farmer fights this destructive insect. Can you think of some other possible ways?

The gypsy moth, which is common in the eastern states from Maine to New Jersey, strips and, in time, may kill trees. The larvae (caterpillars) eat leaves of almost any kind, even the needles of evergreens. The eggs which are laid during the summer in large masses near the ground hatch early the following spring. Figure 343 is a photograph of the dark, hairy, little caterpillars moving up a tree trunk. One of the best ways to protect individual trees is to circle the trunk with a band of sticky material which traps the caterpillar.

Destroying insects with stomach poisons. Poisons of various kinds, frequently arsenic compounds such as Paris green, are sprayed on plants. Other poisonous compounds are dusted on. Sometimes this is done on a large scale by using airplanes. By these means we can kill insects with biting mouth parts which feed on the exposed parts of plants.

Stomach poisons can be used successfully against the larva of the cabbage butterfly. This is a small white butterfly common around gardens where it sucks nectar. It lays eggs on the cabbage and related plants. The larvae with strong biting jaws may be found two weeks later. The inch-long bluish-green larvae match the plant so exactly that they are scarcely visible. This insect came to us from Canada. Within eight years it reached the Gulf of Mexico, damaging cabbage patches along its route. We failed to stop its spread partly because, like many insects, the cabbage butterfly multiplies very rapidly, having three broods in a season, and partly because few farmers took pains to spray their plants. They allowed the insects to multiply and spread to their neighbors' crops.

Another insect we fight by spraying a stomach poison is the codling moth. It attacks apples and pears in its larval stage, costing New York State farmers alone some 3 million dollars every year. The small adult moth matches the color of

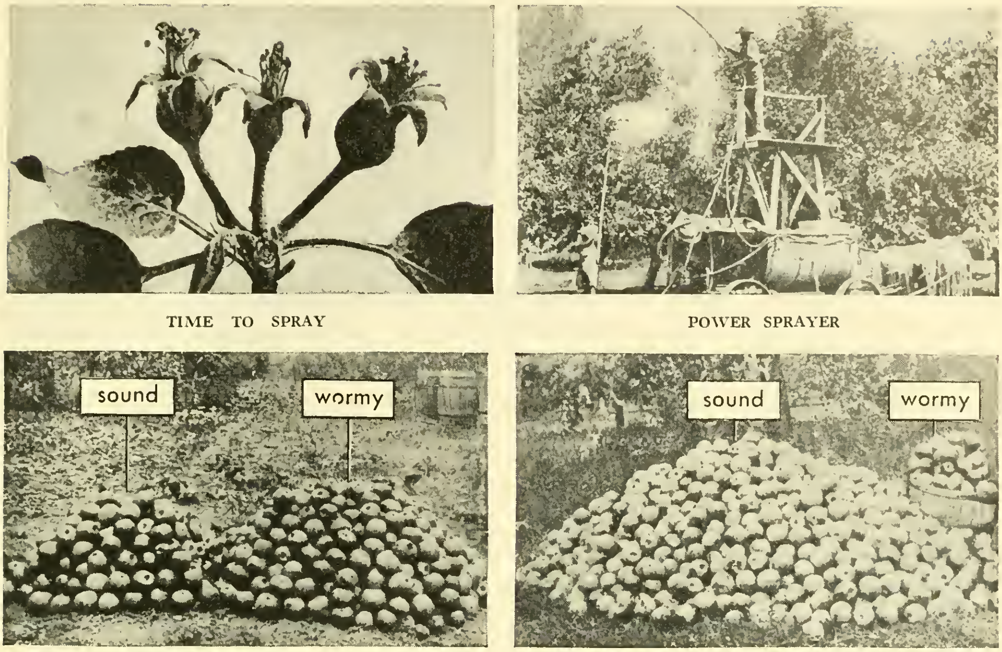
Fig. 345 *The codling moth* (above) *and larva in an apple* (below). *What is the life history of the codling moth? How can it be controlled?* (U. S. DEPARTMENT OF AGRICULTURE)

the bark on which it rests. You may well have overlooked it, but you have all met the larva in a "wormy" apple. Its life history is shown briefly in the table on this page. With an early start and favorable conditions this life history may be repeated four times in a season. Spraying should, therefore, be done in the spring when the apples first begin to form. Since the lead arsenate used is very poisonous, the fruit should be thoroughly washed before it is eaten.

Contact poisons. Stomach poisons are useless for control of insects that do not have biting mouth parts in any stage of their life history. Plant lice and the many scale insects are of this kind. They puncture the stem or leaf and suck the juices of the plant. For such insects contact poisons can be used. Some of these, such as various nicotine compounds, enter or clog up the insects' breathing pores (spiracles). Insects have numerous breathing pores which connect with tiny

Life History of the Codling Moth

1. Moths emerge and lay eggs on leaves of apple trees.
2. Eggs soon hatch into tiny caterpillars.
3. Caterpillars crawl to the developing fruit and bore into it.
4. Caterpillars eat and grow with the apple, often causing it to fall.
5. Caterpillars eat their way to the surface and pupate.
6. Pupae that form late in the season winter over in their cocoons.



TIME TO SPRAY — POWER SPRAYER

FRUIT FROM UNSPRAYED TREE — FRUIT FROM SPRAYED TREE

FIG. 346 *What do you learn about codling moth control from these four pictures? Note especially the heaps of sound and wormy apples from unsprayed and sprayed trees.* (HYLSON — U. S. BUREAU OF ENTOMOLOGY)

air tubes (tracheae) that branch to all parts of the body. The insect inhales by enlarging its abdomen, thus allowing air to enter the tubes. When the abdomen is made smaller the tubes are compressed and air goes out. You can see what happens to the insect when the breathing pores are clogged. It dies from lack of oxygen.

Other contact poisons kill in different ways. The effective insect exterminator, DDT, developed during World War II, is applied as a dust or spray. The poison enters the insect's body through the feet and travels to vital parts. Scale insects on fruit trees are sometimes killed by applying poisonous chemical fumes to the whole tree which is first covered with a sort of tent.

It is sometimes more convenient to keep the insect away than to try to kill it. Chemicals that can be used in this way are called repellents. You use a repellent when you pack your clothes with camphor or naphthalene to protect them against the clothes moth. It is the larvae of the clothes moths that eat holes in furs or woolen clothes. The tiny moth you try to slap to death between your hands is harmless, for it has already laid its eggs before it leaves its dark hiding place. Repellents are also used to protect some plants. You will find EXERCISES 4 and 5 helpful.

Using allies in the fight against insects. The Bureau of Entomology in Washington has long encouraged us to protect such birds as the bluebird, catbird, and

FIG. 347 *The destructive Japanese beetle. The adult destroys leaves; the larvae injure the roots. How does the Department of Agriculture try to stop its further spread?* (U. S. DEPARTMENT OF AGRICULTURE)

kingbird, which are particularly useful to us in eating harmful insects. For many years, too, insect allies have been sought, larger insects which prey on our insect enemies or insects that live as parasites on them. When a species of scale insect threatened the orange crop in California, ladybird beetles, which are natural enemies of the scale, were raised in large numbers and turned loose on their prey. The search for bacterial parasites which might be used against our insect foes is more recent.

You read earlier that serious plant diseases are sometimes known to come from other lands. So, too, some of our worst insect pests such as the European corn borer, the Hessian fly, the Japanese beetle, the Mediterranean fruit fly, the brown-tail moth, and many others have come from other countries. They were all imported accidentally. In their native homes they have various enemies, mostly other insects, which keep them in check. In this country those enemies are lacking. We look for those enemies abroad and attempt to import them or we seek other enemies to serve as our allies.

In 1912 some iris plants were shipped to New York. Concealed in them were small white wormlike grubs (larvae) of the Japanese beetle. Within a few years the Japanese beetle became a major enemy, doing damage to truck crops and orchard trees as well as to ornamental plants. It has been found eating 260 different kinds of plants and has spread as far west as Ohio and as far south as Virginia. Natural enemies were at once looked for but of the many kinds imported only two have proved to be useful allies. At the same time other methods of destruction are used. A trap has been devised to which the beetles are attracted by the odor of geranium oil. Try EXERCISES 6 and 7.

Changing natural relationships. You have seen that when insects enter a country without their natural enemies, they are likely to multiply rapidly and do much harm. And the more communication we have with other countries, the oftener are insects imported accidentally. We must guard against importing insects accidentally from other parts; there must be careful quarantine. Sometimes we get into trouble, not by importing the insect but by importing a new crop. The Colorado potato beetle is native to the United States. Before the potato was introduced this beetle fed only on weeds and was of no importance to us. When we began the cultivation of potatoes, the beetles fed on the new crop and increased rapidly, causing many thousands of dollars of damage annually. You can see that we may create an insect problem when we import insects without their natural enemies or plant a new crop on which native insects feed.

Questions

1. State at least five ways in which insects are harmful to us.
2. Explain how we create an insect problem by planting crops on a large scale. What plant is a good example of this?
3. Explain how insects are harmful not only to the farmer but to all of us. What is the extent of their damage?
4. What is the work of the Bureau of Entomology? What agencies assist in this work? What facts must entomologists know about each insect?
5. Give the life history of the European corn borer. Show how a knowledge of its life history can help in its control. What other methods may be used?
6. Describe briefly the life history of the chinch bug and the gypsy moth and explain how we can partially control each insect.
7. What are stomach poisons and how are they used? In which stage do they kill the insect? Explain. Name two insects we control in this way.
8. Against which insects are contact poisons used? How do they work? What is the advantage of DDT? Explain the life history of the clothes moth.
9. Which vertebrates and which invertebrates do we try to use as our allies against insects? Name two insects which we try to control through using natural insect enemies. Why are imported insects often particularly difficult to keep in check? Name five such serious insect pests. Give some idea of the harm done by the Japanese beetle.
10. How did the planting of potatoes result in an insect problem?

Exercises

1. How does a study of the mouth parts of an insect help to determine the methods of combating it? If you have not already done so, study the mouth parts of the grasshopper and the moth or butterfly (see p. 68). Describe what you see. Which can do more damage to crops? Why? You must remember, however, that the moth has other stages in its life history. See Exercise 2.

2. In which stages of their lives are grasshoppers, moths, and beetles most harmful? If you are not well acquainted with the life histories of grasshoppers and moths refer to Unit I, Problem 1. Study and describe actual specimens of these insects.

3. What are the three or four most harmful insects in your neighborhood? Study all the stages in their life history so that you may be able to recognize them. Use pictures or charts and, if possible, actual specimens. Where and in which season can each stage be found? At which stage is it easiest to fight each insect?

4. Explain why clothes should be sunned and well brushed before being packed away for the summer. Why are sealed newspaper wrappings as useful as cedarized bags in keeping moths from your clothes? If you have successfully prevented damage by clothes moths in your home report on the methods used.

5. What methods of fighting insects are in common use in your neighborhood? If it is not possible to get this information from reliable adults of your acquaintance, ask the class secretary to write to the State Agricultural Station or the State Entomologist.

6. Which of the following are the least and which the most important in enabling an insect to spread over a large area? Explain and discuss.

(a) Swift locomotion
(b) Eating large amounts
(c) Prolific reproduction
(d) Living in concealment
(e) Eating a plant that is widespread
(f) Eating a large variety of food
(g) Having a hard body covering
(h) Resembling its surroundings

7. Answer the following questions:

(a) What connection might there be between insect pests and the invention of the airplane and automobile? (b) Can you explain how insects might affect birds, as well as man, both directly and indirectly? Be specific in your answer. (c) Would this be a better world to live in if all insects were killed off? Explain your answer.

Further Activities in Biology

1. Make a collection of the harmful insects found in your neighborhood. Mount them for display. These mounts should, if possible, illustrate the insects' life histories and habits.

2. Look through the list of titles of Farmer's Bulletins published by the United States Department of Agriculture, as well as the publications of your State Experiment Stations, and write for those that apply to the study of insects. Many interesting articles may be found in the United States Experiment Station Record.

3. Prepare a full report to the class on three or four insects such as the European corn borer, the Hessian fly, the Mediterranean fruit fly, or any other that does great damage in your neighborhood. Consult books, government publications, and the World Almanac regarding insects.

4. Gather information on the vocational opportunities for the entomologist. Consult your state agricultural school. If you live near, perhaps you could visit the school.

5. You will find L. O. Howard's book, *The Insect Menace*, interesting reading. Report to the class.

PROBLEM 4 *Why Must We Practice Conservation?*

Destruction of forests. The destruction of forests in our country has been enormous. Figure 350 indicates how small a percentage of the original 800 million acres is left. Of this area comparatively little has been replanted with new trees for future use. Forests have been removed to make way for farms, for with the increase in human population it has been necessary to devote more and more land to agriculture. Trees have been cut for lumber, for fuel, and for pulp to make paper. Even nowadays, though steel is used for many purposes, vast quantities of lumber are still needed for building houses and ships, for telegraph poles and railroad ties. From trees more than 17 million tons of paper and cardboard are produced each year. And wood is used in countless minor ways, for plastics, for rayon, for alcohol, and during World War II it was even made into feed for cattle. You can see how dependent we are on trees. If we were to continue to waste our forests as we have in the past we should soon be in serious trouble.

Cutting of forests has not been the only source of destruction. We have lost millions of acres of valuable timber through forest fires. While lightning frequently sets forest fires, the large majority are accidentally or intentionally set by man. Flying sparks from railroad start some fires but many are set by lighted cigarettes thrown from an automobile, by careless campers, or through some other form of carelessness. Some are deliberately set to improve pasture conditions or to encourage the growth of such shrubs as blueberries. Most forest fires are avoidable, and, although there is much state and federal control of forest land, about 12 million acres are destroyed by fire every year. Not only are the trees lost in a forest fire but, as a rule, the kinds of plants that grow for many years after a forest fire are of little direct use to us.

Forests prevent floods. The forest floor is a mass of dead and decaying leaves and twigs — all organic matter. Below this is a mixture of soil and decaying organic matter called humus. This material with the tangle of roots near the surface makes the soil in a forest act as a sponge. When large snowdrifts melt or heavy rainstorms come, the water does not quickly flow down a forest-covered hillside. Much of it is absorbed and held by the spongy forest floor. Where forests have been burned or cut, rain and water from melting snow rushes down the bare hillsides into the valleys, and the swollen streams overflow their banks. The floods cause loss of property and life, and the

Fig. 348 *Every year in our country forest fires destroy an average of twelve million acres of trees. What are the other costs of forest fires besides the loss of trees that might have been used for lumber and paper pulp? What can be done to prevent such great losses?* (U. S. FOREST SERVICE)

Fig. 349 *As leaves and small branches fall, collect, and decay, a spongy layer of humus develops on the forest floor. How does this prevent the runoff of water?* (OKERBERG — CHICAGO APPARATUS COMPANY)

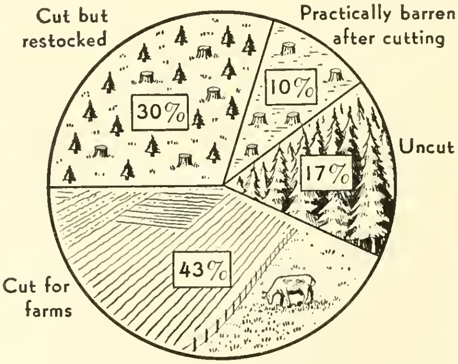


Fig. 350 *When the first white settlers came to this continent, there were more than 800,000,000 acres of untouched forest. How many acres have been cut? Why were the trees cut? How many acres are left? How much is being replanted?*

FIG. 351 *What fire can do to a watershed. What will be the result when rain falls on these burned-over slopes?* (U. S. FOREST SERVICE)

FIG. 352 *The forest ranger watches for the ever-menacing forest fire. The ranger is an important part of the program of conservation of our forests. He not only watches for and reports fires but helps fight and directs the fighting of fires. Some rangers use airplanes to search for fires; others spend much of their time in lonely mountaintop fire towers.* (U. S. FOREST SERVICE)

FIG. 353 *Clean lumbering* (left) *reduces the fire hazard. Digging trenches* (right) *to keep a forest fire from spreading.* (U. S. FOREST SERVICE)

water has been lost from the hillsides. Fewer kinds of plants can grow on dry than on moist hillsides.

Forest conservation. We must continue to cut forest trees for necessary lumber, but we must do it in such a way that the forests will not be destroyed. We must have *conservation.* About sixty years ago, the United States Forest Service was established as part of the Department of Agriculture. Schools of forestry were opened in many parts of the country; new professions, such as those of forester and forest ranger, arose in connection with this work. These men and the biologists who studied forests have learned many important facts. It takes a forest tree between fifty and one hundred years to grow to a size suitable for making into lumber. The first rule of conservation is to use only as much as will be naturally replaced. This rule may be applied as a simple arithmetic problem: the man who owns 50,000 trees ready for cutting should cut no more than 1000 every year. The trees to be cut should be carefully selected. They should be the older trees which provide good lumber or large quantities of pulp and those trees should be cut that hinder most the growth of smaller trees. If it is properly spaced, cutting in a forest is highly desirable, for it gives the small trees an opportunity for faster growth. You should now be able to do EXERCISE 1. Some land now used for crops or pasture is better fitted for forest growth. In some such areas trees are being planted by the Federal government, by the State government, or by well-informed private owners.

The soil problem. The problem of soil destruction is one of the greatest that faces the people of the United States. Unfortunately, most of us do not know about it. The best soil normally lies near the surface, for here, over long ages, organic material from decaying animals and plants has been collecting. This rich soil is called topsoil. You have read how the destruction of forests leads to the rapid run-off of water from hillsides. The topsoil is washed away. And what is left dries up and is later blown away in enormous amounts. Figure 354 shows how serious the effects may be.

FIG. 354 *A hillside that has gone to waste. Can you explain how?* (U. S. SOIL CONSERVATION SERVICE)

Overgrazing causes loss of good soil, too. When too many animals graze on too small an area, they are forced to eat all the green parts above the ground, starving the roots which bind the soil. Sheep and goats are particularly destructive because they crop very close to the ground. Stripped of its cover of grass, much of the topsoil is washed and blown away. (See Figs. 354 and 356.) The land becomes poorer and poorer. In some sections of our country the topsoil is entirely gone. Overgrazing is partially the cause of the treeless slopes of Spain and other Mediterranean countries.

Ordinary farming operations cause much loss of topsoil too. In plowing the land we expose the topsoil to the action of rain and wind. Furthermore, unless the farmer adds fertilizers or takes other precautions, the nitrogen and other mineral compounds will soon be exhausted.

Soil conservation. The United States government through several of its bureaus, some of the State governments, and groups of private individuals who are concerned about the future welfare of the country have attacked the problem of soil conservation in several ways. Education of farmers and city dwellers in regard to the need for soil conservation and the danger of forest destruction is the first job to be done. Government agencies search for plants which may be used to bind the soil. Research workers devise and try out ways of farming to

FIG. 355 *The topsoil is often dark colored. Why must it be kept from being washed away?* (GEOGRAPHIC REVIEW)

FIG. 356 *Not smoke, but dust whipped up from barren land. Introducing plants that bind the soil helps prevent this.* (U. S. SOIL CONSERVATION SERVICE)

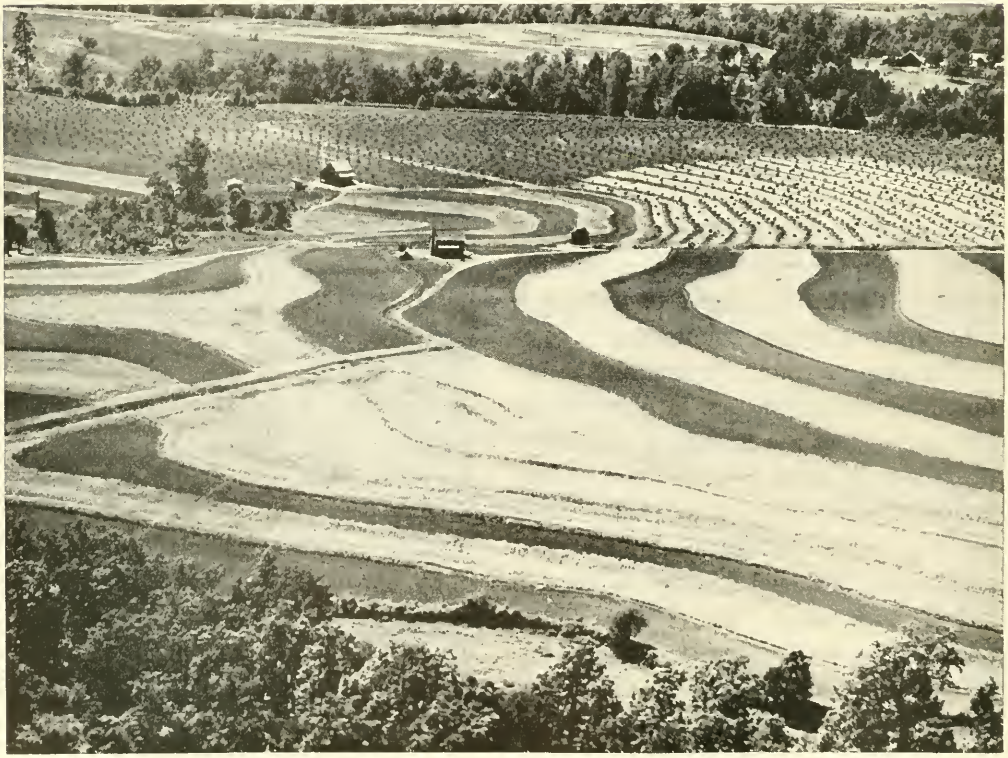


FIG. 357 *Contour planting on slopes in South Carolina. Can you see what else has been done here to save topsoil?*

keep the soil from being washed away and experiment with methods of restoring soil fertility. Let us examine some of these methods more closely.

Contour planting. Most farm land has a slight slope. Water can be prevented from flowing off and carrying away topsoil from slopes by plowing and planting crosswise on the hill instead of up and down it. The furrows catch and hold the water. This is known as contour plowing and planting. Often, too, small ridges are built around the hill to prevent the rapid run-off of water, or the slope is built into a series of terraces.

Binding the soil. Contour planting and the building of ridges also help to prevent a very destructive process known as *sheeting*. In sheeting, the very top layer of soil slowly but steadily moves downhill because it is so soaked with water that it is really floating. To prevent this type of soil loss, farmers can plant *cover crops*, whose chief value is to bind the soil. Sometimes the cover crop may serve a double purpose. When leguminous plants such as alfalfa and clover are planted as cover crops, they add nitrogen compounds to the soil.

Restoring fertility to the soil. When a farmer practices crop rotation he plants alfalfa, clover, beans, or some other leguminous plant every few years to restore nitrates to the soil. In order to make sure that root nodules develop, farmers often sow small amounts of the necessary bacteria with the seeds. The bacteria are raised by state agricultural stations, by the United States Department of Agriculture, and by commercial firms from whom they may be obtained. Farmers also use commercial fertilizers made in factories. Such fertilizers contain nitrogen compounds, phosphates, potassium compounds, and other minerals. They use the decaying solid wastes of farm animals, known as manure; decaying fish, which are exceptionally rich in minerals; and the solid wastes of birds, known as *guano* (gwa'no). Vast deposits of guano are found on the dry coasts of Chile and southern Peru.

The vanishing of wildlife. With the destruction of forests and the settling of the plains, great numbers of wild animals and plants were destroyed. Elk once roamed our eastern woods. Bison were seen by the first white men who landed in what is now Maryland. They lived in the region where the White House stands today. The California grizzly bear is gone. Birds, too, have been crowded out and become extinct. In 1844 the last great auk died. The year 1914 saw the end of the passenger pigeons, which at one time were widely used as food and could be bought in the market for a penny a bird. As recently as 1932 heath hens became extinct. The wild turkey which once lived in most of our states is no longer common.

The tall blue stem grass which over thousands of years built the rich prairie soils of Iowa and neighboring states has been destroyed except for a few scattered patches. Much of the giant redwood forest of the western coast is gone. And many species of wild flowers are being rapidly destroyed. You may have seen warnings in your local post office to protect certain plants which are in danger of becoming extinct.

What is true of the United States is true of other countries, too. The Soviet

Union realized that beavers, so valuable to Russia for fur, were very near extinction. Steps have been taken to restore them by protecting the breeding grounds. Ecologists the world over are stressing the importance of understanding the relationships of living things in order that certain industries may be saved and that wild animals and plants may be preserved.

Steps taken to conserve wildlife. Wildlife conservation has become so important that some colleges now give courses in the subject and men and women are taking it up as a career. Some years ago the Federal Government created the Bureau of Biological Survey to study the relationships between plants and animals, particularly the way in which we have interfered with normal relationships. More recently this bureau was combined with the Bureau of Fisheries into one department known as the U.S. Fish and Wildlife Service. Besides engaging in research this Service has introduced the idea of raising wildlife as one would raise crops; farmers are taught to raise smaller mammals and birds useful as insect destroyers. Fish are being raised, too, in enormous numbers in fish hatcheries; ponds and streams are being regularly stocked with them.

The Wildlife Service works in close cooperation with State agencies and such organizations as the National Association of Audubon Societies, the American Tree Association, and others to protect animals and plants from destruction. They have bought and set aside huge tracts of land as places where hunting is forbidden and no one may interfere with the normal life of the wild animals that live there. Besides our many large national parks, there are smaller sanctuaries, places of refuge and protection. Very important in our attempt to conserve wildlife is preventing its ruthless destruction. Many wild plants and smaller animals may be found even on vacant city lots. You will find EXERCISE 2 most interesting.

Bird and game laws. In an effort to protect birds against the activities of hunters, State and Federal laws have been passed. One law (the Lacey law) prohibits shipping birds out of the state in which they have been illegally killed. In the days when the snowy egret was being killed in huge numbers in Florida swamps to provide feathers for women's hats throughout this country, this law was necessary. Another law (the McLean bill) makes it unlawful to kill all but a few kinds of insect-eating birds. There is a migratory bird treaty between the United States and Canada which protects those birds that migrate from one country to the other.

Other animals are also protected by law. Some mammals are completely protected. Some may be hunted only during a short "open" season, never while the young are dependent on their parents. The open season for some game is made extremely short and the number of animals that may be killed by one person is limited. Often it is only the males that may be caught or killed. If such laws are enforced, destruction of a species is impossible. Fish, too, are protected by similar laws. Your class will be interested in trying EXERCISES 3 and 4.

What have we learned? We make great efforts to conserve forests and wild life

FIG. 358 *Wild flowers that need protection. Which do you recognize?*

a. *Trailing arbutus*
b. *Jack-in-the-pulpit*
c. *False Solomon's seal*
d. *Mountain laurel*
e. *Hepatica*
f. *Bird's-foot violet*

(a, c, f — AMERICAN MUSEUM OF NATURAL HISTORY; b — BROOKLYN BOTANIC GARDEN; e, d — U. S. DEPARTMENT OF AGRICULTURE) because our continued existence depends on our ability to do so. Conservation really attempts to maintain normal relationships which have been disturbed by our civilization. Closely related to keeping normal relationships among living things is conservation of soil, without which we could not obtain sufficient food. You must remember all the ways in which we disturb plant-animal relationships: by destroying organisms; by providing conditions which make it possible for other species to increase at a great rate; and by importing plants or animals which, without their native enemies, increase very rapidly. Each disturbance of normal relationships may create a new problem for us. See EXERCISE 5.

QUESTIONS

1. State some of the many uses of forest trees to us. State two important causes of the destruction of forests.
2. Explain an important indirect result of forest destruction.
3. If we are to have forest conservation what is the limit on the number of trees one may cut each year? Which trees should be selected for cutting?
4. What is meant by topsoil? Describe three practices which lead to destruction of topsoil.
5. Name three methods of saving the soil.
6. Explain contour plowing and planting.
7. Explain sheeting. What is meant by a cover crop?
8. Explain three ways by which farmers may restore fertility to soil.
9. Name four animals that we have destroyed.
10. What steps have been taken to conserve wild plants and animals?
11. Describe two important laws designed to conserve wild animals. If animals are being killed off too fast by hunters or fishermen, what laws can be passed to protect them?
12. Why is conservation so important?

EXERCISES

1. Suppose that you were the director of a lumber company that owned vast stretches of forest land. What regulations would you issue to prevent forest fires on your land? What fire-fighting training would you give your employees? See Figure 353.

2. By class discussion, plan a biological survey of a small field or city lot near your school. Which facts will you need to know about each animal and plant? If the season permits, carry it out. Prepare a scientific report of the work.

3. Divide the class up into committees and obtain information about organizations that help to maintain normal plant-animal relationships. Include the U.S. Fish and Wildlife Service, the U.S. Forest Service, your State Department of Conservation, Fish Hatcheries, the American Forestry Association (Washington), Friends of the Land, and others.

4. Factories and large cities interfere with normal plant-animal relationships with the environment. List some of the ways in which such interference may take place. How may man protect the living things that are harmed by cities and factories? How may he protect himself?

5. The class may be divided into committees to review this problem. Each committee may take one of the following topics and prepare a committee report: (*a.*) The importance of forests to us. (*b.*) How forests are destroyed. Methods of fire prevention and fire fighting could well be included. (*c.*) The causes of our soil problem. Soil conservation practices could well be included. (*d.*) The vanishing of wildlife and its conservation.

Further Activities in Biology

1. Read Pack and Gill's *Forest Facts.* Tell the class the facts of forest destruction.

2. How could you demonstrate that a spongy forest floor prevents water from running off rapidly? Present it to the class. Does it convince your classmates?

3. Have there been forest fires near where you live? Can you find out how they started? Who fought them?

4. Read Paul Sears's *Deserts on the March.* Present a book report to the class.

5. If you are interested in the work of the forester or forest ranger find out where you could prepare yourself for this profession, what the requirements are, and so on. Report to the class.

6. D. C. Peattie has written a most interesting life of Audubon. Read it.

7. Your state agricultural station may be able to supply information about reforestation. If you live where such work is possible some of your classmates and you might undertake a tree-planting project.

8. Can you visit a bird refuge? Report on the bird refuges in your state.

9. Report on any movie you have seen or any broadcast you have heard on the subject of wildlife extermination or conservation.

In UNIT VIII you will consider these problems:

Problem 1. How Do the Simple Animals and Plants Reproduce?

Problem 2. How Do the More Complex Animals Reproduce?

Problem 3. How Do the More Complex Plants Reproduce?

UNIT VIII HOW ANIMALS AND PLANTS MAKE MORE OF THEIR OWN KIND

Fig. 359 *A mare and her two sturdy colts. The instinct of caring for their young is very strong in most mammals. This mare stays by and protects her colts for a long time, even though, when born, they are far less helpless than the young of many other mammals.*

PROBLEM 1 *How Do the Simple Animals and Plants Reproduce?*

Do living things come from lifeless matter? For centuries it was believed that some, probably many, kinds of living things could arise by *spontaneous generation.* Spontaneous generation means the forming of animals or plants from lifeless matter instead of from living things. The ancient Egyptians thought that frogs and mice were made from the mud deposited in the fields when the Nile overflowed its banks. Even today there are people who think that horsehairs left in water can turn into snakes and that decaying meat will give rise to small worms. Many observations have shown that it is not possible for these things to happen.

People frequently saw wormlike forms, called maggots, in rotting meat. Maggots are the larvae of flies. Thus the notion arose that flies can form from meat. About the middle of the 17th century Redi (Ray′dee), 1626–1697, an Italian biologist, proved that the maggots developed from flies' eggs which are laid in the meat. He put decaying meat into several jars. One jar was left open; a second was covered with gauze; and a third was covered with parchment, which was so thick that no odor from the meat could pass through. Redi soon found maggots on the meat in the open jar after flies had visited it. He saw flies gather on the gauze of the second jar and lay eggs which became maggots. There were no signs of maggots or flies inside or outside the parchment-covered jar. From this Redi drew two conclusions: 1. The odor of meat attracts flies and induces them to deposit their eggs. 2. Maggots develop from eggs laid by flies; they do not come from the meat.

Redi's experiments had been performed so carefully that they helped greatly to convince other men that spontaneous generation does not take place.

Belief in spontaneous generation is renewed. Soon after Redi's work, Leeuwenhoek discovered many kinds of microscopic organisms, and the whole problem was reopened. Here certainly were living things for which spontaneous generation seemed reasonable. Nevertheless, experiments performed by Louis Pasteur (1822–1895) and John Tyndall, a famous English scientist, showed that not even the microscopic organisms came from lifeless matter.

Pasteur prepared many flasks (bottles) of liquid food material for bacteria. After bacteria had appeared in the liquid, he boiled it, killing the bacteria. While the liquid was boiling he sealed some of the flasks by melting the glass necks; he left others open. When he examined the

FIG. 360 *Paramecium dividing. Which is the later stage? What happens to the nucleus?* (GENERAL BIOLOGICAL SUPPLY HOUSE)

contents of the open flasks immediately after the boiling, Pasteur found no trace of bacteria. But after these bottles had been in the laboratory for some time, he found that they were full of organisms which were decaying the food. In the sealed bottles, however, there were no signs of decay. Pasteur broke the seal of a few flasks and let them stand open. Very soon bacteria appeared in the flasks and began to decay the food. Pasteur, therefore, concluded that bacteria did not develop from the lifeless food. He decided that bacteria on the dust in the air had settled in the open flasks. They entered the liquid and reproduced until there were very large numbers of them. You can try this experiment for yourself. Do EXERCISE 1.

To check his theory that the bacteria entered the flasks with the dust from the air, Pasteur took some of his flasks to the top of a high mountain where the air was almost free from dust. He found that bacteria rarely appeared in the flasks opened on the mountain top.

Even after these experiments, there were some who were not convinced that bacteria always arose from other bacteria. They thought it likely that lack of air in the sealed flasks prevented the development of bacteria from the broth. To check this final point Pasteur did another experiment using several flasks of a new kind. He prepared more broth exactly like that used in previous experiments. After heating the broth in a flask, he heated the neck of the flask and drew it out into a zigzag, open tube. Again he heated the flasks, then set them aside. Since the zigzag tube was open, air could enter but no bacteria could drop in. No bacteria were found in the flasks even after four years. No objections to this experiment were ever raised.

Tyndall's experiments were different in procedure but were equally convincing. Together the two men provided proof that even the simplest known living things arise only from other living things.

Reproduction of some simple organisms. If you were to examine a rich culture of Paramecium (or similar protozoan) you would find some of them reproducing. Photographs of two stages of the process may be seen in Figure 360. EXERCISE 2 describes how to observe reproduction in Paramecium.

It is not always easy to find an ameba reproducing but the process has been described fully. The ameba begins by pull-

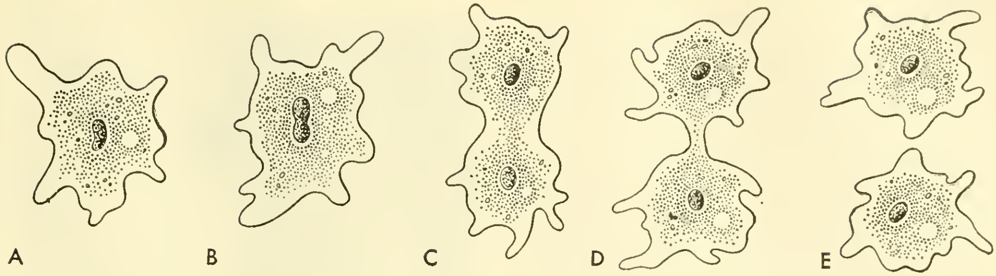


FIG. 361 *Five stages in the reproduction of an ameba. How does* B *differ from* A? *What changes are shown in* C? *What is happening in* D?

ing in its pseudopods; it becomes less active. The nucleus comes to rest near the center of the cell and divides. While the nucleus is dividing, the cytoplasm streams in opposite directions away from the center of the cell. The two new nuclei move away from one another along with the cytoplasm. The two resulting parts then seem to pull away from each other. The cytoplasm connecting them becomes thinner and thinner until finally it is only a thread, which breaks. In about half an hour one ameba becomes two amebae, each with its own nucleus. The new amebae rapidly grow to full size.

This division of the nucleus and the separating of the cell body into two equal parts in a one-celled organism is a process known as *binary fission* (by′na-ree fish′un). In binary fission, as you just read, the parent disappears; the whole organism makes the two offspring. These two are often spoken of as the daughter cells and the parent as the mother cell. Strictly speaking, there are neither daughters nor mothers; but no better names have been found.

Binary fission occurs not only in amebae and Paramecia but in other protozoa and in many single-celled plants. Note that cell division in a many-celled organism is not called binary fission because new organisms do not result. The term binary fission is reserved for the reproduction of a single-celled animal or plant.

A variation from binary fission. An equally simple but far less common method of reproduction takes place in the yeast plant, many thousands of which make up a cake of yeast. In reproduction, the nucleus moves to one

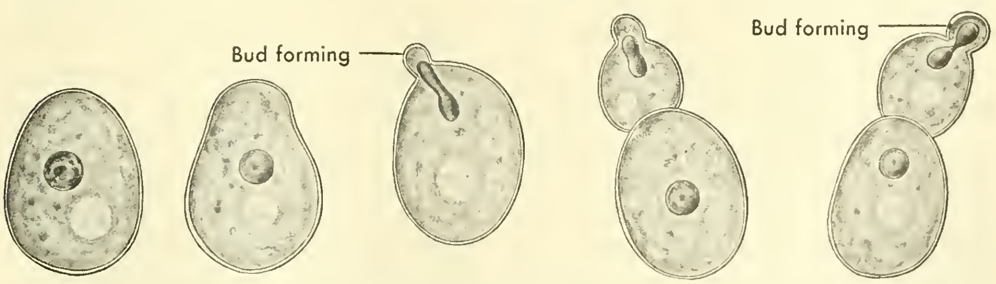


FIG. 362 *The common yeast used for baking. How many cells are in the process of budding? Where is the nucleus when the cell is budding?*

end of the cell and divides into two equal parts. The two new nuclei are therefore at one end of the cell. A new cell wall forms between them, thus two new cells are formed. This is not binary fission because the two cells are very unequal in size. The larger cell is called the mother cell and the smaller one is the daughter or *bud*. This kind of reproduction, in which a small piece is formed that will later grow into a full-sized organism, is called *budding*. In yeast, the bud may remain attached to the mother cell for a time; in fact, sometimes it remains attached until it has itself produced a bud. Thus a small chain of yeast plants may be formed. If the bud is shaken loose, it can also grow and bud. Now do EXERCISE 3 to see budding in yeast.

A process called budding occurs in a few many-celled animals. One of them is *Hydra*. See Figure 85, page 59. In these animals the bud is composed of several to many cells.

Reproduction by spore formation. Sometimes in reproduction a cell divides into many new cells instead of only two. The nucleus begins the process by dividing in two; then each new nucleus divides, continuing until there are eight or sixteen or a much larger number of nuclei. A little cytoplasm gathers around each new nucleus, and from the original cell there are soon formed a large number of tiny cells. Each cell, as a rule, develops a thick, protective wall. A reproductive cell formed in this way is called a *spore*, and the method of reproduction is called spore formation or *sporulation*. Study sporulation by doing EXERCISE 4. If you have a microscope, you can also do EXERCISE 5.

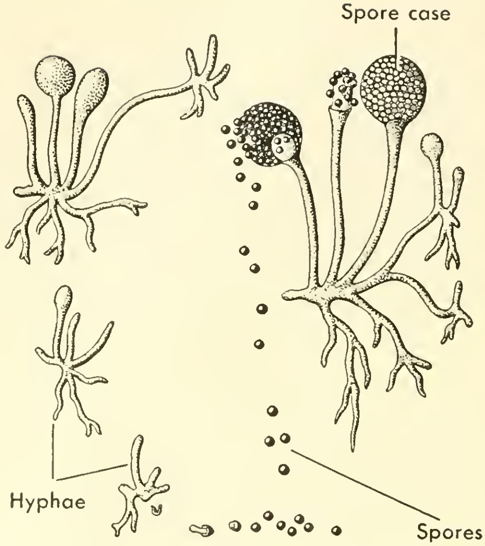


FIG. 363 *Spores of the bread mold (Rhizopus) grow into hyphae. What changes occur in the hyphae? Where are the spores produced?*

Sporulation occurs in molds. Molds grow on a variety of foods under the right conditions, even on damp leather or wood. One of the very common species is the bread mold (Rhizopus), a fuzzy white plant that appears to turn gray and finally black when the spores are ripe. A bread mold plant starts from a spore, a single cell which grows into a small white thread. This thread grows and branches in all directions. Some of the threads (*hyphae* — high′fee) push down into the substance on which the mold is growing and extract food material. Some grow upward into the air. The threads that grow upward are used in reproduction. They swell at the tip, and it is in this tip that sporulation takes place. The several nuclei in the swollen tip are surrounded by bits of cytoplasm, so that finally many small cells are formed. Each tiny cell becomes surrounded with a tough wall; it becomes a spore. While

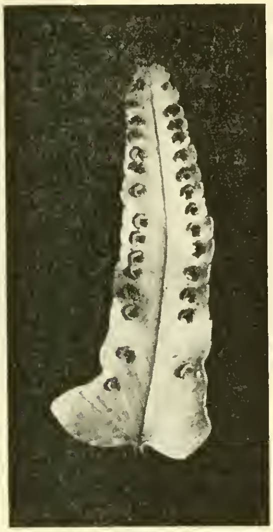


FIG. 364 *The lower side of a small piece of a fern leaf. Each dark spot contains many tiny spore cases. What is in the spore cases?* (BROOKLYN BOTANIC GARDEN)

this is going on, the end of the hypha develops into a large ball or sphere which is called a *spore case* (*sporangium*). The spore case breaks open when the spores are ripe and the spores are scattered by movements of air. The bread mold spores are so light when dry that even slight movements of the air carry them. The spores look colorless when seen singly, but in a mass they appear black.

Spore formation in other organisms. Certain protozoa and a few of the simpler invertebrates reproduce by spore formation too. It is an effective method, for it provides very large numbers of offspring in a short time. While it is rare in animals, it is found in many plants. Spores are formed on the under side of the caps of growing mushrooms, in little capsules that grow on moss plants, and on ferns. The lower side of a fern frond (leaf) at certain seasons may be marked with brown lines or dots. Out of these you can shake a brown powder which is a mass of spores. In ferns as in molds only a small part of each plant produces spores.

A different type of reproduction. In many simple animals and plants, reproduction is more complicated. Let us study *Spirogyra*, one of many green pond scums so common in slowly flowing waters. See Figure 97, page 74. The "scum" is a tangle of bright green threads, or filaments, matted together. Each thread is a separate plant. It is a single row of cells, all alike in structure, each of which can be seen through the microscope to have a beautiful pattern made by the chloroplast.

If you collect Spirogyra in the spring months you will have a good chance to find it reproducing. If through the microscope you see two threads (filaments) joined together you will know that reproduction is taking place. Let us study it in detail. In each cell the spiral chloroplast (or chloroplasts) loses its shape and the mass of cytoplasm begins to shrink away from the cell wall. In the meantime, each cell sends out a projection toward the cell opposite it in the neighboring filament. These projections continue to grow toward one another. When they meet, the cell walls dissolve at the point of contact. This makes a continuous passageway or bridge from a cell of one filament to a cell of the opposite filament. In other words, the cells of neighboring filaments pair off with one another.

When the bridge has been completed, the protoplasm from one cell streams to the opposite protoplasm which remains stationary. Each cell mass of protoplasm fuses with the one opposite, nucleus uniting with nucleus. The cells that fuse are called *gametes* (gam'eats). Every

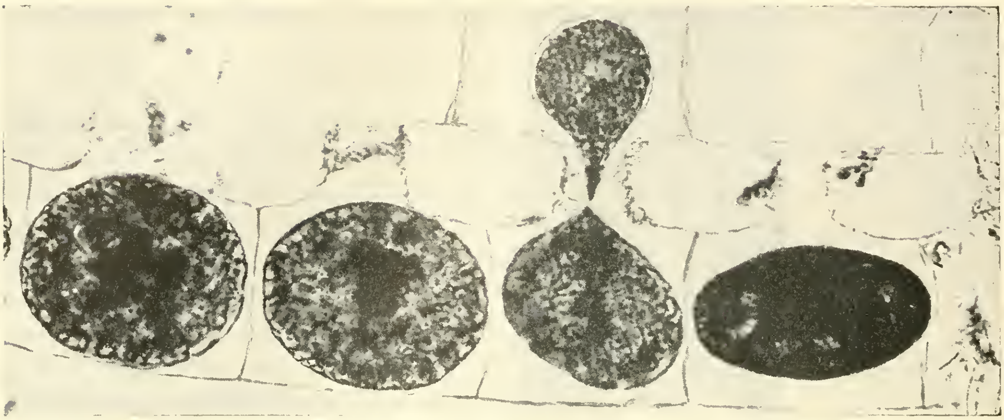


FIG. 365 *Two filaments of conjugating Spirogyra. Conjugation is complete in three pairs of cells. In one the gamete from the upper filament is passing into the lower. Which is the latest stage?* (WARD'S NATURAL SCIENCE ESTABLISHMENT)

cell in a filament of Spirogyra is a gamete. The cell that flows across the bridge into the other cell is called an *active* or *supplying gamete;* the one which remains within its cell wall is the *passive* or *receiving gamete.* After the two gametes have united, the filament which contained the active gametes is left with empty cell walls. The other filament, which originally contained the passive gametes now contains all the fused masses of protoplasm. Each fused mass of protoplasm loses water, shrinks, and secretes a heavy wall around itself. It is then known as a *zygospore* (zeye'go-spore). The zygospore, even though it is made from the fusion of two cell bodies does not even fill the original cell wall. See Figure 365. This cell wall gradually decays and then the zygospore sinks to the bottom of the pond.

But the story of reproduction in Spirogyra is not yet complete. So far, two cells have united, forming one. The second chapter of this story may take many weeks to complete, for the zygospore may rest for a long time. Because of its heavy wall it is usually not killed even if the pond dries up. When conditions become favorable, the living protoplasm within the zygospore wall becomes active. It absorbs water and bursts open its covering. The chloroplast manufactures sugar, the cell absorbs water and minerals, makes proteins, and grows. When the cell has grown to normal size first the nucleus and then the cell body divides. After repeated divisions there is a whole new filament or Spirogyra plant. The process of reproduction is now complete. This second step usually takes place in the spring. Prepared slides that show the various stages in the fusion of Spirogyra gametes can be bought, or you may be lucky enough to collect the plant in just the right stage. See EXERCISE 6.

In this method of reproduction the new individual is formed only after the fusion of the two cells. Thus reproduction in Spirogyra is different from the methods described earlier in this problem. There are many other organisms in which there is a fusion of gametes from two separate individuals. The common

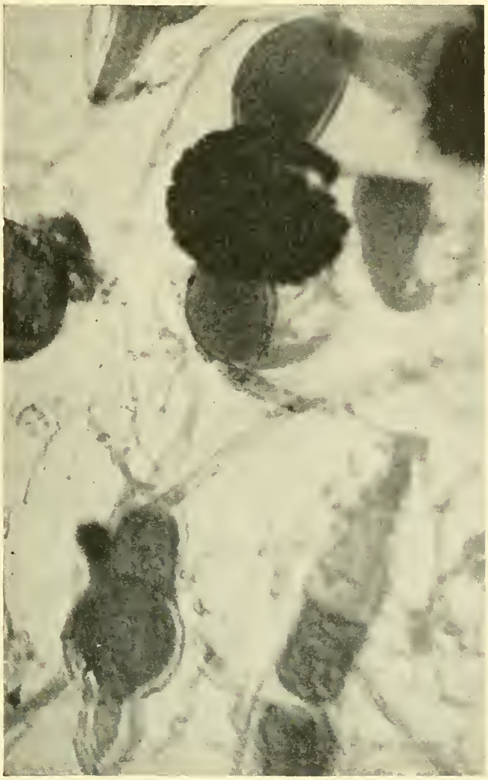


FIG. 366 *Conjugation in bread mold. The filaments from two plants swell at their ends* (lower right corner) *meet, fuse, and form a large zygospore* (above). (KLINE)

FIG. 367 *Paramecia sometimes conjugate and exchange pieces of the small nucleus. Then they separate and each divides. How does this differ from conjugation in Spirogyra?* (KLINE)

bread mold may reproduce in this way as well as by sporulation. See Figure 366.

Sexual reproduction. The process you have just been studying is *sexual reproduction.* Two cells, called gametes, fuse or unite with each other. Nucleus unites with nucleus, and cell body with cell body, forming a new cell that is the beginning of the new organism. Sexual reproduction is the common method of reproduction in animals and plants from the simple to the most complex.

Contrasted with sexual reproduction is *asexual* reproduction, in which there is no fusion of cells. Binary fission, budding, and sporulation are all examples of asexual reproduction. Some species of animals and most plants reproduce sexually at one time and asexually at another time.

Union of like gametes. When the two uniting gametes are similar in appearance as they are in Spirogyra and in bread mold, the sexual reproduction is called *conjugation.* But you will soon see that in most sexual reproduction the gametes are different from each other. When the gametes are different, the process is not called conjugation. It is interesting to note that in the bread mold, although the two gametes seem alike, fusion does not occur unless the threads are of different strains, known simply as plus and minus. Now study conjugation in *Paramecium* (Fig. 367) and if possible do EXERCISE 7.

Union of unlike gametes. In the discussion of malaria (see Fig. 311), you read about a union of unlike gametes. In the stomach of the mosquito some of the malarial protozoa become spherical; these are called female cells. Others become smaller whiplike forms; these are the male cells. When one of the male cells enters a female cell, the nuclei and cell bodies unite. The new cell then goes on to produce more cells like itself. This form of sexual reproduction, where the two uniting cells or gametes are different in appearance, is called *fertilization*. The cell that is produced by the fusion of two unlike gametes is called a *fertilized egg cell* or *zygote* (zeye′goat).* Fertilization is a much more common form of sexual reproduction than conjugation. In higher animals and plants there is always a union of unlike gametes; a male cell unites with a female cell. Reproduction is always by fertilization, not by conjugation. You should now be able to summarize this problem. See EXERCISE 8.

* Zygote is the general name for all cells produced by the fusion of gametes. Thus the zygospore of *Spirogyra* is a zygote. It is a special kind of zygote with a thick spore covering.

QUESTIONS

1. Explain what is meant by spontaneous generation. Outline Redi's experiment and state his conclusions.
2. Why was the belief in spontaneous generation renewed a century after Redi's experiment? Name two scientists who disproved spontaneous generation a second time and describe the experiments performed by one of them.
3. Describe reproduction in a protozoan. What starts the process of division? Define binary fission.
4. Explain how budding resembles and differs from binary fission. Give an example.
5. Explain how spore formation differs from both binary fission and budding. What is a spore? How is it formed? Into what does it develop? Name a common plant that reproduces by spore formation.
6. Name other organisms that reproduce by spore formation.
7. In what important respect is reproduction in Spirogyra different from the methods just studied? Explain reproduction in Spirogyra, using the terms gamete and zygospore. How does a zygospore differ from a gamete? What normally becomes of the zygospore?
8. What is the difference between sexual and asexual reproduction?
9. What is true of the gametes when sexual reproduction is called conjugation? Name a second simple plant that conjugates.
10. How does fertilization differ from conjugation? Name a single-celled organism in which fertilization occurs.

EXERCISES

1. Prepare some sterile broth in sterile test tubes by following directions for the preparation of nutrient agar (page 317) but omit the agar. Before sterilizing you must close the tubes with wads of cotton to prevent the

entrance of dust and bacteria. How can you be sure that the broth in the tubes is sterile? Allow several of the tubes to stand open exposed to the air of the classroom after the broth has cooled to 80° F or below. If possible keep all tubes at a temperature of 80° F. Examine after 72 hours. What do you notice?

2. How do paramecia reproduce? Examine a rich culture under low power. Look for dividing forms. What shape are they? Draw a few important stages in their reproduction. Now examine a prepared slide of division in Paramecium. Use the high power. What must you now add to your drawings to complete them? What is this type of reproduction called? Do all the cells divide lengthwise, crosswise, or some lengthwise and some crosswise?

3. How does the yeast plant reproduce? Stir a small amount of yeast into a flask of dilute sugar water. Allow it to stand for a day at room temperature. Mix a bit of yeast cake in half a tumbler of plain water and examine a drop under high power. (You may need assistance in finding the cells.) Draw one or two yeast cells much enlarged. Now examine a drop of the mixture of sugar water and yeast under the high power. Compare with the yeast plants studied first. Why would you expect this yeast to be reproducing? How does it reproduce? You will not see a nucleus in these cells with an ordinary school microscope. Label "mother" and "daughter" cells in your diagram.

4. How does bread mold reproduce? Place a slice of bread on moist blotting paper in a dish and sprinkle some dust on it. Cover and put it away in a dark warm place. Examine it morning and evening for several days. When threads begin to appear, observe them closely with a magnifying glass and take notes. What color are the threads or hyphae? What do you see on the ends of some of the hyphae? How do these ends change after some days? These structures contain tiny spores that may grow into new hyphae. What makes the bread mold look black? How does the bread mold get the food used in this growth?

5. Mold reproduction studied with a microscope. Examine a bit of the mold mounted in a drop of water under the low power of the microscope. Can you find structures which seem to hold the mold to the bread and absorb food? Examine spore cases. Do you see anything that suggests how the spores escape? Draw what you see. How is this type of reproduction like and how is it unlike that of an ameba? What is it called?

6. How does Spirogyra reproduce? If no living material showing conjugation is available, use prepared slides. Find two filaments which are lying side by side. Look for cells in which a bridge is beginning to form. Find a completed bridge. Do you see any cell bodies crossing from one strand to the other? What can you call these? How do they get across? The other cells are the passive gametes. Have any of the gametes gone completely across? How do you know? Find a cell that has been formed by the fusion of two gametes. Can you see the fused nucleus? Explain.

How does the fused cell or zygospore compare in size with the original cells? How can you tell that the zygospore has a thick wall? You will find no zygospores growing into new plants. Why not? Draw and label all parts.

7. How do paramecia conjugate? Examine prepared slides.

8. Make a table, listing each kind of asexual reproduction, with examples, and brief descriptions. Do the same for sexual reproduction.

Further Activities in Biology

1. If you have a rich culture of Paramecium, prepare several stained slides to show fission. A simple stain is Lugol's solution (potassium iodide and iodine in water).

2. Make an exhibit of models showing reproduction in ameba.

3. Devise an experiment to find out how the rate of budding in yeast is affected by the amount of sugar in the solution.

4. Mushroom spore prints are made by standing the mushroom upright over a sheet of white paper in a box (so that the spores will not be blown about). Spray the sheet with "Fixatif," using an atomizer.

5. Will lowering the temperature of the water cause Spirogyra to conjugate? Keep a jar of Spirogyra in a basin of chilled water and examine at intervals under the microscope.

PROBLEM 2 *How Do the More Complex Animals Reproduce?*

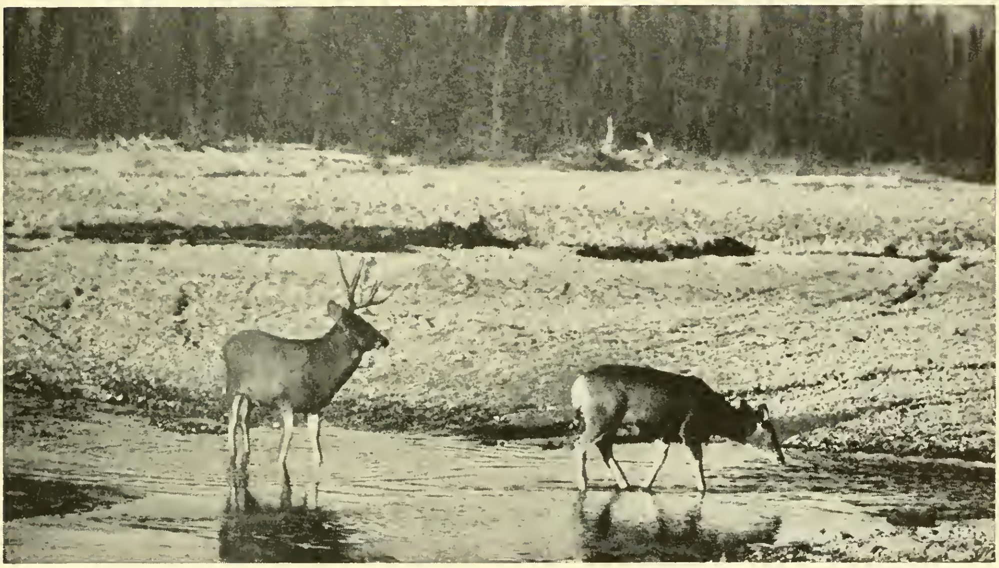


FIG. 368 *What distinguishing secondary sexual characteristics do you see in these deer?* (CANADIAN TRAVEL BUREAU)

Male and female. Just as in the more complex animals there are special organs of digestion and circulation, so there are special organs of reproduction. The male reproductive organs, called *spermaries* or *testes* (singular, *testis*), produce the male gametes or sperms; the female organs, called *ovaries*, produce the female gametes or *ova* (eggs). In a few kinds of invertebrates, earthworms for example, both male and female organs are in the same individual. But in most animals the organs are in separate individuals.

In some kinds of animals it is difficult to distinguish males from females without cutting the animals open to examine the reproductive organs. Other animals develop *secondary sex characteristics* which distinguish the two sexes. For example, in some species of birds the feathers of the male are much more brightly colored. The striking differences between males and females in some wild bird species make an interesting study. See EXERCISE 1. Frequently the males are larger and more powerful than females.

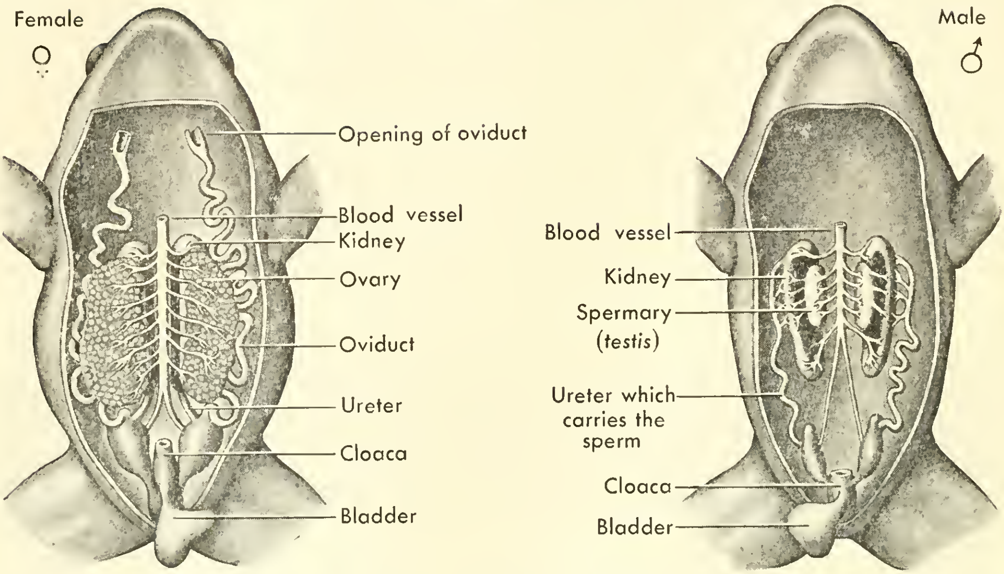


FIG. 369 *Reproductive and excretory organs of the male and female frog. When the eggs are full grown, just before being laid, the ovaries are twice as large as indicated in this drawing. How do the male and female organs compare in size?*

This is true of many mammals. See Figure 368. Among certain spiders and insects on the other hand, the female is the larger and the more ferocious. The smaller male may even end up in the stomach of his mate. Among human beings, besides certain differences between the sexes in bodily size and strength, there are differences in the growth of hair on the face and in the voice.

Secondary sex characters are caused by hormones. Several hormones are formed in the male organs, and others in the female organs. Being hormones, they are carried in the blood to all parts of the body, and their action results in the development of secondary sex characters.

The sex organs. Spermaries and ovaries are usually in pairs. Leading from them there are tubes which carry the gametes to the outside. In the male there are narrow *sperm ducts* leading to other tubes, not directly to the outside; in the female there are wider oviducts (oh'vee-ducts). In the frog the ovaries occupy an unusually large part of the body cavity. If you study Figure 369 and then examine the reproductive organs of a dissected frog, your study of reproduction will be more interesting. See EXERCISE 2.

The gametes. The two kinds of gametes, eggs and sperms, are clearly different in structure. Egg cells are usually spherical (like a ball). They vary in size. In mammals they are microscopic; in birds they may reach an enormous size. In the hen's egg the yolk is a single egg cell; it is so large because it contains a great amount of food material. All eggs have a nucleus, a cell body of cytoplasm, and a membrane around the cell body. Except for the extraordinarily large amount of food material in some eggs, they are much like other cells.

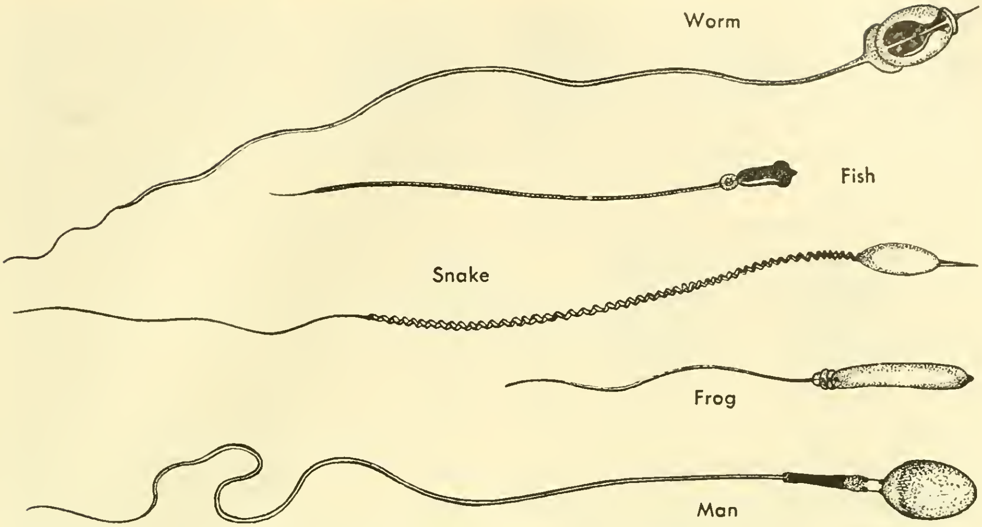


Fig. 370 (above) *Sperm cells from five kinds of animals. In what respect do these five sperm cells resemble each other?*

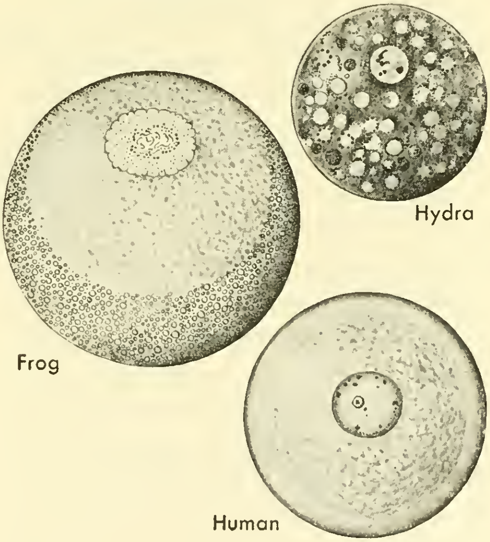


Fig. 371 (right) *These egg cells are not drawn to scale. In what ways, other than in size, are they alike and different?*

The male gamete, or sperm cell, is always very much smaller than the egg cell. It is always microscopic. The cell consists of little more than nucleus and membrane. A tiny bit of cytoplasm is around the nucleus and is drawn out into a long, thin tail. Normally, this tail lashes back and forth, and so propels the sperm cell through any liquid. You can see sperm cells if you do Exercise 3.

Fertilization. Fertilization can take place only if the two gametes meet. Among the various kinds of organisms there are various ways in which this happens. Let us consider first a water-living organism, a fish. At certain seasons, often in the spring, egg cells develop in the ovaries of the adult female. They become separated from the other cells in the ovaries in one or several large masses, consisting sometimes of several million eggs. The egg cells enter the oviducts and are pushed along by cilia lining the tubes. They leave the body by an opening on the lower (ventral) surface. In fish this releasing of egg cells is known as *spawning*. Similarly, the male releases the sperm cells, close to the eggs.

If you could place fresh fish eggs and sperms on a slide under the microscope, you would see the sperms lash their tails and move among the egg cells. Many sperms gather around one egg as if in response to a chemical stimulus. Soon one sperm cell pushes through the cell membrane into the cytoplasm of the egg. The sperm nucleus moves toward the nucleus of the egg and fuses with it. Fertilization has been accomplished; the egg is now a fertilized egg. As soon as one sperm has entered the egg, a tough membrane known as a fertilization membrane forms around the egg and no other sperms can enter. The fertilized egg (or zygote) develops into a new individual.

Is fertilization necessary for development? As a rule eggs do not develop into mature organisms unless they have been fertilized. But there are some exceptions. Plant lice (aphids) have a complicated life history. In the fall they lay fertilized eggs. These winter over and in the spring develop into young females which bring forth live young. They form eggs within themselves which are never fertilized but which develop into new organisms within the parent. Reproduction by means of unfertilized eggs is called *parthenogenesis* (parth-en-oh-jen'e-sis). Bees also may reproduce by parthenogenesis. You have read that the queen bee lays all the eggs. Some of these eggs are unfertilized and develop into male bees (drones). Most of the eggs are fertilized and develop into queens (true females) or into workers (females with incomplete reproductive organs). Whether a fertilized bee egg develops into a queen or a worker depends upon the kind and amount of food supplied by the workers.

Parthenogenesis made to occur in the laboratory. Jacques Loeb, a great biologist, performed many experiments to learn whether eggs could be made to develop without fertilization. In one series of experiments, he transferred the eggs of a sea urchin (a salt water animal) from one particular salt solution to another. This treatment caused some of the eggs to begin their development, even though no sperm had entered. The developing sea urchins had no fathers. In another experiment thousands of frogs' eggs were pricked with a needle; about 200 developed into tadpoles and nearly 100 of these continued their development and became adult frogs. These experiments have been repeated with the same results, and other experiments have been performed. Unfertilized eggs have been made to develop by the use of heat, acids, various salts, electricity, and other agents. Sometimes the eggs developed only partially; sometimes they developed into adult animals. Among the other animals produced from eggs by *artificial parthenogenesis* are starfishes and at least one rabbit.

The fertilized egg becomes an embryo. Let us study the development of a fish. This will help us understand the development of other animals. If the temperature and other conditions are suitable, the nucleus of the zygote (fertilized egg)

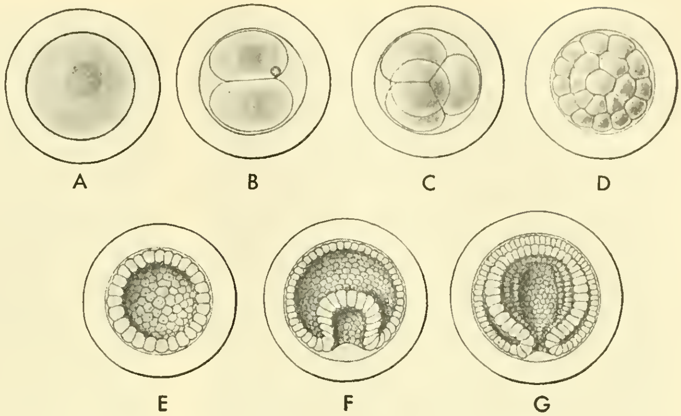


FIG. 372 *Development of the fertilized egg of a simple animal.* A, B, C, *and* D *show cleavage of the egg.* E, F, G, *are sections of later stages. What do they show? How do you explain the very slight increase in size?*

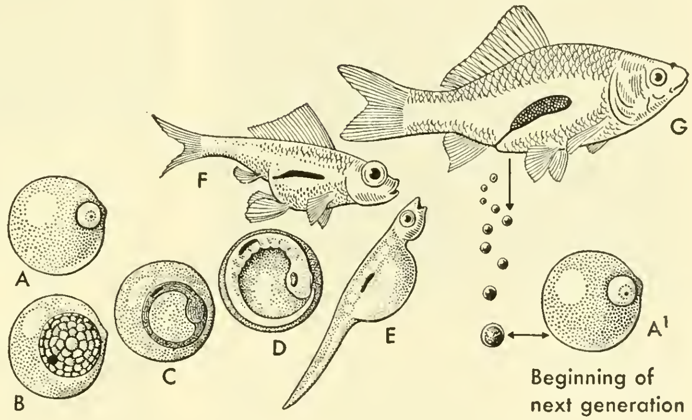


FIG. 373 *From fertilized egg, through embryonic stages, to adult fish. In* E *the "yolk sac" is seen even after the egg hatches. Of what use is it to the growing animal? Note the solid black spot in* D, E, F, *and* G. *The cells here remain undifferentiated at first, and later, in* G, *grow into what organ?*

and the cell body immediately divide. The nucleus begins the division. The two cells remain attached to one another but do not grow larger as most cells do after division. They keep on dividing again and again until after a few hours there is a ball of smaller cells. Divisions of the fertilized egg of a simpler animal are illustrated in Figure 372. In the fish and in all the higher vertebrates the changes are similar but more difficult to indicate in a diagram. The repeated division of the fertilized egg without growth of the cells is called *cleavage* (kleev′aj). Then the cells in the ball become arranged into a larger hollow ball. (The hollow ball is called a *blastula* — blast′you-la.) Still floating in the water the hollow ball of cells sinks in on one side so that it is no longer spherical but forms a double-walled cup (the *gastrula* — gast′roo-la). A diagram of this cup is shown in F of Figure 372. From the time of the first division and through early development the organism is called an *embryo* (em′bree-oh). This description of the development of an embryo holds for all except the simplest of animals. It is possible to see all these stages of development by examining prepared slides. See EXERCISE 4.

If you study next the figure that shows the development of the fish egg (Fig. 373) you will see that part of the egg never goes through cleavage. This part remains as an undivided mass of food or as a "yolk sac" shown in A to E. Because of the yolk sac it is difficult to see the hollow ball and cup stages of the embryo, but they do form.

Germ layers and tissues. The double-walled cup (gastrula) develops a third layer of cells, which lies between the original two layers. There are now three *primary germ layers*. The outer germ layer is the *ectoderm* (ek'toe-derm), the inner is the *endoderm*, and the middle layer is the *mesoderm*. The further development of the three-layered cup is complicated. It took years of study for biologists to discover and describe the many changes that occur. It would take months of study to follow their descriptions. But briefly this is what happens. Cell division continues. The cup lengthens and takes on the outlines of a fish, lying somewhat curled up on top of the yolk sac. By this time there are thousands of cells. These change in various ways and become the tissues, organs, and organ systems of the baby fish. The process by which the many different kinds of tissue cells are produced is called *differentiation* (diff'er-en-she-a'-shun).

The body covering and the nervous system are formed from the ectoderm. From the endoderm are formed the lining of the alimentary canal and several important organs, such as the liver, the pancreas, the thyroid gland and the respiratory system. The alimentary canal develops slowly, the mouth forming from an opening that appears at the closed end of the cup stage of the embryo. From the mesoderm are formed the muscles, bones, blood vessels, the sex glands, and some other body parts. What you have just read about the formation of primary germ layers and differentiations occurs in all higher animals as well as in the fish.

Development is completed. During all this time no food is taken in from the outside. Any slight increase in size is caused by addition of water which enters from the surroundings. The developing animal lives on the foods stored in the original large egg cell. As the animal grows the yolk sac shrinks. By the time the yolk sac is used up the baby fish has organs for food getting and locomotion. When the tiny animal has organs of digestion, breathing, locomotion, and other organs that enable it to keep alive by itself, the embryo stage has ended. This development takes about two weeks in some fish, a longer time in others. See EXERCISE 5.

How reproductive organs develop. You have traced the development of a baby fish from the uniting of the egg cell of its mother and the sperm cell of its father. But in time the baby animal will itself become a parent; one generation follows another.

The reproductive organs do not develop at the same time as the other organs. This is what happens. Early in the development of the embryo, when some cells begin to lengthen into muscle cells or change into any of the other tissue cells (differentiation), a small group of cells remains almost unchanged. Even after the embryo has become a young fish, these cells have not changed to any extent; they have remained as undifferentiated cells.

FIG. 374 *The male sunfish guards the nest he has dug in the sand.* (ENCYCLOPAEDIA BRITANNICA FILMS, INC.)

FIG. 375 *The nest of the stickleback is made of water weeds glued together with a sticky substance secreted by glands in the body of the male. He guards the eggs that the female places in the nest.* (NEW YORK AQUARIUM)

As the fish develops, sex organs are formed partly from these unchanged cells. Then, when the fish has grown to full size, the unchanged cells in these sex organs develop into eggs or sperms. In a female there will be eggs; in a male, spermaries have grown and the gametes are sperms. Thus you see that, while the sperms and eggs are found only in the fully developed fish, the cells from which the gametes came were already present in the very young embryo.

What protection do parent fish give their young? Many kinds of fish deposit eggs and sperms and leave them unprotected and exposed to the elements and to many enemies. A few kinds scoop out a small depression in the sand or gravel under the water and deposit eggs and sperms there. Probably many eggs fail to develop because no sperms reach them. Of those that are fertilized countless numbers are destroyed, for the parent rarely stays to protect the young. Some of the exceptions are interesting. In one kind of fish, embryos are carried about in the mouth of the male parent. Even after they are sizable fish they keep returning to his mouth when danger threatens. How often he yields to the temptation of hunger no one knows. Another exception is the male *stickleback* which builds a true nest and guards the eggs.

Frog reproduction. In the early spring frogs and toads lay their eggs in quiet waters. When mating occurs, the male frog is above the female so that as the

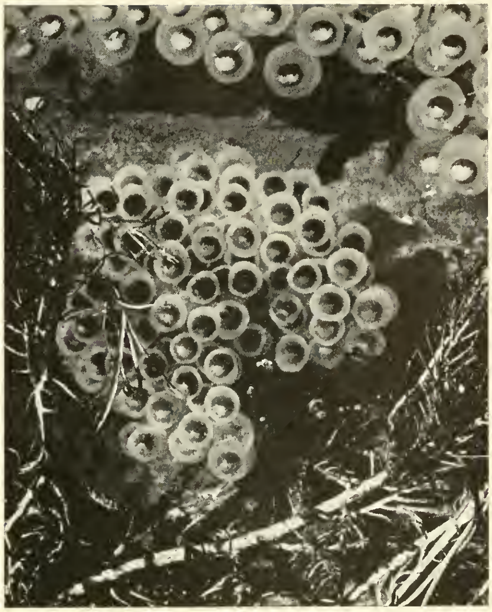


FIG. 376 *Eggs laid by a frog. Each is coated with a jellylike substance which swells in water.* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 377 *A tadpole changes into a frog. What is the first sign of its becoming a frog?* (NEW YORK ZOOLOGICAL PARK)

eggs come out, the sperms are deposited on them. The chances of fertilization are good. As each egg passes through the oviduct it is coated with a thin jellylike material. The sperms pierce this layer, which then swells as water is absorbed. The jellylike material protects the eggs by holding them together. The large slippery mass is difficult to grasp and is not easily eaten by other animals.

The early stages of the development of the fertilized egg are much like those of the fish. But when the organs form and the body takes shape, the embryo does not resemble the parent frog; it is fishlike. We call it a *tadpole* or a *pollywog*. It gets dissolved oxygen from the water by means of two feathery gills which project just back of the head. Young tadpoles wriggle occasionally or hang quietly attached to water plants by means of a sucking organ at the front of the head. Soon the tadpole swims by means of its tail; a mouth forms with horny jaws well fitted for eating plants; and internal gills replace the external gills with which it began. You can see these changes if you are fortunate enough to have live material. If not, use museum preparations as described in EXERCISE 6.

After living this way for several months, or longer in some species, the tadpole goes through other changes. Two lumps appear near the hind end of the tadpole's body, one on either side of the tail. Slowly legs push out here. If you cut the tadpole open at this time,

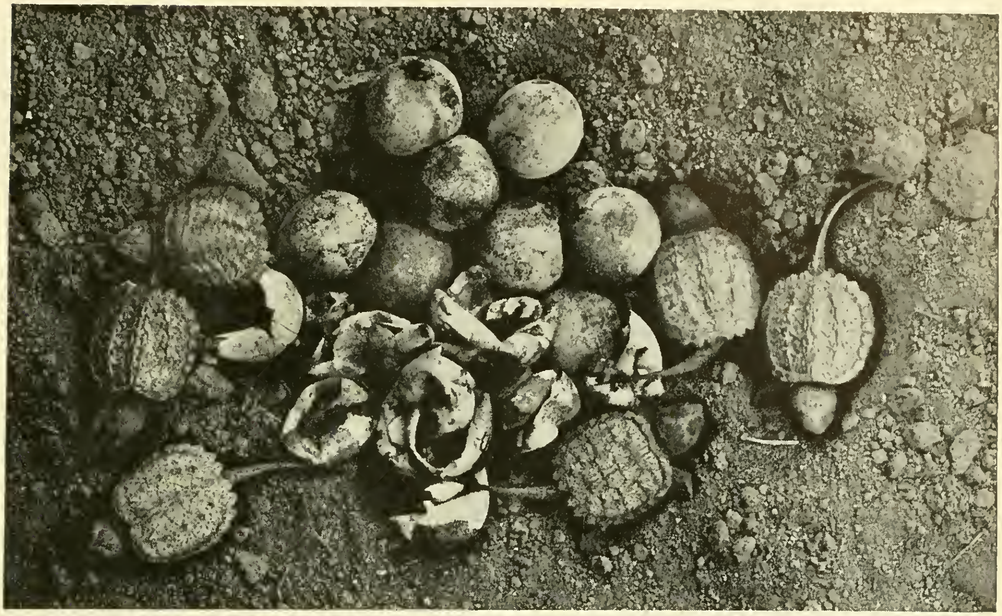


FIG. 378 *Baby snapping turtles. Reptiles have internal fertilization. In some kinds, the eggs hatch inside the female's body, but most reptiles lay eggs that are covered with a leathery shell.* (AMERICAN MUSEUM OF NATURAL HISTORY)

you would find the little front legs already formed under the skin. Its organs of digestion and circulation are different from those of the parent frog; they too undergo changes. Within the two-chambered heart a wall grows, making three chambers. The long, coiled digestive tube gradually forms a true stomach and intestine, much shorter than the original tube. Lungs form; the gills disappear. The tail gradually grows shorter. It is absorbed or in other words it is used as food while the tadpole is changing. Tiny teeth appear in the mouth and the long tongue develops. The animal now feeds on insects and spends part of its life on land. When it is swimming and floating in the water, it must come to the surface from time to time to breathe, even though it gets some oxygen through its skin. In its habits and its appearance it is very different from the tiny tadpole that hatched from the egg. When striking changes of this sort occur between the embryo stage and the adult, the development is called a *metamorphosis.*

Reproduction in land-living animals. In animals that live their whole lives on land, or in amphibious animals that reproduce on land, fertilization takes place inside the body of the female. If this were not the case, these species would have died out since eggs and sperms dry up and die when exposed to air. In internal fertilization the male puts the sperms directly into or near the oviduct of the female. The sperms are in a liquid medium when they are introduced. By lashing their tails they can swim to the egg cells which have passed from the ovary into the oviduct. There may be one or

FIG. 380 (above) *Where did the larvae of these wasp cocoons get food?* (AM. MUS. OF NAT. HIST.)

FIG. 379 (left) *The male midwife toad carries the eggs about with him until they hatch into tadpoles.* (AM. MUS. OF NAT. HIST.)

large numbers of eggs fertilized at one time, depending partly on how many eggs have entered the oviduct. In many kinds of animals a protective covering promptly forms around the fertilized egg or eggs, which are then laid.

Among many kinds of animals interesting examples of instinctive behavior are shown in the care of these fertilized eggs. The crayfish may carry the eggs about with her, suspended from the abdomen. Insects often lay their eggs where they will escape observation. The female grasshopper uses a special organ at the tip of the abdomen to dig a hole for each egg, which remains well protected against enemies and cold. Flies find various kinds of decaying material in which to deposit their eggs; when they hatch, the young are near suitable food. The ichneumon fly starts her brood in the body of a particular caterpillar which will later serve as food for her young. In another kind of insect which also lays eggs in the bodies of large caterpillars, the larvae later chew out of the caterpillar's body and spin cocoons on the outside. See Figure 380.

Reproduction in birds. Only one of the two ovaries develops in birds. The ovary of the hen is readily seen when the organs of a freshly killed chicken are removed. See EXERCISE 7. There are egg cells of many sizes in this ovary. As each egg cell reaches its full size, it leaves the ovary and passes into the oviduct. You know the egg cell as the yolk of the hen's egg. If the male bird has previously introduced sperm cells into the oviduct, they have travelled up the duct to a pouch near the upper end. As the egg cell enters the oviduct it is fertilized by one of these sperm cells. The fertilized egg cell then travels along the oviduct on its way to the exterior. In passing, it is wrapped in protective coverings of various kinds. Study an egg by doing EXERCISE 8. It is surrounded first by the white of egg (albumen). This not only helps to protect the developing embryo but later serves as food for it. Further along, the oviduct secretes two thin but tough membranes around the egg and lastly a hard shell.

In the meantime the fertilized egg has begun to divide; but by far the greater part of the development occurs after the egg has left the body of the mother. This development does not take place unless the egg is kept warm. Generally the bird sits on the eggs during an incubation period, which lasts about three weeks.

FIG. 381 *Young grouse hatching from eggs laid on the ground. How will the feathers look when the birds are a few hours older?* (FRANK GEHR)

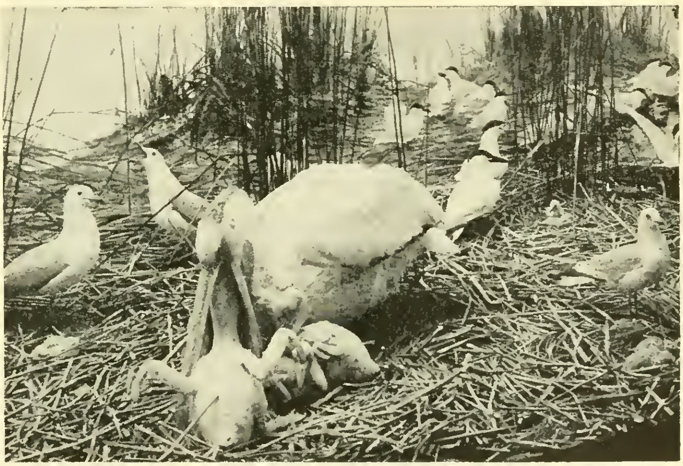


FIG. 382 *Pelican feeding its young. In what respects is the young bird undeveloped? Compare it with the parent bird. The birds at the extreme left are gulls.* (AMERICAN MUSEUM OF NATURAL HISTORY)

At the end of this time the food from both yolk and albumen covering has been absorbed and the organs of the young chick have been formed. By means of its bill it cracks the shell and pecks its way out into the world. Development of the chick can be traced on stained microscope slides, in museum preparations, by moving pictures, or by placing a dozen or more fertilized eggs in an incubator and opening one every day or so. See EXERCISE 9.

Instincts of young and parent birds. Baby chickens, ducks, turkeys, gulls, and the young of some other birds need relatively little attention from the parents. They leave the egg fully equipped to go out with the mother in search of food. They are completely covered with downy feathers, their muscles are well developed, their sense organs perfected.

The young of other birds, such as the songbirds and pigeons, are immature when they hatch. They are completely dependent on their parents' care for several weeks. Newly hatched sparrows are naked, their eyes are closed, and the muscles of their wings and legs take days

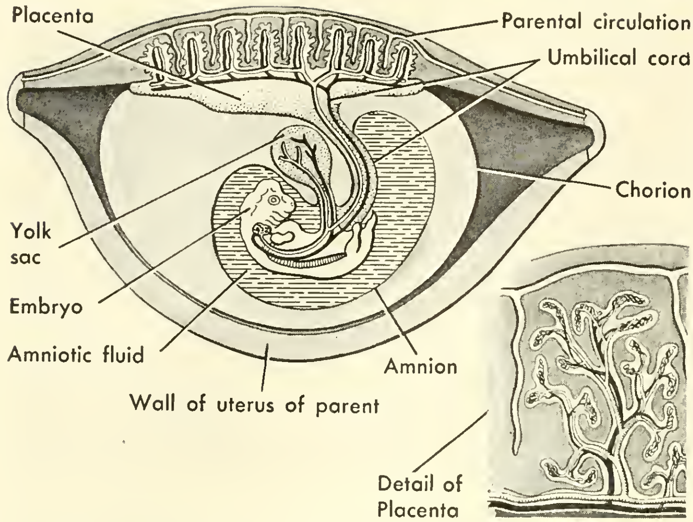


FIG. 383 *In all mammals except a few from Australia, the young develop within the mother's body. The embryo becomes attached to certain membranes of the uterus by a placenta. How does the developing embryo obtain food and oxygen and get rid of waste products?*

to develop. Their appetites are enormous, and the parent birds make hundreds of excursions every day in search of food for them.

When the young birds get a little older they must learn to fly. The parents often force the young to make their first attempt by pushing them out of the nest. But growth and development are slow. Thus among some birds there is a type of family life in which, usually, both parents play an equal part.

Reproduction in mammals. Fertilization is internal in the mammals, even in those few species, like the whale, that spend their lives in water. We say that their young are "born alive" but what we mean is that the young develop within the mother. A bird's egg when laid is also very much alive but undeveloped. In practically all mammals the young develop inside the body. But internal development occurs also at times among plant lice and among some species of snakes. Some fish are also born alive, as you know if you have ever raised guppies. There is a difference, however, in the way the mother among mammals supplies food and oxygen to the developing embryo and removes the wastes from it. You will learn about this presently. In review do EXERCISE 10.

How rabbits reproduce. Let us study rabbit reproduction as an example of reproduction in a mammal. Rabbits have several litters of young in a year. At certain times the ovaries release from one to ten mature eggs. At this time the male is attracted to the female and sperm cells are placed in the lower part of the oviduct. These travel up the oviduct. Fertilization occurs in the upper portion of the duct and the egg cell begins cleavage, going through much the same stages — hollow ball, two-layered cup, formation of three germ layers — that occur in the development of the fish. Before development progresses very far, the embryo comes down to an expanded portion of the oviduct, a sac called the *uterus* (you'ter-us). In some mammals the two oviducts unite, forming a single uterus. The rabbit embryos, surrounded by membranes, attach themselves to the

FIG. 384 *The Wallaby is one kind of kangaroo.* (NEW YORK ZOOLOGICAL PARK)

walls of the uterus. The region of attachment, called the *placenta* (pla-sen'ta), is formed partly from the membranes of the embryo and partly from the lining of the uterus. If several embryos develop at the same time, which is what commonly happens in rabbits, each usually has its own placenta. A cord grows out of the embryo to the placenta. Very early in the embryo's development a simple heart and blood vessels form. Several large blood vessels run from the embryo through the cord. They end in capillaries in the placenta, and the blood is returned by large vessels through the cord. The capillaries in the placenta lie close to other capillaries which are part of the mother's circulatory system. In the placenta food and oxygen diffuse from the mother's blood through the capillary walls into the embryo's blood stream. Likewise, carbon dioxide and other wastes diffuse out of the embryo's blood into the parent's blood. Blood from the parent never flows directly into the embryo; there is no direct connection between the two circulatory systems.

In this way the rabbit embryo is nourished and continues growing for about thirty days. At the end of this period the muscular walls of the uterus contract violently, the contractions causing the young animal together with the placenta to be detached from the uterus. Through further contractions the embryo and the placenta are pushed through the vagina (va-jeye'na), the passage which leads from the uterus to the outside of the body. In all mammals development and birth occur in the same way. But the period of internal development, called *gestation* (jes-tay'shun) varies in length. In the dog it is longer, about 9 weeks. In the cow it is a little over 9 months; in humans about 9 months; in elephants, almost two years. Now do EXERCISE 11.

Care of the young. The amount and kind of care given by mammals varies with the species, but all feed the young on milk produced in mammary glands. Milk is not secreted by the mother until after birth of the young. You may know that farmers cannot expect to milk a cow until after the cow has a calf.

Kangaroo and opossum babies are very immature when born. The mother immediately puts them into a pouch inside of which are located the mammary glands. There the young receive warmth, protection, and a constant supply of food. Among few mammals are the young so immature when born. But in many, such as the dog, cat, mouse, guinea pig, and rabbit, the young are born blind and are almost helpless. When the human baby is born, its eyes are open, but it is entirely helpless and dependent upon the care of parents. On the other hand, the babies of grazing animals are much more independent. They are able to stand, even to walk awkwardly, and are well protected by a coat of hair.

Family life in animals. Among animals that are born or hatched in so immature a state that they cannot obtain their own food there is found some kind of family life. This is true of most birds and of mammals. And where there is family life the number of offspring is always comparatively small.

Family life may continue for many weeks or even years, as among elephants and human beings. In such cases parental care means much more than supplying food and hiding the offspring. The young have an opportunity to learn how to get along in the world. When the lion drags wounded prey to its lair, the cub learns to tear the flesh. To what extent it watches and imitates its parents is not known, but at least it practices the use of claws and teeth. Among apes and especially among human beings there is much learning. The young mature so slowly that family life continues for many years.

Successful reproduction. All species now in existence are successful in producing offspring that survive. If not, the species would have died out long ago. In the more complex animals, as you have just read, the number of offspring is relatively small but the parents protect and feed the young. In some other animals the eggs and embryos and young are fitted in one or more ways to survive the dangers to which they are exposed. Yet in many species there is no protection of any kind and the possibilities for destruction are very great. These species survive because they reproduce in enormous numbers. A female cod, for example, may lay 8,000,000 eggs every season. If only one male and one female of that 8,000,000 grow up and reproduce, the species is provided for. If larger numbers grow up and reproduce, the species will be on the increase.

Questions

1. What are the male reproductive organs called? What are the female organs called? What causes secondary sex characters? Give examples of secondary sex characters in birds, in deer, and in man.
2. Describe the sex organs of a male and female frog.
3. Name the male and female gametes. How do they differ from each other in structure and in size?
4. Describe spawning and fertilization in fish. What name is given to a fertilized egg? State three ways in which it differs from an unfertilized egg.
5. Give two examples among insects of development of the egg without fertilization.
6. By what two methods did Jacques Loeb obtain parthenogenetic animals?
7. Describe the cell divisions which immediately follow fertilization. Describe the changes that occur in the mass of cells. What is an embryo?

8. Name the three germ layers and state which organs or tissues are formed from each.
9. How does the fish embryo get food while the organs for food-getting and locomotion are in the process of development? When is the embryo stage completed?
10. Which organs are the last to be fully developed? When and how do these organs originate?
11. Is protection of the eggs or young the usual or unusual condition in fish? Cite exceptions.
12. When, where, and how are frog eggs fertilized? Give the important stages in the metamorphosis of the frog.
13. How does fertilization in land-living animals differ from that in the fish or frog? How is internal fertilization an advantage to the species? Give examples of instinctive behavior in connection with care of eggs.
14. Why is the thick shell of the bird's egg no hindrance to the entrance of the fertilizing sperm? What in fish development corresponds to the yolk of the hen's egg? Describe and explain the origin of each part of the bird's egg. How long does chick development take? What care is taken of the eggs during this time?
15. Describe some of the instinctive behavior shown by young and parent birds.
16. Compare reproduction in mammals and fish as to: (*a*) fertilization, (*b*) development of embryo, and (*c*) food and oxygen used by embryo.
17. Using all the terms given, explain where the rabbit embryo develops, how it is protected, and exactly how it receives food and oxygen.
18. In what respect is the care of all mammals the same? How does the care differ among various mammals? Give examples.
19. What relation is there between family life and the number of offspring?
20. If codfish, for example, are not on the increase what proportion of the female gametes develop and grow to maturity? What might be the result if the codfish produced fewer eggs?

Exercises

1. How may the sexes be distinguished in some birds? Examine pictures or specimens of both sexes of various species of birds. What differences do you note between male and female? Can you see any advantage in having the female less brightly colored? If pictures are available, trace the outline of the birds through glass and color with crayons or paint.

2. *Demonstration.* The reproductive organs of the frog. Study freshly killed or, if necessary, preserved male and female frogs. Compare the external appearance. Can you distinguish male from female? During the breeding season the male has enlarged thumbs. Are they visible? How can the sexes be distinguished after dissection? How many spermaries has the

male? In what part of the body do they lie? The sperm ducts are very small so you may not find them. Through them the sperm cells enter the kidney, whence they are carried to the exterior. How do the egg-producing organs (ovaries) of the female differ from the spermaries of the male? Can you find ducts which might be oviducts? How many are there? Note that the oviducts are larger than the sperm ducts. Study some of the eggs from the ovary. Note the color. Estimate the number of eggs in one ovary.

3. What is the structure of a sperm? Crush the spermary of a freshly killed frog (or the seminal vesicle of an earthworm) under water. Examine a drop under high power. Describe what you see. Examine a prepared slide of mouse or rat sperm. In what ways are the sperms alike?

4. What are some of the early stages in the development of the fertilized egg? Use prepared slides showing the early development of a starfish or sea urchin. Find and draw one, two, four, and many-celled cleavage stages. How do they compare in size with the fertilized egg cell? Explain. Find a clear section of a hollow-ball stage; of a cup stage. Draw. How many layers of cells does the wall of the cup (gastrula) contain?

5. *Demonstration.* Development of the fish. Using a museum preparation or chart study the changes which occur as the fertilized egg develops into an embryo. Examine the egg closely for the first indication of the formation of an embryo. At this stage has the egg changed in size or shape? As the embryo grows larger, what happens to the egg?

6. *Demonstration.* Development of a tadpole into a frog. In the spring gather frogs' eggs and watch their development. (Water must be changed frequently.) At other seasons, examine museum preparations or charts. How does the tadpole feed? Describe the changes in its feeding and locomotion as it grows older. Which legs appear first? Look for the legs just before they break through. How does the tail disappear? Explain.

7. How do the reproductive organs of the hen differ from those of the female frog? Examine the organs taken from a chicken prepared for cooking. Do you find eggs? How many? What size are they? What indication is there that the eggs are not all produced at one time? Is the same thing true of the frog or fish? How many ovaries and oviducts do you find? Where must the white of the egg and the shell come from? Where must the egg be when it is fertilized? How do you know?

8. What is the structure of a hen's egg? Crack a raw egg into a saucer. What do you find directly under the shell? How many membranes do you find? Examine the shell and the membranes at the blunt end. What do you discover? The yolk is the egg cell. What makes it so large? Do you notice a tiny white spot on the yolk? This is the protoplasm and nucleus which receive the sperm cell. Of what use to the growing embryo is the white of egg? The shell? The membrane? Compare with starfish or sea urchin egg (prepared slide), or frog or fish egg from a dissected animal. How does it differ? When eggs, like birds' eggs, have heavy coverings, what do you know about the type of fertilization of that animal?

9. *Demonstration.* Development of the chick. Stained microscopic slides may be examined with a hand lens for the early stages. Look for the heart and the beginnings of the nervous system in about thirty-six hours. Later stages show the limb buds and the eyes. A museum preparation or a chart will show the later development of a chick. Which part is proportionately large in the early stages? At what stage does the embryo begin to look like a bird? When do the feathers appear? When are you sure that it is going to be a chicken and not a duck?

10. In review fill out a table. Rule vertical lines and write at the top these headings: reproductive organs, secondary sex characters, gametes, fertilization (whether external or internal), development (whether external or internal), care taken of young. Leave the last column without a heading. Fill in the table for the following animals: codfish, frog, turtle, snake, chicken, and deer. In the last column state if possible about each animal whether the temperature necessary for development is obtained through sitting on eggs, water warmed by sun, body temperature, hot sand, or any other method.

11. Answer these questions: (*a*) How does the family life of a social insect like the ant differ from the family life of a bird? (Look back to Unit I.) (*b*) "In general, the more complex an animal, the longer the period of helplessness in babyhood." Cite examples that support this statement.

Further Activities in Biology

1. If you have the use of an incubator study the development of the chick. Be sure to get fertilized eggs, which can be bought from special dealers. Start with twenty-four eggs. Turn them twice daily. Open one every day. Perhaps someone could make models of the different stages.

2. Guppies and some other tropical fish bear the young alive. You will find it interesting to raise some.

3. Pigeon raising is easy if you have the use of a roof. Get instructions when you buy your first pigeons.

4. If you have an opportunity to observe a litter of kittens, puppies, white mice, or rats watch for indications of parental care. To what extent are the young taught by their parents?

5. Report on the work of Dr. Jacques Loeb on the artificial fertilization of the eggs of the sea urchin.

6. Raise tadpoles from frogs' eggs.

7. Make wax or plaster models of the cleavage, hollow-ball (blastula), and cup (gastrula) stages of some simple form such as the starfish.

PROBLEM 3 *How Do the More Complex Plants Reproduce?*

What are seeds? When farmers want oats, wheat, squash, or beans, they plant seeds. It would be interesting, therefore, to find out what is in a seed. We can do this by studying large seeds such as peas, beans, or corn. When we study these seeds, which differ from others only in size or in other unimportant ways, we find that each seed contains an undeveloped plant. This undeveloped plant is the embryo. If you put some soaked seeds into moist sawdust or sand you will see, after some days, that the *seed coats* have been burst by the growing embryo, which soon develops into a seedling. We speak of this growth as *germination* of the seed. EXERCISES 1 and 2 will help you understand what a seed is.

How are seeds formed? It took scientists many years to discover just how

FIG. 385 *This oak seedling has burst open the coats (seed and fruit) which covered it. It is growing on the food stored in the seed.* (AMERICAN MUSEUM OF NATURAL HISTORY)

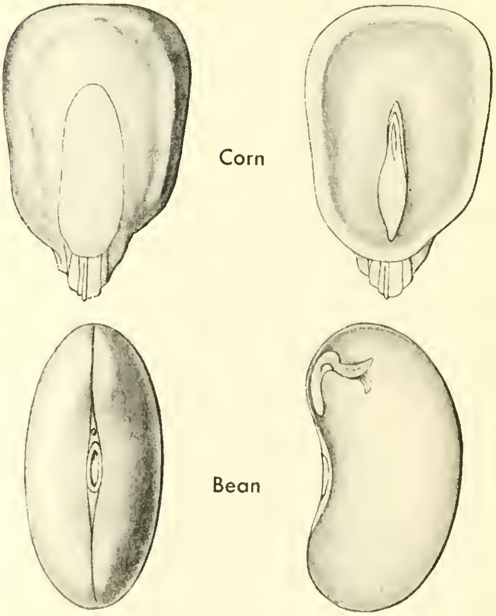


FIG. 386 *All the tissues within the bean seed coats* (below) *is part of the embryo. In corn* (above) *the embryo is buried in a mass of food-storage tissue* (*endosperm*).

seeds are formed. Finally, they discovered that reproduction in seed plants is in many respects like reproduction in complex animals. The embryo you found in the seed grows from a fertilized egg cell which is formed by the union of two dissimilar gametes. The gametes, as in animals, are sperms and eggs. But beyond this we must not expect to find much similarity since plants and animals are so different in structure. The plant does not have organs corresponding exactly to the spermaries and ovaries of an animal. Where are the sperms and eggs produced in plants? To answer this we must examine the blossom or flower.

The flower. Let us find out how a flower is constructed so that we may find the gametes and learn how the seeds are made. Tulips, lilies, or sweet peas are large and easy to study. See EXERCISE 3. The tulip has six brightly colored or white leaflike parts. They are arranged in an outer circle and an inner circle, each consisting of three parts. In many flowers the outer circle (*calyx*) is green and the parts are known as *sepals*. The inner circle (*corolla*) consists of bright *petals* which often are larger than the sepals. Inside the floral envelope is a circle of *stamens* (stay'mens). Each stamen consists of a threadlike part with a knob on the free end. In the very center of the blossom is a single *pistil*. The number, shape, size, and color of all flower parts are different in different kinds of plants. Often it is these differences which are used in classifying the plant.

Flower parts used in reproduction. It is the stamens and pistils that are used in

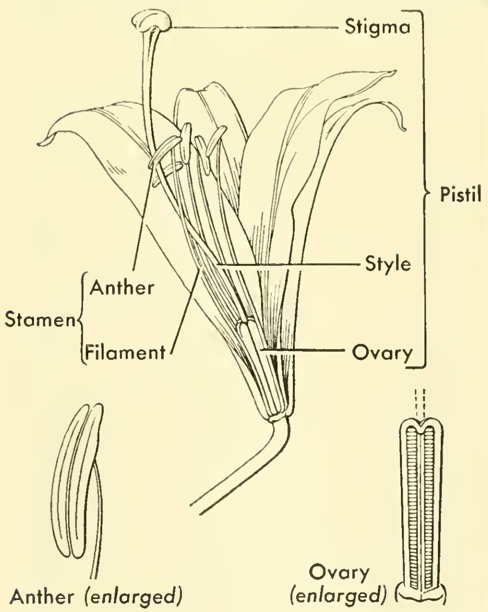


FIG. 387 *The flower parts of a lily. Two of the leaflike parts have been cut away. How many of each of the flower parts were there? Study the stamen and the pistil.*

FIG. 387a *X-ray of a lily. Petals and sepals are similar and attached to each other. There are six stamens, although the photograph seems to show three.* (GENERAL ELECTRIC X-RAY CORP.)

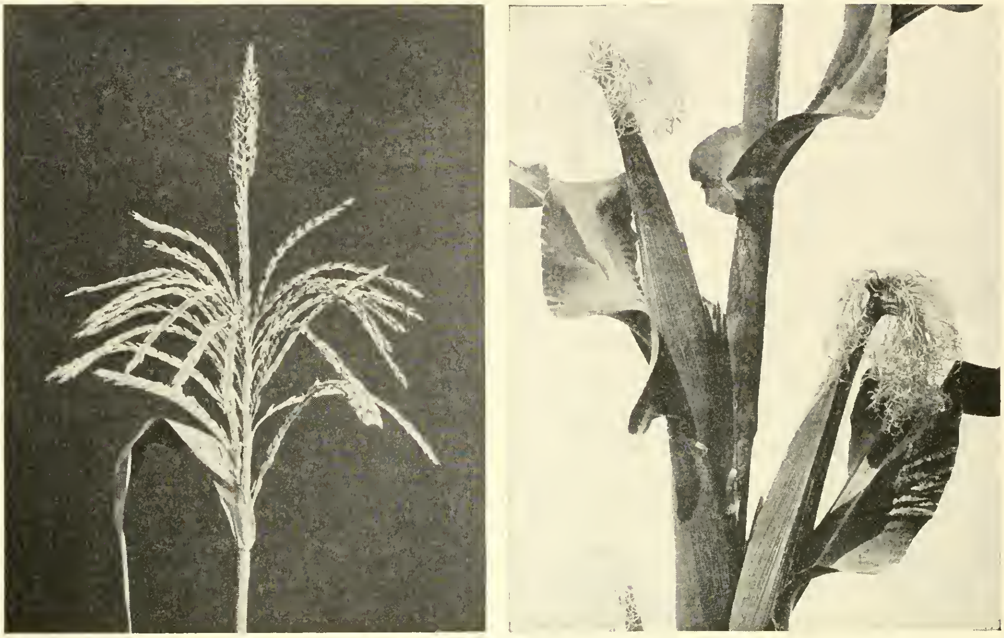


FIG. 388 *The corn plant has two kinds of flowers. One kind has only stamens. These are found at the top of the plant in the tassel* (left). *The ear of corn* (right) *is a group of flowers with pistils only. They are wrapped in the husks; only the ends of the pistils stick out.* (U. S. DEPARTMENT OF AGRICULTURE)

reproduction. For this reason the stamens and pistils are often called *essential organs.* They are essential to reproduction because they contain the gametes. The other flower parts, the sepals and petals, may help indirectly, but they are not necessary. Sometimes they are much reduced in size or even lacking altogether.

Certain species, such as corn and the willows, have stamens and pistils in separate flowers instead of in the same flower as they are in the lily or tulip. A flower that has stamens but no pistil is called a *staminate* flower. A *pistillate* flower is one that has one or more pistils but no stamens. In corn the two kinds of flowers occur on the same plant. Among willows, the staminate and pistillate flowers are found on different trees.

How the pistil is essential. A pistil consists usually of three parts: a top that is often flattened and broad called the *stigma;* a stem or neck below the stigma called the *style;* and a large thickened lowest part, the *ovary.* Examine Figure 387 to see these three parts. In tulips the style is very short. If you cut into the ovary, you will find *ovules* (oh'vules) within. The word ovule means little egg but this word is badly chosen, for an ovule is not an egg at all. In some kinds of flowers the ovary contains only one ovule; in others there are hundreds of tiny ovules crowded into the ovary. Ovules may be so small that one needs a microscope to see them but in many flowers they can be seen with the naked eye if you cut open the ovary. When

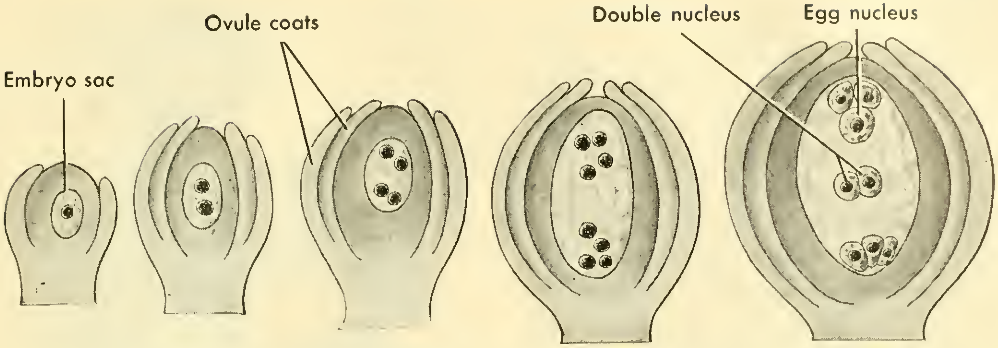


FIG. 389 *Diagrammatic sections showing a young ovule growing into a larger ovule. Note what happens to the nucleus of the large cell.*

FIG. 390 *This bee is gathering nectar from a blossom. How is the bee of help to the plant?* (U. S. DEPARTMENT OF AGRICULTURE)

you examine an ovule under the microscope, you will discover that it consists of many cells. Some of these cells form two protective coats around one very much larger cell. Study Figure 389 and you will see that the nucleus of this large cell divides until finally it is replaced by eight cells. Often these cells are not separated by membranes, so they look like one mass of cytoplasm with eight nuclei. One of these nuclei with its surrounding cytoplasm is the *egg cell*, or female gamete. Two of the other nuclei usually fuse and move to the middle of the large "cell" which is now called the *embryo sac*. The egg cell, or female gamete is the most important cell in the ovule. We shall see what happens to it and to the fused, or *double*, nucleus.

The stamen and pollination. The stamen is composed of a more or less slender stalk (*filament*) with a bulky pollen case (*anther*) on top. If you shake a ripe stamen, large quantities of powdery *pollen* will fall from the pollen case. In nature pollen often falls on a pistil. The top of a pistil, the stigma, is usually hairy or sticky. The pollen may be blown by the wind or may be accidentally carried by insects flying from one flower to another as they gather nectar. Thus, by wind, insects, birds, or other agents the transfer of pollen from anther to stigma is made. This process is called *pollination*. Transfer of pollen from an anther to any stigma on the same plant is called *self-pollination*. If pollen is transferred to the stigma on a different plant the process is called *cross-pollination*. If the pollen is carried to flowers of another species the pollen dies. Much of the pollen never reaches another flower. Sailors at sea have reported "sulfur showers," which are clouds of pollen grains blown off the shore. Self-pollination occurs normally in relatively few plants. In some of these the flower does not open until after the pollen has been shed. Most natural pollination is likely to be cross-pollination by wind or insects.

The pollen grain. Pollen is easy to study under the microscope. See EXERCISE 4. Most pollen grains, when ripe, have two nuclei, so really there are two cells within the thick wall. These cells are not separated by a membrane, however. If a pollen grain happens to fall on the top of a pistil in a flower of the same species, a tube grows out of the grain as shown in Figure 391. This is the *pollen tube;* it grows down through the style and enters the ovary. It can do this because the tip sends out digestive enzymes that digest the tissues of the style and ovary just in front of the growing tube. As the tube grows, the two nuclei move into it. In the meantime, one of the two nuclei divides again, forming two *sperm nuclei.* Thus there are three nuclei. One of the sperm nuclei with its surrounding bit of cytoplasm is the male gamete, corresponding to the sperm cell of the animal. Its twin sperm nucleus may eventually unite with the double nucleus. The third nucleus, known as the *tube nucleus*, remains at the tip of the tube. We need be concerned only with the male gamete (the sperm) which takes part in sexual reproduction. You can see pollen tubes with their nuclei by doing EXERCISE 5.

We have found the two gametes: the sperm hidden within the pollen tube and the egg cell within the ovule. How do these two cells get together in fertilization?

Fertilization. You have read that by pollination pollen is brought from the stamen to the stigma of the pistil. The pollen grain absorbs some of the sugary fluid secreted by the cells of the stigma and grows rapidly, forming a tube with three nuclei. This tube grows longer. It secretes enzymes which dissolve the cells lying in its path as it grows down through the stigma and the style. It enters the ovary with its ovules.

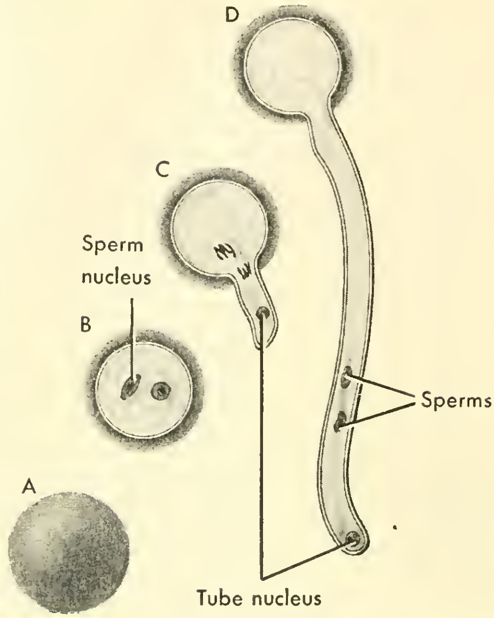


FIG. 391 *A pollen grain much magnified. How many nuclei are there in* B? *What is happening in* C? *In* D? *How many nuclei are there in* D? *Which ones of these are gametes?*

The growth of the pollen tube may take from several hours to many days; the time varies from plant to plant. Hundreds of pollen grains may fall on the stigma. EXERCISE 6 will show you that many of these begin to form tubes.

Eventually, one or more of the tubes reaches the ovules in the ovary. Each ovule has an opening (the *micropyle*). When a tube reaches the opening it enters the ovule. The pollen tubes which

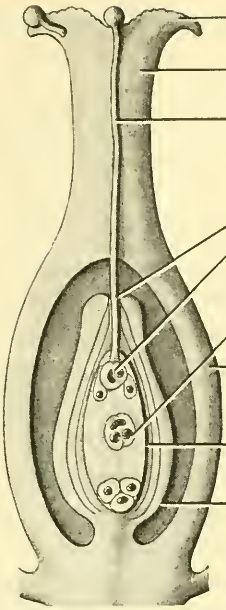


FIG. 392 *Section through pistil after fertilization has occurred. Only one ovule and one complete pollen tube are shown. Compare with diagrams of ovule and pollen (Figs. 389 and 391).*

do not enter dry up and disappear. When the embryo sac is reached by the pollen tube, the cell wall at the end of the tube dissolves. The sperm nuclei pass into the embryo sac and one of them fuses with the egg nucleus, producing the fertilized egg cell.

The second sperm nucleus sometimes unites with the double nucleus lying in the center of the embryo sac. Since the double nucleus is not an egg nucleus, this union does not result in a fertilized egg cell or zygote. The final result in some plants is a large group of food-storing cells called *endosperm.* Sometimes the second sperm nucleus does not fertilize the double nucleus.

Almost always, no doubt, more grains settle on the stigma than there are ovules; then the first tube to reach the ovule is the one to enter. Its nucleus fertilizes the egg cell in the ovule. If some ovule is not reached by a pollen tube its egg cell will not be fertilized.

The embryo plant is formed. The fertilized egg (zygote) becomes surrounded by a cell wall, and a series of divisions begins. Division occurs again and again until a mass of cells is formed; the process is somewhat like that of cleavage in an animal. However, these cells do not later arrange themselves in the form of a hollow ball or cup; such embryonic stages are found in animals only. Differentiation does occur; some groups of cells become pith, some become phloem, some xylem, some epidermis. Soon the tiny root, stem, and leaf become apparent. Although embryos are small and often curled up, the new plant parts can usually be recognized in the seed. The leaves are still without color since the embryo is located within the ovule, which is, as you recall, inside the ovary of the pistil where no light can reach it. The embryo, though small, is considerably larger than the egg cell from which it grew. The food used in this growth enters it from the surrounding tissues.

In seeds such as corn and wheat the endosperm grows during the development of the embryo. In other seeds such as beans and peas the endosperm fails to develop. To study seeds with and without endosperm, use the bean seed and the kernel of corn. See EXERCISE 7. By doing EXERCISE 8 you can determine the importance of the cotyledons in seeds which lack endosperm.

Other changes in the flower. The development of the embryo occupies many days or weeks, and in the meantime the flower petals have dried up and fallen off. A blossom does not last long; it withers, usually leaving nothing but a few shriveled flower parts and the ovary attached to the flower stem. But meanwhile the ovary has begun to grow. This growth continues. After some days, if you cut the ovary open, you will see that the once small ovules are becoming larger too. This is not surprising since the ovule contains the developing embryo. The embryo is growing so much that it would soon burst the wrappings of the ovule if the ovule did not also grow. When full grown it is no longer called an ovule; it is called a *seed*. The seed or ripened ovule, therefore, always consists of an embryo enclosed in wrappings called seed coats; sometimes, too, there is extra food (endosperm) around or alongside the embryo.

Not only the ovule but the ovary too grows. You can study such an enlarged ovary if you examine the bean (or pea) pod. See EXERCISE 9. An enlarged ovary with its enclosed seed or seeds and any other attached parts is known as a *fruit*. It may have grown enormously and its appearance have changed completely, for sometimes other flower parts enlarge along with the ripening ovary so that the fruit becomes fleshy or changed in some other way. A fruit is not always something that can be eaten by man.

In the fruit or the seed of some plants special structures develop which aid in

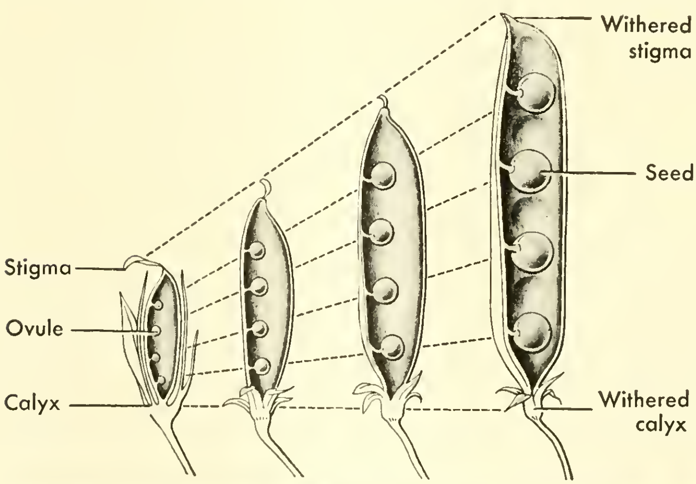


FIG. 393 (left) *Development of an ovary into a fruit. This development takes place after pollination and the fertilization of the egg in each ovule. What happens to each ovule?*

FIG. 394 (below) *Three ripened ovaries or fruits. Only the core of the apple is the ripened ovary.* (BROOKLYN BOTANIC GARDEN AND SCHNEIDER)

scattering the seeds over a wide area. The outside agents that help in this *seed dispersal* are wind, water, birds, and other animals, including man. You probably can give numerous examples of seed dispersal. Do EXERCISE 10.

The life cycle of the flowering plant. At certain times the flowering plant produces flowers containing stamens and pistils. The stamens produce pollen grains which later produce sperms in the pollen tube. The ovary contains ovules each of which forms an egg in the embryo sac. Fertilization occurs within the embryo sac after pollination and the growth of the pollen tube. The fertilized egg cell then develops into the embryo. The ovule which contains the fertilized egg grows into the seed. The ovary grows into the fruit. During the growth of the ovary into a fruit the petals wither and usually fall off. Gradually the fruit and the seeds within it ripen on the plant. The ripe seeds later drop to the ground, sometimes while still in the fruit. There they may rest over the winter. When conditions are favorable, the embryo within the seed bursts through the seed coats and grows into the seedling and gradually comes to look like the parent plant. In time this plant again bears flowers and the cycle is repeated. The organs which have been concerned in one way or another with reproduction are the flower, fruit, and seed.

FIG. 395 *Fruits and seeds. How may each kind be dispersed?*

MILKWEED

BURDOCK

DANDELION

MAPLE

(AMERICAN MUSEUM OF NATURAL HISTORY; SCHNEIDER & SCHWARTZ; BROOKLYN BOTANIC GARDEN)

(Optional) Reproduction in ferns. Ferns never bear blossoms. They produce spores by asexual reproduction. At certain seasons the spore cases show clearly on the lower surface of the frond (leaf). See Figure 364. When the spores ripen, they fall out of the cases and are scattered on the ground. Because of their thick walls, they do not die if the weather is dry. When conditions are favorable, that is, when it is moist and warm, they germinate.

But a spore does not grow into a new fern plant. Instead, there is produced a small, heart-shaped, green body (called

FIG. 396 *A young fern plant still attached to the prothallus. From what structure did it develop?* (WARD'S NATURAL SCIENCE ESTABLISHMENT)

a *prothallus*) which bears no resemblance to the parent plant. This tiny plant lies flat on the ground and has tiny hairs that absorb water from the soil. Since it contains chlorophyll and can make its own food, it grows but never grows much larger than a finger nail. After a few weeks, in certain groups of cells sperms are produced; in other groups egg cells are produced. The sperms swim through the thin film of water on the lower surface of the prothallus, and one sperm fuses with each egg. The fertilized egg cell then divides many times and differentiation takes place. Each fertilized egg becomes a small stem and root; and in time the characteristic fern leaves (fronds) rise up into the air. With their appearance reproduction is completed, for new fern plants like the original fern have been produced.

It is interesting to note that before the new fern appeared by sexual reproduction a little plant quite different from the fern plant was produced by asexual reproduction. There is always asexual and sexual reproduction in regular rotation before the fern cycle is complete. This is called an *alternation of generations:* the fern plant produces spores asexually; these grow into a prothallus; the prothallus produces gametes; and the fertilized egg grows into the new fern plant. To see spores do EXERCISE 11.

(Optional) **Resemblance between reproduction in a flowering plant and a fern.** While a flowering plant seems to be different from the fern in its reproduction, close study shows that it, too, goes through an alternation of generations. The pollen grain develops from a spore, a small spore (*microspore*). The embryo sac develops from a large spore (*macrospore*). The pollen grain with its tube and nuclei is a three-celled prothallus, tiny and colorless, but a prothallus just the same because it produces the sperm cell. In the same way the developed embryo sac is a prothallus which produces the egg cell. Here, as in the fern, the gametes are found in prothalli which grow from spores. These prothalli form asexually. When the fertilization of the egg takes place sexual reproduction is occurring. In other words, fertilization is tied up in regular rotation with an asexual reproduction; there is an alternation of generations in which both the sexual and asexual stages take place right within the blossom. So tiny are the spores and prothalli that the asexual as well as the sexual stage can be studied only under the microscope.

(Optional) Reproduction in mosses. Mosses, too, reproduce by asexual and then by sexual reproduction in regular succession; that is, they also have an alternation of generations. A moss plant consists of small, green, closely-bunched leaves, and tiny stemlike and rootlike parts. At certain times of the year you may have seen a tall stalk with a spore case (sporangium) at its top attached to this leafy plant. The spore case is filled with many spores which form by asexual reproduction. When ripe the spores may become scattered. On the moist earth each spore can grow into a branching chain of cells (called *protonema*), which is green, somewhat like some of the simple algae. Buds form on this thread, and each bud can grow into a leafy moss plant. In time two kinds of reproductive organs are produced by the leafy plants. One kind produces eggs and the other kind produces sperm cells. The sperm cells, like those of the fern, can move about in a film of moisture. Fertilization occurs, that is, the moss plant has sexual reproduction. From the fertilized egg cell, the stalk bearing the spore case described above develops. It looks like a true part of the leafy moss plant; it is really a separate plant which lives as a sort of parasite, getting part of its food from the leafy moss plant on which it grows.

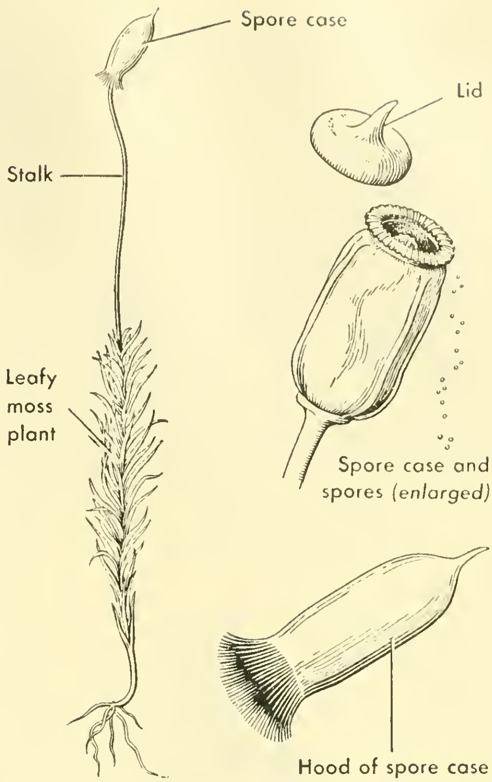


FIG. 397 *Pigeon-wheat moss. One of the largest mosses, this may become eight to ten inches high, but is usually smaller. What step in the life cycle has been omitted from this drawing?*

Vegetative reproduction. If a farmer or gardener wants a crop of potatoes, he does not plant seeds. Neither does the man who raises sugar cane or strawberries plant seeds. If you have a begonia or a coleus plant at home and would like to have more of them, you do not ordinarily plant seeds. All you need to do is to cut off one of the leafy stems and place the cut end in water or moist sand for a few weeks. You will find that roots grow from the sides of the stem and that soon you have a complete plant — roots, stem, and leaves — which will bear flowers just as the original plant did. You can see that this kind of reproduction is not at all like the sexual reproduction you have just been studying. The process is similar to that in which a starfish develops a new arm when one is

FIG. 398 *Three uprooted strawberry plants, two of which have grown from runners. The parent plant is in the center. What kind of reproduction is this?* (BROOKLYN BOTANIC GARDEN)

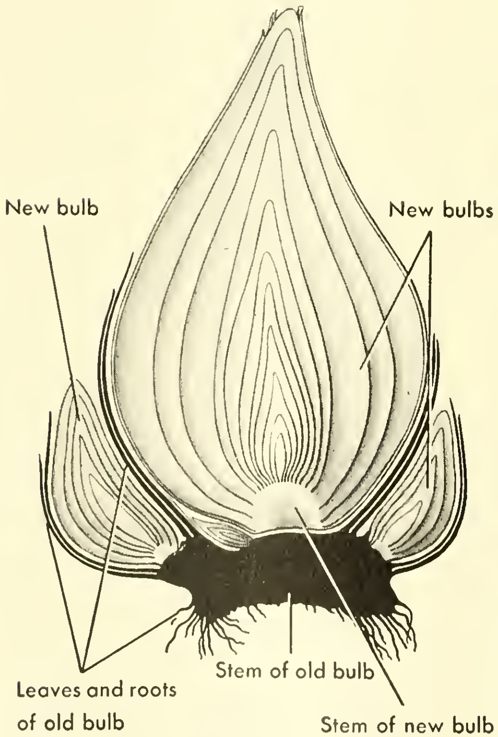


FIG. 399 *Tulip bulbs increase in number. Several buds within the old bulb enlarge forming new bulbs. Portions of the old bulb are shown in black.*

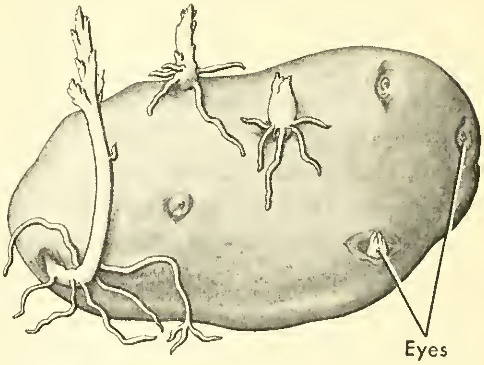


FIG. 400 *When he wants a new potato crop, the farmer cuts up potatoes and plants the pieces. What must he be sure to include in each piece?*

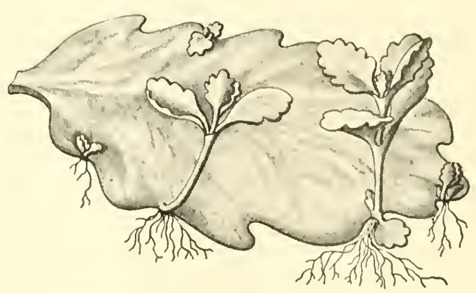


FIG. 401 *Vegetative reproduction by a Bryophyllum leaf. The leaf was removed from the stem, then laid on soil. How many new plants are growing from this single leaf?*

accidentally cut off, or a crayfish or lobster acquires a new claw. In plants it is called *vegetative reproduction* or *vegetative propagation.* Many of our food and ornamental plants are propagated in this way. The piece of stem or a leaf that is used in propagation is called a *slip* or a *cutting*. See EXERCISE 12.

Sometimes new roots and branches form from plants without their becoming completely separated from the parent plant. From the strawberry plant a long stem known as a *runner* grows along the ground. After the runner is several inches long, it produces at its end a short upright stem with leaves and roots. Each plant holds hands, so to speak, with its mother plant and in time stretches out a hand to its daughter. In the black raspberry a drooping twig or *layer* takes root where it touches the ground. This method of vegetative reproduction is called *layering*.

Other examples of vegetative reproduction. There are still other plants that reproduce vegetatively from stems but the stems are not easily recognized as such. The white potato mentioned above is really a stem although it grows underground and has no leaves. It is considered a stem because of the arrangement of its tissues and because it has tiny buds. These buds are commonly called "eyes." The fleshy underground stem is known as a *tuber*. When the tuber or a piece of it is planted, the eyes sprout, and new stems, leaves, and roots grow.

Some stems, unlike the enlarged and fleshy tuber, are very much shortened and compressed. The leaves which ordinarily are found along the sides of a stem are thus very close together. Such a compressed stem with its closely crowded fleshy leaves is known as a *bulb*. Bulbs are usually planted in the fall. During the winter and early spring, roots grow from the base and a longer stem with leaves farther apart grows from the center. There is often a flower or flowers at the end of the stem. From buds in the old bulb, usually one or two large new bulbs and several small bulbs form. During the next season or some later season new roots and shoots can grow from them. This is another vegetative method of reproduction.

Even some roots are used in propagation. Sweet potatoes are roots. Set one end of a sweet potato in a jar of water and set the jar in a window. Both roots and shoots will grow from it. Even a leaf or a part of a leaf from some plants, when cut off from the rest of the plant and kept moist, will produce new stems, leaves, and roots. African violets and bryophyllum are good examples.

(Optional) Variations in the story of reproduction. We are now quite well acquainted with the ordinary story of reproduction in both plants and animals. You may be interested in some of the exceptions to the story. In quite a number of plants – the common dandelion is one – the unfertilized egg or some other cell in the ovule begins to divide just as a fertilized egg would. Divisions continue until there is a good embryo in the seed. This process is known as parthenogenesis and is similar to parthenogenesis in animals (see page 424).

Most of us have eaten seedless oranges, grapes (raisins), and grapefruits; occasionally we may have seen seedless tomatoes, apples, or pears. It is probably safe to say that none of us have seen seeds in bananas or pineapples. You might well ask why seeds do not develop in these fruits. To answer this one would have to study the flower of each plant carefully. This has been done for many seedless fruits by botanists, who have found that certain oranges are seedless because the pollen tube that is produced is defective. Other oranges fail to form seeds because either no embryo sacs are produced or the embryo sacs are imperfect. In some seedless grapes pollination and fertilization occur, but the embryos die when they are very young and the ovules do not grow into seeds. The hundreds of black specks you see in bananas are ovules, not seeds; as a rule, neither the pollen nor the embryo sacs are perfect. When seeds fail to develop, the plant is propagated vegetatively. You will read in a later unit about a method of vegetative propagation called grafting.

It is most interesting to know that the growth of the ovary into a fruit does not ordinarily take place unless the stigma is pollinated. Even though the ovules fail to become seeds, the presence of pollen and growth of the pollen tube is enough to cause the ovary to start growing. Dr. Gustafson of the University of Michigan and others have found that pollen contains a growth-promoting hormone. In recent years much experimental work has been done with plant hormones and hormonelike chemicals which, when sprayed on the stigma or ovary, cause the growth of the ovary but not the ovules. Seedless tomatoes, egg plants, cucumbers, and squash have been produced.

Questions

1. What structures does a seed contain? Define germination. How does a seedling differ from a seed?
2. What plant organ must you study to find out how seeds are formed?
3. Can you name a flower-bearing plant that you had not thought of as such? Name in order from the outside the four circles of flower parts found in many flowers.
4. Which are the essential parts of a flower? Why are they called essential? What names are applied to flowers that have only one of the essential parts?
5. Describe the three parts of a typical pistil. What structures make up the ovary? The ovule? The embryo sac?
6. Describe a stamen. What important cells does it produce? Tell how self-pollination and cross-pollination are alike and how they are different.
7. Under what conditions does a pollen tube form? What is the relationship between the pollen grain and the male gamete?
8. Describe the growth of the pollen tube, telling exactly through what it passes and where it finally ends its growth. State, as specifically as possible, where fertilization in the flower occurs. Which nuclei unite in fertilization? What becomes of the second sperm nucleus?

9. Compare the development of the embryo in the plant with that in the animal. What is endosperm? Name a seed which has no endosperm and one which has a large endosperm.
10. What is a fruit? How may fruits and seeds be dispersed?
11. Starting with a plant in flower describe the life cycle to the point where the new plant is ready to reproduce.
12. Show how there is a regular alternation of asexual reproduction and sexual reproduction in the fern.
13. Which parts of the flower can be thought of as producing asexual spores?
14. What is meant by vegetative propagation? To what process in animals is it similar? Explain what is meant by a slip or cutting, a runner, a layer. Name a plant in each case.
15. Name other methods of vegetative propagation, with an example of each.
16. Explain how fruits can be artificially made to develop without seeds. When they develop naturally without seeds, state which step in the process of reproduction may fail to occur. Give examples.

Exercises

1. What is the structure of the seed? Soak dried lima bean (or kidney bean) seeds overnight. Notice the scar (*hilum*) on the side of the bean. What causes the scar? If you press the bean gently you can see a tiny hole at one end of the scar. This opening is the *micropyle*. You will understand later what must have once entered through this micropyle. Remove the seed coats and carefully separate the two large, fleshy, leaflike structures. These are the *cotyledons*, or seed leaves. They are attached to the *hypocotyl*. Describe it. Describe the *plumule* which lies between the cotyledons. Into what do hypocotyl and plumule grow if the seed is allowed to sprout? Name the three parts of the baby plant. What might be the function of the fleshy cotyledons? Test the cotyledons for starch and protein. What do you find?

2. What happens to the seed under favorable conditions? Line a battery jar or fruit jar with moist blotting paper and place a few soaked lima or kidney beans between the paper and the jar. Keep a record of the development of the seeds from day to day. Which part first bursts through the seed coats? Plant some seeds in moist sawdust. Plant them about an inch below the surface. Which part first appears above ground? How is it kept from being injured as it pushes through the sawdust (soil)?

3. What are the parts of a flower? Study a tulip, gladiolus, or some other simple flower in season. Use the description in the text as a guide. Draw one or several diagrams of your flower and label all of the parts.

4. What is the structure of a pollen grain? Rub the ripe anthers of several different flowers on separate slides, add water and cover slips, and examine under the low power. How do the pollen grains differ?

5. How may pollen tubes be made to grow? Shake pollen from ripe anthers into a 10 per cent sugar solution. (If the pollen fails to produce tubes, vary the concentration of sugar.) Set aside and examine after a few hours. Draw the pollen tubes in various stages of development. Stain with iodine solution and look for nuclei. How many do you find?

6. If a tulip blossom is available, transfer some ripe pollen with a toothpick to the stigma of the pistil. (The stigma must be well expanded.) After three or four hours, cut a small piece from the stigma, crush it on a slide, mount it in water and examine it under low power. Look for pollen grains and note the tubes. Look for nuclei.

7. You have already studied the bean seed. What is found inside the seed coats? Of what three parts does the embryo consist? Does food seem to be stored in this embryo? Where? Now cut a kernel of corn lengthwise. The kernel is a small fruit which is completely filled with a single seed. Lay the cut surface into a dish of iodine and examine. What do you know about the portion that turns blue? This is food material or endosperm. Now draw what you see. What proportion of this seed is embryo, what proportion is endosperm?

8. To what extent is a pea or bean seedling dependent on the food stored in its cotyledons? Carefully cut away the cotyledons from several seeds which have begun to sprout. Give them favorable conditions for growth (moisture and warmth). Leave the cotyledons on several seeds and keep them with the others. Observe closely and record. What conclusions do you draw? Cut away one cotyledon and repeat the experiment. Does this make you more sure of your conclusions? Why or why not?

9. What do you learn from the study of the pea pod? Carefully examine the outside of a pea pod close to the stem. Where have you seen these parts before? If you have a blossom of the garden or sweet pea take out the pistil. Lay it next to the pea fruit. What resemblances do you find? From which part of the flower did the pea pod develop? Open the pod carefully so that the "peas" remain attached. If the pea pod is a fruit what are the "peas"? What were the "peas" when they were young? Does the pod contain any undeveloped seeds? Explain. The region of the fruit to which the seeds are attached is the *placenta*. Why must the ovules (and young seeds) be attached to the ovary? The pea pod illustrates the origin of a fruit. What can you conclude about fruits in general?

10. Study the following fruits and seeds and as many more as possible: Linden, maple, elm, burdock, cocklebur, beggar's tick, dandelion, thistle, milkweed, cotton, strawberry, raspberry. Which of these fruits or seeds have structures which result in their being scattered by the wind? Which would be carried the greatest distance? Why? Examine the burdock, cocklebur, and beggar's tick. How are they likely to be dispersed?

11. Asexual reproduction in ferns. Using a hand lens, examine the lower side of a fern frond (leaf) which has formed spores. You can see masses

of spore cases; each case is too small to be seen. Mount some of this material and study a spore case under the low power of the microscope. Describe. Do you see spores? About how many spores would fit into one case? Why do you say that these spores have been formed asexually?

12. How may the vegetative parts of plants reproduce? With the class organized into committees try to propagate plants vegetatively. Use a geranium or coleus for slipping (place in water or sand), a potato to show reproduction by the underground stem (tuber), and the bulb of an onion, narcissus, etc. Remove the leaf from a begonia, cover the end of the leaf-stalk with soil; keep moist. In each case note the length of time it takes for roots to form, or a new plant to appear. How many plants can you name which can reproduce by vegetative propagation? Try propagating other plants.

Further Activities in Biology

1. If you have patience you can raise fern prothalli from spores. Sprinkle spores of the Christmas fern on moist sterile soil (in a dish) and cover with a plate. Watch for the tiny green structures; it will take several weeks.
2. Make an exhibit of flowers or of a series of charts to show how flowers are constructed to prevent self-pollination or to secure wind or insect pollination.
3. Devise and perform experiments to discover whether moisture and air are needed by germinating seeds. Report on your work.
4. Does light affect the germination of seeds? Devise an experiment.
5. Report on the pollination of the Yucca flower by the Pronuba moth.

In UNIT IX you will consider these problems:

PROBLEM 1. Why Do Offspring Resemble Their Parents?

PROBLEM 2. How Can Some of the Differences between Parents and Offspring Be Explained?

PROBLEM 3. How Can New Hereditary Characters Appear?

PROBLEM 4. How Does the Environment Affect the Characters of an Organism?

PROBLEM 5. What Have We Learned about Producing New Types of Animals and Plants?

PROBLEM 6. To What Extent Can Mankind Be Improved?

UNIT IX THE ORGANISM IS THE PRODUCT OF ITS HEREDITY AND ITS ENVIRONMENT

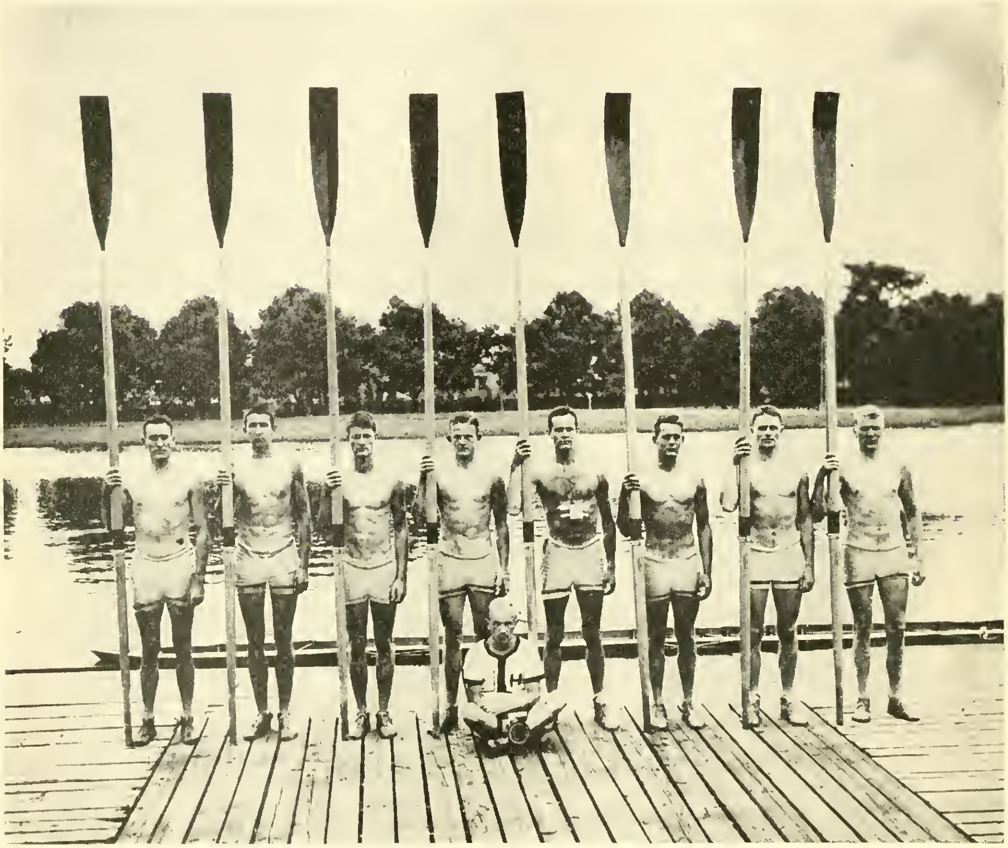


FIG. 402 *The Harvard crew of 1933 at the Intercollegiate Regatta, Long Beach, California. Both heredity and environment played a part in giving these men greater strength and endurance than most men have.* (KEYSTONE VIEW CO.)

PROBLEM 1 *Why Do Offspring Resemble Their Parents?*

Many animals have two different types of cells. Let us examine again the development of an animal such as the fish. After fertilization the egg goes through a series of rapid divisions. Gradually the several kinds of tissue cells appear and the organs are formed of various combinations of tissues. But certain cells remain unchanged; they do not form muscle, bone, nerve, or any of the other tissues you have learned about. Eventually, however, these cells go through special cell divisions and develop into gametes (eggs or sperms). A complex animal, therefore, is really composed of two main kinds of cells. There are the tissue cells that make up the body; they are called *somatic* cells and all their protoplasm is called *somatoplasm.* The other cells, fewer in number, are the reproductive cells. They are also called *germ* cells, and their total protoplasm is called *germ plasm.* The germ plasm in time forms gametes (sperms or egg cells). To test your understanding do EXERCISE 1. In the higher animals this separation of germ plasm and somatoplasm is quite distinct. The somatoplasm is not able to produce another organism; only germ plasm can do that.

In plants and in lower animals, however, there may be no clear cut difference between germ plasm and somatoplasm. In many plants any part of the organism can produce a new plant of the same kind. In some lower animals after the reproductive organs have been cut out, new ones may be made from other tissues. But in the higher animals there is a distinct difference between cells that produce gametes, the germ plasm, and cells that make up the rest of the body, the somatoplasm.

Cats produce more cats. You know that when cats reproduce, the offspring are always cats; human beings produce

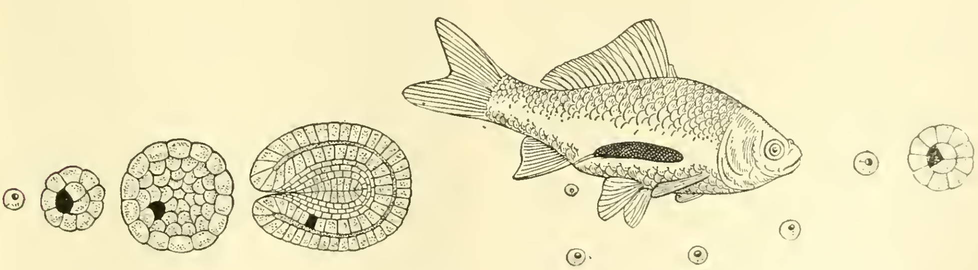


FIG. 403 *A diagram to show continuity of germ plasm. Starting with the zygote* (left) *trace the germ plasm (shown in black) to the body of the fish. In what organ is it found in the adult fish? An egg from the fish, after fertilization, has formed a ball of cells* (right). *What will the "black" cell in this ball become?*

more human beings; horses produce horses; roses produce more roses. Living things are of the same kind as their parents. That seems natural to you. Our problem is to see exactly *why* they are like their parents.

What is contained in egg and sperm? You know that the sperm cell is a tiny mass of cytoplasm with a nucleus. An egg cell, too, is cytoplasm with a nucleus and usually a certain amount of food besides. Now experiments have shown that it is almost always only the nuclei of the sperm and egg that are of importance in making the offspring like the parents. The nucleus differs from the rest of the living matter within cells in that it contains chromatin in the form either of a network or of scattered granules. Chromatin is a living substance that can be stained readily with certain dyes. For many years it was suspected that chromatin was important in causing the similarity between parents and offspring. But nothing could be seen inside the chromatin to explain why this should be so.

The gene theory. A little over twenty-five years ago a theory was advanced that chromatin is composed of parts called *genes* (jeans) which cause the various characteristics to appear in the organism. Professor Thomas Hunt Morgan, who died in 1945, was the author of the gene theory. He and his associates and hundreds of biologists in many parts of the world have been testing the theory for more than twenty-five years. They have much evidence that it is the genes within the chromatin that cause the various characteristics of the organism to appear.

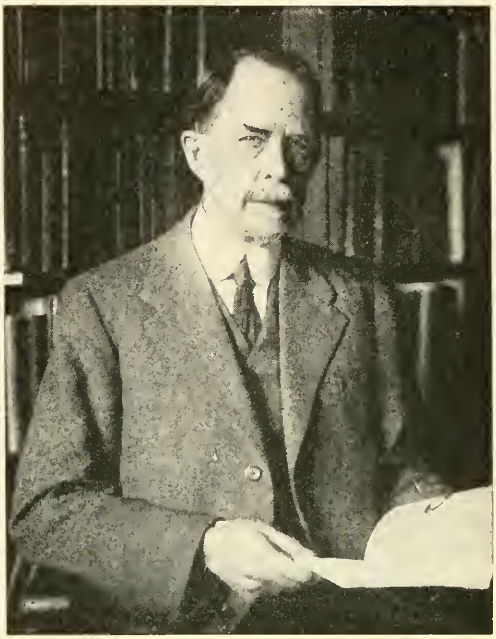
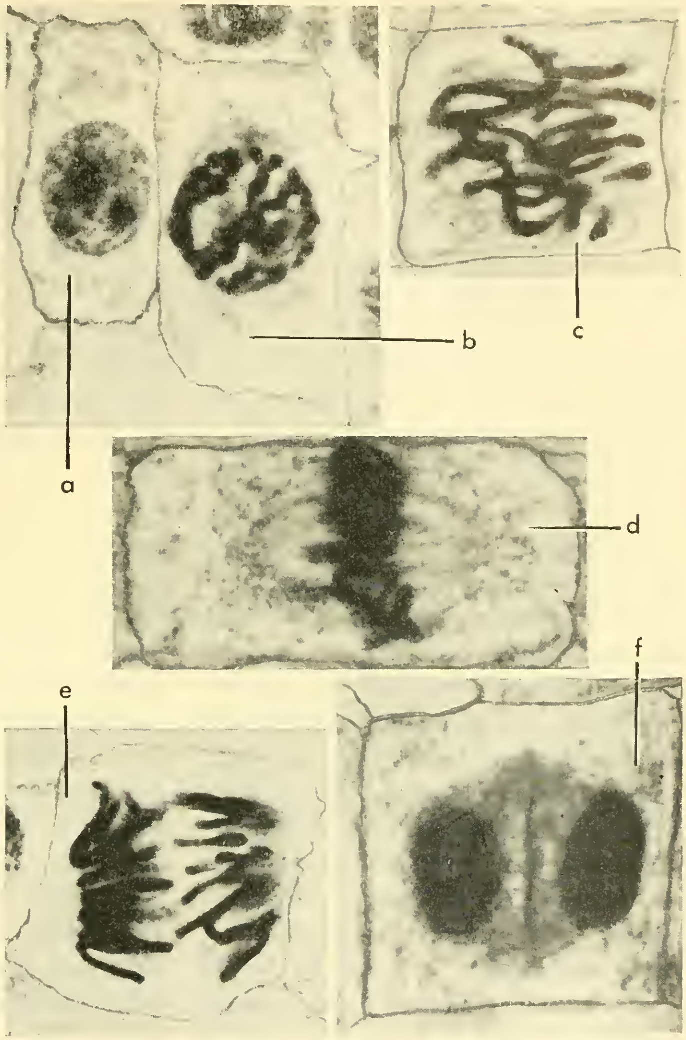


FIG. 404 *Thomas Hunt Morgan, who developed the theory of the gene.* (KEYSTONE VIEW COMPANY)

Genes are thought to be too small to be seen with the microscope; we say they are ultramicroscopic. Their chemical make-up is not known but we know that they must be able to assimilate, grow, and form more of their own kind of substance.

Behavior of chromatin. Since chromatin consisting of genes is the important substance which is found in the gametes, it should be worth our while to watch its behavior as the fertilized egg cell goes through cell division. Before the cell divides, the chromatin seems to be strung out in tiny granules or threads throughout the nucleus. As the cell begins to divide the chromatin material gathers together in long, thin threads which presently become shorter and thicker. These short pieces of chromatin are like rods, some straight, some bent. They are called

FIG. 405 *Stages in nuclear division (mitosis) in plant cells. In* (a) *the nucleus is not dividing. In* (b) *the threads of chromatin have appeared; chromosomes are fully formed in* (c). *In* (d) *the chromosomes are lined up in the middle of the cell. They have already split lengthwise. The halves have separated in* (e). *In* (f) *the two new nuclei have begun to form. The dark line in the middle is the beginning of the new cell wall.* (a, b — KLINE; c, d, e, f — GENERAL BIOLOGICAL SUPPLY HOUSE)



chromosomes (crow'mo-soams). There is evidence that the genes are arranged in a single row within the chromosomes like a string of beads. The chromosomes are jellylike in composition, yet so firm that they can be pushed around with a microneedle. They are in pairs. Each pair differs somewhat from the other pairs in size and shape.

While the chromosomes are forming, the nuclear membrane disappears and the rest of the nuclear material becomes mixed with the cytoplasm. The chromosomes then move to the center of the cell. At this time or even earlier the chromatin makes more of itself, with the result that there is double the original amount. It is believed that in this process each gene reproduces itself. Thus there comes to be a double string of genes in each chromosome. Each chromosome then splits in two along its length from end to end. Each of the two parts gets a complete string of genes. When the

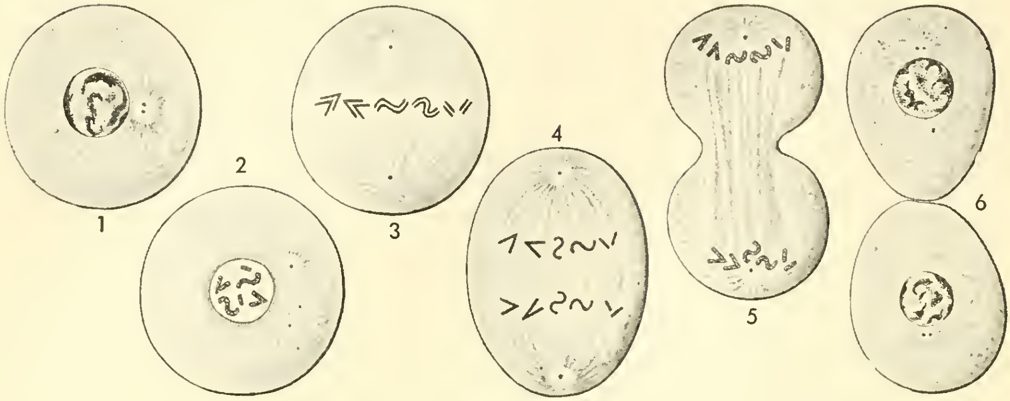


FIG. 406 *Mitosis in an animal cell. Note two centrosomes near the nucleus in (1). How many pairs of chromosomes in (2)? What is happening to the chromosomes in (3)? In (4)? How many chromosomes in each of the cells about to form in (5)?*

chromosomes have split lengthwise there are twice as many chromosomes in the cell as there had been originally. Next the two halves of each chromosome move apart until they are at opposite ends of the cell. If you now counted the chromosomes at each end of the cell, you would find the same number at the two ends; and if you had counted the original number in the cell, you would find as many chromosomes at each end now as there were in the cell before it began to divide.

A delicate membrane then forms around each group of chromosomes. In the meantime, the chromosomes change back into a chromatin network. Thus two new nuclei are formed, each like the nucleus from which it came. Each is exactly like the nucleus from which it came because it contains a string of genes which came from the original genes. When, shortly after this, the cell body splits, cell division has been completed. Two daughter cells have taken the place of the fertilized egg cell. And each has the same kinds of chromosomes and genes as the fertilized egg. The whole process in some organisms takes no more than half an hour. This complicated division of the nucleus, in which each daughter cell receives one half of each chromosome with a complete set of genes, is known as *mitosis* (mit-toe'sis). Now illustrate the mitotic changes in the nucleus by doing EXERCISE 2.

You have just read about mitosis in the division of the fertilized egg cell. When each of these daughter cells divides later, and, in fact, in every cell division thereafter, the nucleus divides by mitosis. There is only one normal exception to this; you will read about it soon. Mitosis, or some modified form of it, occurs in the cell division of the simplest animals and plants as well as in the most complex forms.

Studying mitosis in stained cells. A stained slide can be made of some rapidly growing tissue of an animal or plant. If this tissue is growing, some of its cells are dividing. By hunting over the slide you can find several cells that have just begun to divide, others that are near the end of the process, many in the in-between stages, and many that were not dividing at the moment the tissue was killed. A careful search enables you to put together the whole story told in the preceding paragraph. And in so doing you discover various structures that are usually not seen in unstained cells. One of these is the *spindle*, a structure of threads extending from one end of the cell to the other (see Fig. 406, 3–5). The threads seem to support the chromosomes. The chromosomes line up in the middle of the spindle. Then after the chromosomes have split lengthwise the half chromosomes travel away from one another. In cells which are near the end of division, the new groups of chromosomes are at opposite ends of the spindle.

The diagram of mitosis in an animal cell shows other structures to be present. While there are minor differences, mitosis in plants and animals is alike in that each chromosome splits down the middle after the genes have doubled. As a result each new nucleus has the same number of chromosomes and the same kinds of genes as the original nucleus. The process is easy to study in plant cells. Do Exercise 3.

What is accomplished by mitosis. When a fertilized egg divides, its nucleus divides by mitosis. With continued divisions of the same type, every cell of the new individual will have the same kinds of chromosomes and genes that the fertilized egg had. This means that every cell of the new individual has a full set of genes just like those that were in the fertilized egg. These genes determine the characteristics of the new organism. You may wonder how one part of the body forms an eye and another part a leg if all the cells of both parts have the same genes. This happens because in the place where a leg is to form, only the "leg" genes act; in the place where eyes form, only the "eye" genes act. We do not know with certainty why this is so but this really important fact should not be overlooked: a cat is a cat because the genes in every one of its cells are "cat" genes. Every cell has the same kinds and number of genes as the fertilized egg; and the fertilized egg was formed when an egg with cat genes and a sperm with cat genes came together. The new individual is therefore a cat and not something else. Its muscle is cat muscle, its eyes have the characteristics of cat's eyes, and so on. Every cell is a "cat" cell because of the action of genes and because of the mitotic division of the chromosomes with its genes that occurs whenever cells divide. Note, too, that this mitotic division gives every cat cell the same number of cat chromosomes and genes – no more and no less than the fertilized egg had. And so a certain number of chromosomes, 38 (19 pairs), becomes characteristic of the cat. Every species of animal and plant has a definite number of chromosomes. The table below and Exercise 4 will interest you.

ORGANISM	CHROMOSOMES
Man	48
Monkey	48
Frog (leopard frog)	26
Maize (corn)	20
Evening primrose	14
Pea (garden pea)	14
Onion	16
Housefly	12
Fruit fly	8
Chicken	18
Starfish	18
Mosquito (Anopheles)	6

A problem to solve. Has it occurred to you that it is strange that the species number of chromosomes should stay the same even though two cells unite in fertilization before each new generation is formed? Why does not the fertilized egg have a double set of chromosomes and thus have twice the species number? Evidently something happens that keeps the number of chromosomes and genes from being doubled during fertilization. This something occurs within the cells before they become eggs and sperms. In each one of these cells the number of chromosomes is reduced. The full or *diploid* number of chromosomes is reduced to the half or *haploid* number in sperm and egg cells during their production.

How sperm and egg cells are formed. You will remember that while tissue cells become differentiated in the developing animal the germ plasm remains unchanged. Later this germ plasm divides and forms many *primary sex cells.* Since all the divisions have been mitotic, each primary sex cell has the number of chromosomes and the kinds of genes characteristic of the species. As the young animal develops, connective tissue and some other kinds of tissues surround and support the primary sex cells, forming the organs known as the spermary or the ovary.

After a while changes begin to take place in some of the primary sex cells of the spermary or ovary. These primary sex cells change into sperms or eggs. Then the animal is ready for reproduction. The process by which a primary sex cell becomes a sperm or egg is called *maturation.* During maturation there is always one important step, an unusual type of nuclear division, in which the number of chromosomes is reduced by one half. This is called *reduction division.* It is quite different from mitotic division. Do you remember reading that all nuclei divide by mitosis, *with one exception?* You have just read of the exception.

Let us see what happens when a primary sex cell undergoes reduction division. Chromosomes in every cell are present in pairs. The two members of each pair now come close together. They may even twist about one another. Soon the members of each pair separate and move to opposite ends of the cell. Each pair of chromosomes acts in this way. Then the cell body divides. Thus from a primary sex cell are formed two daughter cells each of which has the half (haploid) number of chromosomes and the half number of genes (Fig. 407). Note that there has been no splitting of chromosomes as in mitosis. Furthermore, note that this separating of chromosomes does not occur in a haphazard way. Each daughter cell normally receives one of each original pair of chromosomes. It has, therefore, only one set of genes instead of two. The daughter cell after a few more changes becomes a gamete. In this way the gamete has only half as many chromosomes as the primary sex cell or any other cell in that animal. In males the daughter cells undergo a number of mitotic divisions,* producing a large number of cells with the half number of chromosomes and a single instead of a double set of genes. These cells then change in shape and thus become sperms.

* In some animals these mitotic divisions occur in the primary sex cells before reduction division takes place, instead of after it. The result is the same.

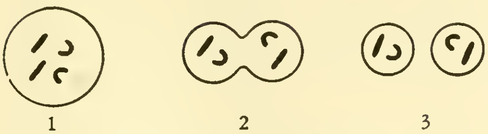


FIG. 407 *Reduction division of a male primary sex cell. How many* pairs *of chromosomes are there? How many chromosomes? How many chromosomes in each daughter cell? Does a daughter cell have any chromosomes in pairs?*

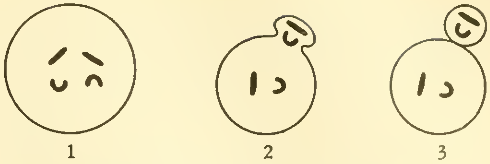


FIG. 408 *Reduction division of a female primary sex cell. How many chromosomes in the primary sex cell? In each daughter cell? Compare the chromosomes in male and female reduction division.*

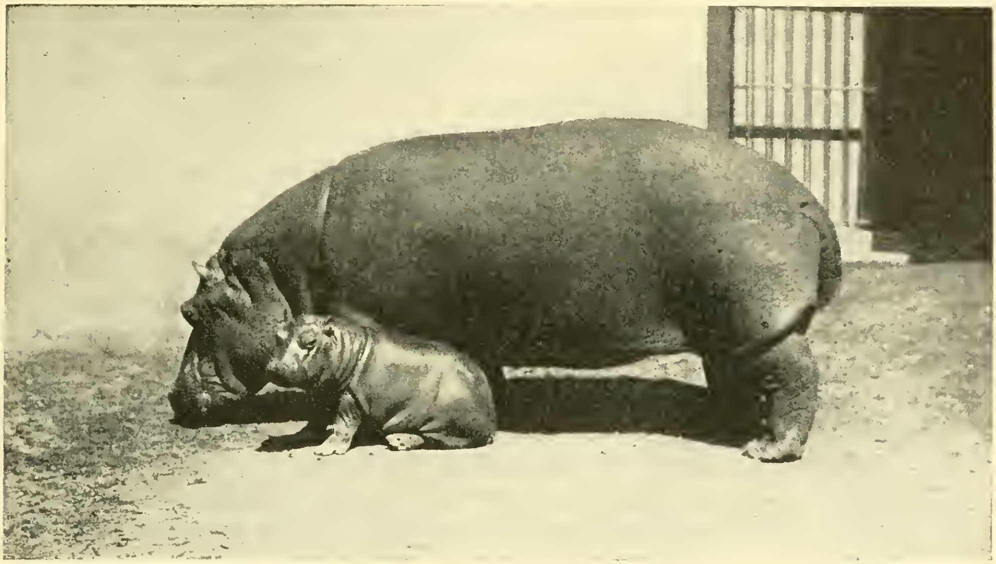


FIG. 409 *Except for the egg cells the mother hippopotamus produces, all the cells in the mother have the same number and kinds of chromosomes. How are the eggs different? The cells of the child formed from a fertilized egg will have the same chromosome number as the cells of each parent. Why?* (NATIONAL ZOOLOGICAL PARK)

Try EXERCISE 5 to review the three steps in maturation of sperms.

In females, when the primary sex cell goes through reduction division, producing the haploid nuclei, the cytoplasm divides unequally. Thus one daughter cell is large, the other small. In the mitotic division that follows, the large daughter cell again divides unequally. In this way, of the four cells that are produced by these two divisions, one is large and three are tiny. Only one cell survives, the large one. This becomes the egg. It, like the sperm, has only one of each pair of chromosomes and only a single set of genes because of the reduction division. In some animals large amounts of food material, called yolk, accumulate in the egg cell, making it very large. Fish and frog eggs, and, particularly, bird eggs are good examples of this.

Fertilization and chromosome number. You have just read how the sperm and egg develop with the half number of chromosomes, one of each original pair. When the sperm and egg unite in fertilization the fertilized egg gets a half set of chromosomes from the sperm and a half set from the egg. Together they make the full diploid number. Thus, the fertilized egg will again have chromosomes and sets of genes in pairs, and the species number remains constant from one generation to another. More important still, the fertilized egg, and every cell that forms from it by mitosis, has the full or double set of genes. To review what you have just read, EXERCISE 6 will be helpful.

QUESTIONS

1. What are the two distinct types of cells in complex animals? What are germ plasm and somatoplasm?
2. Why do offspring look like their parents?
3. Which part of the cell is of great importance in heredity?
4. What is the gene theory? With whose name is it associated?
5. Describe chromosomes as to shape, origin, and composition. What position are genes supposed to occupy in a chromosome? Describe what happens to the chromosomes from the time the nuclear membrane disappears until two nuclei are formed. What is this complex division of the nucleus called?
6. What mitotic structures may be found in stained cells?
7. Why does every cell of a cat normally have the same full set of chromosomes and genes possessed by the fertilized egg cell? What seems to determine that a cell grows into a muscle cell or an eye cell? What interesting facts about chromosome number does the table show?
8. Why does fertilization not double the number of chromosomes in each generation? Define haploid and diploid.
9. What is meant by maturation? Which cells go through maturation? Describe the reduction division which occurs during maturation. In what minor respect does maturation in the female differ from that in the male?
10. In what process does the haploid number become diploid?
11. Write the letters A to K on a sheet of paper and opposite them write the corresponding words missing from the account that follows: Somatoplasm forms *A* cells. Germ plasm forms cells called *B*. Chromatin is supposed to contain *C* which produce the various *D* of the organism. All the cells of a higher organism (with one exception) have a complicated nuclear division called *E*. As a chromosome splits lengthwise each half gets a *F* of genes. After a mitotic division the number of chromosomes in each daughter cell is the *G* as in the mother cell; the number and the kind of genes are the *H*. Every cell developing from a fertilized cat egg cell will have *I* genes. In reduction divi-

sion every gamete gets the *J* number of chromosomes. The full number is restored in the process of *K*. Now make a short statement explaining why offspring resemble their parents.

Exercises

1. Draw a dissected animal, such as a frog or fish, with mature sex organs. Using different colored crayons, shade in all the somatoplasm in one color; the germ plasm in another color.

2. Illustrate mitosis by drawing a series of clear diagrams. Assume that the cell has four chromosomes when cell division begins.

3. *Demonstration.* Mitosis in onion root tip (or similar material). Examine stained sections of onion root tips under the microscope. Can you find nuclei that are dividing? Can you find chromosomes? Draw or describe the chromatin material in cells that are at the beginning of division, in cells that are half through division, and in cells that are near the end of division. What structures do you find that have not been described?

4. Study the table of chromosome numbers. How can you explain the fact that the numbers are all even numbers?

5. The mosquito has six chromosomes. Draw a series of diagrams to show the three steps in the maturation of its sperm.

6. Why is it that the primary sex cell has chromosomes exactly like those of the fertilized egg? Explain and draw. Compare the number and kind of chromosomes of a skin cell with those of the fertilized egg and those of the primary sex cell. In what process is the number of chromosomes reduced to one half? Explain and draw. In what process is it restored to the full number?

Further Activities in Biology

1. Mitosis and maturation can be shown by means of movable chromosomes. You might make small wooden chromosomes of different shapes to be hung on a board. Draw the outlines of cells on the board and put in screw hooks on which to hang the chromosomes. This demonstration can be made in less permanent form by using paper chromosomes with thumb tacks. You could use small, painted bar magnets on a sheet of tin or iron.

2. There are many devices for making permanent models to illustrate the whole process of mitosis: the frame of a box could represent the cell wall; wires, the spindle; and so on.

3. If your school has a good slide showing mitosis in a root tip, photograph parts of it under low power. If your pictures are very good, enlarge them for use in the class.

PROBLEM 2 *How Can Some of the Differences Between Parents and Offspring Be Explained?*

"You look just like your uncle." Do you look more like a grandparent than like one of your own parents? Perhaps you resemble more closely some aunt, or uncle, or cousin. You may have blond hair and blue eyes and differ from your brother who has dark hair and brown eyes, or dark hair and blue eyes, or blond hair and brown eyes. Again you may have blue eyes although both your parents and your brothers and sisters are brown-eyed; you may be taller than either of your parents. In many ways your characteristics may be different from those of your close relatives. Why is there such variety in members of the same family? Is it all haphazard or are there laws of heredity? Study Figure 410.

Much experimental work has been done to solve the problems of heredity in other animals and in plants. Let us examine some of this work and learn to apply the results to ourselves.

Color inheritance in the four-o'clock. The four-o'clock is a plant which resembles the more familiar morning glory. How does heredity operate when red-flowered and white-flowered plants are crossed (mated)? To answer the question the following procedure is used. Pollen from a white flower is transferred by hand to the pistil of a red flower on another plant. Sometimes the reverse is done: pollen from a red flower is put on the pistil of a white flower. To make sure there is no accidental pollination, the stamens of the flowers that are to receive the pollen are removed and after the desired pollen has been added the flowers are covered with paper bags. This keeps off other pollen (Fig. 412). Fertilization occurs, the flowers wither, and the fruits and seeds develop under the paper bags. Careful records are kept so that the parentage of every seed is known. The seeds from these fertilizations are planted the next season. When the plants grow up and bloom, their flowers are pink. That probably does not surprise you.

Then the experiment is continued by crossing those pink-flowered plants, and a strange thing happens. The offspring are of three different kinds: some have pink flowers, as you would expect, but others have white flowers and still others red. When the number of plants in the experiment is large, about 25% of the offspring are white-flowered, about 50% are pink-flowered, and about 25% are red-flowered. This is in the ratio of 1:2:1. The experiment can be continued. If the red-flowered grandchildren are crossed with red-flowered grandchildren

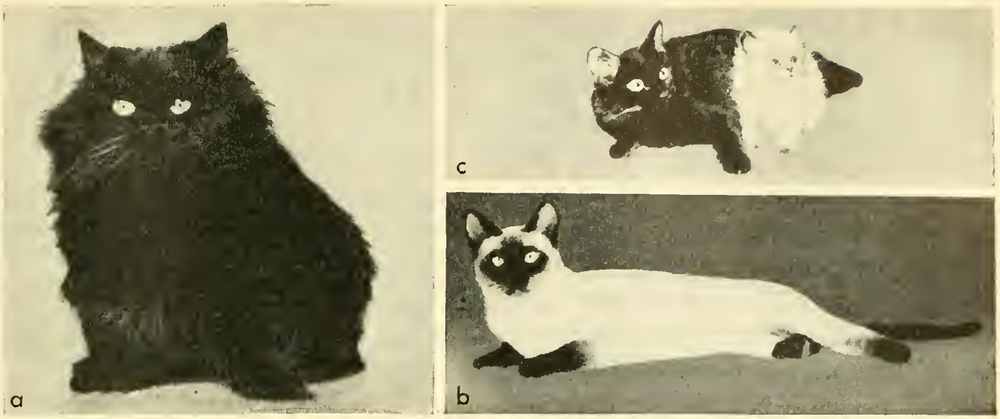


FIG. 410 *Inheritance of length of hair and coat color. The Persian cat (a) and Siamese cat (b) are the parents of the black, long haired daughter in (c). The light colored kitten in (c) is a grandchild of the cats in (a) and (b). Which of its ancestors does it resemble?* (JOURNAL OF HEREDITY)

FIG. 411 *The blossom of the four-o'clock. Some four-o'clock plants have red flowers; some, white; and some, pink. How are the pink flowers related to the others?* (GEHR)

FIG. 412 *The method used to prevent accidental pollination in an experiment with onion plants. What kind of experiment might this be?* (U. S. DEPARTMENT OF AGRICULTURE)

only red-flowered plants are produced. If the white-flowered grandchildren are crossed with each other only white-flowered plants appear. But if the pink-flowered grandchildren are crossed with each other, the offspring include plants with red flowers, plants with pink flowers, and plants with white flowers in the ratio of 1:2:1. You readily recognize that this is the same ratio that was obtained when pink-flowered plants were crossed before. In order to fix these facts in your mind, make the drawings suggested in EXERCISE 1.

Pure and hybrid organisms. Chromosomes carry the genes that determine the characters in organisms. Chromosomes and their genes are present in pairs in the fertilized egg and in every other cell (except the sperm and egg cells). One chromosome of a pair comes to the fertilized egg with the sperm, the other with the egg. That is, the fertilized egg and every cell of the red-flowered plant (except the gametes) have two genes for redness, making a pair. If, for the moment, we disregard the many other genes and use letters as symbols for the genes for redness we may represent such a plant by *RR*. The white-flowered plant can be represented by *WW*, since every cell has a pair of genes, *W* and *W*. Such *RR* and *WW* plants are called *pure*, meaning that the pair of genes being studied consists of two genes that are alike.

A pink-flowered plant comes from the crossing of a red-flowered one (*RR*) with a white-flowered one (*WW*). Because reduction division occurs in the production of gametes (see p. 460), gametes have only one member of each pair. So, obviously, the pink-flowered plant receives a gene for redness (*R*) from one parent and a gene for whiteness (*W*) from the other parent. It, therefore, has the make-up, *RW*. The *RW* plant is not pure; it is known as a *hybrid*. In a hybrid the two genes of a pair are different.

Why there is a 1:2:1 ratio. A pink-flowered plant has the pair of genes *RW* in its primary sex cells and in all its other cells except sperm and egg cells. When the primary sex cells go through maturation the two chromosomes that make up the pair part company as indicated in

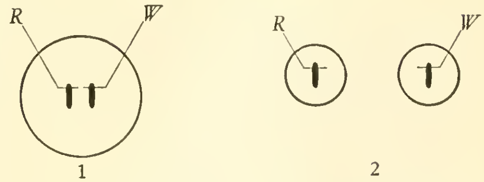


FIG. 413 *Each primary sex cell (1) of the pink-flowered four o'clock forms two kinds of gametes (2). Half the gametes from such a primary sex cell have a gene for redness. Half have a gene for whiteness. What kind of cell division takes place in primary sex cells?*

Figure 413. The chromosome containing gene *R* goes into one gamete and the one containing *W* goes into another gamete. The two are, therefore, not together in one gamete. Gametes (sperms and eggs) are always pure, which means that they contain only one chromosome of a pair and therefore only one gene of a pair. When the many primary sex cells of the *RW* (pink) plant form gametes, about half will contain the *R* gene and half the *W* gene. Under normal conditions if there are large numbers of gametes there will be about the same number of gametes containing *R* as there will be gametes containing *W*.

You can see better what happens when two pink-flowered plants are crossed if you study the diagram in Figure 414. The two pink-flowered plants which started the experiment are represented as rectangles containing the genes *RW*. The sperms formed by one plant are of two kinds. They are shown as circles; 50 per cent have the gene *R* and 50 per cent the gene *W*. The eggs formed by the other parent are likewise shown as circles.

If now fertilizations occur between the gametes shown in the diagram, there are four possibilities:

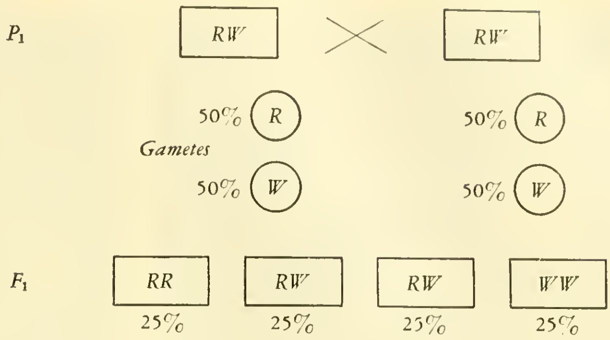


FIG. 414 (P_1) *means the* first parental generation; *that is, the first mating in this particular experiment. The* × *means that matings occur. What kinds of gametes are provided by each parent?* (F_1) *means the* first filial generation, *the children of the first generation. The next generation would be* (F_2).

R *sperm might meet* R *egg, producing* RR *offspring.*

W *sperm might meet* W *egg, producing* WW *offspring.*

R *sperm might meet* W *egg, producing* RW *offspring.*

W *sperm might meet* R *egg, producing* RW *offspring.*

The results of these matings are diagramed in Figure 414. To get some practice in such crossings, do EXERCISE 2.

Since these four kinds of fertilizations are a matter of chance, the first one to occur may be the *WW* cross. If, because of some accident, no more fertilizations were to take place there would be only one offspring, *WW*. But when there are large numbers of fertilizations, a thousand or more, there are on an average 25 per cent of *RR* produced, twice as many or 50 per cent *RW*, and 25 per cent *WW*. This is the 1:2:1 ratio of 25 per cent red-flowered plants, 50 per cent pink, and 25 per cent white. By using beads or beans to represent genes you can demonstrate the ratio obtained in crossing hybrids. Do EXERCISE 3. You can test your understanding by doing EXERCISES 4, 5, and 6.

When contrasting characters do not blend. Most of the characters in plants and animals do not blend as red blends with white in the four-o'clock, or as black and white blend in the Andalusian fowl (see Fig. 415). For example, when pure black guinea pigs (*BB*) are crossed with pure white (*ww*) all the offspring are as black as the black parent. There is no blending (see Fig. 419, page 470). Yet the F_1 black guinea pigs contain a gene for blackness (*B*) and one for whiteness (*w*); they are hybrids just as the pink-flowered four-o'clock. Notice that the gene for whiteness is represented by a small letter. You will soon find out why.

Almost a century ago an Austrian monk, Gregor Mendel (1822–1884), experimented with garden peas in his monastery garden. His experiments are models of clear thinking, accurate observation, and careful recording. His work is considered particularly brilliant, in part because he knew nothing about chromosomes, which had not yet been seen. He crossed tall pea plants six to seven feet high, with short ones less than eighteen inches high. All the offspring were as tall as the tall parent. As in guinea pigs, there was no blending of the two contrasting characters. Mendel called the character

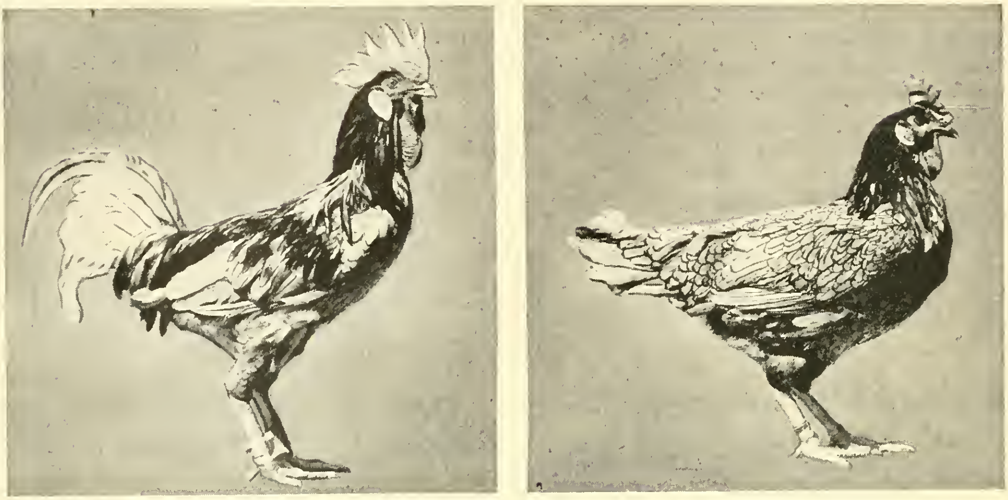


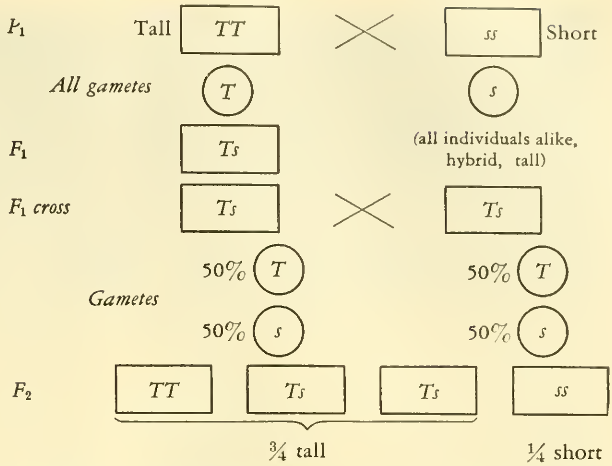
FIG. 415 *Blue Andalusian Fowl. These "blue" (slate gray) Andalusian fowl are hybrids containing a gene for blackness of feather and one for whiteness. Is this a case where contrasting colors do or do not blend?* (SNYDER'S PRINCIPLES OF HEREDITY)

that showed in the hybrid, *dominant*, and the character that did not show he called *recessive*. He experimented with other contrasting characters in the garden pea and in every character he found no blending in the hybrids. He therefore formulated his "law of dominance." More recent experiments show that in the majority of cases there is dominance when contrasting characters are crossed. There are numerous exceptions such as flower color in the four-o'clock and feather color in the Andalusian fowl. In crosses such as these where there is no dominance, there is *blending inheritance* or *incomplete dominance*. Because there are exceptions we no longer speak of a *law* of dominance. Do EXERCISE 7 and if materials are available you will find EXERCISES 8 and 9 very interesting.

Mendel's experiments with the garden pea. Among the seven pairs of contrasting characters which Mendel studied in garden peas are these: tallness and shortness, smoothness and wrinkledness of seed coat, yellowness and greenness of seed. In all of these experiments he started with plants that were pure for the particular character he was studying. He got pure plants by permitting the plants to self-pollinate for several generations. If the offspring always *bred true*, that is, all had the same character as the parent, he was sure the plant was pure and not hybrid. When Mendel started with two pure parents, no matter what character he studied, the results were always like those diagramed in Figure 416. Can you predict, by using diagrams, the results of a cross between plants with other contrasting characters? Try EXERCISE 10.

The law of segregation. Mendel also formulated a second law, the *law of segregation*. This states that, when hybrids are self-pollinated or crossed, the character which had been hidden in the F_1 separates or *segregates* out again in some

FIG. 416 *This is how Mendel's results with tall and short peas can be explained. The small letter is used for the gene for shortness because the character is recessive. How do all the offspring in the* (F_1) *look? Are they pure or hybrid? What 3 kinds of offspring appear in the* (F_2)*? When* (TT), (ss), *and* (Ts) *were self-pollinated to give an* (F_3) *what kinds of offspring were produced by each?*



of the F_2 offspring. For example, when the hybrid tall peas were crossed shortness segregated out in the F_2; *ss* plants appeared.

We now think of the law of segregation in terms of genes and reduction division and state it as follows: The two members of a pair of genes separate or segregate in reduction division without having changed or contaminated one another. When the hybrid *Ts* forms gametes, some will have the gene called *T*, some the gene called *s*. Neither gene was changed while associated with the other in the hybrid plant. Try EXERCISES 11 and 12.

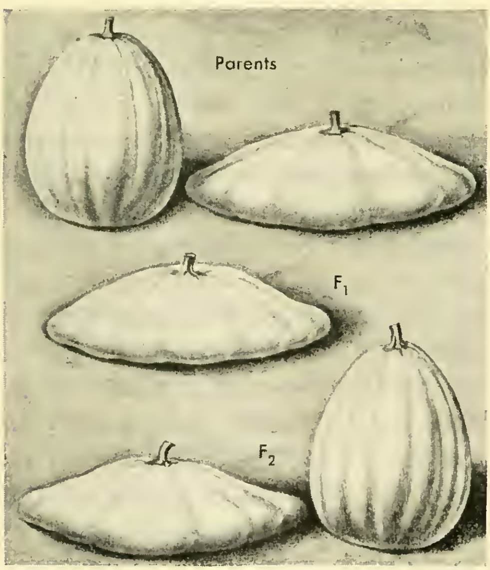


FIG. 417 *Fruit shape has been studied in squash. Is this dominance or blending inheritance? Which law explains the offspring in the* F_2*? What might the genes be in the flat* F_2 *squash?*

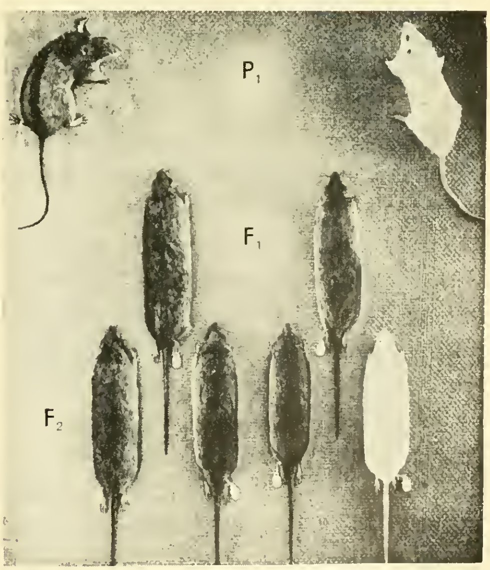


FIG. 418 *Mendelian inheritance in rats. Which coat color is dominant? Where does segregation show?* (AMERICAN MUSEUM OF NATURAL HISTORY)

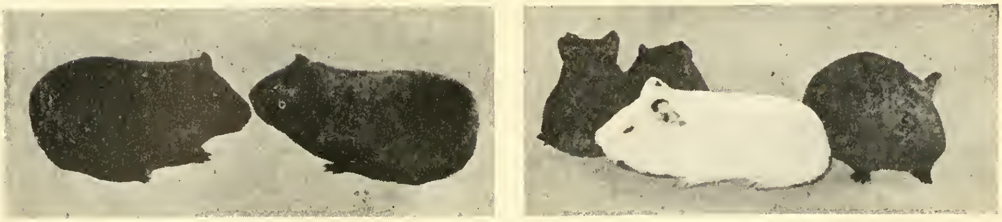


FIG. 419 *The guinea pigs at the left were the parents of those at the right. Were the parents pure black or hybrid? Explain.* (CASTLE'S GENETICS AND EUGENICS)

Mendel's law of segregation is truly a law, for it holds for all of the plants and animals which have been studied. There are many. Among others tobacco, corn, Jimson weed, squash, and snapdragon have received much attention. Among animals studied extensively are rats, mice, cattle, rabbits, fowl, dogs, cats, horses, insects, fishes, and man himself. But the animal with which most experiments have been performed is the fruit fly (Drosophila melanogaster).

The famous fruit fly. The fruit fly is a tiny fly frequently found near ripe fruit. You can show by diagrams the results of one crossing of the fruit fly. See EXERCISE 13. Its heredity has been studied in laboratories all over the world because it is particularly suitable for such work. It is small, needs little food, and is easy to raise. Its life cycle takes only two weeks, so 25 generations can be studied in one year. There are about 400 offspring from one mating; these large numbers give us reliable ratios. Then, too, it has a relatively small number of chromosomes, only four pairs, each pair differing from the others in size and shape. Biologists probably know more about the heredity of the fruit fly than of any animal or plant. Morgan and his students and fellow workers succeeded in developing a map of its chromosomes, showing at which point each kind of gene must lie.

Innumerable experiments with the fruit fly have shown that in the inheritance of some characters there is dominance, in others there is blending inheritance. But no matter which character is studied, the law of segregation holds. Can you explain the results indicated in Figure 422? See also Figure 420.

(Optional) Two pairs of characters. Mendel asked himself this question: If a tall plant with yellow seeds is crossed with a short plant bearing green seeds, will the tall plants always have yellow seeds in later generations or will all or some of them have green seeds? Experiment showed that in the F_2 some tall plants had green seeds and some short plants had yellow seeds. He thus discovered that the characters of size and seed color are inherited independently of one another. All the other pairs of characters he studied were also inherited independently of one another. Mendel therefore formulated the *law of independent assortment of characters or the law of unit characters*, meaning that every character is passed on to the offspring independently of every other. This is not now accepted as a law because there are important exceptions, as you will see later.

FIG. 420 *Half-pint milk bottles make cheap homes for families of fruit flies. In a laboratory where fruit flies are studied, you would see row after row of such bottles. Each contains flies with some character or group of characters to be followed in experiments.* (PROFESSOR H. CHARIPPER)

We can explain Mendel's results in crossing pea plants that were pure for tallness and for yellow seeds with pea plants that were pure for shortness and for green seeds. If you will examine Figure 421 you will note that all the F_1 plants were tall and bore yellow seeds.

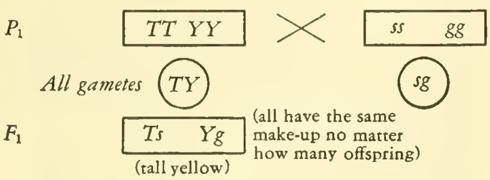


FIG. 421 *What characters does each parent have? Is each parent pure or hybrid for size? For seed color? Is the* (F_1) *pure or hybrid for size? For seed color? How does it look?*

Mendel then mated to each other the F_1 plants which were hybrid for both size and seed color. Four kinds of plants resulted. Some were tall with yellow seeds, some tall with green seeds, some short with yellow seeds, and some short with green seeds.

(Optional) Independent assortment. Since we understand reduction division, we can see the reason for the results. The genes for size are located in one pair of chromosomes and the genes for seed color are in a different pair. Because of this there are four possible kinds of gametes when the primary sex cells of the

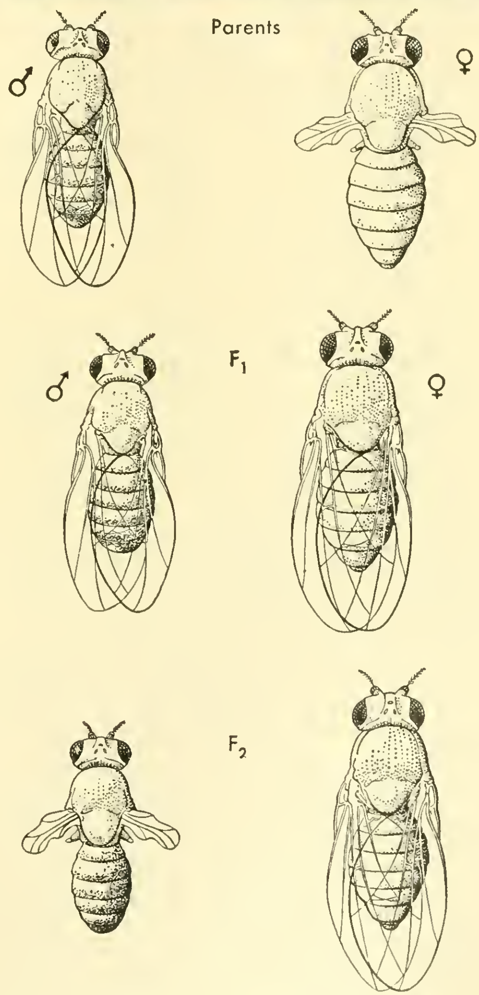


FIG. 422 *Heredity of fruit flies with long and with short (vestigial) wings. Which character is dominant? How do you know? In what ratio will long and vestigial wings appear in the* F_2 *if large numbers of flies are produced?*

dihybrid TsYg go through reduction division, as diagramed in Figure 423. The gametes may be *TY*, *Tg*, *sY*, *sg*. Try it on paper. This is what is meant by independent assortment of genes. The pair of genes for one character will act independently of the pair of genes for the other character. Figure 424 illustrates all the possible offspring when these dihybrids are crossed. You can demonstrate this by doing EXERCISE 14. EXERCISES 15 and 16 are more difficult. Try them.

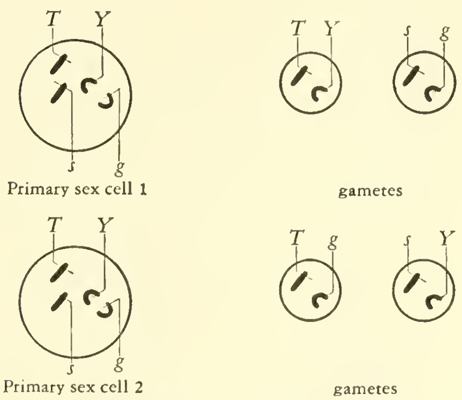


FIG. 423 *Diagram of two primary sex cells of a plant that is hybrid for size and for seed color. How many different kinds of gametes may a dihybrid produce?*

(Optional) Linkage. Research workers soon found that genes did not always assort independently. When they happened to study the inheritance of two genes which lay in the same chromosome, the results were different. In the fruit fly the gene for black body lies in the same chromosome as the gene for short (vestigial) wing. When reduction division occurs these two genes naturally remain together. They are said to be *linked.* Since there are genes for many different characters in one pair of chromosomes, there are many cases of linkage. The characters determined by such genes are not inherited independently. Mendel happened to study only characters whose genes were in different pairs of chromosomes and for this reason he believed that every character is inherited as a unit, independently of the others. EXERCISES 17 and 18 are difficult. Try them.

(Optional) Sex is inherited like other characters. Long ago it was noticed that the male and female organisms of a species differed in one pair of chromosomes. In many animals the male had one

F_1 cross Ts Yg × Ts Yg

Female gametes	*Male gametes:* TY	Tg	sY	sg
TY	TT YY tall yellow	TT Yg tall yellow	Ts YY tall yellow	Ts Yg tall yellow
Tg	TT Yg tall yellow	TT gg tall green	Ts Yg tall yellow	Ts gg tall green
sY	Ts YY tall yellow	Ts Yg tall yellow	ss YY short yellow	ss Yg short yellow
sg	Ts Yg tall yellow	Ts gg tall green	ss Yg short yellow	ss gg short green

FIG. 424 *Crossing two dihybrids. The parents were hybrids for both size and seed color. See also Figure 423. How many of the sixteen kinds of crossings result in tall yellow plants? In short yellow? In tall green? In short green? What ratio does this give when you are dealing with large numbers? How many different kinds of gene combinations are obtained in this 9:3:3:1 ratio?*

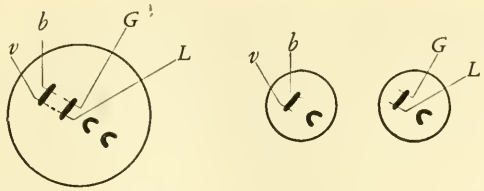


FIG. 425 *Diagram to help you understand linkage. The primary sex cell represents a hybrid fruit fly. In one chromosome are genes for vestigial wing (v) and black body (b). In the other member of the pair are genes for long wing (L) and gray body (G). When the primary sex cell goes through reduction division, the genes (v) and (b) remain together. So do (G) and (L). What kinds of offspring would be produced by mating this hybrid to a similar one? In what ratios?*

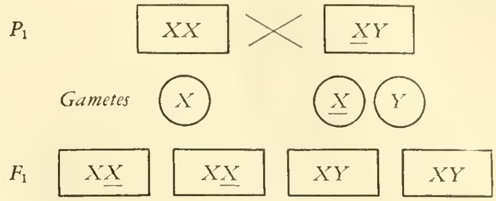


FIG. 426 *Inheritance of color blindness in man. Only the sex chromosomes are shown. In the* (P_1), *which rectangle represents the male? The female? Color blindness is recessive to normal sight. The chromosome* (X) *carries the gene for color blindness. The father is color blind because the* (Y) *chromosome carries no gene which can "dominate" the recessive color blindness gene. Why do the daughters have normal eyes? Why do the sons have normal eyes?*

"pair" in which the two chromosomes were somewhat unlike. These chromosomes were therefore called *sex chromosomes.* The cells in a man contain 23 pairs of chromosomes which are just like those in the cells of a woman. But in addition to these, in a man there is a pair of dissimilar ones, called *X* and *Y*, while in a woman there is a pair of similar chromosomes, two *X* chromosomes. Some of the genes of these chromosomes determine the character, "sex," just as other genes determine other characters.

(Optional) Sex-linked characters. There are certain characters that appear far more often in one sex than they do in the other. They are said to be sex-linked. Red-green color blindness in human beings is one of these; another is hemophilia (the trait of being a "bleeder"). Both of these are far more common in men. From the way each of these characters is inherited it is known that the gene that determines the character is in a sex chromosome. See Figures 426 and 427.

Hemophilia is inherited in the same way as color blindness. It, too, is caused

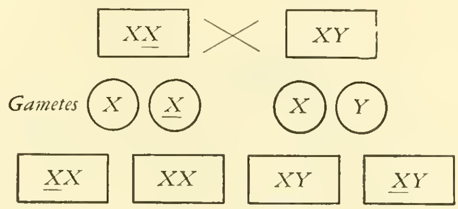


FIG. 427 *One of the females of the* (F_1) (above) *is mated with a normal male. What are the chances that the sons will be color blind? Will any of the daughters be color blind?*

by a recessive gene which is in the sex chromosome. Can you do EXERCISE 19?

Why individuals of the same species differ. Your brief study of genetics has explained several important facts:

1. An individual that has two parents is not exactly like either parent. Under laboratory conditions, after long and careful breeding, a relatively simple organism like the fruit fly may be made pure in every character. Each of its sex cells, therefore, will be like every other. But except for self-pollinated plants this does not happen normally in organisms that reproduce sexually.

2. The offspring does not resemble the two parents equally.

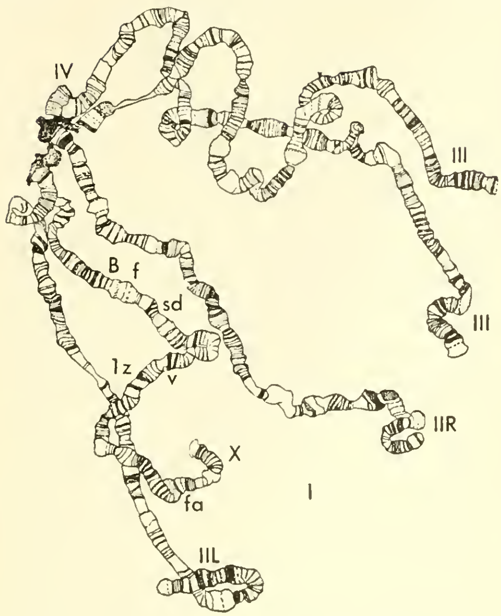


Fig. 428 *A drawing of the giant chromosomes in the salivary gland cells of fruit fly larvae. The lines, of course, are not genes. The letters mark the location of some genes.* (T. S. PAINTER)

3. The offspring may have a character that is not found in the parents or grandparents. A recessive gene may be carried for many generations without meeting its mate; it may, therefore, be many generations before it makes itself noticeable in any of the offspring. Such an individual may be called a "throw-back."

4. Genetics explains further why the many offspring of the same parents are all different from one another. When you studied the inheritance of two characters at the same time you saw that there were nine different genetic make-ups possible in the F_2. If you study three genes which are not linked in one chromosome you get twenty-seven different possible offspring. Four pairs of genes will produce 81 different genetic make-ups.

5. Mathematicians have calculated that in man, with 24 pairs of chromosomes, there are many millions of possibilities for different combinations. No two human beings will have the same gene combination, except for identical twins about which you will read later.

6. By independent assortment and fertilization, new combinations and recombinations are continually occurring. Individuals of the same species are not exactly alike; they are different from one another, or as it is more often stated, they show variations. Some variations are caused by the fact that in each reduction division the chromosomes (and genes) assort independently and at each fertilization new combinations are made.

Questions

1. List as many ways as you can think of in which you are different from either of your parents.
2. Explain how artificial cross-pollination is done. What color of flower do you get by crossing a red four-o'clock with a white? What is the result of crossing two pink four-o'clock plants?
3. If *R* represents the gene for redness why must a red four-o'clock be represented by *RR?* How would you represent a white plant? A pink plant? Which of these are pure, which hybrid? Explain.
4. What two kinds of gametes might be formed by primary sex cells which have a pair of genes, *RW?* Show by diagram why you might

expect red, white, and pink offspring when you cross two pink plants. If there is a very large number of offspring what ratio may you expect?

5. Is the offspring of a pure black and a pure white guinea pig pure or hybrid? How does the result of this cross differ from the result of a red and a white four-o'clock cross? Explain the difference between blending inheritance and dominance.
6. Name three contrasting characters with which Mendel experimented? How did he obtain pure plants to use as parents? What is meant by the expression "breed true"?
7. Illustrate by diagram what Mendel meant by the law of segregation. Nowadays, how is the law stated? Which plants and animals have been used particularly for experimental purposes?
8. List four good reasons why the fruit fly is a good animal for genetic experiments.
9. (*Optional*) Explain, by giving an example, what is meant by Mendel's law of unit characters.
10. (*Optional*) How many kinds of plants differing in appearance from one another can be expected when you cross two identical dihybrids?
11. (*Optional*) Under which circumstances do genes fail to assort independently of one another? In all Mendel's experiments with the garden pea did he find linkage, independent assortment, or both?
12. (*Optional*) How do the chromosomes in a man's body cells differ from those in a woman's cells?
13. (*Optional*) Give two examples of sex-linked characters. Is the gene responsible for the abnormal condition a dominant or a recessive in each case?
14. State six important generalizations arrived at from a study of this problem.

Exercises

1. Draw (diagrammatically) a four-o'clock plant with red flowers (use crayons). Draw one with white flowers. Below, draw their offspring. Imagine that two of these are crossed. Then show what types of grandchildren might be expected.

2. Make diagrams using rectangles for organisms and circles for gametes to illustrate as far as the F_1 the result of crossing a pure red with a pure white four-o'clock.

3. To demonstrate the ratio of the offspring of a hybrid cross. Put 200 red beans and 200 white beans into a jar. Imagine that each bean represents an egg formed by a hybrid pink blossom. The red bean (egg) has a gene for red-flower color. (Do not get the impression that the egg would in reality be red.) The white bean (egg) carries a gene for whiteness. Why do you have the same number of red and white beans in the jar? Set up another jar like it; in this case imagine that each bean represents a sperm.

Shake each jar to mix the beans that are in it. With your eyes closed pick one bean out of each jar and put the two beans together as though the cells were forming a fertilized egg. Make a record of the kind of "fertilized egg" you get. Return the beans to their jars, shake the jars and repeat. Do this until you have a record of many "fertilizations." How many of each kind of offspring did you obtain? What ratio is this?

4. A biologist, studying his experimental four-o'clock plants in the greenhouse, discovered that he had 294 with white flowers, 311 with red flowers, and 629 with pink flowers. They were all children of the same parents. What was the gene make-up of the parents? How do you know?

5. If the plants in Exercise 4 are the F_2 of a cross, what were the grandparents (P_1) like? What genes did they have? How do you know?

6. By using letters can you show the results of crossing Andalusian fowl through the F_2 generation if you start with a pure black and pure white? See Figure 415.

7. Diagram the guinea pig cross through the F_2 generation. Since whiteness is recessive how should you write the letter to represent it?

8. Sorghum is a plant much like corn. If you can obtain seedlings that are the F_2 generation of a cross between red-stemmed and green-stemmed plants, find out how many are red-stemmed, how many are green-stemmed. Which is dominant? What is the ratio?

9. If purple and white F_2 ears of corn are available, count how many kernels there are of each color on one ear. What ratio do you find? Which color seems to be dominant over the other? Add together the results obtained by other members of the class examining different ears. What ratio do you obtain now? Can you explain this?

10. By using a diagram show the results to the F_2 of crossing a plant which bears yellow seeds with one bearing green seeds (yellow is dominant). Be sure to show dominance by using a capital letter. Explain how each type of offspring in the F_2 would look. What would be the ratio of yellow to green?

11. If a biologist were to cross tall garden peas (not permitting self-pollination to take place), what offspring might he obtain? (This is a catch question; study it carefully.) Explain your answer. Can you state the "ratios"?

12. Suppose that you have a black guinea pig. Black is dominant over white. You wish to find out whether or not this is pure black or hybrid. How could you find out by performing one kind of cross? You might need to obtain many offspring before being sure. Use a diagram. (Will it help you to know that this is called a backcross?)

13. Diagram the cross between pure long-winged and pure vestigial-winged ($LL \times vv$) fruit flies to the second filial, F_2, generation.

14. (*Optional*) You can demonstrate how chromosomes assort themselves when a primary sex cell with two pairs of chromosomes forms sex cells. Imagine you are dealing with a dihybrid which has genes for red

and white in one pair of chromosomes and tall and short in a second pair. Let a red bean represent the chromosome with a gene for redness; a white bean its mate. Cut small squares of paper of the same size and write *T* on half of them and *s* on the others. Put the paper and beans into one jar. As this jar "makes" gametes you must be sure that each gamete gets one of each pair; that is, a chromosome for color and a chromosome for size. Pick out many gametes without looking. How many chromosomes must there be in each? Keep a record of the kinds of gametes produced.

15. (*Optional*) To test your understanding of reduction division when you are working with two pairs of chromosomes show what possible gametes may be formed from a primary sex cell with these pairs of characters: black and white, and rough and smooth.

16. (*Optional*) Work out the kinds of gametes produced by a *trihybrid*, *Ts Yg Pw* when *T* stands for tallness, *s* for shortness, *Y* for yellow seed, *g* for green seed, *P* for purple blossom and *w* for white blossom.

17. (*Optional*) In one kind of sweet pea there are purple flowers (*P*), and the gene is linked with a gene for long pollen grains (*L*). Another kind of sweet pea has red flowers (*r*) and a linked gene for spherical pollen grains (*s*). The parents, therefore, are *PL PL* and *rs rs*. Illustrate by diagram what offspring may be expected in the F_1 and the F_2 generations.

18. (*Optional*) The two chromosomes of a pair may be so twisted in reduction division that when they separate the two have exchanged pieces. This is called *crossing over*. A trihybrid might have genes *abc* in a row in one chromosome and *a′b′c′* in another. After twisting, one chromosome may have *abc′*, the other *a′b′c*. What effect has crossing over on the usual ratios?

19. If a mother has a recessive gene for color blindness and has four children, two of whom are sons, must one son be colorblind? Work out a diagram and explain your answer. How could a colorblind woman be produced?

Further Activities in Biology

1. There are many interesting breeding experiments that you can carry out. Mice breed quickly and the inheritance of coat color can be studied. Do not attempt experiments before you know how to care for the mice. Cross gray and white mice. If you can obtain them, cross yellow and black mice. Consult your teacher, for some crosses involve complications which you will not be able to explain until you know much more about genetics.

2. Fruit flies can be obtained at any supply house and can be bred easily. A Turtox leaflet gives you full instructions for culturing them.

3. The Brooklyn Botanic Garden, Brooklyn, New York, will sell you sorghum and pea plants which show a three to one ratio. You will be interested to discover the characters for yourself.

4. If you have a garden, there are many other experiments you can perform. Find out which flowers self-pollinate. Perform artificial pollination, using all precautions. By self-pollinating for several generations you may establish pure forms. Do you know why? Cross these forms. These experiments would, of course, extend over several seasons.

5. Your school is probably in need of charts and other demonstration material for showing the results of various crosses. Prepare some, using college textbooks as the sources of information.

6. A group of pupils (representing chromosomes) with a string of genes pinned on each, can move themselves about to explain reduction division in dihybrids. You can also show linkage in this way. Can you plan it?

7. Look up and write a report on how Morgan and his co-workers were able to assign a definite location to genes in the chromosomes of the fruit fly. Consult Snyder, *Principles of Heredity*, or Scheinfeld, *Heredity and You.*

PROBLEM 3 *How Can New Hereditary Characters Appear?*

Entirely new characters may appear. In the last problem you learned that with the reshuffling of genes in every mating new combinations are formed and thus offspring differ from their parents. From time to time, however, parents produce offspring with a really new character; something that is not the result of the normal recombination of genes. Such a new character appeared in 1910 in a fruit fly culture in a laboratory. A fruit fly was found that had white eyes, not the normal red ones. This was the first white-eyed fruit fly that anyone had recorded. When the fly was crossed with a normal red-eyed fly the F_1 were red-eyed; but in the F_2 some flies had white eyes. Thus, it was learned that this new character could be inherited. Evidently a change had occurred in the chromosomes of the germ plasm. This discovery led to many others.

It has been estimated that in about one out of 50,000 flies there occurs some change in the chromosomes which can be detected as a new character. In the many millions of fruit flies that have been studied, more than 500 changes in characters have been noted. In Figure 429 a very few of these are shown. Such changes have been observed somewhat more often in fruit flies than in other organisms, but changes of this kind have been known to occur in all organisms studied.

Changes in genes. The changes that occur in the chromosomes of the germ plasm are of different kinds. The simplest possible change is a change in a single gene. Just what this change is no one knows for no one yet knows the chemical make-up of the gene. There is a theory, however, that a gene is a single large protein molecule. Every molecule has its atoms arranged according to a definite pattern. According to this theory, it is believed that the atoms may rearrange themselves, thus making a new definite pattern. But, however it may happen, the change in the gene is sudden and complete. Such a change in a gene is now called a *mutation* (mew-tay'shun). The mutation (gene change) may produce a large or small change in the organism. That is, the new character may be readily noticeable or scarcely visible. However small the difference, if the new character can be inherited and follows the law of segregation it is clear that it was produced by a gene not present in the organism before.

When a single gene mutates, the other member of the pair is not changed. The organism is then a hybrid for this pair of genes. Most new genes are recessive to the unchanged gene; some are dominant.

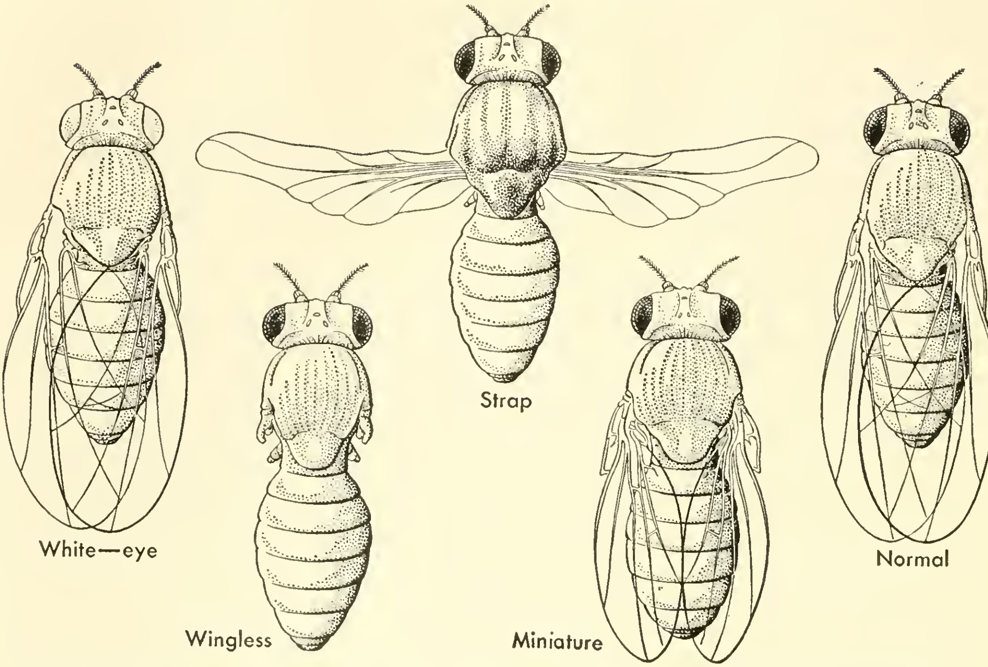


FIG. 429 *The fruit fly on the right is normal. The others show four inheritable changes that have occurred. What are they? What do the words strap and miniature refer to? What other wing character have you read about?*

FIG. 430 *Mutant* (left) *in barley produced by x-ray treatment. How does it differ from the normal plant at the right?* (STADLER)

Of course, when the new gene is recessive there is no outward sign of the change until a later generation, when two such new genes may come together. Try to illustrate how this works out by doing EXERCISES 1 and 2.

Changes in genes may produce harmful effects in the organism. Most mutations do. Short (vestigial) wings are clearly harmful to the fruit fly; most of the other mutations shorten the life of the fly. By far the greater number of mutations are so harmful that the organism dies; others merely weaken the animal or plant; a few are an advantage to the organism.

Mutations have been discovered in many organisms — corn, chickens, rabbits, mice, man, and many others. Any organism that shows the result of a mutation is called a *mutant*.

FIG. 431 *Dr. H. J. Muller in his laboratory x-raying flies. What mutations might occur? See Figure 429 for possible results.* (LIFE)

The rate of mutation may be increased. Some years ago Professor Hermann J. Muller, an American biologist, succeeded in increasing the rate of mutation in the fruit fly by the use of x-rays. He counted the number of mutations that occurred among flies that had been x-rayed and among flies that had not been exposed and found that far more mutations occurred in the x-rayed flies. Similar results have been obtained in experiments with plants.

Changes in chromosome number. Biologists have examined the chromosomes of the organisms in which new characters appeared. Sometimes they do not have the chromosome number normal to the species. The plant or animal may have half the number (haploid); more often it has one whole set of chromosomes beyond the normal number, or two extra sets, or even more. Mitosis or maturation may be irregular and cause changes

FIG. 432 *The Jimson weed (Datura) on the left has the half (haploid) number of chromosomes in its cells; the one on the right has the normal (diploid) number. What differences do you note besides height of the plants?* (BLAKESLEE — AMERICAN GENETICS ASSOCIATION)

FIG. 433. *The evening primrose* (left) *and one of its mutants* (gigas *or giant*). *What do you notice about the flowers and the leaves of the mutant?* (B. M. DAVIS)

in chromosome numbers. What kind of irregularity would double the chromosome number? See EXERCISE 3.

Normally a plant or animal has two genes that affect some character. If instead of two genes there are three or four genes, or only one, the character is often changed. Recently such changes in chromosome number have been artificially produced by chemical means. Colchicine can be used to cause doubling of the number of chromosomes in some plants.

Other chromosome changes. Still other irregularities occur in chromosomes. Sometimes a piece of a chromosome breaks off and attaches itself to the other chromosome of the pair. When reduction division takes place one gamete gets the chromosome with the added piece and will have two genes for some characters; the other will have the short chromosome and will lack certain genes. New individuals produced from such gametes are likely to have new characters.

De Vries and mutations. The term mutation was first used about 1901 by a Dutch botanist, Hugo De Vries (1848–1935), as a result of his experiments with the evening primrose (*Oenothera Lamarckiana*). By controlling the matings and keeping careful notes De Vries was able to show that new types of plants appeared and that some of the new types bred true, that is, produced offspring with the same new character. Among his plants appeared some with red-veined leaves, some with broader leaves, some that were dwarfed, and some that were giants. Some of the changes were striking and others were scarcely noticeable but they bred true.

De Vries said that changes took place in the germ plasm and that these changes were inherited. He used the word mutation, to mean a change in the germ plasm which was inherited. Now since we know more about genes and chromosomes, we reserve the name mutation only for those cases in which there is a change in a single gene.

Great changes are possible. You have learned that a character is produced by the action of a pair of genes. You must now broaden that understanding. Many characters are inherited in a more complicated way. Frequently a character is the result of several pairs of genes working together. And besides this, usually, one pair of genes has an effect on many characters. Since this is true you can readily see that a change in one gene might produce most unexpected results. For example, the gene for white eye in Drosophila (a mutation) not only produces white eyes instead of the normal red but also makes slight changes in the other characters of the fly. Changes in parts of chromosomes or in single chromosomes, or in sets of chromosomes would, therefore, produce even more marked changes. The offspring produced by such chromosomal changes may therefore be very different from their parents. This problem is easy to summarize. See EXERCISE 4.

QUESTIONS

1. Give an example of a new character that appeared in a fruit fly. How was it known that this character was not merely the result of a reshuffling of genes but a change in the chromosomes of the germ plasm? About how frequently may one expect such a new character to appear in the fruit fly?
2. Define mutation and tell what is known about mutations, stating where they occur, how they may affect the organism and so on.
3. How can the rate of mutation be increased? What scientist did this first?
4. Explain the connection between chromosome numbers and new characters; mention a specific plant.
5. What else may happen to chromosomes to produce new characters?
6. How, by whom, and when was the word mutation first used? How does our present use of the word differ from the original meaning?
7. What new ideas must you add to what you originally learned about a gene producing a character? Explain how a tiny mutation might cause a great change in an organism.

EXERCISES

1. Assume that whiteness appears as a mutation in the sperm cell in a species of dark animals. This sperm cell fertilizes a normal egg. If the gene that causes the whiteness is a recessive one, what is the appearance of the animal developing from the fertilized egg? Suppose the same mutation appeared in an egg and in the sperm that fertilized it. What must be the genetic make-up of all the cells of the animal developing from such a

fertilized egg? How does the animal look? Suppose that only one such animal appeared. What would have to be done to obtain more of the white animals? Use a diagram to illustrate.

2. Suppose a changed gene were dominant to the normal. Hornlessness appeared as a dominant mutation in a breed of cattle. Show by letters what must be done to get a pure breed of hornless cattle. (Let (h) represent horned condition, (H) represent hornlessness.)

3. Draw diagrammatically the normal mitosis which occurs (after reduction division from four to two) making a gamete which has two chromosomes. Then show by means of a series of diagrams what might happen to produce a gamete which has twice as many chromosomes as it would normally have.

4. Summary. You will find it easy to make this summary. Read the paragraph titles carefully. What is the one main topic under which the others will fit as subtopics? Write your outline and fit in the few necessary facts briefly. The last paragraph, though short, is extremely important and might well stand as a second main topic.

Further Activities in Biology

1. Consult some textbook in genetics such as Snyder or Sinnott and Dunn (see bibliography) to discover how many of the mutations that have appeared in the fruit fly are dominant, how many are recessive, and how many are unfavorable to the species.

2. Jaffe's *Outposts of Science* contains some interesting information about Morgan and Muller.

3. Demonstrate to the class the various types of chromosomal changes by using plasticine of various colors.

4. What kinds of mutations have taken place in corn, in the soybean, or in other cultivated plants? Prepare a report for the class. (The *Yearbook of Agriculture*, 1936, 1937, contains information.)

PROBLEM 4 *How Does the Environment Affect the Characters of an Organism?*

Variations caused by genetic make-up. Occasionally variations within a species are caused by mutations and chromosomal changes. These are not of frequent occurrence because they are not part of the regular machinery by which gametes are formed and fertilization and development take place.

Much more common are the variations produced by normal sexual reproduction. Since, in reduction division, the chromosomes with their genes assort in various ways and since, in fertilization, genes from two individuals are brought together there is a constant reshuffling of genes in every generation. The new combinations cause endless variation among the individuals of the same species. Examples of such variations in human beings are: color of skin, hair, and eyes; length of nails and of fingers and toes; height; shape of nose and chin.

The environment causes variations. New gene combinations only partly explain variations that occur. You are affected by your food, by the amount of exercise and sleep you get, by the kind of air you breathe, as well as by many other factors of your environment, such as insects, bacteria, clothes, cosmetics, radios, theaters, books, school, friends, family, and many others. These factors cause changes in you. Disease germs may change your blood or other tissues; cosmetics and sunlight may change parts of your skin; practicing the violin may cause changes in your nerve and muscle cells; every other factor in the environment may produce changes in the tissues and organs of your body or in your behavior. If you do EXERCISE 1, you may discover some interesting facts about environment.

All animals are changed by the environment. Every plant, too, is affected by the soil it lives in, by the amount of water it gets, by the amount of light, by the force of the wind, by the degree of temperature, and by the kinds of living things that surround it. Simple experiments like the one described in EXERCISE 2 will show this.

Since organisms are changed by the environment, they differ among themselves. They vary. Even if there were no genetic causes of variations, differences in the environment would cause enormous variation among members of the same species.

Careful measurement of variations. Biologists have long known that, upon close examination, no two dandelions are exactly alike; no two black bears; no two grasshoppers. You can convince yourself of this by doing EXERCISE 3. It should not surprise you to find no two living things

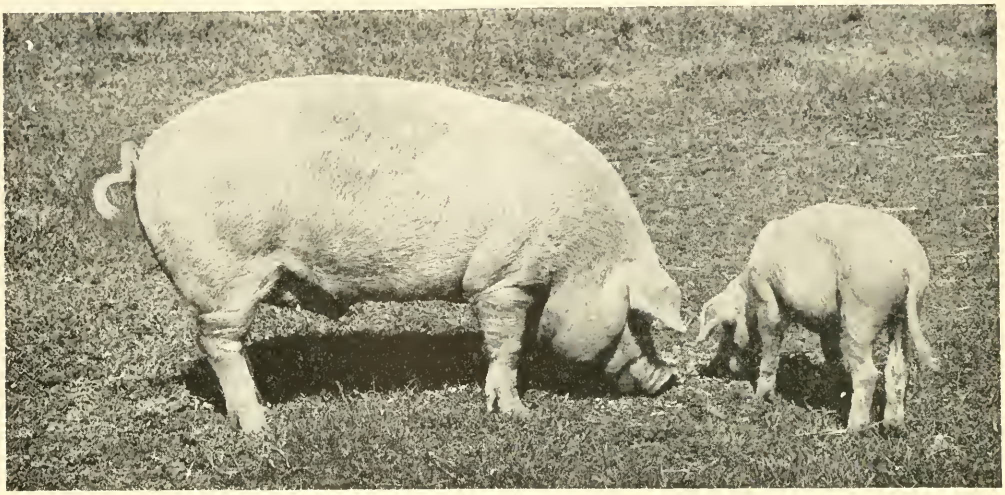
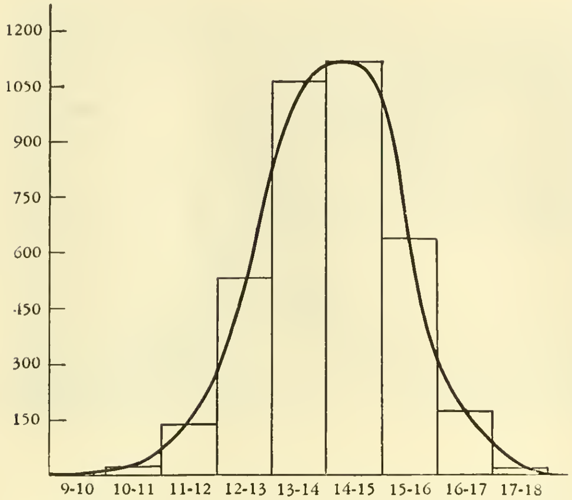


FIG. 434 *These hogs are of the same age. The one on the left was raised on clean ground; the other was raised on ground infected by parasitic worms. Of what importance is the environment? Might there be another reason for the difference between the hogs?* (U. S. DEPARTMENT OF AGRICULTURE)

FIG. 435 *Two plants of the common evening primrose, grown under normal conditions, are shown on the left. The single plant on the right received fewer hours (only 10) of daylight each day. What effects did this have on the plant? Why can you not draw conclusions from this picture alone about the effect of light on plants? What other information would you need?* (JOURNAL AGRICULTURAL RESEARCH)



Length of Beans Millimeters	Number of Beans in Each Group
9-10	2
10-11	20
11-12	136
12-13	540
13-14	1068
14-15	1125
15-16	636
16-17	180
17-18	18
Total	3725

FIG. 436 *The results of measuring large numbers of beans are given in the table. These results were used in making the graph at the left. Note the few extremely small and extremely large beans, the many medium-sized beans. Variations of this kind arranged in a graph give a bell-shaped curve.*

exactly alike, for you know that individuals differ, first, in their genetic make-up and secondly, in their environment. Many years ago someone recorded the chest measurements and heights of the soldiers in a Scottish regiment. He found a wide range from the short men to the very tall men, from those with a narrow chest to those with a broad chest. Whenever a single character is measured and the measurements are carefully listed we discover an interesting fact. If enough individuals are measured there is usually a very gradual change from those at one end of the scale to those at the other. This shows up best when one makes a diagram of the table of figures. Such a diagram is called a *graph.* After studying the graph in Figure 436, you will find it interesting to make graphs as described in EXERCISES 4 and 5.

What Lamarck thought about variations. About the year 1800 Jean Baptiste Lamarck (1744–1829), a French biologist, called attention to the fact that the environment causes changes in organisms. The person constantly exposed to strong sunlight acquires a darker skin. He saw, too, that frequently as an animal used some part or organ, the part or organ grew larger or stronger; when allowed to fall into disuse, it became smaller or weaker. We all have seen examples of this many times. The muscles of a bookkeeper are usually smaller than those of a steel worker. Lamarck was convinced, as you are today, that the environment causes changes in animals and plants.

But then Lamarck went one step further. He said that a variation of this kind would be passed on to the offspring, even if only to a slight degree. He believed that if an organ had been much used by the parents it would be slightly better developed in the offspring; and that if the organ had grown less efficient because of disuse, it would be slightly

FIG. 437 *Sentinel Pine, Yosemite National Park. Its one-sided growth is caused by wind. If seeds from this tree were planted in a sheltered valley how would the new trees look? Would Lamarck have agreed with your answer? Explain.* (U. S. DEPARTMENT OF INTERIOR)

less well developed in the offspring. In other words he believed that *acquired characters are inherited*, even if only to a very slight degree. Do you agree with Larmarck? Do EXERCISES 6 and 7.

Weismann's beliefs. Almost a century after Lamarck, a German biologist August Weismann (1834–1914) called attention to this important fact: as the fertilized egg (germ plasm) develops into a new individual it produces both somatoplasm (tissue cells) and more germ plasm (primary sex cells which later form gametes). The diagram, Figure 438, should make this clear. Since this goes on in every generation, germ plasm is passed on in an unbroken line. If the animal should die without having reproduced, that particular germ plasm dies off and that line is broken. But under normal conditions the animal does reproduce and the germ plasm is immortal; it is continued from generation to generation. Weismann spoke of this as "the continuity of germ plasm." Strictly speaking, then, offspring do not really come from their parents; they come from the germ plasm carried within the soma or body of the parents.

Since, according to Weismann, the fertilized egg produces both somatoplasm (tissue cells) and more germ plasm (primary sex cells), it follows that the primary sex cells are not made by the body which houses them; they come directly from the line of germ plasm carried from earlier ancestors through the parents. Examine the diagram again.

Weismann believed that the sharp distinction between germ plasm and somatoplasm held for all organisms. But you read earlier that while it does hold for the more complex animals, it is not true of some of the lower animals nor is it true of plants. In these organisms, tissue cells (somatoplasm) *are* capable of producing reproductive cells. Therefore, we now accept Weismann's statement as applying only to the more complex animals.

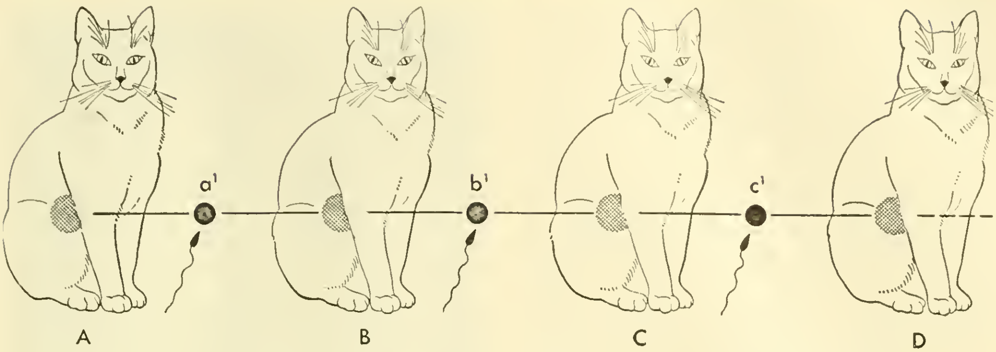


FIG. 438 *The cats shown are female cats. A sperm cell is shown about to fertilize the egg* (a¹)*; other sperms fertilize the eggs of succeeding generations. What is the shaded substance in each individual? Where is the somatoplasm? The egg* (a¹) *and the sperm cell can be spoken of as germ plasm. The resulting fertilized egg forms more germ plasm like itself and it also forms somatoplasm, the body of cat* (B). *You can see that cat* (B) *did not produce its germ plasm. It only carries the germ plasm which is a continuation of the germ plasm of cat* (A) *plus the sperm.*

Can the body affect the germ plasm? Remember that the germ plasm (primary sex cells) is held within the body or soma; it is not produced by the soma. Therefore Weismann argued that, even though the soma may become changed, even though it may acquire new characteristics during the lifetime of the animal or plant, these acquired characteristics are not passed on to the germ plasm or primary sex cells. This was a reasonable conclusion for Weismann to arrive at. And nowadays we still accept it as true. In fact, since we have learned about mitosis and genes we have all the more reason for believing that acquired characters are not passed on to the new organism. Even in those lower animals and plants which do not have distinct somatoplasm and germ plasm there is every reason to believe that the genes are not changed even though environmental changes may occur in the cells.

Weismann arrived at his conclusion as the result of a famous experiment in which he cut off the tails of white mice for almost twenty generations. As each generation grew to maturity he measured the tails of the mice before cutting them off. He found that the tails neither disappeared nor grew shorter. From this he concluded that the environment changes the body but that the germ cells are not affected by changes in the body. In other words, acquired characteristics (somatic changes) are not inherited.

There has been much criticism of Weismann's experiment. It has been pointed out that cutting tails produced such a crude acquired character that no change need have been expected. No one believed that if a man lost his leg in an accident his child born later would have a shorter or a weaker leg. More evidence on the question of inheritance of acquired characters was needed. See EXERCISE 8.

More convincing evidence. For centuries in many Chinese families the feet of girl babies were tightly bound to keep them fashionably small. In each generation the body or soma was changed by this practice; a new character was acquired. But measurements showed that in those many generations the size of the foot had not decreased — the acquired character had not been inherited.

A most interesting experiment was performed by two American scientists. They removed the ovaries from a pure black (*BB*) guinea pig. Naturally every egg produced by this guinea pig had a gene for blackness. They transplanted these ovaries to the body of a white (*ww*) guinea pig in place of its own ovaries. After a while this white female was mated with a white male (*ww*). You would expect two white guinea pigs to produce white offspring. But what were the results? All the offspring were black! It is clear that the genes for blackness in the transplanted ovaries were not affected by the body of the *ww* female. Other biologists have performed experiments of many kinds on many types of animals and plants to find out whether acquired characters can be inherited. In all these experiments the results show that acquired characters are not inherited.

(Optional) The environment affects the action of genes. It is clear from what you have just read, that the environment affects the body or soma, causing changes. We have all noted this. We know, too, that these changes are not inherited.

It is also true, however, that the environment is important in making it possible for a gene to produce its effect. For example, all green plants have genes for the production of chlorophyll. Yet in most plants these genes do not produce chlorophyll unless the plant is in the light.

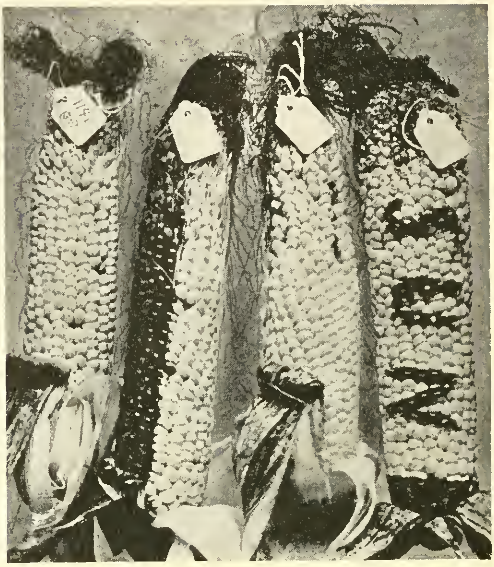


FIG. 439 *This corn contains genes for the production of red kernels. But red kernels are produced only when light reaches them. Professor R. A. Emerson cut away part of the husks in the second and fourth ears. How did the word* SUN *appear?* (BROOKLYN BOTANIC GARDEN)

The light affects the action of the genes. How light affects the action of the genes in a certain variety of corn is strikingly shown in Figure 439.

Sometimes temperature, too, has a profound effect on a particular gene. In some fruit flies there is a gene for vestigial (shortened) wing. But the size of the vestigial wing is determined not only by a gene but by the temperature of the fly's surroundings. If the fly is raised at a high temperature in an incubator the vestigial wing is nearly as long as the wing of a normal fly.

Among Chinese primroses there is one variety that has genes for white flowers; another variety has genes for red flowers. But there is a third variety that has genes that produce different colors depending on the temperature in which the plant is raised. At low temperatures the genes produce red flowers; at high temperatures they produce white flowers. That does not mean that the temperature changes the genes. The genes have remained unchanged for many generations. But, evidently, these genes have different effects under different environmental conditions.

What makes the individual what it is? We must not think of heredity and environment as factors that work separately in producing the organism. What is really inherited is genes which have a tendency to produce certain effects under certain environmental conditions. If conditions of the environment are changed, different effects or characters may be produced. The heredity and the environment act together in producing the characters of an individual.

Questions

1. Why does normal sexual reproduction result in variations among individuals of the same species?
2. What environmental factors may cause variations? Give examples of variations in you and your classmates caused by the environment.
3. Explain what we have learned by careful measurements about variations in man and in the bean.
4. What did Lamarck notice about the effect of the environment on an organism? Do you believe that acquired characters are inherited? Defend your answer.
5. When and by whom was the phrase "continuity of germ plasm" introduced? Explain what he meant by it. To what extent have we modified Weismann's beliefs? Explain how Weismann's beliefs have led someone to say: "The parent is rather the trustee of the germ plasm than the producer of the child."
6. Describe the object, the method, and the conclusions of Weismann's experiment on rats. What criticisms have been made of this experiment?
7. Cite a fact that seems to support the idea that acquired characteristics are not inherited. Explain the method and results of an experiment which seems to show that acquired characteristics are not inherited.
8. (*Optional*) Give three examples of genes that produce effects only in special environments.
9. What two factors are always involved in producing the characters of an organism?

Exercises

1. List the factors of a child's environment which would affect it during the first year of its life. List other factors besides those mentioned in the text which affect you. Compare the number of factors in your environment with those in the environment of a young child; of a dog.

2. Try the effect of a variation in hours of daylight on young plants. Plant 20 or 30 oat seeds in each of three flower pots. When the seedlings are about three inches high place the pots next to each other at a window. Get two boxes a foot in height. Leave one pot uncovered. Give the second pot one half as many hours of daylight by covering it with a box at noon each day and uncovering it in the evening. Place a box over the third pot and leave it on at all times except while watering and measuring the plants. Measure and examine the seedlings every two days. Record results.

3. Study carefully a handful of bean or sunflower seeds and list all the small characters in which they vary. Are any two seeds exactly alike?

4. Study the variation among members of your class, in regard to some easily measured character, such as height. Draw a curve to show the results of your measurements. If this differs from the curve in the text, explain.

5. Can you suggest a character in some plant or animal (of which you can obtain large numbers) which might be measured to see whether the curve is like the one shown in Figure 436? Make such a graph.

6. You may have heard that a man who spent much time during his youth developing the muscles of his body had a child who was particularly good at athletics. How can you explain this? Can you use this case as evidence to support any theory? Why or why not?

7. Ask your parents or other adults for examples of what they consider cases of the inheritance of acquired characters. Discuss these carefully in class. Is evidence presented in any of these cases? Why or why not?

8. Give several reasons why Weismann's experiment does not convince you.

Further Activities in Biology

1. If you did Exercise 4, you studied variation in height of the members of your class. You could make a much more complete study of variation in height by obtaining figures not only of the members of your class but of the whole school. It would be interesting to see how this curve compares with the class curve.

2. Read up on Lamarck (*Green Laurels*, by D. C. Peattie, or elsewhere).

3. By using an animal that breeds rapidly (Drosophila) you could perform an experiment on the inheritance of an acquired character. How could it be done?

4. Collect examples of different types of variation observed by you or your classmates in various organisms.

PROBLEM 5 *What Have We Learned about Producing New Types of Animals and Plants?*

A chapter in man's history. Long before history was written men had learned to domesticate animals and to cultivate plants. Then many centuries ago they became interested in improving these animals and plants. They wanted wheat that would grow in the cold, oat plants that were tall and strong, sheep with more wool, cows that gave better milk, horses that could pull heavier loads or run faster. Through the centuries their progress in producing better types of animals and plants was slow but steady. Examine Figure 440. From ancestors, no doubt like this wild horse, the race horse and the work horse have been developed. From the wild sheep has come the merino sheep with wool that is thick and of good quality. Men did all this before they understood heredity. Within recent years there has been great improvement in cattle, hogs, chickens, such animals as the mink and fox, and many others. The plant breeders, too, by applying their knowledge of chromosomes and genes are now taking far more rapid strides than in the early days.

How does the breeder work? You will see that there are three methods of producing new and better types of plants and animals.

The first method — selecting the best gene combination. Producing better plants and animals by selection is a method that has been used by men as far

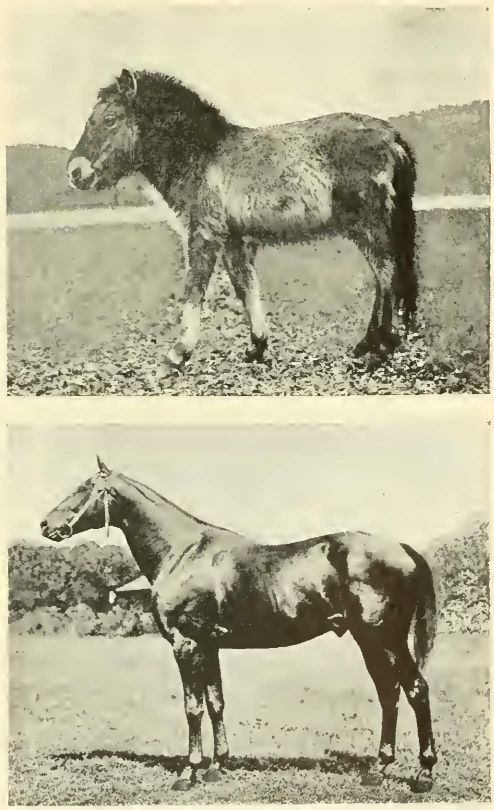


FIG. 440 *How does the wild horse from Asia* (top) *differ from the thoroughbred? What other breeds of horses have been developed?* (U. S. BUREAU OF ANIMAL INDUSTRY)

back as the records go and was undoubtedly used before the dawn of written history. A description of the method used with soybeans will make it clear. The soybean is a plant that has long been cultivated. You probably know that it has many uses. It is excellent food for animals, either as fresh forage in the pasture or when dried to make hay. The seeds yield oil which may be used as food or in many different commercial processes. The seeds are also eaten by man because of their large amounts of protein.

Now the first step in breeding is to determine the aim or goal; the breeder must decide what kind of improvement he wants to make in the plant or animal. Let us suppose that the breeder wants to produce plants that have beans (seeds) with larger oil content. He begins by analyzing seeds from different plants to discover which plants produce beans with the largest oil content. He discards the seeds from plants which produce little oil. This is the process of *selection* or of choosing the organisms that have the desired character (large oil content). Then he sows seeds of those plants which produce most oil.

The plants that appear the next season will probably produce beans with a higher average oil content, since the plants that produced little oil had been discarded and were not used as parents. Selecting the plants with the highest oil content is then repeated. Since self-

FIG. 441 (above) *These few strawberry plants were selected from the whole field for breeding. Why did the breeder destroy all the others?* (U. S. BUREAU OF PLANT INDUSTRY)

FIG. 442 (left) *Merino sheep have been bred for their wool. This one sold for $13,425. Why such a high price?* (JOURNAL OF HEREDITY)

FIG. 443 *Two varieties of corn, developed at the University of Illinois. One tall and one short plant were selected. Then, for several corn generations, breeders planted seed from the tall offspring of the tall plants and the short offspring of the short plants.* (SCIENCE SERVICE)

fertilization is the usual method in soybeans, the breeder selects only one plant as the parent for the next generation. This is continued each season until he discovers that the percentage of oil in the seed no longer increases. He has then reached the highest oil content that selection can achieve with his soybean plants. From this time on the breeder can do nothing more than prevent cross-pollination from soybean plants that may have a lower oil content. He strives to keep his plants at the same high level in each generation. Try EXERCISE 1.

Improvement through selection stops after a time. Until about twenty-five years ago no one knew why selection produced improvement up to a certain point and then stopped. Now we can apply the gene theory and explain the facts. Each time the breeder selected plants with the highest oil content in the beans, he was choosing those plants that had the best gene combination for oil production. These "good" gene combinations tended to be inherited when the plants were used as parents. Over a number of generations through selection the breeder can separate plants with "good" combinations from plants with "poor" combinations. By consistently discarding the "poor" ones he eventually has only the "good." By using the plants with good combinations as parents he can expect offspring with the same good combinations, but he cannot expect to get offspring that are better than the "good" parents.

Test your understanding of selection as a method of improving organisms by doing EXERCISES 2 and 3.

Varieties and species. When the breeder produces a soybean plant whose seeds have a much higher percentage of oil and the plant obtained is pure and breeds true he has produced a new *variety* or *strain*. In animals it is often called a *breed*. The plant is different from the original one but it is still a member of the same species because the change is a minor one. In this case there would be no doubt in your mind about its belonging to the same species as the soybean plant whose seed contains little oil.

But in many instances it would be impossible for you to determine whether two organisms that differ are sufficiently different to be considered separate species or merely separate varieties within the same species. It is difficult even for biologists to draw the line and they do not always agree, but they often use reproductive ability as a test. If two organisms which are seemingly different can be mated with one another and produce offspring that can live and reproduce and cross with the parent organism, these two organisms can then be classified as belonging to two varieties within the same species. If they do not readily interbreed they are different enough to belong to separate species. There are many exceptions, however.

Selection has improved animal types. Many new and better varieties or breeds of animals have been produced by selection. For centuries men selected the fastest horses in every generation for breeding. In fact, selection has been practiced in horse breeding so successfully and for so long a time that in recent years there has been little or no improvement in the records set by race horses. Cattle, too, have been improved by selection. The best Holstein-Friesian cow in 1880 produced 18,004 pounds of milk during one year. By 1942 this breed had been improved so much that one cow set a new record of 41,943 pounds, and at least one herd of 12 cows averaged more than 20,000 pounds of milk per year. This increase was accomplished largely by the careful selection of the best genetic combination in each generation and the use of these animals for breeding. See EXERCISE 4.

Improvement of animals is usually slower than improvement of plants because animals can never be self-fertilized. The closest the breeder can get to the self-fertilization found in some plants is to mate close relatives, such as father and daughter or brother and sister. The genetic make-up of close relatives is sometimes very similar. Therefore *inbreeding*, the breeding of close relatives, is practiced after successful selection of the most desirable gene combination has been made. In this way new and better breeds of horses, cattle, sheep, and other animals are maintained.

Inbreeding and outbreeding. It is often said that inbreeding is not desirable, that it leads to offspring that are defective in one way or another. This may happen for the following reason: all organisms have recessive genes and close relatives are likely to have the same recessive genes. In fertilization, two like recessive genes may come together, producing a character that was possessed by neither of the parents. If the recessive gene is undesirable, and many recessives are undesirable, the inbreeding results in poor offspring. If on the other hand, the parents have many desirable genes, inbreeding is advantageous; it prevents the introduction of less desirable genes. And if undesirable offspring appear through inbreeding they are discarded, so that in each generation the breed becomes pure for more and more desirable genes. However, except in self-fertilized plants inbreeding has never gone on long enough to produce organisms that are pure in all characters.

In *outbreeding* or *crossbreeding*, two organisms are crossed that belong to the same species or even the same variety but have no family connection. Could you demonstrate the method of outbreeding in plants? See EXERCISE 5. After outbreeding, the offspring sometimes has *hybrid vigor*. See Figure 444. You will find an explanation for hybrid vigor in

FIG. 444 *Wheat* (right) *crossed with another grass* (left) *produced the hybrid in the center. Hybrids frequently show increased vigor.* (U. S. DEPARTMENT OF AGRICULTURE)

FIG. 445 *This purebred bull is valuable because he carries genes for the production of milk rich in butter fat. His daughters are always better than their mothers in giving rich milk.* (U. S. BUREAU OF ANIMAL INDUSTRY)

Altenburg's *Genetics* or Snyder's *Principles of Heredity*.

Pedigreed animals. The animal breeder or progressive farmer keeps careful records so that the exact ancestry, or *pedigree*, of every animal is known. He makes practical use of this information. For example, it was noticed that bulls can transmit to their daughters the characteristic of producing much or little milk; when, therefore, cows prove to be good milk producers, the male parent, the *sire*, is used for further breeding. From the registries of the cattle breeders' associations one can learn which animals have desirable gene combinations for a certain character and which have produced the best offspring. Thus, by carefully choosing one or both parents, stock is kept up to standard or even improved.

The second method – gene or chromosome changes start new varieties. You have read how the patient breeder, through systematic selection and wise crossing, establishes new and better varieties. There is a second way in which new varieties start. A short-legged lamb was born on a New England farm in the latter part of the eighteenth century. The farmer kept this lamb for breeding in the hope of establishing a new breed of sheep that would be too short-legged to jump fences. He was successful in starting the Ancon breed shown on the next page. The sheep was apparently a mutant; it bred true. This proved to be a highly desirable breed until fence building became easier and other qualities were sought in sheep; then the Ancon breed was permitted to die out.

Another desirable mutation that has occurred on several occasions in different parts of the world is hornlessness in cattle. The polled (hornless) condition is desirable because such cattle are easier to handle. Several breeds of polled cattle

Fig. 446 (left) *Mammoth tobacco. It had 112 leaves when photographed. It arose as a mutation from parent plants like those at the left in the photo.* (YEARBOOK OF AGRICULTURE, 1936)

Fig. 447 (above) *An Ancon sheep used in breeding experiments. What new character did this sheep possess? This mutation occurred a second time in a Norwegian farmer's flock many years later.* (STORRS AGRICULTURAL EXPERIMENT STATION)

Fig. 448 (left) *This mink has an unusual combination of white hair and jet black hairs scattered in a pattern. The normal mink is brown. This color combination is a dominant mutation and can thus be readily reproduced in the offspring.* (WARD'S NATURAL SCIENCE ESTABLISHMENT) have been established. You already know that hornlessness is a dominant mutation.

Before fox farming was begun early in this century a mutation from the common red fox to the so-called black or silver fox had apparently occurred twice. One seems to have occurred in eastern Canada, the other in Alaska. These mutations have proved to be of considerable economic importance since silver foxes are now raised in large numbers.

The plant breeder has a better chance of finding gene or chromosomal changes than the animal breeder. Plants, as a rule, have so many more offspring that there is a greater chance that changes will occur. There are many examples of such changes. Figure 446 shows you the result of one very profitable chromosomal change. Many years ago in Brazil a seedless orange appeared on an ordinary orange tree. Naturally, this particular mutation could become established only through vegetative propagation. A wild common yellow sunflower in Boulder, Colorado, suddenly produced a red blossom. In 1895 a florist near Boston discovered a mutation among ferns which had grown wild, unchanged, for a century. This became the desirable Boston fern used so much as a house plant. Within a few years there appeared in five different states six mutations of normal Boston ferns. By 1947 more than two hundred varieties had come into existence.

These are but a few examples of gene and chromosomal changes that have occurred; some are useful to the breeder, some are of little or no commercial importance. In such cases the breeder lets the new form die out.

FIG. 449 *At the left is one leaf from a Boston fern. The other leaves are a few of the more than two hundred varieties of the Boston fern that have come into existence by mutation. All these mutations have occurred since 1895.* (BROOKLYN BOTANIC GARDEN)

The third method – uniting desirable characters in one variety. This third method used by breeders has great possibilities. The method is based on crossbreeding. Some cattle in our southern states produce good meat but they are unable to endure intense heat and they are susceptible to the disease known as Texas fever. Brahman cattle, a breed originally imported from India, thrive in a hot climate and are resistant to Texas fever but the quality of their meat is poor. For some fifteen years experiments were carried on in crossing Brahman cattle with our native good beef cattle. This cross breeding, or *hybridization*, resulted in the Brahman-Shorthorn breed which combines in one organism the good qualities of both the

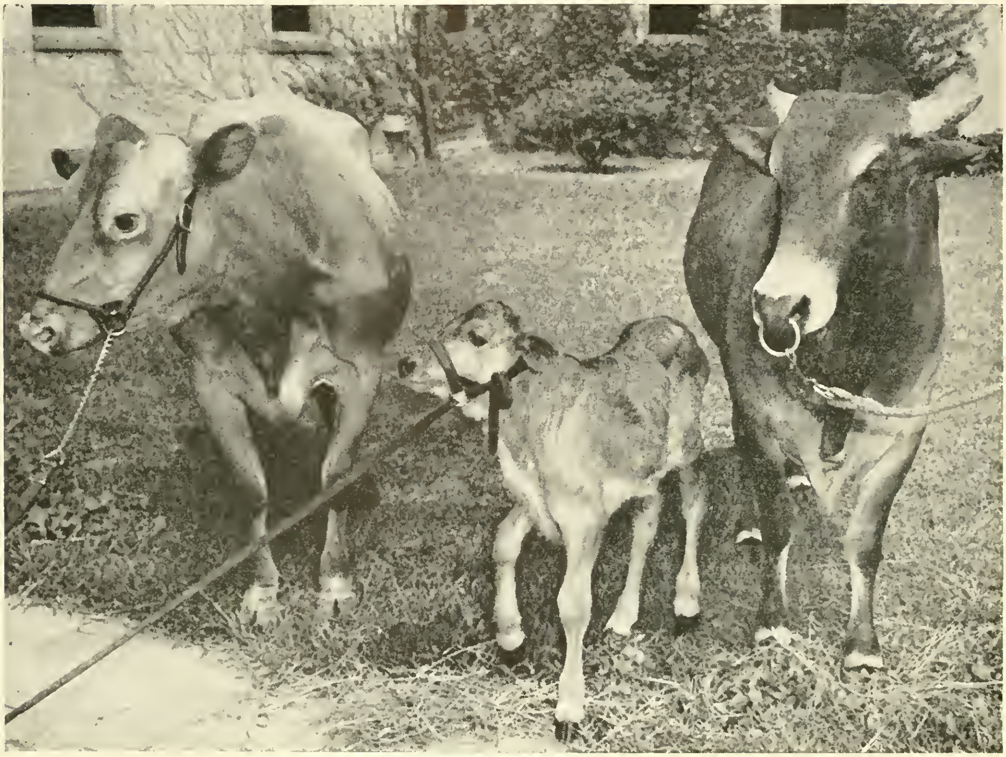


FIG. 450 *The Jersey cow* (left) *and the Brahman bull* (right) *are the parents of the calf between them. The cow is a good milk producer in cool climates but does not produce well in warm climates such as our southern states have. The bull thrives in warm climates but cows of this breed are not good milk producers. What characters are the breeders trying to combine in a new type?* (U. S. DEPARTMENT OF AGRICULTURE)

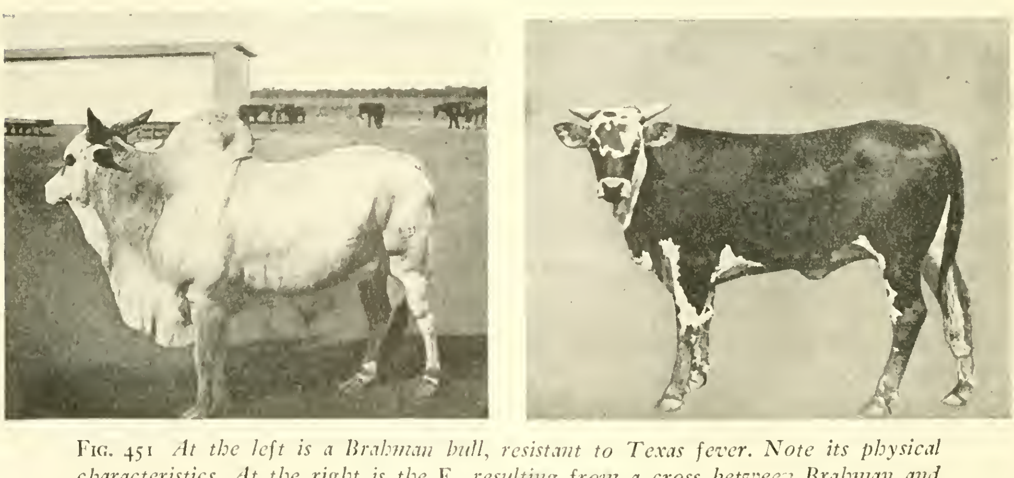


FIG. 451 *At the left is a Brahman bull, resistant to Texas fever. Note its physical characteristics. At the right is the* F_1 *resulting from a cross between Brahman and Hereford cattle. Which of the physical characteristics of the Brahman were not inherited by this* F_1? (NABOURS — KANSAS AGRICULTURAL COLLEGE)

FIG. 452 *These blueberries are a little over one inch across but they lack flavor. This plant has been hybridized with a plant known for its flavor. Selection was practiced. One bush was obtained whose berries combined large size and flavor. What step is necessary before such a plant can be said to be a successful variety?* (U. S. DEPARTMENT OF AGRICULTURE)

ancestors. After the first crosses were made a reasonably pure breed was established through careful selection and inbreeding. You can see that this is not haphazard hybridization; the breeder deliberately selects two parents each of which has a desirable character *which the other lacks.* If he is successful, an organism is produced with a combination of the desired traits. The breeder has made a new type to order. Crosses between our native beef cattle and cattle from South Africa promise even greater success. Try EXERCISE 6.

Crosses between different species rather than between different varieties, have also been attempted. Of course, hybridization between the horse and donkey is not new. The highly desirable mule results. But the mule, with rare exceptions, is sterile (cannot reproduce). We now have crossed the bison (buffalo) with domestic cattle and produced the cattalo. Sometime this new kind of animal may become commercially valuable. There are many interesting reports for you to make to your class. See EXERCISES 7 and 8.

Hybridization in plants. Dutch scientists in Java decided to make a new sugar cane to order — one that combined the good qualities of two different varieties. The sugar cane that grows wild in Java contains almost no sugar but it is highly resistant to disease and to insect enemies. The cultivated cane is rich in sugar but is particularly susceptible to disease. Hybridizing put together into one plant the desirable combination of genes which had never existed together before. In three years the new variety was established. In plant hybridization it is easier as a rule to "fix the type" than in animal work. Can you foresee the reason? You will read about it later.

The United States Department of Agriculture has sent biologists to other foreign lands: to Manchuria and Mongolia to search for drought-resistant, soil-binding plants; to Russia for wheat that is resistant to drought and cold and is immune to our "rust" disease. The red wheat of Kansas, known as Kanred, famous for its resistance to rust, was developed by hybridizing native wheats with a variety imported from the Crimea. Costly expeditions will more than pay for themselves if just one desirable plant is brought back.

The American breeder, Luther Burbank, is famous for the many new forms he produced. He wanted a cultivated daisy that would be hardy and have large showy blossoms. His first step was to cross the sturdy but modest appearing American wild daisy with the less sturdy but large-blossomed English daisy. After hybridizing these two forms and selecting for several generations, he got the desired combination of genes. He crossed this new plant with a Japanese daisy noted for the whiteness of its flower. In this way another desirable gene was introduced, and the result was the "Shasta" daisy named after California's giant snow-capped peak, and now so common in all our gardens. See EXERCISE 9.

Producing new varieties that combine more than two desirable characters is common practice. The Conqueror watermelon combines at least five desirable characters: it is disease resistant, is covered with a rind which is thin but tough enough to stand shipping, has flesh of the right quality, and is full of juice.

Sometimes, in trying to hybridize, experiments fail because a desirable gene is linked with an undesirable one; to get one, you must take the other. In oats, for example, the desirable quality of many seeds on a stem is caused by a gene which is linked with an undesirable gene. Test your understanding by doing EXERCISE 10.

Plant breeders have one great advantage. Hybridization produces hybrids. Also, when a mutation occurs the mutant is often a hybrid. According to Mendelian inheritance, when hybrids are crossed they produce offspring of different kinds. Assuming that the hybrids had desirable characters, there will then be some offspring that are desirable, some undesirable. It takes much crossing and selecting to get an organism that is pure for a desirable character. But a plant hybrid which has a desirable character or combination of characters can often be propagated vegetatively. If you have forgotten vegetative propagation, turn back to it now. Some plants can reproduce asexually by means of slips, or bulbs or tubers, or other plant structures. Offspring produced in this way will have exactly the same gene combinations as the parent; no new genes are introduced. Whether the desirable new form is hybrid or pure, therefore, makes no difference; the offspring will have all the desirable characters, for it has the same genes as the parent. See EXERCISE 11.

Grafting. Besides the methods of vegetative propagation mentioned above, breeders use a method called *grafting*. It can be used only with plants that have a certain amount of woody tissue. Grafting consists of attaching a small twig to a branch of a growing plant. The small stem that is cut off, known as the *scion* (sy'on), is placed against or in the stem of the rooted plant called the *stock*, in such a way that the growing layer (cambium) of one is in close contact with the growing layer of the other. To prevent infection and too much loss of water the two parts are bound tightly together and

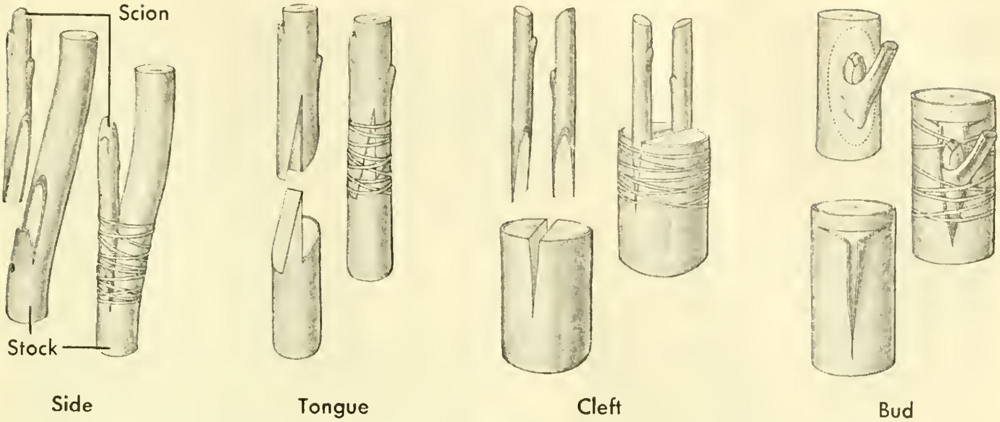


FIG. 453 *There are many ways of grafting the scion to the stock. What tissues of both scion and stock must be placed in contact?*

waxed. After a short time the scion grows onto the stock, forming a part of the rooted plant. But the genes of the scion and the genes of the stock remain unchanged. They do not mingle or affect one another. When the cells of the scion divide and the scion grows, it will keep the genes it had before it was grafted. Grafting is not a method of hybridizing. It is a convenient way of propagating or obtaining more of a certain type of plant, for the grafted scion grows larger every season. If a breeder has a plant with a particularly desirable combination of characters he can graft many such scions on other stock and be sure that the desirable characters will continue to appear in every scion. All commercial varieties of fruit trees are propagated by grafting. And grafting is, of course, the only method by which seedless fruits can be propagated. When the first scion from a seedless orange tree was grafted on an ordinary orange tree, the scion grew and branched; twigs were again cut off and grafted. Soon there were whole orchards of trees bearing seedless fruits. You will find EXERCISES 12, 13, and 14 helpful.

FIG. 454 *A pecan stock has been grafted with pecan scions of a better variety. How many scions were grafted? The grafts were made on August 10; the lower branches (not grafted) were removed on September 1. Why were the lower branches not removed when the grafting was done? Why were the lower branches ever removed?* (U. S. DEPARTMENT OF AGRICULTURE)

FIG. 455 *How many important environmental factors can you name which have improved these cows on a modern dairy farm? Are the characters due to this good environment inherited?* (WALKER-GORDON LABORATORIES)

The breeder seeks the best environment. The modern farmer houses his cattle in barns that are light and clean; he knows that sunshine is as necessary to his animals as to himself. He feeds them scientifically and inoculates them against disease. Thus his cattle grow to a larger size and produce more milk. He raises his crops in fields that have been carefully tilled and he fights the insects and fungi that attack his plants. By such methods the yield per acre of wheat, corn, and of other food plants can be much increased. In a good environment animals and plants are given an opportunity to grow big and strong. If the breeder has plants with desirable mutations or good gene combinations they are able thus to thrive. But the characteristics dependent on the environment are acquired characters. They are not passed on to the offspring. While a good environment does not produce new types it is a factor which must not be neglected.

The work of plant and animal breeders. Every breeder, besides giving his plants and animals the best possible environment, decides on what he wants and then proceeds along one of three lines to get new and better varieties. He can select the most desirable form in each generation. Careful selection and breeding produce varieties with a better gene combination than had been present before. This is a gradual and slow method of improving animals and plants. The breeder is also alert to detect new desirable characters caused by mutations or other chromosomal changes. These can be used for establishing new varieties but they occur rarely. And, lastly, through hybridization he can sometimes bring together in one organism the desirable characters of one parent and the desirable characters of the second parent.

The breeder's final step after he has obtained a desirable mutant or a successful hybrid is to "fix the type." He must be able to get more of the same kind; to do this he will inbreed. If he is dealing with certain kinds of plants, it is not necessary to fix the type for he may resort to vegetative propagation. By these methods ma has made great improvements in the plants and animals he makes use of for many purposes.

Questions

1. Through the centuries there has been progress in the breeding of some animals. Which? Why is there more rapid progress in recent times?
2. Show that selecting the best gene combination is a method of getting better types of organisms; name a specific plant and mention a specific improvement.
3. When must the breeder expect to find that no further improvement is possible by this method?
4. What, in general, enables biologists to decide that two organisms are members of the same or different species? What does the plant breeder usually call the subdivisions of a species? What name does the animal breeder commonly use for them?
5. State how one breed of cows was improved within forty years. Explain inbreeding. Of what importance is it in animal breeding?
6. State possible advantages and disadvantages in inbreeding and also in outbreeding. In which organisms can one obtain pure forms through continued inbreeding?
7. What is a pedigree? How is it made use of by the breeder?
8. Name two animal mutations and several plant mutations which have been preserved because of their desirability. Name two methods of getting new or improved types of plants and animals.
9. Give two examples of new varieties or kinds of animals which were developed by hybridization. For each one tell what traits the breeders were seeking and what animals were used to supply these traits.
10. Explain how hybridization and selection produced an improved sugar cane and the Shasta daisy. How does the breeder frequently obtain desirable parents?
11. Explain why vegetative propagation is a great advantage to the breeder.
12. Explain grafting, using the terms stock and scion. Explain why grafting is a help to breeders of certain kinds of plants.
13. To what extent is a good environment important to the breeder?
14. Review briefly the three methods used to get new and improved types of animals and plants.

Exercises

1. If the genetic make-up of a plant is *Hl* (*H* stands for high oil content; *l* stands for low oil content, assuming that the character is due to a single pair of genes) and it is self-pollinated, what offspring might you expect? Illustrate by diagram. How could you get a pure strain of plants with high oil content?

2. For some purposes corn should be low in oil content; for others it should be high. If a breeder had an otherwise desirable variety whose grains yielded what is considered a medium amount of oil (from 3.84% to 6.02%), what steps would you recommend that he take to obtain corn with a high and corn with a low content?

3. If you were raising strawberries on the very best kind of soil and under the best conditions of moisture, temperature, and light, what would you try to do next to improve your plants? State specifically what you would consider desirable characters in a strawberry plant.

4. Between 1880 and 1942 the record milk production advanced from 18,004 to 41,943 pounds per year largely through careful selection. What would you expect the record milk production to be in 1960 if similar methods were used? Read again carefully the paragraph on "The first method." Then explain your answer.

5. Can you demonstrate with two living flowers how the breeder would cross-pollinate them artificially? What precautions must be taken?

6. Show by diagram what might happen in the hybridization of Texas and Brahman cattle. Assume that quality of meat and susceptibility to disease are each due to a single pair of genes (which they probably are not) and that good meat is dominant to poor meat and resistance is dominant to susceptibility. Let *M* stand for good meat (dominant) and *m* stand for poor meat (recessive). Let *R* stand for resistance to disease (dominant) and *r* for lack of resistance or susceptibility (recessive). What then would be the genetic make-up of the Texas cattle? Of the Brahman cattle? Of the offspring in the F_1? What qualities would be shown by this offspring? What would the breeder do next? What offspring might he expect?

7. If your class were divided into committees you might obtain much interesting information about the work done by your State Agricultural Experiment Station, about the Department of Agriculture at Washington, the Bureau of Animal Industry, the Bureau of Plant Industry, and the Cattle or Poultry Breeders' Association of your state.

8. Let your imagination create some plant or animal type that would be desirable in the future. Give several reasons why such a form might be made to order now when it would have been impossible a hundred years ago.

9. Luther Burbank gave the world a variety of new and improved plant forms but left no valuable records. How would you rate him as a

scientist? Why is the breeder's notebook more important to the biologist than the desirable fruit he may produce?

10. A breeder has two varieties of apple trees. One bears sweet green apples and the other sour red ones. He discovers that he would have a market for sweet red apples. What could he do about it? Would he be sure of success? Can you illustrate possible results by diagram?

11. Plant breeders have advantages over animal breeders. Can you state five distinct reasons why the plant breeder could make more progress than the animal breeder?

12. Read about plant breeders in De Kruif's *Hunger Fighters*, and write a report.

13. A plant breeder nowadays can take a patent on some new "creation" if it can be propagated vegetatively. Discuss the desirability and undesirability of the law permitting plant patents.

14. Would you be interested in finding out how to prepare yourself to become a plant or animal breeder? Your State Agricultural College will give you information.

Further Activities in Biology

1. If you have a garden and are ready to carry a long experiment through to completion you can do breeding experiments of your own. Careful records are all-important. You can also learn to make grafts. Ask your teacher for help.

2. Many newspapers give descriptions and pictures of the many breeds of dogs. Make a chart placing together the dogs that are most similar.

3. Seed catalogues often give information on improved types. Write for some.

PROBLEM 6 *To What Extent Can Mankind Be Improved?*

Heredity in man. If physical characteristics are inherited according to the Mendelian laws in plants and in animals other than man, it is sensible to suppose that they must be inherited in the same way in man also. But it is extremely difficult to obtain facts about heredity in man. To begin with, human beings grow up so slowly that it takes about thirty years to get a new generation. Therefore it would take about sixty years to get an F_2 from any P_1 mating that we wanted to study. Secondly, the number of offspring produced is very small — far too small to give reliable ratios. When a pair of fruit flies are mated there are four or five hundred offspring. Just a few pairs can provide thousands of offspring. Although human parents sometimes have twelve or more children, five or six is more common and very often there are fewer than that. In the third place there is the difficulty that we cannot have experimental matings among human beings.

You may wonder how biologists can study human heredity at all. One method is to study the inheritance of a certain physical character in hundreds of families. After obtaining very large numbers of cases scientists use the facts as best they can. Suppose we consider eye color. This is not a simple character to study because eyes are of many shades. Biologists must use a complicated machine that enables them to match eye colors. By this means they have discovered that when both parents have one special type of blue eyes *all* the offspring have blue eyes. When both parents have a certain type of brown eyes some of the children may be blue-eyed. By gathering figures in many such families scientists found a ratio of about three brown to one blue, a typical Mendelian ratio. From this it was concluded that this particular type of blue is recessive to this type of brown. Could you make a diagram to show this inheritance of eye color? See EXERCISE 1.

Many eye colors seem to be produced by two or more pairs of genes, and the inheritance is much more complicated. The same thing is true of the inheritance of skin color. This also is too complicated for us to trace here.

Recording human inheritance. Besides the method described above biologists attempt to study human inheritance by recording the heredity of a specific character in as many generations of individual families as possible. Such a record of family history is known as a pedigree. A human pedigree can be shown in a chart in which males are represented as squares and females as circles. Mating is shown by a line connecting square and circle; and children are shown below attached to

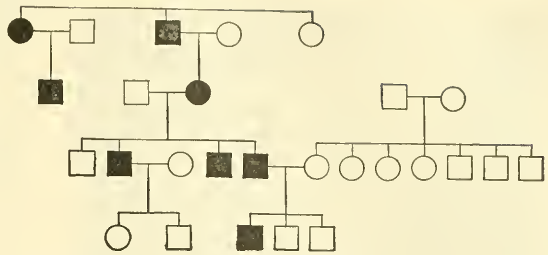


FIG. 456 *This pedigree shows the inheritance of an abnormal skin condition in which the slightest friction causes blisters to form. Squares represent males; circles represent females. Blackened symbols represent individuals having the abnormal skin.* (SNYDER)

this line. To show that an individual has the trait being studied the square or circle is filled in. Do EXERCISE 2 to see whether you understand Figure 457.

There are institutions in London and elsewhere that obtain and keep records of human pedigrees. They often use the word *eugenics*, which means "improving human beings by breeding." As you read further you will learn that, with our present knowledge, little can be done to improve human beings by breeding. You must, therefore, read very critically all that is written about eugenics to see whether it rests on opinion or on fact. Sometimes people who call themselves eugenists attempt to defend a belief rather than to advance understanding.

Inheritance of physical traits. Certain types of physical characteristics, such as bodily defects, can be studied easily for two reasons: the environment does not ordinarily affect such characteristics and many of the genes seem to act as simple dominants and recessives. For example, it has been discovered that six-fingeredness (*polydactyly*) and short-fingeredness (*brachydactyly* in which each finger has only two bones) are dominant to the normal condition. Both of these characters are known to have appeared suddenly; they were mutations.

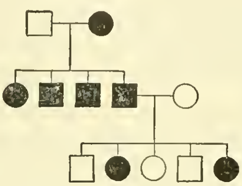


FIG. 457 *A pedigree showing the inheritance of one type of extreme shortsightedness. In the* F_2 *are the shortsighted individuals (black symbols) pure or hybrid?* (SNYDER)

Another character, lack of pigment (coloring matter) in the skin, hair and eyes is known to be a recessive. This character is called *albinism* (al'bin-ism). An *albino* (al-bine'oh) has pink eyes (just like an albino rabbit or white mouse) because there is no pigment in the eye to hide the color of the blood. See Figure 458, page 510. It is believed that albinism has appeared again and again as a mutation. We know that it is recessive because only albino children are produced if both parents are albinos. You will be interested in doing EXERCISE 3. EXERCISE 4 is more difficult; can you do it?

The inheritance of complex physical traits. Such ordinary characters as size, weight, skin color, shape of head, and features of face are complex characters about whose inheritance we know little. Each character is apparently produced

FIG. 458 *An albino child. Do you know why he keeps his eyelids half shut when he is in strong sunlight? How does this character act in heredity? Was either parent necessarily an albino?* (ACME)

by two or several pairs of genes working together. Besides, many of them are clearly affected by the environment, and it is difficult for us to arrive at sensible conclusions when we do not know how much influence the environment has had in each case.

The inheritance of disease. Diseases caused by bacteria or other microorganisms, such as tuberculosis for example, are caused by infection; they are not inherited. Yet it is possible that susceptibility to a disease may be inherited. Susceptibility may depend in some way on bodily characteristics, and thus be transmitted from one generation to the next.

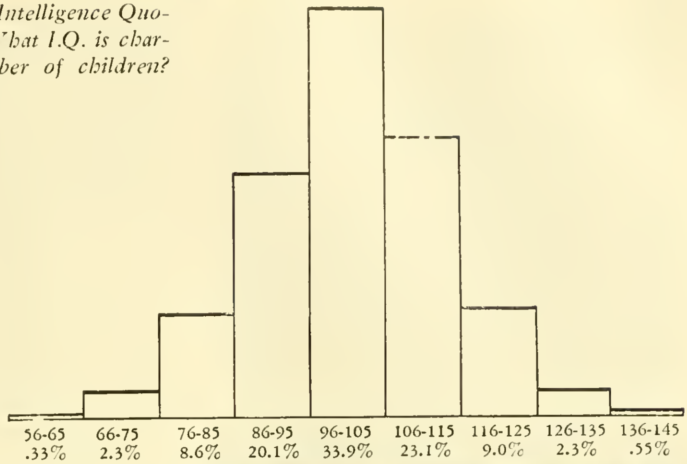
Very little is known about the heredity of organic diseases – diseases due to the abnormal structure or working of some organ. But there is one unusual disease of the nervous system (Huntington's chorea) which is caused by a dominant gene and is inherited in the Mendelian fashion.

Mental traits. Strictly speaking, "mental" traits are also physical, because they seem to depend on the structure of the nervous system and on the ductless glands. For convenience, however, we often separate the two. Intelligence, personality, and behavior traits may be called mental.

What is intelligence? It is quite different from knowledge. It is the ability to obtain knowledge and to apply it in solving problems. We know that it varies in people. As you know, school children are often given "intelligence tests." These tests contain some questions that require certain kinds of knowledge and others that test the ability to apply this knowledge. The score that is made on the test is compared with the age of the child. If the score of a fourteen year old boy exactly matches the score accepted as common for his age, his intelligence quotient or I.Q. is said to be 100. If his score is higher, his I.Q. is said to be higher. Figure 459 shows the graph or curve obtained when the I.Q.'s of many children are tabulated.

Intelligence tests as they are given in schools often result in inaccurate I.Q.'s. For one thing, since the test is written in English a child who is not familiar enough with the language is at a disadvantage. However, although intelligence quotients are often inaccurate, testing is likely to show up the highly intelligent and those of very low intelligence, known as feeble-minded.

FIG. 459 *A graph showing the Intelligence Quotient (I.Q.) of 905 children. What I.Q. is characteristic of the greater number of children?* (ADAPTED FROM L. M. TERMAN)



Feeble-mindedness is vaguely defined as intelligence so low that the person is unable to meet the conditions of life satisfactorily. But there are all degrees of feeble-mindedness. The scores of the lower grades of feeble-minded are not even shown in Figure 459. Such individuals never go to school. They need supervision and care throughout their lives since they never advance, mentally, beyond the age of a very young child. There are many institutions where the feeble-minded are cared for and taught by specially trained teachers so that in their own institution they may be useful citizens. There are not only all degrees of feeble-mindedness but there are apparently several causes, about which we know little.

FIG. 460 *This boy spends many days in a mine. Would his I.Q. score be a correct estimate of his intelligence? Explain.* (NATIONAL CHILD LABOR COMMITTEE)

Inheritance of mental traits. Since mental traits depend on physical structure, it seems reasonable to believe that they should be inherited. But so far we know very little about their inheritance. Pedigrees often show the reappearance in each generation of special abilities or skills. There are families in which great skill in boat designing appears in many members for several generations. The family of Johann Sebastian Bach shows musical talent and even genius in several generations. Such facts are often used as evidence that mental traits are inherited. Do you think it is good evidence?

A famous pedigree you may read about is that of Deborah Kallikak, a feeble-minded girl whose real name is withheld. Her ancestry was traced back to Revolutionary times when Martin Kallikak, a

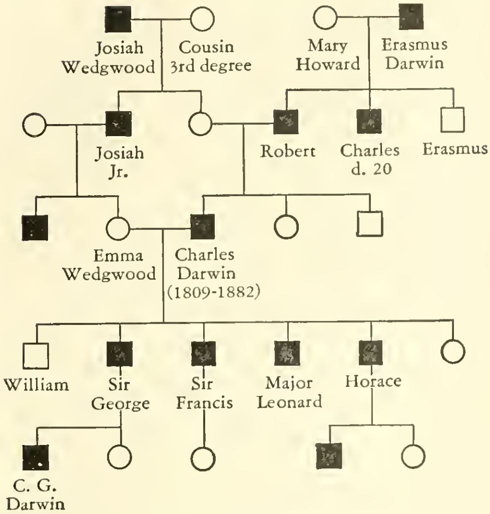


FIG. 461 *A part of the pedigree of five generations of an illustrious family. Note the cousin marriages. What kinds of factors might explain the large number of famous descendants?*

soldier, had a son by a feeble-minded girl. Four hundred eighty descendants of this union have been traced through five generations. About many of these nothing could be learned, but one hundred forty-three are said to have been feeble-minded and forty-six normal. Later in his life Martin Kallikak married a normal wife and started a second line of descendants. Four hundred ninety-six of these have been reported on; as far as the records show all were normal. It looks as though at least some types of feeble-mindedness might be inherited.

Other pedigrees you may read about are those of the Jukes and the Edwards families. The Jukes (a fictitious name) are described as a line of shiftless good-for-nothings, poor, and a burden to the community. From Jonathan Edwards, a New England clergyman of colonial times, who married a brilliant wife, have been traced almost one thousand four hundred descendants. Many of these were professional men who became successful in one way or another. Do these family histories give evidence of the inheritance of mental traits?

Criticism of the evidence. In all these cases we depend on records written many years ago. These cannot be verified. They were written by people, who, in general, were not trained to be accurate. Frequently they were written by people who allowed their prejudices to color their reports. Can you rely on such as evidence?

But a far more important criticism is that the effect of the environment has not been taken into account. Certainly in the case of the Jukes and Edwards families we know that a large part must have been played by the environment. In short we are forced to admit that we have little definite information about the inheritance of mental traits.

Improving germ plasm in man. With so few facts at our command there is little we can say about breeding better men. We do know, however, that defective germ plasm which shows as feeble-mindedness tends to be transmitted to the offspring. For this reason it has been argued that the feeble-minded, wherever possible, should be segregated in institutions where they will be unable to pass on their defective germ plasm. More than half the states have followed the example of Wisconsin in issuing marriage licenses only to those who have been examined by a physician for certain communicable diseases. In some states, but not in all, the license to marry is refused to those who have these diseases. It has been suggested that the examination might be made to include a mental as well as a physical examination. Other states keep feeble-minded men and women from having children by practicing sterilization. This is done by a simple operation which apparently affects the person in no other way. But even with these measures some scientists believe there can be but little improvement in germ plasm. Between 1906 and 1927 the recorded number of feeble-minded in Great Britain increased 100 per cent while the population as a whole increased 14 per cent. It is true that during those years many more mental tests were given and therefore many more feeble-minded children were discovered. But this factor accounts for only part of the increase, by no means all of it. It is believed that for certain kinds of feeble-mindedness there are recessive genes that are found in a large portion of the population. For this reason it would take many centuries at best to wipe out feeble-mindedness. Others think that occasional mutations keep adding such undesirable genes to human germ plasm. Although we must provide for these people in institutions we cannot expect to get rid of feeble-mindedness in the human race.

It is sometimes suggested, too, that germ plasm could be improved by giving a cash bonus to desirable parents who raise large families. But which are the desirable, which the undesirable parents? Those with money and power often charge the less successful with lack of ability and ambition. Those less successful in accumulating wealth accuse the others of greed and selfishness. It would be difficult, indeed, to know which qualities should be bred for, even if it were

FIG. 462 *Different environments. List all the ways in which a child brought up in the home below has a better environment.* (ABOVE, AMERICAN MUSEUM OF NATURAL HISTORY. BELOW, HOWE AND ARTHUR)

possible to suggest practical measures. This problem lends itself to a fruitful discussion. See EXERCISE 5.

While there is little we can do about improving germ plasm let us see to what extent we can improve man through his environment.

Man's complex environment. The environment of a human being includes many more factors than that of other animals and for that reason it is of very great importance in determining the characteristics of man. You could prepare a long list of factors — including churches, places of amusement, books, newspapers, advertisements, shops, automobiles, radio,

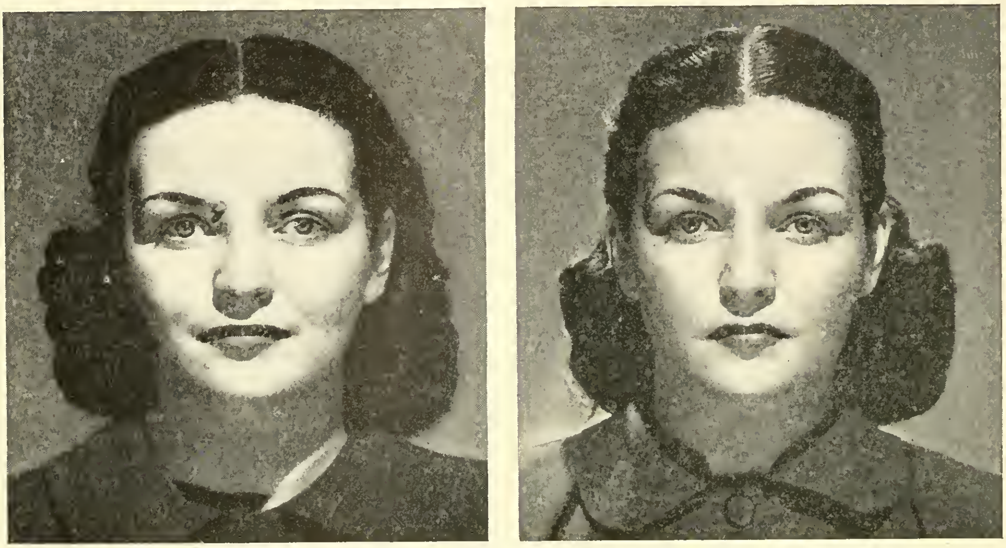


FIG. 463 *These identical twins have the same gene make-up. What striking similarities and what differences do you find? Can you explain?* (SCIENCE ILLUSTRATED)

not to mention all the people you know, even the people in your town whom you never speak to. A person's job also makes a great difference in the kind of life he leads, not only because the wages will vary with the particular kind of work, but also because the kind of work he does influences his opinions. The housewife often has opinions different from those of the office worker or the factory hand. And the kind of job may cause physical differences too. See EXERCISE 6.

Slight differences can cause great changes. It is difficult to realize that even the slightest difference in the environment may cause great differences in people. You may think that two children in the same family have the same environment. Studies on identical twins show that this is not true. Identical twins have the same genetic make-up. They are formed from a single fertilized egg. In the early stages of cleavage, two equal masses of cells separate; each gives rise to a child. There are other twins (fraternal) which develop from two separate eggs fertilized by two separate sperms; these are no more alike than any two brothers and sisters. But identical twins are really "identical" in genetic make-up. Yet identical twins, even when brought up together, do not grow up to be exactly alike. Evidently, environments which would seem to be the same are never exactly the same. In EXERCISE 7 you will find examples of differences.

Identical twins in different environments. In one study, biologists came as close as they ever can come to a controlled experiment in human heredity when they did the following. They succeeded in locating 19 pairs of identical twins who, for one reason or another, had been separated shortly after birth and were thus exposed to different environments. Since identical twins start with the same gene make-up, any differences found later between two twins must have been caused by the environment. In physical traits the twins brought up in different environments showed comparatively slight differences but in several pairs the differences in I.Q. were astonishingly large. When carefully measured by means of I.Q. tests, one pair showed an I.Q. difference of 17 points, another, 19 points, and a third, 24 points. These facts would indicate that the environment has some effect on "intelligence" and the ability to succeed in school. Great differences in personality and in character, too, were found in those twins who were identical in gene make-up but who had been exposed to different environments. More facts on this subject can be obtained by doing EXERCISES 8 and 9.

Improving man through the environment. You have read of the great effect of environment on human beings. Of course, these effects are not inherited. But in each generation the good environment can be repeated or improved upon. Consider what has been done in your environment to improve you physically: the prevention of epidemics; the control of water supply and foods; the building of hospitals and clinics; the playgrounds and parks; better housing and the clearance of slums. Schools are provided; education is made compulsory; child labor laws are passed; and vocational guidance bureaus are established to help young people find suitable jobs. There are libraries, theatres, and other places of recreation and amusement. More recently there have been attempts to reduce worry and strain in adults by many measures such as regulating seasonal industries, passing workmen's compensation laws, and planning for old age security. Do you know the child labor laws of your own state? See EXERCISE 10.

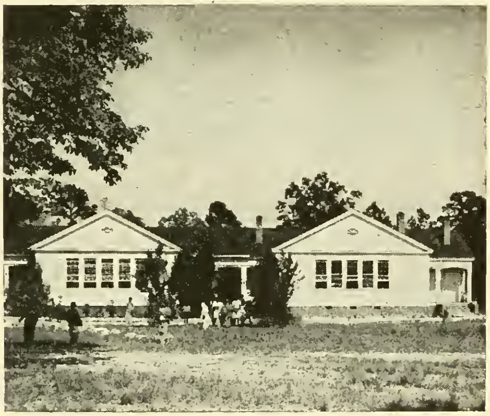


FIG. 464 *The little old wooden buildings are two of the Negro schools of Alabama which are being replaced by modern schools like the one below. How does this aid the welfare of our country?* (W. HARDIN HUGHES)

There is evidence that much has been done in the United States and in many other countries to improve man, both physically and mentally, by improving the environment. The heights of young men and women are greater now than in preceding generations. You saw in an earlier unit how much our life span has been increased. The good effects of a

FIG. 465 *The fire in the background was deliberately started by scientists so that they might study it. Such experiments may save lives as well as dollars in the future. Wisely used, science can make for greater human happiness.* (U. S. FOREST SERVICE)

satisfactory environment are almost immediate; that is, they are produced within one generation. Consider this problem by doing EXERCISE 11.

Many scientists are convinced that the greatest hope of improving human beings lies in improving the environment rather than in trying to breed better men. The improvement of the human race through improvement of the environment is known as *euthenics,* in contrast to eugenics.

Improvement of mankind through science. Many of the improvements made by man in his environment have come about within recent years. Rapid progress came when man began to apply the scientific method more generally. Thus he learned to understand something of his environment and of himself. He made many discoveries and inventions that gave him better food, that protected him against diseases, and that brought him into closer touch with other men. He also made countless discoveries and inventions which brought more leisure and more comfort in life. Science has given us much more than the benefits just listed. It has given us greater security; it has taught us to banish certain fears and to conquer superstition to a great extent. Do EXERCISE 12. And it has shown us, if we will but learn, how we can all use the methods of science; how we must train ourselves to seek out all the facts, to face them squarely, to suspend judgment while we weigh the facts carefully, to reason accurately, and to report truthfully. While we do this we must learn how to work with others, for progress is greatest when men work together, sharing information freely, as scientists do.

Questions

1. Give three reasons why it is difficult to study human heredity. Explain how inheritance of eye color in man has been studied.
2. What is meant by eugenics? Why is it necessary to read critically what is written about eugenics?
3. For what two reasons is the inheritance of physical defects more easily studied than the inheritance of other physical characteristics? Give examples of the inheritance of physical defects.
4. Why do we know so little about the inheritance of size and weight?
5. Why can an infectious disease not be inherited? What did you read about the inheritance of organic diseases?
6. What kind of traits may be spoken of as mental? Distinguish between intelligence and knowledge. With what do we compare the score made on an intelligence test in order to get the I.Q.? Why are I.Q.'s often inaccurate? What is meant by feeble-mindedness?
7. Why does it seem reasonable to believe that mental traits may be inherited? Give some facts that are used as evidence of the inheritance of mental traits, referring to three or four different families. Which evidence do you consider most convincing?
8. What criticisms can be made of this evidence?
9. Name three measures adopted by some of our states and by some other countries to prevent the increase of defective germ plasm. Why do some people believe that feeble-mindedness cannot be wiped out? What has been suggested as a method of improving the human race by breeding? Comment on this.
10. Discuss the complexity of man's environment, listing at least ten important factors.
11. What reason have we for believing that slight changes in the environment can cause great changes in the individual? What is the difference between identical and fraternal twins?
12. Explain the nearest approach to controlled experiments on human beings. Do different environments seem to make a greater difference in physical or in mental traits?
13. Is there more hope of improving man through breeding or through providing a better environment? Name six measures a community can adopt to improve the people in the community. Define euthenics. Since the effects of the environment are not inherited how can the race be improved by euthenics?
14. How can scientific knowledge be used to improve mankind?

Exercises

1. Using *B* to represent brown-eyedness and *b* to represent blue-eyedness, show what eye color might be expected in the children of large numbers of matings of pure brown-eyed parents; blue-eyed parents; hybrid brown-eyed parents.

2. Study the pedigree illustrating shortsightedness. Using the letters *n* (normal) and *S* (shortsighted) illustrate this pedigree by using letters instead of squares and circles.

3. Can you find out about any unusual character (no matter how small) in your family, or in that of some friend's family? Obtain all the information you can and construct a chart. Be sure to state fully the sources of your information; your classmates will want to know how reliable your facts are.

4. Careful study of the pedigree illustrating the inheritance of an abnormal skin condition will show whether the character is caused by a recessive or dominant gene. Explain the genetic make-up of each individual that shows the defect.

5. Discuss with your family the possibility of arriving at a decision as to which genes are desirable and which undesirable. In general, do the most intelligent people earn most? Write down your thoughts in an orderly way and discuss them with your classmates.

6. Prepare a short list of occupations, including such work as coal mining, nursing, teaching, and waiting on table. For each type of work name the part of the body that may be affected or injured. Discuss this with adults and with your classmates.

7. Can you explain why identical twins are likely to vary less in features than in weight? Explain in what respects the environment of twins brought up in the same family and going to the same school might be different.

8. From your own experience and by reading reliable articles on identical twins (such as in the Journal of Heredity) prepare a report to the class. There are books on the subject that you can consult.

9. Look through the files of newspapers carefully for news items on heredity in twins or related topics. Bring the information to class and discuss it. How much of what you read can you believe? Which tend to be more reliable, these news items on twins or those on such a subject as "changes in the earth"? Explain.

10. Find out what your state laws on the subject of child labor are. Find out which states have failed to ratify the child labor amendment.

11. Add to the list of ways in which man has improved his environment within the last century. In which respects is his environment not as good? What else might be done to improve your environment?

12. Make as long a list of superstitions as you can. Discuss these with the class. Try to determine how each arose. Show how science has freed man from unnecessary fears.

Further Activities in Biology

1. You may be interested in reading about the Kallikaks in more detail (Goddard's *Kallikak Family*). You will also read how the feeble-minded are trained.

2. If you have never taken an "intelligence test" ask your teacher to show you one. Look up a Binet-Simon individual test.

3. Intelligence tests were given to the soldiers in both world wars. Look up the results and if possible make graphs of some of them.

4. If some of your classmates are interested, organize a committee to study the ways in which the environment provided by your community might be improved. This activity will undoubtedly extend over a long period of time. You might provide for a series of committees for several terms.

5. Some euthenic measures, such as the Child Labor Amendment, are in dispute. Organize a discussion (*not* a debate) in which the facts may be presented and considered.

In UNIT X you will consider these problems:

PROBLEM 1. What Can We Learn from Rocks about the History of the Earth?

PROBLEM 2. What Can We Learn from Fossils about Prehistoric Living Things?

PROBLEM 3. What Puzzling Facts May Be Explained by Our Theory of the Origin of New Organisms?

PROBLEM 4. What Theories Have Been Offered to Explain the Origin of Different Kinds of Animals and Plants?

PROBLEM 5. What Were the Stages of Man's Development on the Earth?

UNIT X THE EARTH AND ITS INHABITANTS HAVE CHANGED THROUGH THE AGES

FIG. 466 *Removing the stone from around a rare fossil lizard which was found in Utah. The work is being done by Mr. Norman H. Boss of the United States National Museum. Most of our knowledge of prehistoric animals and plants is gained from the study of fossils. Our knowledge of fossils helps us understand many things about the animals and plants living today.* (SMITHSONIAN INSTITUTION)

PROBLEM 1 *What Can We Learn from Rocks about the History of the Earth?*

The forming of our earth. Before considering theories of the origin of the earth we should remember that the earth is one part of the solar system. It is one of several planets that revolve about the sun. Some of these planets have moons — smaller bodies that revolve around them. The sun itself is considered to be a star. The solar system, then, consists of the sun, its planets, their moons, and other smaller bodies.

Several theories have been proposed to account for the origin of the earth and the other planets in this system. One theory that seems reasonable to many astronomers is that the planets were once part of the sun. According to their theory, about three billion years ago another star passed near the sun. Although the distance is thought to have been many thousands of millions of miles, this is relatively close as star distances go. These two stars were so close that large and small masses of material were torn out of the sun. The larger masses became the planets. They attracted to themselves most of the smaller masses which were nearby and increased in size. Ever since then the size of each planet has remained about the same. Then came the cooling of the planets, which took place with comparative speed, but a long, long time ago.

Although we do not know and may never know just how or when the planets came into existence, there is abundant evidence that at one time our planet, Earth, was made up principally of molten rock. When the rock cooled, it hardened. Such rock is called *igneous* (ig′-nee-us) rock. A common example of igneous rock is granite. After a time, water appeared. Many scientists believe this happened before the earth had cooled to its present temperature, so the oceans of those days must have been hot. The rocks that rose above the seas were bare. When it rained, the heavy downpour dashed down the steep slopes, for there was no soil and no vegetation to hold the water back. Pebbles and boulders (large rocks) were broken loose by the rushing waters and changing temperatures; slowly they were ground up and changed chemically, forming sand and clay; thus soil was formed. Of course, there were no living things. They could not have existed on such a harsh, forbidding planet. This is what *geologists* (gee-ol′-o-jists) think happened a long time ago, perhaps three billion years ago.

Changes in the surface of the earth. What started perhaps three billion years ago is still going on. Heavy rains and running water loosen the soil and smaller rocks. Carried along by a large or small

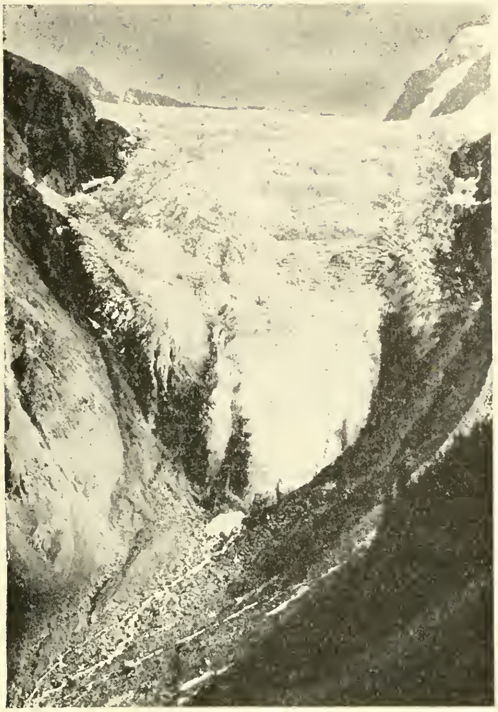


FIG. 467 *Rivers of ice, known as glaciers, wear away the land, breaking up hard rock. Note the broken rock below the glacier.* (GEOLOGICAL SURVEY OF CANADA)

FIG. 468 *As the temperature changes the expansion and contraction of the surface layer causes the rock to scale. This is weathering.* (GILBERT — U. S. GEOLOGICAL SURVEY)

stream, the small rocks wear away even the hardest rock by their rubbing and pounding. Wearing away of soil and rock is called *erosion.* You have seen it on a small scale after every heavy rain. Even strong winds may erode the soil; and animals, burrowing in the ground, by loosening the particles of the soil, help erosion by wind and water.

Rocks are broken up in other ways too. Changes in temperature cause them to crack and crumble. This breaking up of rocks in air is called *weathering.* Sometimes a seed falling into a tiny crack grows and splits up the rock. Or acids produced by the roots of plants and by organisms of decay dissolve some rocks, such as limestone. In connection with this try EXERCISES 1 and 2.

In general, erosion is most rapid on steep mountain slopes. Thus mountains tend to flatten out gradually, throughout the ages. It has been calculated that erosion reduces the average height of the United States one foot in every seven thousand to nine thousand years.

New land is formed. What becomes of the rock and soil that crumbles and is washed or blown away? Some of it is piled up elsewhere on the land, and as the mountains flatten, the lowlands tend to be built up. But most of it is carried by streams to the oceans or lakes into which they empty. It has been estimated that

FIG. 469 *How new land may form. As the plants advance into the lake, it becomes swampy. How does the swamp, in time, turn into a meadow?* (NEW YORK STATE COLLEGE OF AGRICULTURE)

FIG. 470 *At one time these strata of rock must have been sand and mud under water. How do you know?* (GEOLOGICAL SURVEY OF CANADA)

the Mississippi River carries each year a load of 517,000,000 tons of solid material. When the river current is slowed up at its mouth, much of its load of sand and silt (fine earth) settles to the bottom. The sediment piles up. As the years go on, this deposit may rise above sea level, forming mud flats. Seeds fall on the mud and plants grow. Their roots bind the soil together and make it firm. As the plants die their decaying bodies make the soil richer. Other types of plants appear, finally shrubs and trees. Thus deltas form. You can demonstrate how deltas begin to form and learn about erosion by doing EXERCISE 3. You may have seen the same process of building land on the shores of a small lake. As mud settles and collects, the shores seem to march out into the lake. In time, where once there was a lake, a forest will stand. See Figure 469.

The sediment may form rock. If the land sinks under the floor of an ocean or inland lake, the sediment of sand or silt sinks with it. It will be buried deep beneath the water and its particles will be pressed together by the great weight of the water above. Even without this enormous pressure the sediment slowly hardens, for substances dissolved in the water act as a cement that binds the particles together. Thus rock is formed out of the sediment. It is known as *sedimentary rock*. When the sediment is mostly sand the sedimentary rock is sandstone; when it is mostly silt (mud) the rock that forms is shale. Since the materials deposited by the water change from time to time, both the sediments and the sedimentary rocks usually occur in layers or *strata* (stray′-ta). If you do EXERCISE 4, you can see strata forming on a small scale.

FIG. 471 (above) *What has happened to these layers of sedimentary rock?* (GEOLOGICAL SURVEY OF CANADA)

FIG. 472 (left) *Lava from one of the Hawaiian peaks approaching a fishing village. These lava flows have been known to extend 50 miles.* (AERONAUTICAL CHAMBER OF COMMERCE)

The strata of sedimentary rock may later be pushed up so that they stand on end. They may be crushed and twisted by the terrific pressure of the earth and the heat which is generated, until their structure is completely changed. This may happen to igneous rocks, too. All such changed rocks are called *metamorphic* rocks. Marble is a metamorphic rock that was once limestone. Slate is a metamorphic rock that formed from shale; gneiss is a metamorphic rock that formed from granite. To learn more about rocks do EXERCISE 5.

The earth is constantly changing. Sometimes there are sudden changes in the earth as when an earthquake raises a mountain range as much as twenty feet in a few seconds; or as when during an eruption in the last century the famous volcano Krakatoa blew away a cubic mile of rock, sending up clouds of ashes seventeen miles high. Such changes occur rarely but in the long history of the earth there must have been many of these changes. Then there are the slow changes that take place when a less explosive volcano pours out masses of molten rock known as lava. The island of Hawaii was once little more than a few volcanic peaks rising out of the ocean. As the lava flowed out it hardened and built up the shores of the present island. Changes like this in addition to the wearing down of mountain ranges by erosion, the building up of land, and the laying down of sedimentary rock are constantly going on. This earth of ours which seems to us so steady and so stable has been undergoing changes throughout its estimated three-billion-year life.

How we estimate the age of the earth. Several methods of estimating the age of the rocks and thus of the earth have been used. What is considered the most accurate method was discovered recently. In some parts of the earth there are rocks which contain the element uranium. Uranium gradually changes into lead, always at the same rate. The lead remains in the rock and does not change any further. Thus by calculating the proportion of lead and uranium in such rocks one can tell for how long uranium in these rocks has been changing to lead or, in other words, for how long these rocks have been in existence. By this method it is estimated that the oldest rocks are about three billion years old. And if these estimates are a few million years out of the way it is unimportant. The error is slight in terms of billions of years.

The history of the earth. As the historian speaks of centuries and years, the geologist counts time in *eras* and *periods*. An era, as you will read later, is a stretch of time from many millions to a billion years long. Periods are subdivisions within an era just as years are divisions within a century.

Historians depend on written records. Geologists, too, depend on records but they are not written records. Their records are in the rocks. By studying the records in the rocks geologists have discovered that this changing earth has been inhabited by plants and animals for perhaps two billion years. How did they know this? They found *fossils*, the remains of plants and animals in rock. The study of fossils soon grew so complex

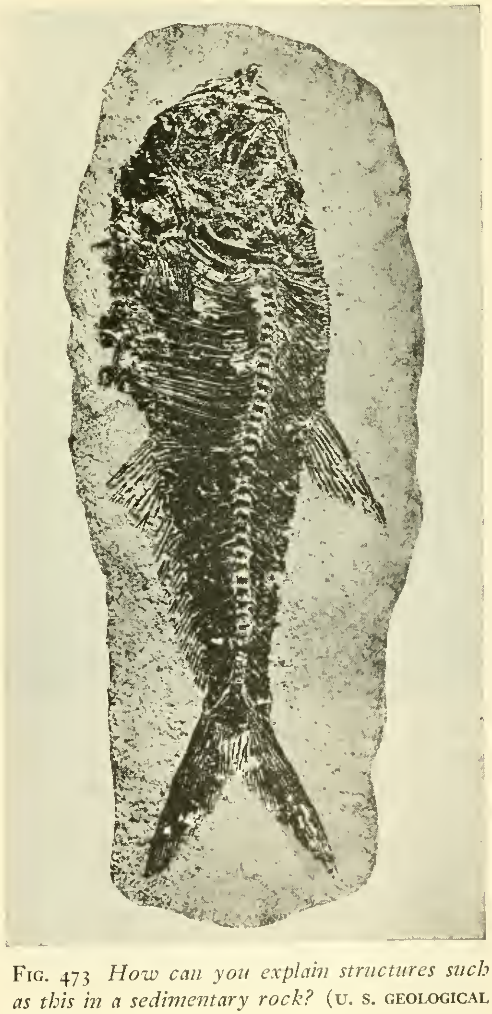


FIG. 473 *How can you explain structures such as this in a sedimentary rock?* (U. S. GEOLOGICAL SURVEY)

Fig. 474 *Part of a petrified root and trunk from the Petrified Forest of Arizona.* (GRANT — U. S. DEPARTMENT OF INTERIOR)

Fig. 475 *These petrified eggs, laid by a dinosaur ages ago, were found in the Gobi Desert.* (AMERICAN MUSEUM OF NATURAL HISTORY)

that it became a new branch of science known as *paleontology* (pay-lee-on-tol′-o-jee). Geologists and paleontologists now help one another in reconstructing the history of the earth throughout its various eras.

Fossils. You can imagine the confusion of the early scientists at finding stone animals and plants! Yet in the fifteenth century the great Italian artist and scientist, Leonardo da Vinci, was convinced that these fossils must have come from animals and plants that had once lived. It took a long time to convince the world of this, and longer still to explain how they could turn to stone. The explanation is simple. Before sedimentary rock became rock it was soft sand or mud. Any organism that died on or above the sand or mud would sink into it. If conditions were favorable the hard parts of the organism remained in the mud without decaying. During the long period of time during which the sediment changed to rock the bones or shells of animals and the harder woody portions of plants might also change to rock if mineral matter replaced the parts which were once living organic matter. This replacing of organic matter by mineral matter is called *petrifaction.*

Some organisms left nothing but an imprint in the sand or mud. By chance the imprint remained, so that we now find it in the rock. There are huge numbers of such imprints just as there are

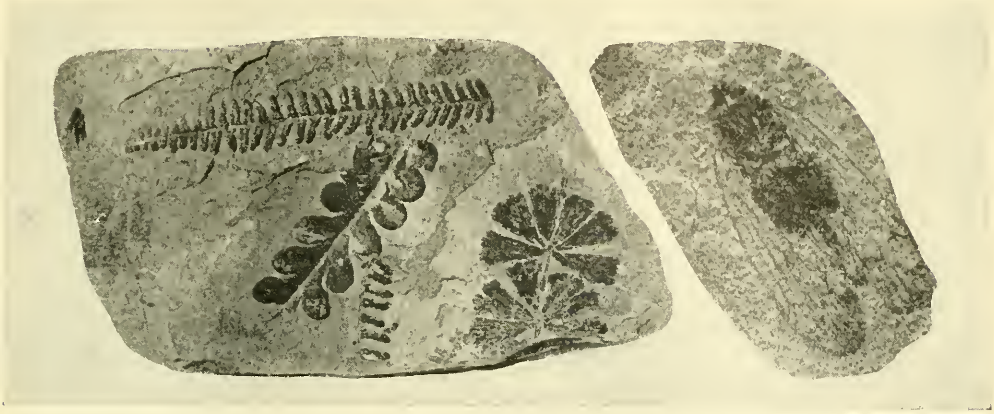


FIG. 476 *Plant and animal fossil imprints found in Pennsylvania. Some of the fern-like plants are much like existing ferns. What is the fossil at the right?* (WARD'S NATURAL SCIENCE ESTABLISHMENT)

huge numbers of petrifactions. Heavy animals left footprints, but even jellyfish and delicate water plants have left imprints in the mud which hardened into rock. You can demonstrate how such fossils could have formed by using plaster of Paris. See EXERCISE 6.

Coal is a rich source of plant fossils. Coal was formed in past ages from forests growing in swamps. As the land slowly sank the trees gradually became submerged (covered with water). Thus the leaves, branches, and trunks of the trees were kept from decay. The tremendous pressure and heat caused a chemical change that removed almost all the elements except carbon. The almost pure carbon is our coal, and in it are many imprints of the parts of plants. There are often solid leaves and stems of carbon.

Occasionally fossils have been formed on dry land too when sand, dust, or volcanic ash was blown over the body of an animal or plant. These materials may harden into rock, thus embedding hard parts of the organism.

FIG. 477 *Dinosaur footprints hardened in stone. From a quarry in West Orange, New Jersey.* (AMERICAN MUSEUM OF NATURAL HISTORY)

Other types of fossils. In Los Angeles are pools of tar or asphalt. Animals caught in this sticky tar sank and were killed. The flesh gradually disappeared but the tar preserved the skeletons without the usual petrifaction. Since they are the remains of bygone ages, they are also called fossils.

FIG. 478 *This painting by Charles R. Knight shows an ancient ground sloth stuck in a tar pool. The saber-toothed tiger appears ready to step in. This is one way in which fossils form.* (AMERICAN MUSEUM OF NATURAL HISTORY)

Insects crawling on the trunks of evergreens ages ago were trapped in the sticky resin which oozed from these trees. Through the ages the resin hardened into amber; the insect caught in the center of the mass remained preserved and unchanged. Enormous numbers of such fossils have been found in the amber near the Baltic sea.

From the icy bogs of northern Siberia, there have been recovered several bodies of mammoths, a type of woolly elephant no longer in existence today. The animals had been so perfectly preserved that the flesh could still be eaten. In the mouth of one mammoth was found the unchewed grass which it had cropped supposedly just before it fell into an ice crevasse (crack) thousands of years ago! Of course, fossils formed in this way are rare. You will find it interesting to study examples of different types of fossils. See EXERCISE 7.

The word fossil is difficult to define. It means the remains of animal or plant life from bygone ages preserved in any form whatever; it may be nothing more than an imprint of an animal or plant.

Fossil hunting. Since fossils were formed in earlier eras you would expect them to be buried deep in the earth, covered by the more recently formed sedimentary rock. No one knows what great fossil treasures may lie hidden beyond man's reach. But fortunately there are several ways in which fossils may become exposed. Sometimes a river cuts a deep channel through sedimentary rock as in the Grand Canyon of the Colorado. Thus walls of rock to a depth of thousands of feet are laid bare. Frequently, where a mountain chain has been uplifted, strata of rock have been broken through and the edges upturned and raised far above sea level. In this way strata millions of years old and thousands of feet deep are brought to the surface. Thus fossils can be found in many parts of our country, in such large numbers that in some regions any boy or girl may discover them. Also in mining operations where men sink shafts into the earth, they find fossils which are buried relatively near the surface.

Frequently the location of fossil beds is known or suspected, as in the Gobi

FIG. 479 *The Grand Canyon of the Colorado. Ages ago these strata of sedimentary rock were laid down, then raised, forming a plateau. Then the Colorado River gradually cut a channel through the rock. Thus fossils buried in very early rocks became exposed.* (AERONAUTICAL CHAMBER OF COMMERCE OF AMERICA)

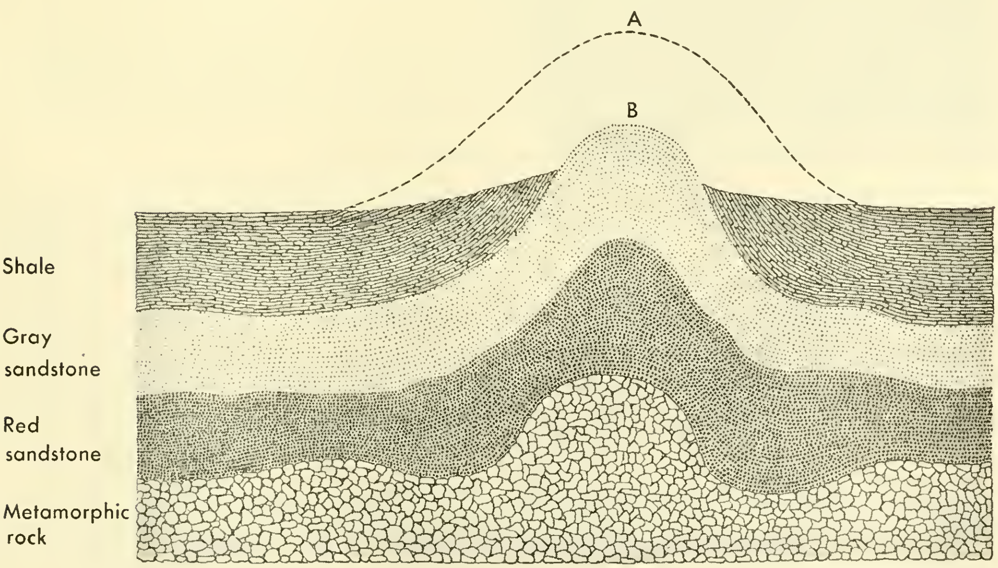


FIG. 480 *Ages ago a mountain was pushed up at* A *(dotted lines) and later worn down to* B. *How do geologists know this? In time more rocks would wear away at* B *until the land became level. Explain how fossils can be found near or at the surface, although they are in rocks that are very old and that were at one time buried deep below younger rock layers.* (AMERICAN MUSEUM OF NATURAL HISTORY)

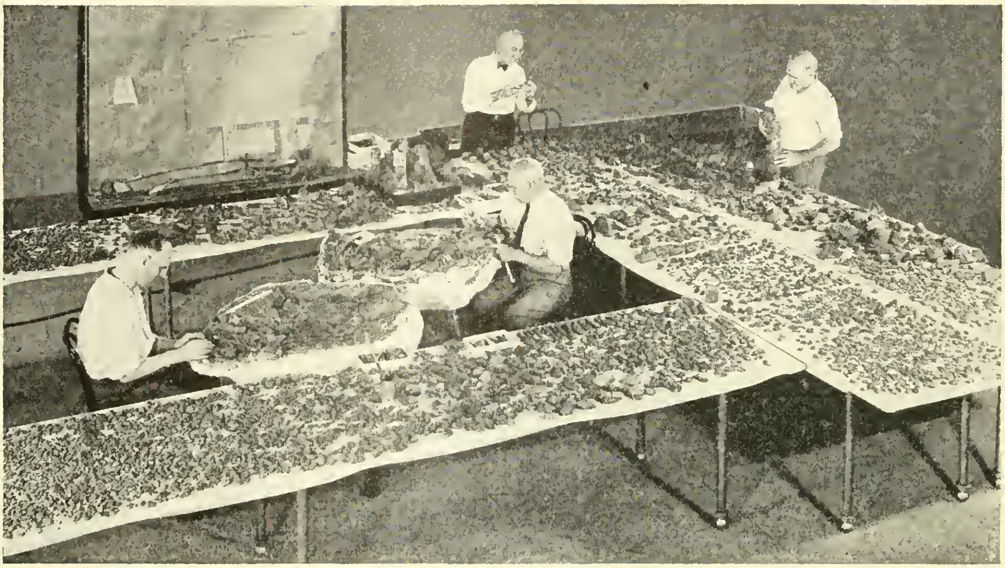


FIG. 481 (above) *Much work remains to be done after an expedition. Only experts can identify and piece together the fossil fragments sent home.* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 482 (left) *An assistant is helping the scientist to cover up gigantic bones with burlap and flour paste for shipment. Large bones must be carefully protected.* (AMERICAN MUSEUM OF NATURAL HISTORY)

Desert or in Wyoming where dinosaurs used to live. Then large expeditions are equipped for exploring them. Sometimes the bones of one animal are all found together; more often they have been shifted in position so that they are widely scattered; many are much broken or completely lost. Digging out and later transporting the petrified and often fragile fragments of bone is a task requiring training and skill. Later, in the laboratory, the bones are examined by experts and assembled. Missing bones are replaced by models and thus whole skeletons are reconstructed.

We learn much from a study of fossils. Not only has the earth changed throughout the ages but fossils indicate that the inhabitants of the earth have changed, too. There are no longer any mammoths, saber-toothed tigers, or dinosaurs. Many other kinds of plants and animals have died out, become extinct. Furthermore, existing animals and plants are almost always different from the animals and plants of former ages. The changes were so slow that they become evident only as we look back millions of years. And there is every reason to believe that changes continue to go on.

Questions

1. State one theory of the origin of the earth. Describe the earth in the early stages. What is igneous rock? How did soil gradually form? What does a geologist study?
2. Define erosion. Define weathering. What effect has erosion on the height of mountain ranges?
3. Explain what becomes of the rock and soil carried by streams.
4. How is sedimentary rock formed? How do strata form? How do metamorphic rocks differ from sedimentary? Give three examples of metamorphic rocks.
5. Give examples of sudden earth changes and of slow changes.
6. What is now considered to be the most accurate way of estimating the age of the earth? How old is the earth supposed to be?
7. How long a stretch of time is an era? Into what are eras divided? How do we learn about the early inhabitants of the earth?
8. Explain how fossils form by petrifaction. What kinds of fossil imprints have been found? Why is coal a rich source of plant fossils?
9. Describe three ways besides petrifaction by which remains of animals or plants of past ages can be preserved. Give a full description of the term fossil.
10. How may deeply buried fossils be discovered? Why are fossils frequently found at or near the surface of the earth?
11. What important facts about the former inhabitants of the earth have we learned from a study of fossils?

Exercises

1. *Demonstration.* The slow action of carbonic acid on limestone can be shown, speeded up enormously, by using a stronger acid. Pour dilute hydrochloric acid on marble chips. What becomes of the marble?

2. You can show the force of germinating seeds by planting some soaked pea and corn seeds in moist sawdust or sand in a tumbler. Cover the surface of the sawdust or sand with paraffin, making holes in several places (where no seed has been planted) so as to allow the air to reach the germinating seeds. Can you devise any other experiment to show the force of germinating plants?

3. *Demonstration by teacher or pupil.* (*a*) Prepare two mounds of earth (preferably clay), each in a box. Cover one mound with sod. Leave the other unsodded. Using a watering can, pour equal amounts of water at the same rate on each mound. What do you demonstrate by this means? (*b*) When doing the demonstration in (*a*), collect, in separate containers, the water which has run off each mound. Allow the sediment to settle. Does the kind of country drained by a river make a difference in the speed with which a delta forms? Explain.

4. If a large, shallow, waterproof box is available you may watch sedimentation on a small scale. Send a stream of water carrying sand into one end of the box; the overflow can pass out the other end through an opening at the bottom of the side. What happens? Why? Now send water carrying mud into the box. Describe what happens. Explain.

5. *Demonstration of types of rock.* Examine samples of sedimentary, igneous, and metamorphic rocks. In general, which are the hardest? Which the softest?

6. It is possible to imitate the formation of an imprint fossil by the use of plaster of Paris. Use vaseline on the object (a scallop shell is suitable) so that the plaster will not stick to it. Two types of fossils may be formed, one showing the outside of the shell, the other the inside. Both types are found in the rocks.

7. Examine the different types of fossils provided in a standard set. Which are the unchanged remains of plants and animals? What kinds of changes may take place in the organism as fossilization goes on? Are there fossils which do not contain any part of the organism, changed or unchanged?

Further Activities in Biology

1. Look through back numbers of the *National Geographic Magazine* and report to the class on earthquakes or volcanoes. The story of Paricutin is told in *Life* as well.

2. Using two flat rocks and some packed, wetted soil, demonstrate how the slipping of the underlying rock causes rifts in the soil or displacements.

3. Prepare a short report on the "bad lands" of the West. Explain how they were formed and why the soil is not yet completely washed away. Consult a geology or physiography textbook.

4. If you are interested in photography, take pictures of lakes which seem to be in different stages of change. Arrange them in a series and mount them to demonstrate how a lake disappears.

5. The camera is the best recorder of all types of earth changes. Why not prepare a list of subjects such as a bare slope before and after a heavy rain?

6. Start now to make a fossil collection. You will be surprised to learn how common fossils are in many parts of the country.

7. Read some of the books written by Carroll Lane Fenton and Roy Chapman Andrews. Report briefly to your class. (See bibliography.)

8. By reference to chemistry texts find out how scientists have measured the rate at which uranium becomes lead. Explain this briefly to the class. How does the scientist know that the lead came from uranium?

PROBLEM 2 *What Can We Learn from Fossils about Prehistoric Living Things?*

Reading the history of the earth. If you laid this book down with its front cover against the table, the first chapter would be at the bottom. The last chapter would be on top. If each chapter had been printed on paper of a different color you would see many distinct layers, some thick, some thin. To geologists the rocks are like an enormous book in which the history of the earth can be read. At the bottom are the rocks laid down first, the oldest rocks. The most recent rocks lie on top. In the rocks, too, there are layers or strata, "chapters" of different colors. In these strata are fossils of animals and plants; and since the lowest rocks are the oldest, they contain fossils of the plants and animals that lived in the earliest days; just above them lie the remains of slightly more recent organisms. In the uppermost strata lie the remains of the most recent plants and animals. Thus there is a succession of fossils in the rocks just as there is a succession of ideas in a book. See Exercise 1.

To be sure, the rock strata are harder to read than the pages of a printed book because in places they are torn and twisted so that pieces of the lowest, or oldest, strata now lie at the surface of the earth, or on edge, or on top of younger rocks. The book has been mutilated to such an extent that at times it is difficult to know which are the earliest chapters. However, through long study of the rock and the fossils, geologists have learned to read the book quite accurately. They have worked out the sequence of fossils and have learned much about the different eras and periods of the earth's history. Let us examine the geologists' book. We shall find the following chapters listed in the "table of contents of the Book of the Rocks." But we must remember to read from the bottom up.

Would you be interested in a rapid glance at the earth as we think it must have looked in these various eras? As you read you might illustrate what you read, as suggested in Exercise 2.

Table of Contents

The Book of the Rocks

7th era	Era of man	(Psychozoic)
6th era	Era of recent life	(Cenozoic)
5th era	Era of middle life	(Mesozoic)
4th era	Era of old life	(Paleozoic)
3rd era	Era of first life	(Proterozoic)
2nd era	Era of most ancient life	(Archaeozoic)
1st era	Era of no life	(Azoic)

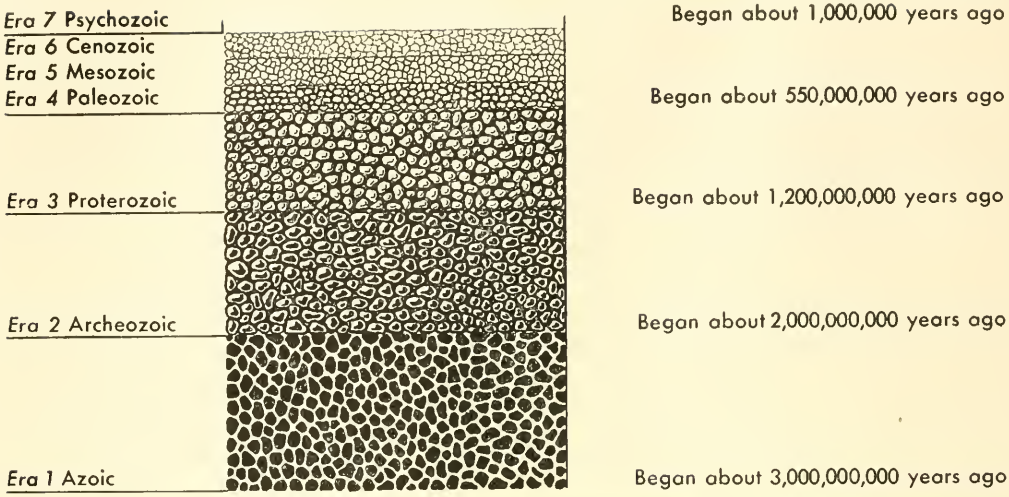


FIG. 483 (above) *A diagram of the 7 eras of time. Read from the bottom up. The rocks of the first era were the first to be laid down and are generally deepest down in the earth. Note that about five sixths of the earth's history was over when the fourth (Paleozoic) era began. But that was scarcely recent. It was 550,000,000 years ago!*

FIG. 484 (left) *After long years of careful study of the rocks, geologists think this map represents North America during an early period of the Paleozoic era. Seas are shown in white. Was your hometown location under or out of water at this time?*

The earth in the first three eras. The first rocks, it is estimated, were formed three billion (3,000,000,000) years ago as the earth cooled. Geologists think it probable that no life existed during the first billion years, the first era (Azoic). After about a billion years great changes occurred that have left their mark on the earth. Geologists therefore say that a second era began. In the rocks laid down

FIG. 485 *A Cambrian underwater scene. The large animal near the center is a giant trilobite. What others can you recognize?* (SMITHSONIAN SCIENTIFIC SERIES, INC.)

in the latter part of this second era there is some evidence that life existed, probably simple one-celled plants and animals. The rocks of the third era contain only a few fossils but it seems clear that seaweeds and various kinds of very simple sea-dwelling invertebrate animals lived in this third era (Proterozoic). It will help to study the diagram, Figure 483. Note that five sixths of the earth's history was already over when the fourth era began. But that was far from recent. It was 550,000,000 years ago.

The fourth era (Paleozoic). Examination of Figure 483 shows that this, too, was a long era. Much of our continent seems to have been under water in the early periods. The only fossils in the oldest Paleozoic rocks are those of water-dwelling plants and animals. It is believed that there was no soil covering the rocks since no fossils of land-living plants or animals have been found. Seaweeds were plentiful and, judging from the large number of fossils, the oceans and inland waters were teeming with jellyfish and sponges, animals like our modern starfish, corals of many kinds, and snails. There were more complex invertebrates, too, shrimplike forms. In one early period of this era (the *Cambrian* period) the most common animal type was one which has since disappeared from the earth, the *trilobite* (try'lo-bite). It is classified in the lobster group (Crustacea). Some species were two inches long; others reached a size of two feet or more. Trilobites were so numerous and of so many kinds

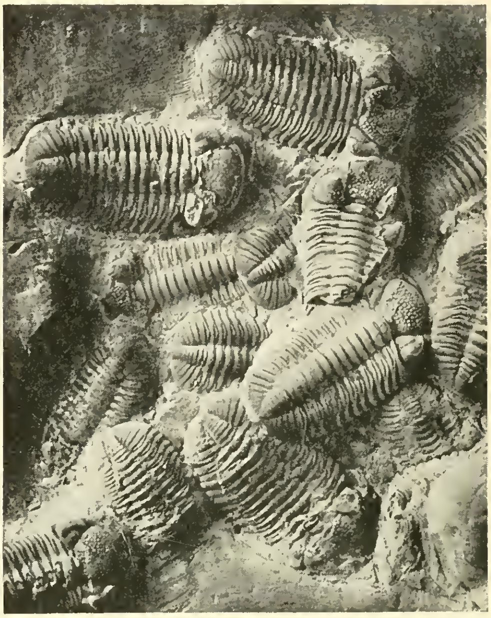


FIG. 486 (right) *Trilobite fossils in limestone formed early in the fourth era. This gives you some idea of how crowded with trilobites the seas must have been.* (U. S. NATIONAL MUSEUM)

that the Cambrian period is sometimes called the Age of Trilobites. Perhaps by this time you have forgotten just where the crustacea fit in the classification of animals. In the next few problems various phyla and classes will be mentioned so this would be a good time to review parts of Unit I. You will find summaries of the classification of animals on pages 65–66 and of plants on pages 90–91.

Imagine that another 150 million years have passed; we are still looking at the earth in the fourth era (the Paleozoic), but it is toward the close of the fourth era. The period is the *Carboniferous*, the period in which the coal beds were formed. In this period there must have been enormous swamps in many parts of the globe with a thick growth of ferns and fernlike plants. Although tree ferns are still to be found in South America and on southern Pacific islands, most ferns of the present time are small annual plants. Most of the Carboniferous ferns were trees, forming dense forests. Fish abounded in the ocean, and amphibians, like our newts and salamanders,

FIG. 487 *This is a photograph of a reconstruction of a forest of the Carboniferous period. Ferns varied from small plants to huge trees. The animal on the tree at the left is a cockroach.* (FIELD MUSEUM OF NATURAL HISTORY)

FIG. 488 *How one artist pictures a landscape during the age of reptiles.* Tyrannosaurus rex *and the three-horned dinosaur,* Triceratops horridus. (AMERICAN MUSEUM OF NATURAL HISTORY)

crawled over the earth. There were very few reptiles. Certain kinds of insects existed in enormous numbers, huge dragonflies with a wingspread of a foot, and cockroaches three to four inches long. Toward the close of the Carboniferous period the earth must have sunk in many of the swampy regions. The plants died and were covered by water and then by sediments that eroded from higher ground. Then chemical changes, together with pressure and heat, changed the submerged plants to coal. It took millions of years to make the coal; meanwhile more and more sedimentation and rock formation occurred above the coal beds. This happened more than 200 million years ago.

The Age of Reptiles. This is the fifth (Mesozoic) era. It is believed that it lasted for about 140 million years. The huge evergreens of this era can be seen petrified in Arizona. From the fossil evidence, there were reptiles of many species on the land, in the sea, and in the air. A few kinds of small mammals were in existence and some strange birds had appeared. Representatives of the other groups, the fishes and the many types of invertebrates were in existence still, but by far the most numerous among animals were the reptiles, both in numbers and in species. Toward the close of the era the dragonlike reptiles known as *dinosaurs* flourished. Some species of dinosaurs were small; others gigantic. The thunder lizard (*Brontosaurus*) reached a length of sixty-six feet. It apparently waded about in swamps and shallow lakes and must have eaten about 300 pounds of plants daily. Although it had an estimated weight of more than 70,000

FIG. 489 *Imprint of a strange birdlike animal* (Archaeornis) *which lived in the Mesozoic era.* (SMITHSONIAN INSTITUTION)

pounds, its brain must have weighed little more than a pound. So poorly developed a nervous system might be reason enough for its becoming extinct when it was obliged to compete with more intelligent animals, but no doubt there were many other factors which contributed to its dying out.

The "King Tyrant" reptile (*Tyrannosaurus rex*) with a monstrous body and enormous mouth armed with great teeth was probably a flesh eater and a powerful fighter. Many of the flesh eaters were apparently heavily armored, and many were provided with long, strong tails. Marks in the fossil bones indicate that many bone fractures had occurred while the animal was alive; this leads us to the belief that these dinosaurs must have been mighty fighters. You will find EXERCISE 3 interesting.

The dinosaurs died out completely in what seems to us like a sudden catastrophe. There is not a single dinosaur fossil in the rocks of the next era. But, if you recall the length of a geologic era, you will realize that the dinosaurs may have died out gradually over a period of thousands and thousands of years.

The Age of Mammals. This is the sixth (Cenozoic) era. It started about 60 million years ago and lasted to within a million years of the present. The dinosaurs had become extinct at the close of the last era but there were many other kinds of reptiles. There were many species of amphibians, thousands of species of fish, and countless thousands of species of invertebrates. But the earth in the sixth era came to look very different from the earth in the earlier eras. There were now many kinds of flowering plants growing in large numbers; a few of these had appeared in the fifth era. Birds became common; and the mammals, of which there had been only a few kinds in the age of reptiles, were represented by thousands of species. There were many more species of mammals then than now; many died out before modern times.

Geologists have found evidence that many changes in the earth itself occurred during the age of mammals, just as in previous eras. The Alps and the Himalayas were thrust up as mountain ranges. The outlines of the continents changed. During the early and middle part of the age of mammals there seems to have been a broad land connection between North America and northern Asia and also between North America and northern Europe; many kinds of mammals could have roamed from one continent

FIG. 490 *Using our knowledge of fossils, an artist painted this scene of an early period in the age of mammals. Which reptile do you recognize? How does the vegetation differ from that of earlier eras?* (ROYAL ONTARIO MUSEUM, TORONTO)

FIG. 491 *Western Nebraska during the age of mammals. In those days, according to the fossils that have been found, horses roamed the plains. Later they died out. What other animals can you recognize?* (AMERICAN MUSEUM OF NATURAL HISTORY)

to another. But during most of this time it seems likely that there was no land connection between North and South America. The two continents were again connected by land toward the end of this era.

The Age of Man. About a million years ago the seventh era (Psychozoic – psy-ko-zo'ik) began. Manlike creatures appeared. You will read of them in the last Problem of this Unit. Meanwhile, the earth was undergoing great changes in climate. It was alternately cold and warm. During the colder periods glaciers formed on the mountain sides; thick

FIG. 492 *How far south did the ice sheets extend? Glaciers are still to be seen in our western mountain ranges. The greater part of Greenland is still covered with ice.*

sheets of ice, miles deep, accumulated in the northern parts of this continent and Europe. Many plants were killed; animals retreated southward before the wall of ice. In North America, during one of the cold periods, the arctic musk-ox lived in what is now called Oklahoma; the woolly mammoth was driven from the far north to points south of the Ohio River, and the walrus of the arctic seas lived off the shores of the present state of New Jersey. After a long period of extreme cold the climate changed. The glaciers, melting at their edges, retreated northward. Plants and animals followed them. During at least one of the warm periods the temperature must have been higher than it is now, for in the British Isles lions and hippopotamuses roamed among palm trees. At that time semitropical plants grew in central North America. There is evidence that four times during this age glaciers moved into the United States from Canada and each time they retreated. The last of the ice sheets melted away from North America not more than 25,000 years ago.

Progression from simple life to complex. In reading the last few paragraphs you could not help noticing this striking fact: in the lowest (oldest) rocks we find fossils of the simplest single-celled animals; in the next layers appear fossils of simple invertebrates (corals, starfish, sponges, and others); somewhat higher in the rock layers are found fossils of the more complex invertebrates, such as lobsterlike animals and insects, and vertebrate fossils of fish and amphibians. In these rocks are found no fossils of mammals or birds. But in the next higher layer fossils of reptiles are very common and there occur the remains of a few birdlike animals and of simple mammals. EXERCISE 4 will be of help to you now. It would seem that in the earliest ages there lived only the simplest kinds of animals, and that gradually they became more complex. A careful study of plant fossils would lead you to the same conclusion about plants. What seems like a progression from simple life to complex took a long, long time — two thousand million years.

A diagram can be used to illustrate how biologists believe plants and animals must have changed through the ages. In this diagram the types of animals now alive are connected by branches to some unknown kind of living thing at the bottom of the diagram. By tracing the lines back from the top you will see that biologists believe some organisms to be more closely related, some more distantly related. And if you trace the lines back far

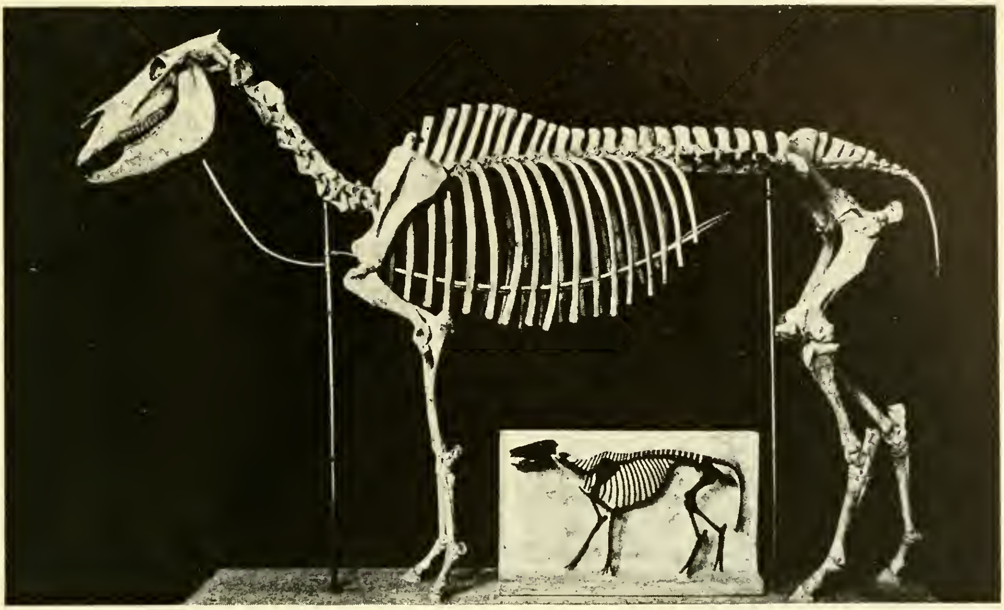


FIG. 493 *Skeletons of the modern horse and Eohippus to show comparative sizes. What resemblances and differences can you see?* (AMERICAN MUSEUM OF NATURAL HISTORY)

ERA	AGE OF
Psychozoic 1,000,000 years	Man
Cenozoic 60,000,000 years	Mammals
Mesozoic 200,000,000 years	Reptiles
Paleozoic 550,000,000 years	Amphibians
	Fishes
	Invertebrates
Proterozoic 1,000,000,000 years	Simple living forms
Archeozoic 2,000,000,000 years	Earliest living things

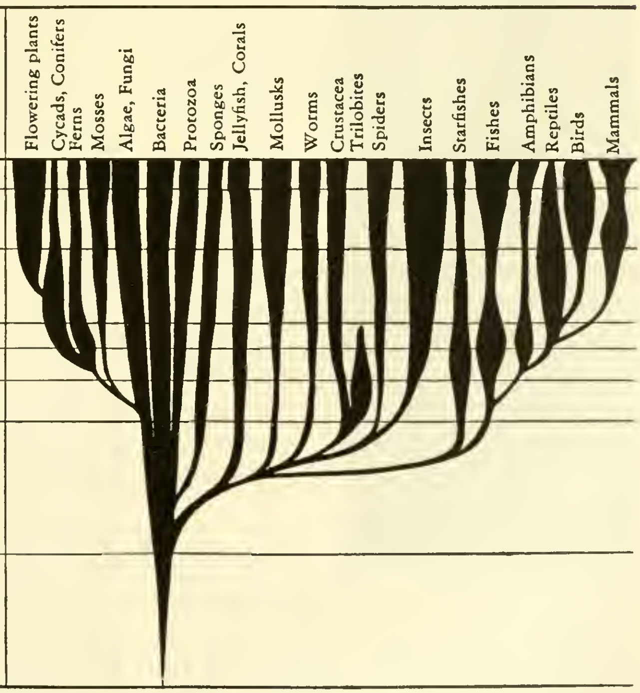


FIG. 494 *The numbers in the left column tell when each era began. The wider a branch at any level the more numerous were the species at that time. Which is the widest branch now? Some grow narrower near the top. Why?*

FIG. 495 *In the lowest strata of the sixth era are found front and hind leg bones like those shown at the bottom. In somewhat higher, more recent strata, were found those in the second row, and so on to the top. Do you recognize the bones on top? What does this series seem to show?* (WARD'S NATURAL SCIENCE ESTABLISHMENT)

enough you will see that biologists believe all living things have sprung from some common ancestor, some bit of living matter represented at the bottom of the diagram. Judging from the fossils, life changed throughout the ages from simple to more and more complex.

The origin of the horse. We know that horses roamed over our continent a half million years ago, before our continent was inhabited by man. See Figure 491, page 539. Their bones can be found in the upper layers of the rock.

The horse has characteristic long leg bones. Each hoof is really the tip (toenail) of a much lengthened single toe. On each side of the toe is a small remnant of other toe bones ("splints"). The horse also has a characteristic skull with complex grinding teeth which are different from those of other grass-eating animals.

As expeditions explored the rich fossil beds of Wyoming and Montana they uncovered many fossils of greater or lesser resemblance to the modern horse. The exploration is still going on but already fossils have been found that tell an astonishing story. The fossils from the various layers may be arranged in a series. In the oldest strata are found fossils of a curious small animal, *Eohippus* (ee-oh-hip'pus), which is now believed to be the ancestor of all the horses of today. It seems to have lived 60 million years ago. Until scientists found other fossils intermediate between it and the modern horse no one would have thought of connecting Eohippus with the horse. The little Eohippus was about as big as a large cat, with four toes on the front legs and three on the back and with simple teeth that had no cement. See Figure 493.

In recent strata are fossils of animals like the modern horse. Between the bottom and the top are the intermediate stages. More than a hundred species have been found. Many of these are intermediate steps and fit into this series between Eohippus and the modern horse. In Figure 495 are photographs of the leg bones of two of the intermediate species connecting Eohippus with the horse. If you understand this you should be able to do EXERCISE 5.

Other interesting series of fossils. An equally interesting, though somewhat less complete, series of fossils has been found which seems to show the development of the elephant from an animal that was only three feet tall and was without tusks or the flexible trunk. Fossil series of camels and pigs have been found, too. In each, the series starts with an animal that is so different from the modern species that it would not be recognized as the distant ancestor, if it were not for the transition, or intermediate, forms. There are plant series, too. Some fossil series are extraordinarily complete. Figure 497 is an illustration of snail shells found in successive layers of rock. Such complete series are particularly important to biologists.

What we learn from fossil series. These various series of fossils seem to show that one species of animal can give rise to another. They seem to show that by a series of changes, over a long period of time, new kinds of organisms develop that are very different from their remote ancestors. In general, the longer the time during which changes occur the less resemblance do the later organisms bear to the earlier.

Comparatively few complete series have been found. This is not surprising

FIG. 496 *Restorations of animals in the elephant series.* (d) *is a small shovel-tusker whose remains were found in Egypt.* (a), (b), *and* (c) *are later forms.* (AMERICAN MUSEUM OF NATURAL HISTORY)

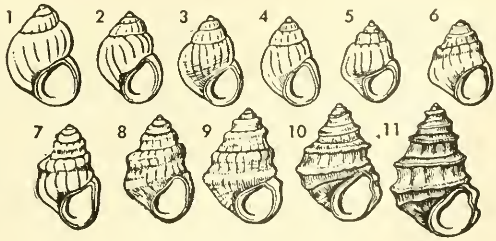


FIG. 497 (right) *Fossil snail shells. Numbers* 1 *and* 11 *are very different. What do you learn when you look from each shell to the next?*

because comparatively few organisms leave fossil remains and those that do are often destroyed by the folding and twisting of the rocks.

Summing up our study of fossils. According to the record in the rocks the first living things were simple forms; the more complex forms appeared later; and the most complex appeared only in most recent ages. It looks, therefore, as though the more complex animals and plants are descended from simpler types. If this is true, it means that all animals are related to one another, some very closely, some very distantly. By the same reasoning it seems likely that all plants are related to one another and through common ancestors many millions of years ago plants may even be related to animals. Plants and animals are quite alike in some ways.

When we say that the more complex animals and plants seem to be descended from the simpler forms we are implying that simpler organisms must have changed, giving rise to organisms that were more complex. But is it possible for one type of animal to give rise to another? The complete series of fossils leading from Eohippus to the modern horse seems to show that it happened, that it is possible. One sees little resemblance and little connection between Eohippus and the modern horse, but the resemblance and the connection are very great between Eohippus and the next form in the series, and between this and the succeeding one, and so on to the modern horse. Each change was a comparatively slight one but the time was so long that it was possible to have countless minor variations. These added together make the difference very great between the first and the last in a series.

Biologists are no longer surprised at the thought that one species may have given rise to another during the ages for recently such changes have happened right before their eyes in the laboratory. Earlier in this book you read that from existing plants new species of plants with unusual numbers of chromosomes have been produced. These new species have characteristics quite different from their parents. Furthermore, in hundreds of cases of animal and plant breeding, man has succeeded in producing new types of living things in a few centuries or even in a few years. The methods used by breeders are not different from processes that can go on in nature. Changes from one type of organism to another can take place, therefore, without man's help, although much more slowly. Together with the fossil record this seems to be good evidence that plants and animals have changed during the ages of earth history, new and more complex species appearing as time went on.

Questions

1. Explain in what way the rocks are like an enormous book. Why is it often difficult for geologists to read this book?
2. Describe the earth in each of the first three eras. About how long ago did the fourth era begin? What fraction of the earth's whole history is occupied by the last four eras?

3. Describe the early part and the late part of the fourth (Paleozoic) era.
4. Name some of the many kinds of animals that lived during the age of reptiles. Describe the reptiles that flourished near the close of the era.
5. Which large group of animals seems to have been the last to appear on the earth? How did the earth change in its appearance and in its inhabitants during the age of mammals?
6. What changes in climate occurred during the age of man and what effect did this have on plants and animals? About how long ago did this era begin?
7. Compare the animals and plants that seem to have lived in the earliest ages with those in later ages. What important biological idea does this observation lead us to?
8. Explain fully what the rocks seem to show about the origin of the horse. Why are biologists justified in saying that the Eohippus is the ancestor of the modern horse, even though it bears little resemblance to a horse?
9. Name other mammals the development of which can be traced by means of fossil series.
10. What important biological fact can we arrive at from a study of fossil series?
11. What direct evidence is there that a new species of organism can be produced from an existing species? What indirect evidence is there that species can change throughout the ages? What important biological ideas grow out of the evidence that species can change? Of what importance is the knowledge that there has been life on this earth for almost 2000 million years?

Exercises

1. Which do you think are more reliable, the records written in the rocks (fossils) or the records written by man in early ages? Defend your opinion.

2. Organize a class committee to do this exercise. Using wrapping paper begin now to prepare a large wall chart showing the geological eras by means of parallel lines. As you read each paragraph fill in the names of the animals (and plants) the fossils of which have been found in each of the eras.

3. If you are near a museum you can visit it and write a report. If there is no museum near have the class secretary write to the Chicago Natural History Museum, the American Museum of Natural History in New York, or to any other large museum for a price list of the publications and pictures on the subject of the history of the earth. See how interesting a collection of pictures you can build up in this and other ways.

4. List in order in a column the invertebrate phyla beginning with the simplest and mention some common examples in each phylum. Then,

continuing the same column, list in order, beginning again with the simplest, the classes of vertebrates. Next to each phylum and class show in which era the form first lived in large numbers, judging from fossils found. What interesting fact, if any, do you note?

5. The recent sedimentary rocks of Wyoming and Montana have remained comparatively undisturbed throughout the ages. How did this affect the work of building up the fossil series of the horse?

Further Activities in Biology

1. Make models of prehistoric forms. You could use plasticine or soap.

2. If you can draw, you can make very interesting drawings of some of the scenes in earth history. Of course, you will have to do some reading first to be sure that you have correct information. Perhaps a friend could help you do some of the research. A mural showing the stages in earth history would be suitable for the halls or library.

3. The "tree of life" has been drawn in several ways by biologists. Examine zoology and botany books to see whether you can find some. Explain them to the class. Sometimes there is fossil evidence that the descendants of a form changed in two directions, some giving rise to one kind of organism, others to another type. Can you show this in a tree diagram?

4. A series of drawings showing the development of plants through the ages would be interesting.

5. What kind of evidence has convinced biologists that birds came from a reptilelike organism? Present it to the class for discussion.

PROBLEM 3 *What Puzzling Facts May Be Explained by Our Theory of the Origin of New Organisms?*

Resemblances in structure. It has been known for a long time that animals as different in their outward appearance and in their way of life as birds, cats, codfish, and snakes, for example, have similar skeletons. You will recall that each of these animals has a backbone composed of many short bones called vertebrae. Each vertebra has a large hole through it; the spinal cord passes through this hole. The skulls of all these animals are much alike; many of the bones that make up the skull are similar in structure and position. The bones attached to the backbone, such as the ribs, the hip girdles, and the appendages (legs and arms) are strikingly alike. See the photographs of skeletons in Figure 499. When you examine the front appendage of two mammals that are as different as man and the whale you will be struck by the similarity in bony structure. See Figure 498. In fact the arm of the monkey, the wing of the bat, the front leg of the cat, and the flipper of the seal are all similar in bony structure, yet these animals live in different environments and use their appendages in very different ways. See Figure 500, page 548.

Animals as different as fish, frogs, turtles, birds, and cats are similar in other ways. In Figure 257, page 273, are drawings of the brains of several vertebrates. Note the similarities and differences. Almost all the organs of one vertebrate resemble those of the other vertebrates even though the animals are different in outward appearance and in their modes of living. You will find it interesting to summarize this paragraph by doing EXERCISE 1.

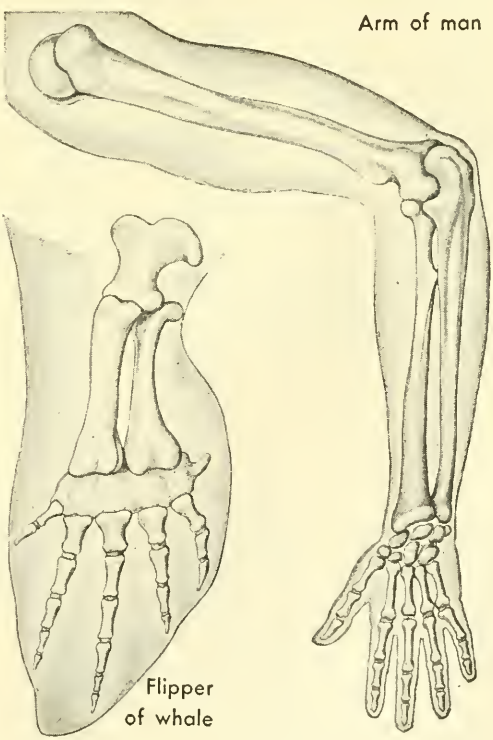


FIG. 498 *Although the whale and man have different habits of life and are different in appearance, the bones of the whale's flipper are much like the bones of a man's arm. What resemblances do you find?*

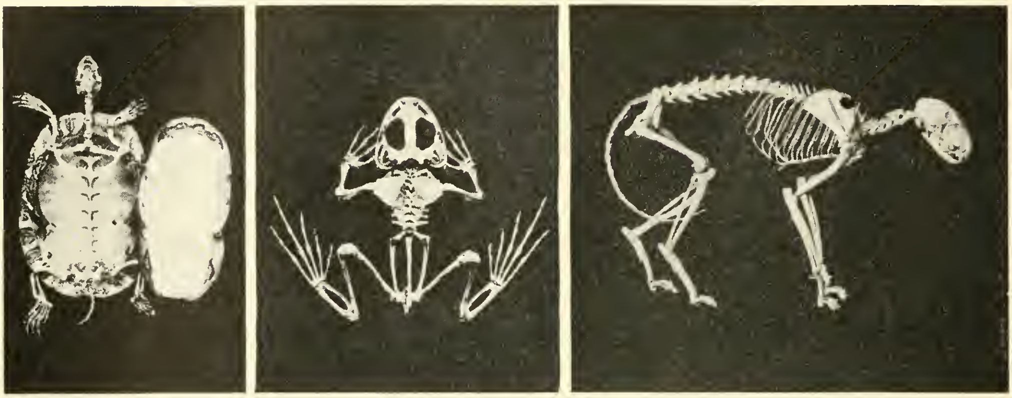


FIG. 499 *Note the similarities in the skeletons: turtle at left, frog in center, and cat at right. All three are vertebrates. To what class does each belong? Are the skeletons exactly alike?* (WARD'S NATURAL SCIENCE ESTABLISHMENT)

How can resemblances in structure be explained? The study of the structure of organisms is called *anatomy*. The comparison of the structure of different animals is a whole division of biology known as *comparative anatomy*. Students of comparative anatomy have long been puzzled by the resemblances in the internal structure of animals that are so different in outward appearance. From their study of fossils they can now explain these resemblances. Fossils seem to show that all vertebrates are related more or less distantly. If they are related one would expect them to have similarities.

The study of fossils helps further to explain why a particular animal (or plant) should be more like one form and less like another. A fish resembles a frog more than a cat. According to the fossils, frogs appeared soon after the first fish. Mammals appeared much later. This makes it seem likely that fish are more closely related to frogs than to cats.

Similarity in embryos. One of the most interesting things about vertebrates is that the embryos of all of them are so much alike. In all of them there is cleavage of a fertilized egg, followed by the hollow ball (blastula) and cup (gastrula) stages. Then differentiation occurs forming the various tissues and organs. Even after much differentiation the embryos are much alike, no matter whether the animal will finally be a fish, an amphibian, a reptile, a bird, or a mammal. Figure 501 shows that it is difficult to tell one from another.

You will note that not only the fish and frog, but the land-living forms as well, have gill slits in their early stages. Even the human embryo in its early stages has gill slits. For a considerable time, too, the human embryo has a tail. This region stops growing at an early stage, and as the embryo gets larger the tail becomes less and less evident. A few small bones remain as the coccyx (cock′-six). Also, in the course of the development of the human embryo there is a time when its heart is like that of the lower vertebrates; only gradually does it develop the four chambers. It is apparent that the human embryo in its early stages

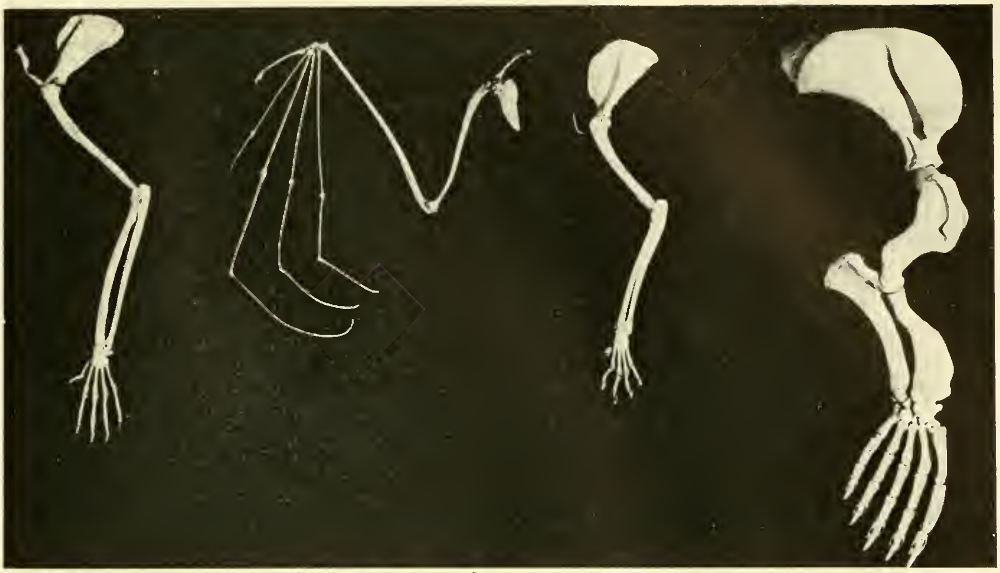


FIG. 500 (top) *Front appendage of monkey, bat, cat, and seal. What similarities do you note? In what region do you note the greatest differences? How can these similarities and differences be explained?* (WARD'S NATURAL SCIENCE ESTABLISHMENT)

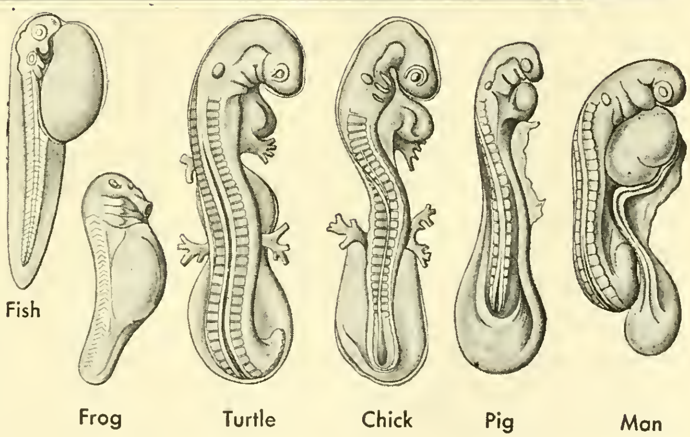


FIG. 501 (right) *In what ways are these early embryos alike? By what differences can you tell them apart?*

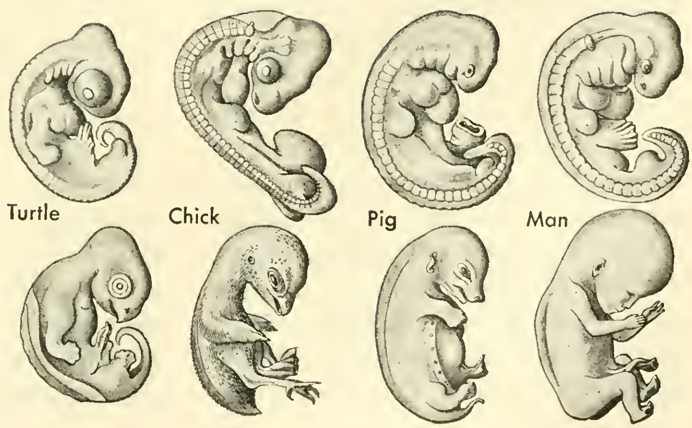


FIG. 502 (right) *Embryos in later stages. As differentiation goes on, the embryo looks more and more like the adult.*

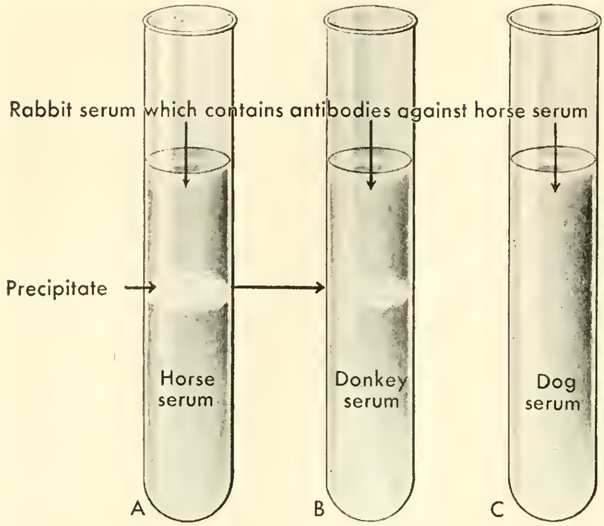


Fig. 503 *Into* A *was put horse serum; into* B *was put donkey serum; and into* C *was put dog serum. Then serum from a rabbit which had formed antibodies against horse serum after inoculation was added to each tube. Note the precipitate which forms in* A. *Compare with* B *and with* C. *What does this experiment seem to show about the closeness of relationship of horse and donkey as compared with horse and dog? Explain.*

is strikingly like that of the lower vertebrates. It only gradually comes to look like a human baby. Compare Figures 501 and 502. These similarities do not seem strange if we assume that all vertebrates are descendants of a common ancestor. If they are related to each other, it is not surprising that their development should be similar. Exercise 2 will help in summing up this paragraph.

Chemical similarities. You already know that all living cells, from the simplest to the most complex, are much alike. All get energy by oxidation of food; all consist of protoplasm containing, among other substances, water, carbohydrates, fats, and proteins; all produce enzymes of one kind or another. These things are true of both plants and animals. If we assume a common ancestor for both, these facts are not too difficult to understand and explain.

More striking chemical similarities exist. Those forms which are alike in structure are also frequently alike in chemical make-up. Only vertebrates have hemoglobin in their blood cells. Only those plants which, because of their structural similarity, are classified in the same genus (lemons, limes, oranges, grapefruit) produce citric acid. These chemical resemblances would be difficult for us to explain did we not believe that the organisms which show these similarities are descended from common ancestors.

In delicate tests with serums and antibodies it is found that chemical resemblances are greatest in those forms which seem from their characteristics to be most closely related. Figure 503. Exercise 3 will test your understanding.

How can apparently useless structures be explained? Man has an appendix which seems to be of no use and may do harm. Some people have scalp and ear muscles which can be used, though to no purpose. The bones at the lower end of the spinal column in man are small and fused; as you learned, they form a short tail. The whale has no hind legs, but it carries through life a number of small

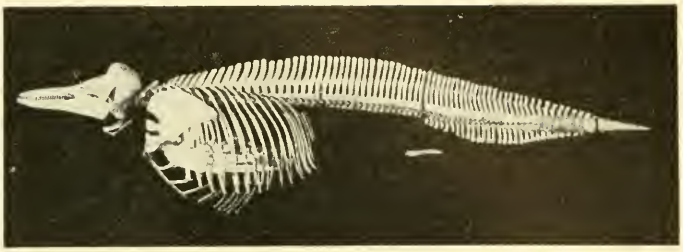


FIG. 504 *Skeleton of a porpoise, relative of the whale, which never leaves the water. What vestigial structure do you see?* (WARD'S NATURAL SCIENCE ESTABLISHMENT)

bones on each side of the spinal column in that region where in most other mammals the hind legs would be attached. These are but a few of many examples of apparently useless structures called *vestigial* (ves-tij′ee-al) structures. These structures seem to be remnants or vestiges of structures that in related animals are useful. It is believed that the bones in the whale are vestiges of the bones possessed by the whale's distant ancestors, animals which had and used hind legs. So with the appendix in man. In rabbits and in some other mammals the appendix is a large organ used in digestion. All such seemingly useless organs are puzzling unless we assume that the different types of animals are descended from some distant common ancestor or ancestors.

Resemblances and classification. You know that we classify plants and animals according to their resemblances in structure. All those that have in common a few striking structures are placed together in a large group known as a phylum. For example, animals with a hard outside covering, segmented bodies, and jointed legs are placed together in the arthropod phylum. The animals of each phylum are then separated into different classes according to some other definite resemblance. Those within a class are again subdivided into orders according to other similar structures; those within each order are subdivided into different families, those within each family into genera, and lastly those within each genus are put into different species. As a result the animals within a species are similar in most of their structures. The animals of two different species within one genus are alike in fewer of their structures. Animals of two different genera within one family have even less in common, and so on. At first it seemed astonishing that plants and animals should fit so neatly into this scheme of classification. But remember that we believe that fossils seem to show that animals and plants changed step by step throughout the ages. If this is true, they are descended one from another and are related, some more closely, some more distantly. Then it becomes clear why some have a great deal in common, others have less in common. And if this is true they will naturally fit into a phylum which is subdivided into classes, then into orders, into families, into genera and species. Now do EXERCISES 4 and 5.

(Optional) Distribution of plants and animals. In general, animals and plants tend to spread far and wide over the earth to areas which are suitable in climate, provide the right food in sufficient amounts, and have not already been occupied by enemies. They spread until they meet barriers, such as mountain ranges, great bodies of water, or even large deserts like the Sahara and the Kalahari in Africa. If it were not for such barriers animals and plants would be more widely spread.

Long ago some puzzling facts were noted about the distribution of animals and plants. Why should almost all native mammals in Australia and nearby islands be of a primitive type, simpler in structure than the mammals of other continents? There are many kinds but, like the kangaroo, all have pouches in which their young are kept for a time after birth. Of all the very many kinds of mammals found outside of Australia, there is only one group that is pouched, the opossums of North and South America. It puzzled biologists that the pouched mammals should be limited almost entirely to Australia and its neighboring islands. An explanation of this puzzling fact can be found if we assume that more complex animals come from simpler forms. We can then explain this unusual distribution somewhat as follows. In past ages there developed a simple type of mammal with a pouch. At this time, according to evidence of the rocks, Australia was connected with Asia and Asia with Europe. Since there were no barriers to stop them, these early pouched mammals could have spread all through Australia, Asia, and Europe. Then Australia was cut off from the rest of the world by oceans. Ages later, elsewhere in the world, a type of mammal developed that did not carry its young in a pouch. This form gave rise to the many more advanced types of mammals we know. The same change did not happen to occur in Australia. In Australia the pouched mammals continued to live and to change in many ways throughout the ages. But no matter how they changed in other respects, they remained as pouched mammals of one type or another. Many of the plants of Australia are also different and more primitive than those of the rest of the world.

FIG. 505 *An Australian koala carrying her offspring. For a short while after it was born she carried it in a pouch.* (NATURE MAGAZINE)

On many of the remote islands of the earth both the plants and animals are different from the plants and animals in other parts of the world. There are many puzzling problems of distribution that still remain to be solved.

Explaining puzzling biological facts. The idea that living things are related and descended one from the other has developed from a study of fossils and from breeding experiments. Fossils show that animals and plants changed in past ages. In breeding experiments we can actually see changes going on. This idea that plants and animals change enables us to understand many puzzling facts. It helps explain such observations as these:

1. the striking similarities in the skeleton and internal organs of vertebrates.
2. the great similarity in the development of vertebrate embryos.
3. the great chemical resemblances between certain animals and between certain plants.
4. the strange vestigial structures found in certain organisms.
5. the classification of organisms.
6. some puzzling cases of plant and animal distribution.

If any idea or theory explains puzzling facts the idea or theory is thereby strengthened. Such facts can then be called evidences of the theory. Now the idea or theory that new types arise from preceding types, the more complex forms appearing as the descendants of the simpler ones, so that all living things bear a relationship to one another, is called the theory of *organic evolution.* The many puzzling facts explained in this problem can thus be called evidences of organic evolution.

Questions

1. What are the similarities in general skeletal structure of vertebrates belonging to different classes (fish, amphibians, reptiles, birds, and mammals)? What similarities do you note when you compare the front appendages of a number of very different kinds of mammals? Compare also the brains of members of the various vertebrate classes. What do you discover?
2. Define "anatomy" and "comparative anatomy." How do students of anatomy explain similarities in vertebrate structure?
3. In what respects do the early embryos of fish, frogs, reptiles, birds, and mammals resemble one another? In which embryos do you find gill slits and a tail? How do biologists now explain the striking resemblances of embryos?
4. What examples of chemical resemblances can be explained by assuming that organisms are related?
5. What is meant by vestigial structures? Give three examples of vestigial structures in man and one in the whale.
6. Describe briefly the modern scheme of classification. Why is it that animals of similar species can be placed in the same genus, animals of similar genera always fit into one family, and so on all the way back to the phylum?
7. Give an example of interesting animal distribution. What barriers are there to distribution? How can some cases of unusual distribution of plants and animals be explained by biologists?
8. Give a brief summary of this problem.

Exercises

1. In what ways are some of the vertebrate skeletons alike? In what ways different? Study the skeletons of a frog, a reptile, and a cat. How are the hind legs attached in each case? The ribs are attached to the vertebrae; to what are they attached at the other end? How does the breastbone of the bird differ from those of other vertebrates? What other resemblances and differences do you note in these skeletons?

2. How do the embryos of vertebrates resemble each other? Use museum preparations, models, charts, and pictures. In what kind of environment does each embryo spend the early part of its life? Which structures appear first? Which structures change last? Among which embryos do you find the greatest degree of resemblance? Is there greater resemblance between embryos of animals that appeared on the earth in closer succession? Sum up your observations.

3. What is meant by precipitation? You can see a simple precipitation by adding some silver nitrate solution to a test tube containing some sodium chloride (table salt) solution. Suppose a rabbit had formed antibodies against police dog serum so that a precipitate would be formed when the blood of the two animals was mixed in a test tube. If you mixed blood from the following animals with rabbit serum, which should theoretically form the largest precipitate, which next, and so on to the smallest: spaniel, fox, wolf, cat, robin, crocodile, trout, and toad?

4. Reread Problem 3, Unit I on classification. (*a*) Why are insects and vertebrates classified in different phyla? (*b*) Why do fish and mammals belong to different classes but the same phylum? (*c*) Why do the horse and the cat belong to different orders but the same class? (*d*) Why do the cat and the dog belong to different families but the same order?

5. Can you show by diagram what you learned in Exercise 4?

Further Activities in Biology

1. By using college textbooks, find other examples of resemblances in structure between vertebrates. Prepare a report. Make a list of resemblances among groups of invertebrates.

2. There are many examples of vestigial organs in man. Look up this subject in college textbooks.

3. If you are good at using clay prepare a series of models showing vertebrate embryos at various stages. If you use several colors you can show similar organs and how they change.

4. Prepare a report on the life of Linnaeus. Donald Culross Peattie's book, *Green Laurels*, is an interesting source of information.

5. Draw a large map to show the distribution of certain types of plants and animals. Which organisms will you choose? Why?

PROBLEM 4 *What Theories Have Been Offered to Explain the Origin of the Different Kinds of Animals and Plants?*

De Vries's contribution. In the preceding problem you learned many reasons for believing that animals and plants were not always like those existing now; that the first animals and plants that appeared on the earth were simple; and that they have given rise throughout the ages to more complex forms. Our problem now is to discover *how* it might be possible for an organism to give rise to another, resulting in the origin of new species.

De Vries made an important contribution toward an explanation of the origin of new species. Early in this century he noticed that inheritable changes occurred in the evening primrose plants that he was studying. His experiments showed that the changes were sudden. He called them mutations. De Vries noticed that some of these plants continued to mutate. If such mutations were to continue through long periods of geological time many new characters would appear. Thus, said De Vries, entirely new organisms that could be classed as new species could arise by the addition of many small mutations. De Vries's explanation of how evolution takes place is called the mutation theory.

Effects of gene changes. Gene changes (or other chromosomal changes) in the germ plasm may lead to characters which weaken the organism; then the organism dies and fails to produce offspring having the new character. Most gene changes that we know about are of this kind. These would never produce new species. Some gene changes, however, seem to have little or no effect on the organism's ability to survive; a new sunflower plant may have red blossoms instead of yellow like its parents. But some changes make the new organism more fit to meet the conditions of life and therefore to leave offspring with this desirable change. For example, a wheat plant that, because of a mutation, acquires the ability to resist a disease will live and reproduce when its neighbors that cannot resist the disease may die and fail to reproduce. In time resistant wheat plants will establish themselves. The nonresistant ones may not all die out, however. They may never be attacked by the disease or they may have some other highly desirable character which compensates for their weakness. Thus both varieties may continue to live.

Changes may have complex effects; it is not easy to say whether or not a change will in the end help to produce a new type of organism. See EXERCISES 1 and 2.

Charles R. Darwin. De Vries built on the work of Charles R. Darwin (1809–1882), who had done his work almost half a century before. Darwin lived at a time when geologists had just begun to find evidence that the earth and its inhabitants had a long history of change. It had been believed by most scientists of earlier days that the earth had always been inhabited by the kinds of living things they saw about them. Darwin believed so too when he began to work. He changed his mind as his work progressed. As a young man of twenty-two he took a post as naturalist aboard the "Beagle," a British vessel which was to make a trip around the world. For five years Darwin made observations, recorded them, and collected specimens. He studied rock layers and the fossils in them, the formation of coral islands, and the places in which animals and plants lived. He observed, recorded, and collected specimens from the oceans, deserts, and jungles. He noticed many puzzling facts about animals and plants. But gradually he was able to read some meaning into these observations. By the time he returned to England he thought it probable that plants and animals had changed throughout the ages. He thought it likely that new types arose from preceding types.

But Darwin needed more evidence. At the time when Darwin was studying the problem, the great fossil beds had not been exposed. Nothing was known about chromosomes or genes; in fact when Darwin returned from the voyage of the "Beagle," the cell theory was not yet well known. The problem was a difficult one for him to solve; but he continued to search for facts and more facts. For another twenty years he kept on collecting facts that would support or disprove his theory of organic evolution. The longer he studied, the more facts he found to support the theory. As he studied he formulated a theory to explain how new species could be derived from existing species. He called this the *theory of natural selection.* During all this time he made no public mention of his work.

Darwin and Wallace. Before Darwin was ready to publish his views, he received a report from Alfred Russell Wallace who had just finished studying the animals in the East Indies. In this report Wallace presented the very ideas that Darwin had so long been turning over in his mind but had not yet published: first, that the different species of plants and animals arise by evolution; and second, that evolution takes place by the particular method that Darwin considered most probable – by the method of "natural selection."

With characteristic fairness and generosity, Darwin was at first inclined to publish Wallace's report and say nothing about his own conclusions. But friends insisted that, since he had been working on the problem for twenty years, both he and Wallace should present their reports at the same time. Darwin's generosity was matched by the fine spirit of Wallace, who always gave Darwin credit for having been the first to develop the idea of evolution and for having studied the problem more thoroughly. Darwin is considered one of the world's greatest scientists. Why? See Exercise 3.

FIG. 506 *A puffball is related to the mushrooms. It cracks open and discharges its spores. It has been calculated that a large puffball may contain 6,000,000,000 spores.* (CLARKE)

Darwin's theory of natural selection. In the theory of natural selection Darwin tried to explain by what method organisms changed throughout the ages or how new species originated. His theory includes five steps. Let us examine them:

1. *Overproduction.* Most animals and plants produce offspring at so great a rate that if all lived and reproduced there would not be standing room on the earth for the individuals of even one species. If a microscopic one-celled animal like Paramecium divided twice a day for only a few months it would produce a ball of paramecia as big as the earth. The total number of descendants after ten generations of a fish like the cod, which lays about 8,000,000 eggs every year, is staggering. It would fill the oceans from shore to shore with codfish. Darwin stressed the well-known fact that there is overproduction of living things, both plant and animal. See EXERCISE 4.

2. *Struggle for existence.* Since there is not food enough or room enough for all the offspring of plants and animals, some of them must die before growing up. If the number of codfish in the ocean remains about the same it means that only two of the 8,000,000 eggs result in mature codfish and 7,999,998 of that family die before they can reproduce. Darwin pointed out that overproduction leads to a struggle for existence among plants and animals. Under ordinary circumstances, the more offspring produced, the keener is the struggle. This struggle is not necessarily a fight between codfish or between codfish and other animals. For the most part, the struggle for the necessities of life is a quiet, steady struggle that is difficult to observe. It is a struggle that goes on steadily between members of the same species and between different species. All organisms in nature enter into the struggle; on the average, only two of a family survive to take the place of their parents. For one reason or another sometimes more survive; then the species increases in numbers for a while, but the struggle goes on.

3. *Variation.* Which of these many organisms will survive? Darwin answered this question by pointing out that all the members of a species are different in many small ways. You know that this is true; you even know the causes of such variations. They may be

FIG. 507 *Countless thousands of seeds fell in this daisy field. In which ways may these daisies have been better fitted for survival than those that failed to grow? What kind of inheritable variations might survive here? What kind might be eliminated?* (AMERICAN MUSEUM OF NATURAL HISTORY)

caused by the environment or by constant recombinations of genes or by gene and chromosomal changes that are passed on to the next generation. Darwin knew nothing about chromosomes or genes but he did know that no two individuals are exactly alike.

4. *Survival of the fittest.* Since there are always variations among the members of a species, Darwin argued, some organisms will be more fit to meet existing conditions, some less fit. In general, those organisms that are more fit will survive, the others will die. Darwin pointed out that this would hold true particularly when conditions changed or emergencies arose. In general, the survivors tend to be those organisms that are better fitted than others to meet new conditions. This is what Darwin meant by the survival of the fittest. It is clear that the word *fittest* does not mean the strongest. It means the organism that fits into the whole environment best, whatever the environment may be at that particular time.

5. *Inheritance of variations.* This is the last step of Darwin's theory of natural selection. Evidently, the variation which happens to make one organism more fit than its competitors must be passed on to its offspring if a new species is to arise. The horse could not have evolved from Eohippus through natural selection unless there were *inheritance of variations.* Natural selection can account for the origin of new species only if the variation that made an individual more fit was one that could be passed on to the offspring.

Darwin lived before there was much scientific understanding of heredity. He was therefore unable to explain clearly why some variations are inherited and others not. He was aware of the weaknesses in his own theory and stated them frankly so that others might look for a more complete explanation.

FIG. 508 *The okapi (close relative of the giraffe) feeds from the lower branches of trees in the forest. Note its short neck.* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 509 *The giraffe eats leaves from higher branches of trees. How might De Vries have explained the origin of the giraffe's long neck?* (AMERICAN MUSEUM OF NATURAL HISTORY)

Darwin's theory summed up. According to Darwin's theory: Animals and plants normally produce more offspring than there is room for. Since there is overproduction, there is naturally a struggle for existence. In this struggle the fittest survive. There will always be some organisms that are more fit than the others because no two organisms are alike; in other words there is variation. In this way organisms are "naturally" selected for survival. That is why Darwin called his theory the theory of natural selection. If, however, the theory is to explain how new species arise, one must assume that these variations are inherited. To review what you have read do EXERCISE 5.

De Vries modified Darwin's theory. When De Vries found that certain variations (mutations) can be inherited, he fitted this idea into Darwin's earlier theory. According to the De Vries theory, there is a struggle for existence because most organisms tend to reproduce in enormous numbers. When a mutation occurs which makes the organism more fit than others of its species, this mutant will be more likely to survive. Since the mutation can be inherited, the desirable change will continue. Thus, after long periods of time, new species become established. To test your understanding, do EXERCISE 6.

As modified by De Vries, the theory of natural selection is acceptable to most biologists. There are still many unsolved questions about many of the details of natural selection and even about the importance of the various factors that Darwin listed. Most biologists today believe that species originate by natural selection of individuals that vary in hereditary characteristics.

Lamarck had a theory which is not generally accepted. The Chevalier de Lamarck in 1809, long before Darwin's time, offered one explanation for the origin of species. Lamarck suggested that an organ changes according to the amount it is used and that this change could be inherited. He made much of the terms "use and disuse." This is the name given to his theory. It is true that a muscle, for example, becomes larger through use and smaller through disuse. Lamarck believed that this character of larger or smaller muscle resulting from use or disuse could be inherited.

We now know that such acquired characters are not inherited. But Lamarck, who lived long before Weismann, did not know that acquired characters are not inherited. He believed that if the changes were small and if they continued over long periods of time, the small changes would accumulate and thus a new species would appear. If Weismann was correct in stating that acquired characters cannot be inherited, Lamarck's theory cannot be accepted as an explanation of new species. While biologists are still performing experiments to determine whether an acquired character can ever be inherited under any circumstances, most biologists believe that there is little or no evidence for it. Lacking the proof that acquired characters can be inherited, Lamarck's theory is not satisfactory. Do you understand his theory? See EXERCISE 7.

Protective resemblances and adaptations. Many plants and animals are astonishingly fitted, or adapted, to their environment. Because of their structure, their coloring, or their behavior, some animals resemble their environment so closely that it is difficult to see them. This is called *protective resemblance,*

FIG. 510 *Spruce grouse on the ground. Of what advantage are the mottled brown markings on the feathers?* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 511 *Find the geometrid moth caterpillar in the photo. It is the color of a twig. It holds itself at this angle all day. It moves and feeds at night. How can we explain such behavior?* (AMERICAN MUSEUM OF NATURAL HISTORY)

FIG. 512 *This insect is called the walking stick. Why? Can you see how its structure helps it to hide from its enemies?* (SCHNEIDER AND SCHWARTZ)

which is one form of *protective adaptation.* Figures 511 and 512 illustrate striking examples of protective resemblance in insects. Figure **510** is an example of protective resemblance in vertebrates. Other animals have special structures which fit them to their environment in different ways. The ichneumon fly can place its eggs in the body of a caterpillar buried an inch deep in wood because it has a long and very strong ovipositor or egg-laying organ. Moles have large, strong front legs and feet that enable them to burrow rapidly through the soil. You can think of many other examples.

Many plants, likewise, have adaptations useful to them. Cactus plants living in the desert have a thick epidermis and a thick cuticle that help prevent loss of water. Mistletoe has a rootlike structure that grows through the bark of trees enabling it to get water and minerals. The grape and many other vines (Figure 280, page 302) have tendrils which hold the stems upright. Some plants, such as most lichens (Figure 326, page 375) remain alive even though they may become so dry they can be crushed to a powder.

These adaptations can be reasonably explained by assuming that they are the result of mutations which made the mutants especially well fitted to get along in their environment.

Evolution and how it might occur. The theory of evolution is a complex idea. It states that all living things are related to one another because they all came from the same common ancestors far back in geologic time. It states that new species arose from preceding species of plants and animals that were simpler, that this has been happening since plants and animals first existed on this earth, and that it is still going on. This statement of the theory of organic evolution is commonly accepted by biologists.

But all biologists do not agree on a theory that can explain *how* this happened. Most biologists today accept De Vries's theory or modifications of it. This is really Darwin's theory with the idea of mutations and chromosomal changes substituted for the general idea of variations. If you use the five steps of Darwin's theory of natural selection, substituting mutations (germinal changes) for the step "variation," you will have a clear statement of De Vries's theory of the origin of species by mutation.

Questions

1. What is one important question that still remains to be answered in regard to evolution? What was De Vries's contribution to this answer? Define mutation.
2. How do gene (or chromosome) changes differ in their effect on an organism? Give two examples.
3. Tell a few important facts about Charles Darwin's life. How did Darwin arrive at the conclusion that evolution had occurred? What important body of knowledge had not yet been discovered in Darwin's day? What did Darwin call his theory to explain how species originate?
4. Who developed a theory of evolution at the same time Darwin did?
5. Name the five steps in Darwin's theory of natural selection. Describe or explain each step. What is one of the weaknesses in his theory?
6. State Darwin's theory of evolution briefly without numbering the steps.
7. Tell how De Vries modified Darwin's explanation of the origin of new species. Which of the steps of Darwin's theory did De Vries accept?
8. What is the name of Lamarck's theory? Describe the two parts of his theory. Why do most biologists nowadays reject it?
9. Describe two or more examples of protective adaptation. How does De Vries's theory explain the presence of such adaptations?
10. Sum up the idea of evolution and the best theory we have at the present time for explaining *how* new species originate.

Exercises

1. List certain types of changes in the corn plant and the deer (or other organism) that might weaken them.

2. What kinds of changes in corn plants and deer might make it easier for them to meet the competition of other organisms?

3. Would you say that Darwin is known as one of the world's great scientists because of his results, because of his methods, or both? Explain fully by stating his results and describing his methods and his traits of character.

4. Prepare a list of your own observations of overproduction of organisms. Compare it with the lists prepared by your classmates.

5. Name in order the steps of Darwin's theory of natural selection, and explain each.

6. Keeping in mind the five steps of Darwin's theory of natural selection state how De Vries would have explained the origin of the modern species of horse from the Eohippus. Remember that this change is believed to have occurred in very many different steps.

7. Look back to Figure 509. How would Lamarck have explained the origin of the giraffe species from an ancestor like the okapi? *Hint:* Assume there was a shortage of food in the part of the world where the okapi lived. Which part of your explanation sounds reasonable? Which part are you unable to accept?

Further Activities in Biology

1. Prepare a short talk on Lamarck. Deliver it to the class. Consult D. C. Peattie's *Green Laurels.*

2. The story of Darwin's life is fascinating because he never lost his courage in the face of a lifelong illness. Prepare a report on the way he worked. You will find the *Life and Letters of Charles Darwin,* by his son, interesting.

3. If you keep Drosophila in your school laboratory or at home you can test the theory of the inheritance of acquired characters. Keep Drosophila in darkness to find out whether they will still respond to light. What will be your control?

4. You can see the results of evolution in the many species of such genera as *Viola* (the violets), *Aster, Solidago* (the goldenrods), and *Ranunculus* (the buttercups). If you live where there are fields and woods collect specimens of these groups and arrange them to show similarities and differences.

PROBLEM 5 *What Were the Stages of Man's Development on the Earth?*

Man is one of many animals. Men fit into Linnaeus' scheme of classification as do all other animals. They fit into one small order within the class of mammals, the *Primates* (prime-ay'tees). This includes the animals with the most highly developed brains: the monkeys, the great apes, and man. The order has several families; one is the family *Hominidae* (Home-in'-i-dee). This family has only one genus, *Homo*, which is the Latin word for man. The genus has only one living species, *Homo sapiens*.

During earlier periods in the world's history there lived organisms closely enough related to Homo sapiens for us to classify them within the genus Homo. There were other forms too different to place in the genus Homo but that fit into the same family. All of these forms are extinct (have died out). You will read about some of them in this problem. The only species in the whole family that has survived is Homo sapiens, man as you and I know him. All men, whether white, black, or yellow belong to this species. On the surface, men may look very different; actually they are so much alike in internal as well as external structure that they are classified as members of one species.

How we learn man's early history. How can we learn about prehistoric men—the men who lived before written records were kept? It is through fossils, of course. Unfortunately, relatively few fossils of early men have been found. Petrifaction occurs only under special conditions, and the chances of preservation are always small. Unless organisms lived in large numbers their fossil remains must be few and far between. However, enough teeth, bones of the jaw and the top of the skull, leg bones, and some others have been found to give us an idea of how prehistoric men of various geological ages must have looked. We know how tall they were, how they must have held themselves and walked, how large the brain must have been, and in a general way what type of features they must have had. The trained anatomist needs only small portions of a skull to tell him such things as whether the head was held forward or erect, how large the brain case was, and which parts of the brain were well developed.

How else can we learn about early man? Sometimes we can learn much about prehistoric men from the tools and other articles they left behind them. All such tools and implements are called *artifacts*. Sometimes the fossil bones of ancient men are discovered in a cave where bones and artifacts have been kept together. Because of this we can get a fairly complete picture of how these men must have lived. There may be

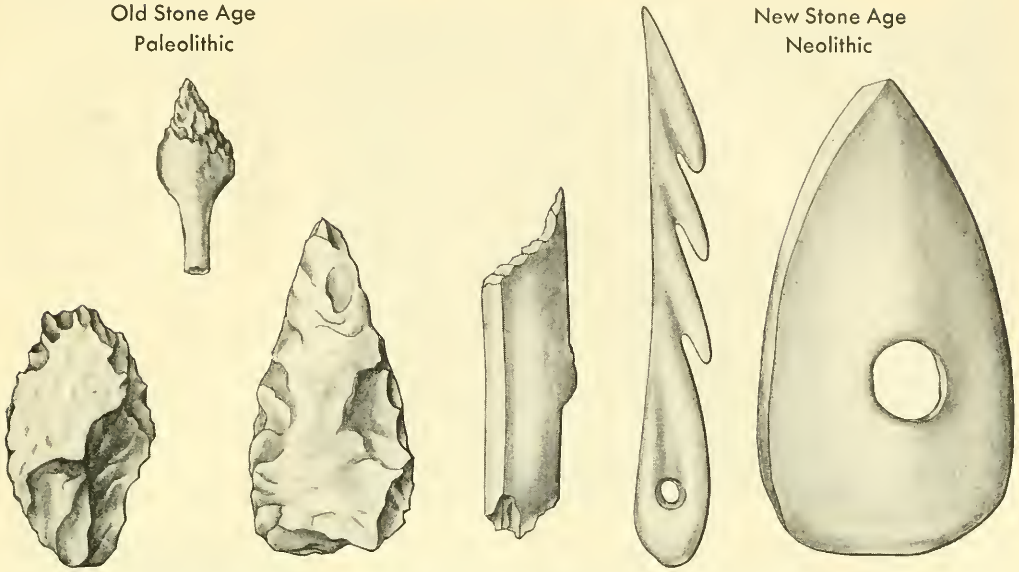


FIG. 513 *Compare these Old Stone Age and New Stone Age artifacts.*

bones of other animals in the cave, indicating what probably was used as food. If charcoal or charred bones are present we may assume that these men knew the use of fire. All this gives us an idea of their *culture*. By the word culture, applied to a group of men, we mean how they live, what they do, and what they think. Studying the cultures of early men is as interesting and as important as the study of their bones. Do EXERCISE 1.

The date of man's beginnings. You learned earlier that the age of fossils can be roughly calculated from the kinds of rock deposits in which they are found. The presence of other fossils that have already been given a date helps, too. But setting the time of the appearance of manlike forms on the earth presents difficulties. For one thing the fossils of these early forms are sometimes found in sand or gravel, not in rock. For this and other reasons experts have not agreed on the exact date. Most believe that manlike animals appeared at least a million years ago; some think it was somewhat earlier or later, perhaps two million, perhaps half a million years ago. In this book we shall assume that manlike forms appeared about a million years ago. But Homo sapiens appeared much more recently. It is usually believed that the first sure fossils of Homo sapiens, our own species, date from about 25,000 years ago.

Twenty-five thousand years seems a long time, but considering the age of the earth it is a very short time. To help you realize this and to help you keep track of man through the ages, suppose we let the twelve hours of the clock represent a million years. By studying Figure 514 you can see that, if the first manlike organisms appear at 12 o'clock noon, the hour hand must move well on toward midnight before we can show the appearance of Homo sapiens. On this clock his appearance would be shown at 11.42, at eighteen minutes before midnight. And our written history, which seems so long and full in the history books, is all crowded into the last three to four minutes. As you read of other fossil types examine Figure 514 again to see at what time on this clock they made their appearance.

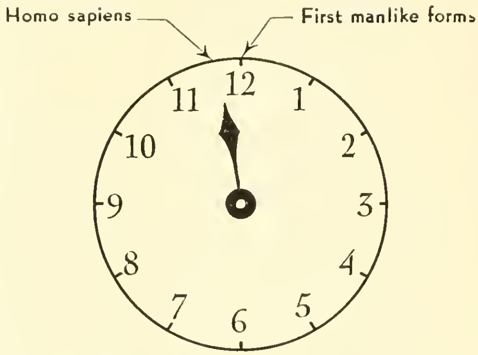


FIG. 514 *If the first manlike forms appeared at 12 noon on the clock, 1,000,000 years ago, when did Homo sapiens arrive?*

A glance at early forms. Fossils show that a manlike form referred to as the Java ape man lived between half a million and a million years ago in Java, at a time when the island was still connected with Asia. His name, *Pithecanthropus* (pith-e-can-throw′pus) *erectus*, indicates that these men are not classified in the genus Homo. They stood about five and a half feet high; we believe that they walked erect. The skull shows that the brain was small but was much larger than that of any ape. The first skull bones that were found caused much discussion. A few experts even doubted that the bones were the remains of a manlike creature. But, since the discovery of four more similar skulls, there is no longer any doubt about the existence of Java ape men. No tools of any kind were found with the bones so that we can only guess at the culture of these men. Figure 515 shows you the flattened forehead and the large ridge over the eyes. It is believed that he had no chin and had large heavy jaws.

Another early man has been named Peking man, *Sinanthropus* (sin-an-throw′pus) *pekinensis*. Many remains, including bones from at least forty individuals, have been taken out of caves near Peiping (Peking), China. Study of the bones indicates that Peking men walked erect and were similar in many ways to Java men; but they had a somewhat larger brain. We date Peking men at about half a million years ago. On our clock it would show as six o'clock. It is probable that Peking and Java men were related, but there is no reason to believe that Peking men were direct descendants of Java men.

The culture of Peking men was surprisingly advanced. Associated with the bones that have been found deep in the floors of the caves are heavy stone tools and smaller scraping tools which are crude but which are undoubtedly tools of a sort. There is some evidence that Peking men knew the use of fire. They seem to have been right-handed, and judging from the development of that lobe of the brain which is used in speech it is believed that probably they were able to talk.

(Optional) Fossils that are difficult to place. We have evidence of other prehistoric men about whom little is known and whose age cannot be stated with any degree of certainty. There must be more study of unearthed bones before we can be sure of the facts. But scientists

Fig. 515 (right) *Prof. J. H. McGregor has painstakingly modeled these heads of Java and the more recent Neandertal man, using the few bones that are available. How did these ancient men differ in structure?* (AMERICAN MUSEUM OF NATURAL HISTORY)

Fig. 516 (above) *Skull of Peking man. Note the heavy eye ridges and lack of chin.* (ROCKEFELLER FOUNDATION)

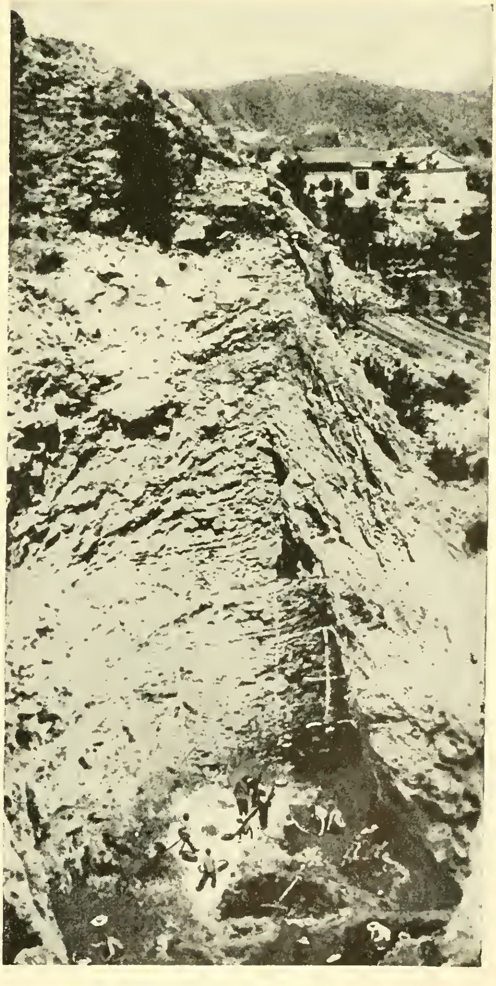


Fig. 517 (right) *Excavating for Peking man near Peiping (Peking), China. Why are the squares drawn on the side?* (ROCKEFELLER FOUNDATION) do speak of a *Rhodesian* man (*Homo rhodesiensis*), known from a well-preserved skull found in South Africa. This skull is interesting because it shows that this man suffered from decayed teeth. Some parts of the skull seem to indicate that he was primitive; other parts are so much like modern skulls that he is classified in the genus Homo. We cannot date him.

One unusual fossil uncovered near Heidelberg in Germany is known as Heidelberg man (*Homo heidelbergensis*). A single jaw bone is all that has been found, and no tools of any kind. But this jaw bone tells the expert a good deal. It is a thick, massive jaw like those of primitive forms with sixteen solidly rooted teeth. These resemble our teeth closely; they are without doubt human teeth. Judging from the animal fossils found in the same deposits, Heidelberg man may have lived as much as three quarters of a million years ago (at three o'clock). But so modern are the teeth that he is placed in the genus Homo, though not in the species Homo sapiens. Thus we find a form belonging to the genus Homo living, it seems, about three quarters of a million years ago, long before the Java ape men and Peking men.

Neandertal men. Much later than the primitive Java ape men and Peking men came Neandertal (nee-an′der-tall) men (*Homo neanderthalensis*). The earliest of these men appeared about 150,000 years ago (roughly at about nine o'clock on the face of the clock shown in Figure 518. These men are well known to scientists, for more than one hundred skulls or other bones have been found. Even complete skeletons have been discovered.

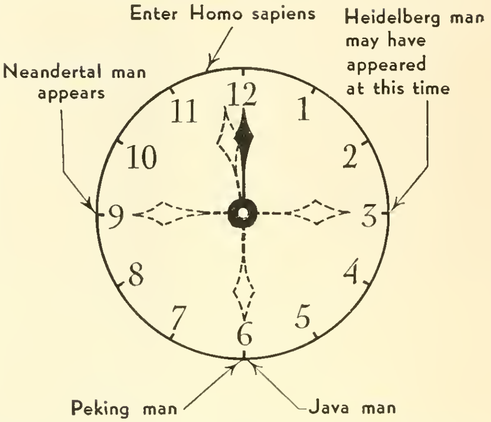


FIG. 518 *If the first manlike forms appeared at 12 noon on the clock, 1,000,000 years ago, what happened at 3, at 6, at 9, and at nearly midnight? Only the hour hand is shown.*

Neandertal men were widely spread through Europe and western Asia. Bones have been found in Germany, Belgium, Yugoslavia, France, Gibraltar, and Palestine. These men rarely reached a height of more than five and a half feet and they had broad frames with large muscles, big heads, and short arms and legs. Their knees were bent a little so that it is believed they must have walked with a shuffling gait; and they evidently stooped at the shoulders. Their low foreheads, projecting eye ridges, heavy jaws, and prominent noses separating deep sunk eyes must have given them a very different appearance from that of Homo sapiens. Their brains were large in proportion to their size, somewhat larger than our brains. But the small front portion makes us think they were less intelligent than modern men. Yet there is evidence that Neandertal men were far superior in intelligence to Peking men and the Java ape men. They seem to have met the conditions of their environment successfully for long ages.

FIG. 519 *Some scientists believe that toward the end of Neandertal man's development he used spears tipped with flint. He was perhaps not so well formed or equipped as this artist has shown him. How long ago did Neandertal man live?* (LOGAN MUSEUM, BELOIT COLLEGE)

The culture of Neandertal men represents a great advance over the cultures of preceding primitive men. They not only used fire but they probably had learned to make fire. They were able to fashion a fair variety of flint tools. When they chipped flint they used the flakes, making them into real tools that could be used for cutting, drilling, boring, and scraping. Judging from the tools they possessed, we believe that they wore skins as protection against the cold. When you have studied Figure 519, turn to EXERCISE 2.

The location of the fossils shows that there were times when Neandertal men roamed about and other times when they lived in caves. It is believed that they took to the caves when the most recent ice age began. In these caves burial places have been found. This is probably a remarkable advance over previous prehistoric men; it indicates that the Neandertals must have had some special beliefs or thoughts about death.

Neandertal men of various types must have lived on the earth for a long period of time, during the third warm interglacial period and well into the fourth or last ice age. For 75,000 or 100,000 years they inhabited Europe and Western Asia. Then about 25,000 years ago they seem to have disappeared. It is not known whether they became extinct at this time or whether they were at least partly absorbed by Homo sapiens, who appeared in Europe then.

Homo sapiens appears on the scene. You know that Homo sapiens populates the earth today; all living men belong to this one species. They have lived on the earth for at least 25,000 years. We don't know where they came from, although many experts think they first appeared in Asia. We believe that over a period of thousands of years they gradually replaced Neandertal men. You will read why this might well have happened.

FIG. 520 *Using available facts, an artist made this painting of Cro-Magnon life in a cave. One man is sculpturing on a wall.* (LOGAN MUSEUM, BELOIT COLLEGE)

The skull of Homo sapiens differs from that of all other species in having much thinner walls and a much more rounded or vaulted form. The face is far more delicate and the large eye ridges of more primitive men are absent. The first skeletons of prehistoric Homo sapiens were found many years ago in Europe. Since then the number of discoveries has increased year by year. Fossils of Homo sapiens have been found in China, too.

One type of Homo sapiens living in southern France and Spain some 25,000 years ago was Cro-Magnon man. Because of the size of Cro-Magnon men, their well-proportioned bodies and regular features with large eyes, many of us would like to claim them as our ancestors. Since their bones were among the first remains of Homo sapiens to be found, Cro-Magnon men attracted much attention, and they have been much written about. But they were just one of many types of the early Homo sapiens.

How Homo sapiens lived 25,000 years ago. From the large number of artifacts found in the caves inhabited by men of our species during the last glacial period, we have a rather complete picture of their culture. It shows a great advance over that of Neandertal men. As the glaciers once more began to recede and summers became warm these modern men lived in the open, hunting and exploring. During the winter they retired to their caves. Existing animals were the woolly rhinoceros and mammoth left over from the age of Neandertal men. Gradually horses, bison, and deerlike animals appeared. There is no evidence that the horse was domesticated but it probably served as food. In one spot alone the remains of 100,000 horses and 35,000 flint implements were found. There is reason to believe that these men sometimes used lamps in the caves. It is possible that, besides roasting meat over an open fire, they had learned to cook their meat by dropping heated stones into water. Instead of using pots they

FIG. 521 *Drawing found in a cave in Spain. What does this show about the culture of Cro-Magnon men?* (AMERICAN MUSEUM OF NATURAL HISTORY)

may have hollowed the earth and lined this depression with skins. Like the earlier species these men knew how to make weapons and tools of chipped flint but they made use of new materials, too, bone and ivory. Thus Homo sapiens, twenty thousand years ago, could fashion darts and pointed instruments like awls and large sewing needles. Skins were sewed and substantial clothing worn. These early men were expert hunters and fishermen, so that food must have been more plentiful in spite of the arctic conditions against which they were sometimes obliged to struggle. The large supply of food led to more leisure. There was time for luxuries as well as for the necessities of life. Bone and ivory were shaped into beads and personal adornments of various sorts. Cro-Magnon men developed the art of painting and sculpture to a very high degree. Many of the objects they used and the inner portions of their caves were often decorated, perhaps not so much to satisfy an artistic sense as belief in magic.

That Homo sapiens of about 25,000 years ago had some sort of social organization is shown by recent discoveries in Moravia in the Balkan peninsula. The site of an ancient village was uncovered. Here were living quarters with fireplaces in front of what must once have been houses of some sort, a large workshop where the men could gather to fashion tools, and huge refuse pits containing bones of mammoths, horses, and reindeer. Countless artifacts were unearthed, including household utensils such as spoons and two-pronged forks.

The Old Stone Age. Let us briefly examine the history of civilization as we know it. The first period in this long history was the Old Stone Age (Paleolithic – pay-lee-oh-lith'ic). It lasted a long time, roughly almost a million years, ending about 10,000 years ago. It includes cultures as different as those of the Java ape men or Peking men and those of Neandertal men or even of the early Homo sapiens. Throughout this long period men were dependent on

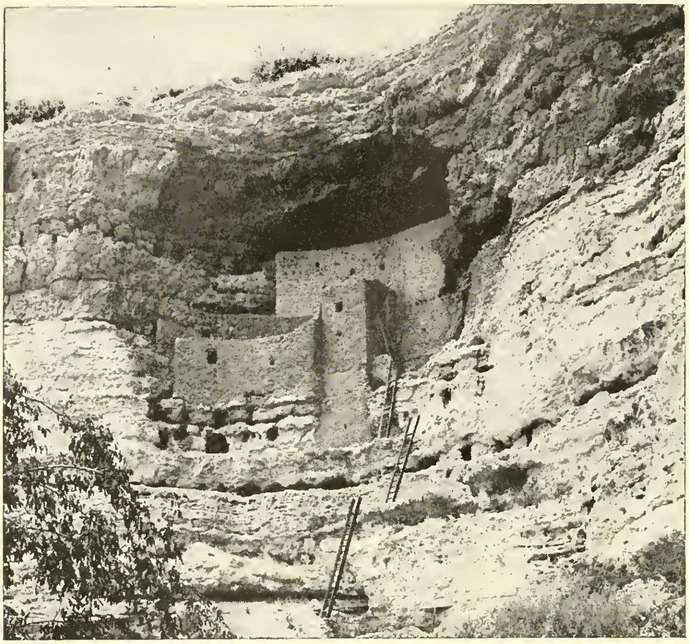


FIG. 522 *The remains of ancient cliff dwellings in southwestern United States. The men who lived here were extraordinary builders.* (GRANT — U. S. DEPARTMENT OF INTERIOR)

more or less roughly chipped flint for all their implements. There was a slow but very marked advance in culture during the Old Stone Age. Gradually men learned to provide for their food and no longer lived from hand to mouth. They learned to depend on their fellow men; community life began. They had religion of some sort; they must have believed in an after life, for they buried their dead surrounded by objects that were used by the living. They learned to sew skins for clothes, and they adorned themselves and decorated their caves. Their life at the end of the Old Stone Age was not unlike that of some of the living Australian primitive men. While they grew to be very skillful in the chipping of stone and thus made a wide variety of tools, it was only the small flakes of stone that were really sharp. You will find EXERCISE 3 interesting. Can you answer the questions?

The New Stone Age. There came a time when men learned how to grind and polish stone. This was the beginning of the New Stone Age (Neolithic — nee-oh-lith′ic). It began after the end of the last glacial period when the climate had become like that of today. At this time Homo sapiens was fairly well spread over the earth. Men could do much with polished stone and progress was made along many lines. To begin with they could make axes for chopping trees. Simple wooden shelters were constructed; rafts were built; soon the dugout, a form of canoe, was made; then came larger boats. Men could travel over large bodies of water. They came in contact with other peoples. Plants of many kinds seem to have been imported into Europe and Asia. Besides weapons, hoes of polished stone are often found. Agriculture existed on a small scale. Useful animals were tamed: the dog was first; then cattle, sheep, pigs, and donkeys were domesticated; horses were tamed later on. Men settled together in groups and undoubtedly had some sort of social organization.

Even before they planted crops, they learned to make pottery and to weave baskets. The remains of villages show that these early men not only buried their dead with much ceremony but engaged in worship of some kind. It is believed that some of them worshiped the sun, for stones are found in lines leading in the direction of the rising sun.

The Bronze and the Iron Age. The stone ages lasted until six thousand years ago. At this time men learned how to smelt copper from its ores; that is, they heated copper-bearing rocks until they obtained copper. They melted copper and cast it into tools and other articles. At about the same time they learned how to obtain tin. About 5000 years ago they learned how to combine copper and tin to make bronze, a much harder metal than either of the other two. Thus the Bronze Age is associated with the beginnings of a new and much more advanced culture. For one thing the search for copper and tin led to far more extensive travel. Goods and ideas were exchanged to a much greater extent than before. Civilization spread rapidly and advanced more quickly.

About 3500 years ago men began to enter into the Iron Age. This metal is better than bronze because it is even harder. At the time when the smelting of iron was discovered the period of written history begins, though monuments with inscriptions date farther back. At this point we end our story of the slow development of men and their cultures.

Did you notice that the first, or Old Stone Age, lasted for many hundreds of thousands of years until after Homo sapiens was well established and spread over the earth? The first discoveries were slow in coming. Each of the others came in more and more rapid succession. Does that mean that modern men are more intelligent than Neandertal men or the early men of the species Homo sapiens, or the men who gave us the cultures of early Egypt, Greece, and Rome? There is no reason for believing this. Each discovery opens up new possibilities for discoveries. They pile up so fast that in another few thousand years the Atomic Age may have been left so far behind that in an account of man's civilization it, too, may be dismissed in a few sentences.

What is a "race"? Race is a word we hear frequently and we think we know its meaning until we are asked to define it. A race is a subdivision of the species Homo sapiens whose members tend to have certain inborn physical characters in common. But you can see that as soon as members of two different races intermarry new combinations of physical traits arise. Naturally, in thousands of years this happened frequently. For this reason races are not sharply distinguished one from another. There are many in-between individuals who are placed in one race or another according to whether a majority of their characters are of one kind or another.

Man's classification of man. A race is not the largest or first subdivision of the species Homo sapiens. We divide man first into several large groups or *stocks*. Then the stocks are subdivided into races. Scientists do not all use exactly the same classification; we shall give you one that is frequently accepted. According to this classification practically all men fall into one of three large stocks: the white or *Caucasoid* (caw′kass-oyd) stock; the black or *Negroid;* and the yellow or *Mongoloid* stock. If you examine the table, Racial Classification of Man, you will see into which races each stock is further subdivided. This table lists not only the races but it shows, too, some of the characteristics which are considered in classifying into races. Among these are such physical traits as size, shape of head, texture of hair, and shape of nose. Now examine Figure 523. It shows you the three main stocks one above the other and shows typical representatives of three races within each stock. In these pictures the scientist has purposely chosen as a representative of the Nordic race a man who shows most strikingly all the Nordic characteristics, a man who is tall and broad with blond hair and blue eyes and who has many of the other traits characteristic of a Nordic. You must not get the idea from this that all those belonging to the Nordic race are equally tall and blond with blue eyes. He was purposely chosen to emphasize how the typical Nordic differs from the others of the white stock. Remember that to be classified as a Nordic a man need not have all the characters of a Nordic but only a majority of them. Nordics vary all the way from tall or blond to a much shorter stature or a much darker color; some may be smaller and darker than some Alpines but in the

RACIAL CLASSIFICATION OF MAN*

STOCKS AND RACES†	TEXTURE OF HAIR ON HEAD	HEAD	STATURE
Caucasoid ("White")			
Nordic	Wavy	Narrow	Tall
Alpine	Wavy	Broad	Above average
Mediterranean	Wavy	Narrow	Medium
Hindu	Wavy	Narrow	Above average
Mongoloid ("Yellow")			
Mongolian	Straight	Broad	Below average
Malaysian	Straight	Broad	Below average
American Indian	Straight	Variable	Tall to medium
Negroid ("Black")			
Negro	Woolly	Narrow	Tall
Melanesian	Woolly	Narrow	Medium
Pygmy Black	Woolly	Broadish	Very short
Bushman	Peppercorn	Narrow	Very short
Of Doubtful Classification			
Polynesian	Wavy	Variable	Tall
Australoid	Wavy	Narrow	Medium

* A few minor races of doubtful classification have been omitted.

† Adapted from Kroeber's *Anthropology*, Harcourt, Brace and Company (1948).

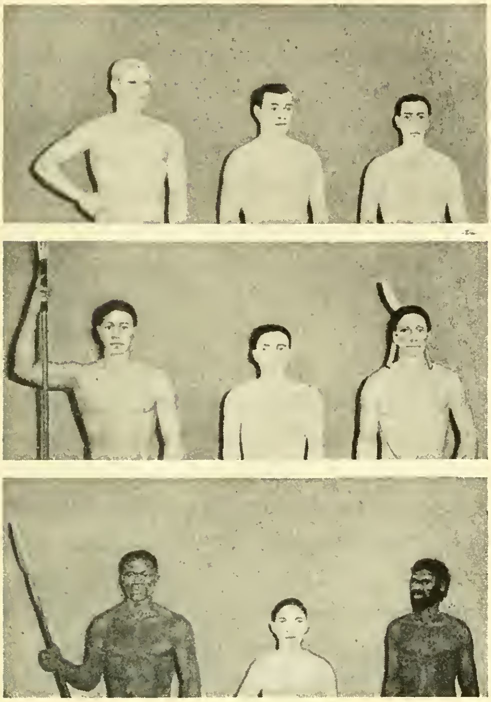


FIG. 523 *By making use of thousands of measurements, Dr. H. L. Shapiro has been able to construct figures illustrating some of the races of the three great stocks of mankind. At the top is the Caucasoid stock with three of its races: the Nordic, Alpine, and Mediterranean. The Mongoloid stock is next, showing the Polynesian, Mongolian, and American Indian. At the bottom is the Negroid stock: the African Forest Negro, the Bushman (Black), and the Australian. Note that this anthropologist makes slightly different subdivisions of the Mongoloid and Negroid stocks from those given in the preceding table.* (SHAPIRO — AMERICAN MUSEUM OF NATURAL HISTORY)

majority of their characters they are distinctly Nordic. All this applies to every other race. At this point the class should work together to do EXERCISE 4.

Is there a difference in the blood? There are four different types of blood, and in giving transfusions the physician must determine the blood type of the donor and of the patient who is to receive the blood. The different types of blood must be kept separate by hospitals. Now some people have hastily jumped to the conclusion that the blood of the different races must be of different type. But it has been shown that the same four blood types occur among the members of all the races. For this reason it is not necessary to keep separate the blood of different races for use in transfusion.

Wrong uses of the word race. Man is subdivided into stocks and races merely as a matter of convenience to *anthropologists* (an-throw-pol'oh-jists), those who study man. But the word race has been picked up by many people who use it in common speech in a variety of ways. Some people speak of the "white race" when they should speak of the white or Caucasoid stock. You may have heard people speaking, too, of a Jewish or an Aryan or an Italian race. When they speak of an Italian race they are confusing a race with a nation. People who live within certain boundaries and pay taxes in Italy are Italians. They may have white or black skins and straight or wavy hair, yet they belong to the Italian nation. Italy contains members of all three Caucasoid races, not to mention people of other stocks. The same is true of all other European countries. Even Scandinavian countries, which are often thought of as Nordic, have many inhabitants who belong definitely to the Alpine or Mediterranean races. The most that can be said is that the proportion of Nordics in Scandinavia is larger than in other countries.

When people speak of a "Jewish race" they are making a different type of error; they are confusing religious or cultural groups with races. Religion has nothing to do with the physical traits of man. It is true that most people who follow Buddha, for example, have yellow skins; they are Mongoloids. But people of the Nordic race have been known to become Buddhist; changing religion does not cause a change in physical traits. In the same way when we speak of Jewish people we are not talking about race.

And there is no "Aryan race." To the student of languages, Aryan refers to the group of languages to which, among others, the German and English languages belong. All German- and English-speaking people, therefore, are Aryans. They may have the physical traits of Nordics or Negroes. If English is their native tongue, they are Aryans. They may profess the faith of a Christian or of a Jew or of a Mohammedan, but if they belong to a group that speaks English or German they are Aryans.

How race prejudices arise. Most of us like to associate with people like ourselves. We feel more at ease with those who not only speak our language, but who have the same customs and religion and who share our political beliefs. Since we feel more comfortable with people of our own kind we may begin to look with suspicion at those who differ from us. The less we have in common with them, the less close do we feel to them. It is then that we begin to draw comparisons between them and ourselves. Now in making comparisons we unconsciously attach importance to the points in which we feel ourselves to be superior; we think less about the traits in which we feel inferior, and we tend to forget these as we compare ourselves with other persons. So, in our comparisons, the other persons or the other groups usually do not show up well. Thus, gradually, from the feeling that we are different we slide into a feeling of superiority. In the meantime, our friends or associates have also, many of them, arrived at the same feeling of superiority. We bolster each other up and gradually the feeling becomes stronger and stronger in all of us. In this way many of us feel first a difference, then a certain superiority, and soon a distrust, even a dislike. When these feelings have grown to be a part of us we do not stop to check them with the facts. In most of us, unfortunately, "feeling" and "knowing" amount to the same thing. The stronger our feelings, the surer we are of what we think we know. This feeling of superiority, unsupported and unreasoned, is what we call "prejudice."

What are the facts? Is any one stock superior to another or, worded differently, is one stock less primitive in its physical traits and further removed from our early ancestors? Let us assume that you and I are Caucasoids. Can we show that our Caucasoid stock is less primitive? Anthropologists say we cannot. In hairiness of body and face — a trait characteristic of lower mammals — the Negroid and Mongoloid stocks are far more advanced than the Caucasoids. The Caucasoids are the most primitive. On the other hand, protruding jaws and low forehead can also be considered primitive since these were the characteristics of prehistoric man. In this respect the Caucasoid is most advanced.

Now when we consider round-headedness, which the anthropologist says is less primitive than long-headedness, which of the stocks is most advanced? The answer is none, for each stock includes one race which has the round head form. And so it goes for all the other characteristics. At present, studies seem to indicate no superiority in bodily form of one stock over another.

Perhaps you think some races are superior to others in intelligence. Again anthropologists who have tried to discover facts are not ready to agree. We may be sure that we differ from the other races and stocks in mental traits as well as in physical traits. It is easy to note differences; but it is difficult to prove superiority. It is impossible to measure and compare intelligence in people of different cultures. This should not surprise you for you know that "intelligence," as we loosely use the word, depends on the combination of two factors: the genes and the environment. We have no evidence that people of certain races are born mentally superior. There is much evidence that they differ because of their cultures. Let us be careful not to draw comparisons when we know there are no facts on which to base our opinions or statements.

Man is still in the making. We have read that man has been in the making for at least 1,000,000 years. Modern man, Homo sapiens, has left his bones on the earth only a tiny fraction of this time, about 25,000 years. All other species have become extinct. Just as man has been long in the making, the culture of modern man has been long in the making. The Old Stone Age lasted until some time after the arrival of Homo sapiens. It was followed by a much shorter New Stone Age, and that was followed in rapid succession by the Bronze Age and the Iron Age.

Modern men, though belonging to one species, have differences. For convenience they are divided into three main stocks (Caucasoid, Negroid, and Mongoloid) and the stocks are further divided into races, according to certain physical traits. The members of these different races may intermarry and thus the sharp line between races tends to break down. This has gone on for thousands of years and is still going on. Will there be more merging of different races? Can we expect changes to occur in man? As there have been changes in all living things in the past history of the earth, we may expect that changes will continue to occur. Cultures, too, have changed throughout the period of man's existence on the earth. Therefore we may expect cultures to merge and change even more rapidly now than in the past. Man's physical form and man's culture are still in the making.

Questions

1. Give the classification of man starting with class and ending with species. How many species of man are now in existence?
2. Give two reasons why relatively few fossils of man have been found.
3. Define the words "artifact" and "culture." Explain how we can learn about prehistoric man in ways other than studying fossils.

4. About how long ago did manlike forms appear on the earth? About how many years has Homo sapiens been on the earth?
5. Where have fossils of two early manlike forms been found? Tell about each — how he was supposed to have looked and how he lived. Explain how scientists arrive at these conclusions.
6. State one interesting fact about Rhodesian man.
7. How long ago is Neandertal man believed to have lived? Compare his appearance with that of modern man. Describe his culture. Which parts of the earth did he inhabit?
8. In what ways did the early Homo sapiens differ in structure from Neandertal men? Where have fossils of these men been found?
9. Describe the life of early Homo sapiens.
10. Describe life in the latter part of the Old Stone Age? What type of men were living then?
11. Which discovery led to the culture described as the New Stone Age? Explain what advances in civilization came as a result of this discovery.
12. What are the approximate dates and the names of the cultural periods which followed the New Stone Age? Explain the rapid advances in civilization during these ages.
13. Define race. Explain why sharp lines cannot be drawn between races.
14. Name and describe the three main stocks into which Homo sapiens is often divided. Name the important races into which each stock is subdivided. What physical characters are made the basis for this division? Explain how and why the members of one race may differ among themselves.
15. What are the facts in regard to the blood of the various races?
16. Explain and give an example of how some people confuse race and nation; race and religious or cultural group; race and language group.
17. Granting that we feel more at ease with people who share our language and customs, show how prejudices against other groups or races may arise.
18. Give facts to show that when all traits are considered together no one stock is less primitive or more advanced than any other. How do races compare in intelligence according to anthropologists? How has your study of genetics prepared you for accepting this opinion?
19. Summarize briefly what you have read in this problem in regard to: (*a*) Different types of prehistoric men with approximate dates. (*b*) Different cultures. (*c*) The classification of man into stocks and races. Do you believe that man is still in the making? Explain.

Exercises

1. If modern man had no written records what could you learn about his culture from the objects he makes and uses? Discuss this with your classmates. Be specific.

2. After studying Figure 519 answer these questions. Why is it believed that Neandertal men wore skins? Why is it believed that these skins were not fashioned into real clothes? Which animals are illustrated? Why does the artist depict these rather than other animals? What other questions to which you would like an answer come to your mind?

3. Discuss these problems in class: (*a*) How might speech speed up the development of cultures? (*b*) How might a study of the cultures of primitive peoples living today help to explain the development of early man?

4. What nationalities and which races are represented in your class? List them all. How many pupils are descended from more than one racial group? If you have representatives of several races in your class of what advantage is this to you?

Further Activities in Biology

1. By the examination of ruins scientists have been able to discover that the Incas and Mayas of this continent had complex religions, a well-developed social organization, and were good scientists. Read up on them and report to the class.

2. Take pictures of pupils who represent the various racial groups. Take pictures of pupils of various nationalities. Do those of the same nationality resemble each other? Do those of the same racial group resemble each other?

3. If you draw well, paint murals showing the development of man.

4. Various peoples have contributed to modern culture. Divide the class into committees to learn about the culture of the Chinese, the early Egyptians, the Babylonians, and the Greeks.

5. If flint, bone, or even ordinary hard rock can be obtained, try to produce artifacts like those made by primitive man. Are you as successful as he?

READING REFERENCES

Under each subdivision books are listed first, alphabetically by author; magazines are listed second, alphabetically by title.

General Good Reading

Magazines

Cornell Rural School Leaflets, Fernow Hall, Cornell University, Ithaca, N.Y.

National Geographic Magazine, 16th and M Street, N.W., Washington 6, D.C.

Natural History, American Museum of Natural History, 79th Street and Central Park West, New York 24, N.Y.

Nature Magazine, The American Nature Association, 1214 16th Street, N.W., Washington 6, D.C.

Science News Letter, Science Service, 1719 N Street, N.W., Washington 6, D.C.

Many magazines print interesting and useful articles about recent advances in various fields of science. *Harper's Magazine*, especially, is notable. Your teacher can tell you about the many government publications that make good reading.

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GLOSSARY

A glossary is a partial dictionary of the words used in a book. In this glossary you will find short explanations or definitions of a great many of the words that are used in biology. These are called "biological terms," although some of them are used in other sciences as well as in biology. Some words have one meaning in biology and one or more meanings in other sciences or in ordinary conversation or writing. In this glossary the biological meaning of such words is given, so you must take care in using these definitions.

Some of these terms are often pronounced incorrectly. To help you with these a phonetic pronunciation is given in parentheses.

abdomen (ab-doh'men): the posterior (hind) region of an arthropod's body; in the higher vertebrates that part of the body which contains the stomach and lower digestive organs.

abscess (ab'sess): a gathering of pus accompanied by inflammation in a definite spot in the body, usually caused by bacteria.

absorption (ab-sorp'shun): the movement of water, digested food, and other soluble substances into the blood or cells of animals; in plants, diffusion of soil water into the root.

acne (ack'knee): a skin condition which shows as an eruption, especially on the face.

acquired characters: characteristics or traits of organisms developed during their lifetimes in response to environment.

acromegaly (ac'row-meg'al-ly): a condition in man and other mammals caused by excessive secretion of the pituitary gland, showing itself in enlargement of certain bones, such as those of the feet, hands, and parts of the face.

adaptation (a-dap-tay'shun): any change in the structure or activities of organisms which fits them for their environment.

adrenal (ad-ree'nal) glands: ductless glands, one next to the upper end of each kidney, secreting adrenin and cortin and probably other hormones.

adrenin (ad-ren'in): hormone secreted by the adrenal glands, bringing about many changes in the body which help an animal in an emergency.

agar-agar (ah'gar): gelatin-like product of certain seaweeds used in raising bacteria.

agglutinin (ag-glu'tin-in): antibody which causes bacteria to clump.

air sacs: little thin-walled sacs making up the lungs in higher vertebrates, each connected with a fine branch of the bronchial tubes; for exchange of air.

albino (al-bine'oh): person or other animal whose skin, hair, and eyes lack most or all of their pigment; applied also to plants with a deficiency of pigment.

algae (al'jee): plants of the thallophyte phylum which have chlorophyll.

alimentary (al-i-men'tary) canal: food tube in an animal from mouth to anus.

allergy (al'er-jee): a state of abnormal sensitiveness to a particular substance, such as pollen, foods, dust, etc.

alternation of generations: regular rotation of sexual and asexual reproduction in the life cycle of an organism; mostly in plants. (Both steps are necessary for the production of organisms of the same general appearance as the parents.)

amino (am-ee'no) acids: complex compounds made by plants which, when chemically united in various combinations, make up the proteins of all organisms; also the end products in protein digestion.

amphibians (am-fib'i-ans): members of a class of vertebrates with soft, naked skins, usually breathing by means of gills in their early stages; in later stages, breathing by means of lungs.

amylase (am'i-lace): one of several starch-splitting enzymes.

anaesthetic (an-es-thet'ic): something that causes a general or local loss (or partial loss) of pain or other sensation.

anatomy (an-at'o-me): study of the structure of plants and animals.

anemia (an-ee'me-a): condition in which there is a deficiency of hemoglobin; often accompanied by a reduction in the number of red blood cells.

angiosperms (an'jee-o-sperms): plants of the spermatophyte group with seeds lying in an ovary; true flowering plants.

annelids (ann'ell-ids): members of a phylum of invertebrates which have ringed or segmented bodies, such as the earthworms.

annual (an'you-el): plant that lives for only one growing season.

annual ring: easily distinguished ring forming each year in the woody tissue of dicot trees and shrubs through the growth of cambium cells. (The number of rings gives the age of the stem.)

anoxia (an-ox'ia): condition in which the body has an insufficient supply of oxygen; occurring mostly at high altitudes.

antenna (an-ten'na): one of a pair of projecting sense organs on the head of insects, crustaceans, etc.

anterior (an-teer'i-er): applied to the front or head end of an animal.

anther: the pollen case found on the top part of the stamen in a flower.

anthropologist (an-throw-pol'oh-jist): one who studies the science that treats of the origin, classification, and culture of man.

antibiotics (an'ti-by-ot'ticks): substances produced by living organisms and used in medicine to kill or hinder growth of disease-producing organisms. Example is penicillin.

antibody (an'ti-bod'y): any of the various substances which are formed by the animal body and which counteract foreign organisms or their products.

antiseptic (an'ti-sep'tic): substance which prevents the action of germs and hinders their increase in numbers.

antitoxin (an'ti-tox'in): substance formed in the body of an animal which counteracts a particular toxin (poison) made by an organism.

aorta (ay-or'ta): single large artery in vertebrates which leads the blood out of the heart to be distributed to parts other than the lungs.

aphids (ay'fids): small insects living on plants and sucking their juices.

appendage (ap-pend'aj): any part of the body of an animal arising from the main trunk, such as a leg.

appendix: in man and some other mammals a narrow outgrowth from the blind sac at the beginning of the colon.

arachnids (a-rack'nids): members of one of the five large classes of the arthropod phylum, such as spiders.

archaeornis (are-key-or'nis): extinct birdlike animal which had teeth and a long tail with vertebrae.

artery: blood vessel that carries blood away from the heart to capillaries.

arthropods (are'thro-pods): members of a large phylum of invertebrates which have a segmented body, jointed legs, and a firm covering (exoskeleton).

artifact (are'te-fact): any article made by man for his use, especially products made by prehistoric man.

ascorbic (ay-skor'bic) **acid**: vitamin C; prevents scurvy.

aseptic (ay-sep'tic): free from living microorganisms which might cause disease, fermentation, or decay.

asexual (ay-sek'shoo-al) **reproduction**: forming of a new individual without the uniting of two cells.

assimilation (as-sim'il-ay'shun): changing food substances to protoplasm in the cell.

auricles (or'i-k'ls): chambers in the vertebrate heart which receive blood from veins and send it to the ventricles.

autonomic (au-toh-nom'ic) **nervous system**: system of nerves and ganglia which works closely with the central nervous system and controls the behavior of some of the internal organs.

auxin (awk'sin): class of substances which in very small amounts regulate the growth of particular parts of plants; sometimes called growth hormones.

axon (ak'son): part of a neuron; projection from the cell body carrying impulses out of the cell.

bacillus (ba-sill'us): rod-shaped bacterium.

bacteria, pl. of **bacterium**: microscopic fungi, very simple in structure, of many species; most are useful, some very harmful.

bacteriology (back-teer'iy-ol'o-jee): study of bacteria and their effects.

bacteriophage (back-teer'iy-o-faj): a filterable, ultramicroscopic agent which breaks up certain bacteria.

balanced aquarium: aquarium in which under proper conditions of light and temperature the plant and animal organisms produce substances necessary to each other in quantities that enable both kinds to live.

bark: tough, often hard, external covering of woody stems.

behavior: the sum total of the responses of an organism to its environment.

beriberi (ber'ree-ber'ree): deficiency disease caused by an insufficient intake of vitamin B_1 (thiamin).

bicuspids (bye-kuss'pids): teeth with two points, lying between the canines and molars in mammals; also known as premolars.

biennial (bye-en'i-al): plant that lives for two growing seasons, bearing flowers and fruits the second year.

bilateral symmetry (bye-lat'e-rel sim'e-tree): arrangement of the parts in an animal in such a way that the right and left sides are similar.

bile: bitter greenish liquid secreted by the liver; stored in the gall bladder.

binary fission (bye'na-ree fish'un): division in half of a one-celled organism in asexual reproduction.

biology: study of living things.

birds: members of a class of vertebrates distinguished by a covering of feathers.

blade: broad part of a leaf as distinguished from the petiole (stalk).

blastula (blast'you-la): an early stage (a hollow ball of cells) in the development of the embryo of many kinds of many-celled animals.

bleeders: persons who have hemophilia.

blending inheritance: inheritance in which there are no dominant and recessive characters but a mixing of the two.

blood count: count of red or white blood cells in a small drop of blood. (White are counted to diagnose infection; red for anemia.)

botany: study of plants.

brachydactyly (brak'i-dak'te-lee): condition of having short fingers or toes with two instead of three bones in each.

breathing: inhaling and exhaling of air in animals.

breed: relatively homogeneous group of animals within a species developed and maintained by man.

breed true: to have all the offspring show the same character as the parent or parents through the generations.

bronchi (bron'kye) pl.: two branches of the windpipe, one of which enters each lung.

bronchial (bron'kee-el) **tubes:** tubes with many branches in the lung leading from the bronchus; the finest branches of the tubes end in air sacs.

bryophytes (brye'o-fites): members of the large group or phylum of plants which includes the mosses and liverworts.

bud: in higher plants an outgrowth from the end of the stem or from cells in the axils of the leaves, containing undeveloped leaves and/or flowers; in lower organisms a small outgrowth that forms asexually and develops into a new organism; also applied to other small structures, as taste buds.

budding: form of asexual reproduction in some lower organisms in which a small outgrowth (bud) develops into a new organism; a kind of grafting in which the scion is a bud.

bulb: structure formed in some monocots, consisting of a bud with fleshy leaves and a reduced flattened stem, capable of producing a new organism by vegetative reproduction.

Calorie (kal'o-ree): unit for measuring heat energy. The large Calorie (used to measure heat energy released by living things or by food) is the amount of heat required to raise the temperature of 1000 grams (a little more than a quart) of water one degree Centigrade.

calorimeter (cal'o-rim'e-ter): apparatus used to measure the number of calories in foods or other substances.

calyx (kay'lix): group of sepals in a flower; outermost circle of leaf-like flower parts, usually green in color.

cambium (kam'be-um): narrow cylinder of thin-walled, actively growing cells between xylum and phloem in dicot stems and sometimes their roots.

Cambrian (kam'bree-an) **period:** an early period of the Paleozoic era in which trilobites and many other aquatic animals flourished.

canines (kay'nines): when well developed, as in some mammals, teeth used for tearing flesh; the eye teeth in man.

capillaries (cap'ill-a-rees): microscopic blood vessels with very thin walls, located all over the body; they receive blood from arteries and give it to veins.

carbohydrates (car-bo-hy'drates): group of compounds, such as starches, sugars, and others, composed of carbon, hydrogen, and oxygen, with the hydrogen and oxygen in the proportion of two to one, as in water.

Carboniferous (car-bon-if'er-us) **period:** a late period in the Paleozoic era in which the coal beds were formed.

carnivores (car'ni-vores): members of an order of mammals that are chiefly flesh-eating, with well-developed canines.

carotene (care'o-teen): yellow substance found in some plants, such as carrots, which can be changed to vitamin A in animals.

carrier: person or other animal that carries germs of a particular disease without having the disease and in some cases without ever having had the disease.

cartilage (car'til-aj): firm, flexible connective tissue in animals, often found making up part of a bone and in some animals occurring instead of bone; gristle.

cattalo (cat'a-lo): species produced by crossing any of the domestic breeds of cattle with the American bison (buffalo).

Caucasoid (cau'kass-oyd) **stock:** one of the three main stocks of living men; it includes, among others, Nordics and Hindus.

cell: a small, usually microscopic, mass of protoplasm, normally consisting of nucleus, cytoplasm, and cell membrane; all organisms consist of one or more cells.

cell body: part of the cell that is outside the nucleus and inside the cell membrane.

cell membrane: thin layer of thickened living matter which surrounds every cell; also called **plasma membrane.**

cell theory: all living things are made of cells and the products of cells. This has been so well established that it can be called the **cell doctrine.**

cell wall: thick layer of lifeless material outside the cell membrane of most plant and some animal cells.

cellulose (cell'you-lohss): a carbohydrate found in the cell wall of plant cells.

central nervous system: the brain and spinal cord in a vertebrate.

centrosome: tiny protoplasmic body close to the nucleus, mostly in animal cells; it seems to play some part in mitosis.

cerebellum (ser-e-bel'lum): that part of the vertebrate brain which lies back of the cerebrum and in front of the medulla; it is concerned with coordination of voluntary muscle movements and equilibrium.

cerebrum (ser'e-brum): that part of the vertebrate brain in which lie the centers for voluntary acts, sensation, and conscious mental processes; in mammals the most anterior part; it is particularly well developed in man.

chemical change: a change in the nature or composition of a substance or group of substances, as opposed to physical change, which leaves the nature or composition of the substance unchanged.

chemistry (kem'is-tree): the science that deals with the composition of substances and the changes in composition.

chitin (ky'tin): horny substance in the covering of arthropods.

chlorophyll (klor'oh-fill): green coloring matter in plants; necessary for making sugar.

chloroplast (klor'oh-plast): small body of living matter containing chlorophyll; found in leaf and other green cells.

cholesterol (koh-less'ter-ole): fatty substance found in the tissues of man and other animals which changes into vitamin D when acted on by ultraviolet rays.

chordates (core'dates): members of the animal phylum that includes the backboned animals and a few kinds of simpler animals which have a rodlike structure instead of a backbone.

choroid (core'oid) **coat:** middle layer in the wall of the vertebrate eyeball; between the retina and sclera.

chromatin (crow'mat-in): that substance in the nucleus that readily takes stain; at certain times found in the form of chromosomes.

chromosome (crow'mo-soam): one of several rodlike or threadlike bodies of chromatin that form during nuclear division.

chrysalis (kris'a-lis): hard-covered pupa of some insects, especially butterflies.

cilia (sil'ee-a) pl. of **cilium:** short hairlike projections from a cell, usually animal; their waving may result in locomotion or production of a current.

class: in classification the largest subdivision of a phylum or subphylum.

classification: grouping plants and animals according to their structure, origin, etc.; also the whole system of groups that has been developed.

cleavage (kleev'aj): repeated division or partial division of the fertilized egg of an animal, resulting in a mass of small cells.

club mosses: members of a small subdivision of pteridophytes (fern group); creeping plants with erect stems bearing spores in conelike structures.

coccus (kok'us); pl. **cocci** (kok'sye): spherical bacteria.

cochlea (kok'lee-a): that part of the inner ear in man and other mammals which contains the endings of the auditory nerve.

cocoon (kuh-koon'): silky covering spun by the larvae of many insects which protects them in the pupal (nonfeeding) stage; the silky case in which certain spiders enclose their eggs.

coelenterates (see-len'ter-ates): members of a phylum of water-living invertebrates whose bodies have a single internal cavity, such as jellyfish and corals.

colchicine (kol'chi-seen): a drug (extracted from a plant) which, when applied to plant tissues, doubles or triples the number of chromosomes in the cell by interfering with normal cell division.

cold-blooded: applied to an animal whose body temperature varies according to the temperature of its surroundings.

colon (koh'lon): large intestine.

colony: group of animals or plants of the same kind living together, usually descendants of the same parents.

composites: members of a family of flowering plants having two kinds of flowers gathered together into one head, as in asters and daisies.

compound: substance of which the molecules are made up of two or more kinds of atoms chemically united.

conditioned response or **conditioned reflex:** learned response in which there is reflex response to a new stimulus. Pavlov produced it in dogs by causing saliva to flow at the sound of a bell.

cone: a structure consisting of a mass of scales bearing the reproductive parts of such plants as pines, firs, and hemlocks.

conifers (kon'i-furs): cone-bearing trees and shrubs, such as pines and firs.

conjugation (kon-jew-gay'shun): in sexual reproduction the uniting of two cells similar in appearance.

connective tissue: animal tissue that connects, supports, or surrounds other tissues or organs; occurring in various forms such as white fibrous, yellow elastic, etc.

conservation (kon-sir-vay'shun): using natural resources in such a way that they will not become exhausted.

contour (kon'toor) **planting:** planting crops on a slope in rows which follow the curve of the slope so that washing away of topsoil is reduced.

contractility (kon-trak-til'i-ty): that property of protoplasm which enables it to change its shape; particularly developed in muscle cells.

convolutions (kon-voh-lew'shuns): ridges or folds in the surface of the cerebrum or cerebellum in the higher vertebrates.

cornea (kor'nee-a): transparent layer that covers the front of the vertebrate eye.

corolla (ko-rol'a): whole group of petals of a flower; inner circle of leaflike flower parts, usually of some color other than green.

coronary (kor'o-ner-y): applied to arteries which start from the aorta and supply the heart tissues. **Coronary thrombosis** (throm-boh'sis): clot forming in one of these arteries.

corpuscles (core'pus-ls): blood cells of vertebrates. Red corpuscles carry oxygen to the body cells; white corpuscles defend against bacteria.

cortex: the "rind" (outer layers) of an organ such as the brain or kidney. In a root or stem the region between the conducting tissue and the epidermis.

cortin: hormone extracted from the cortex cells of the adrenal glands.

cotyledon (cot-e-lee'don): undeveloped leaf in the embryo of a seed plant; a monocot has one cotyledon, a dicot has two, and gymnosperms more.

cranium (cray'nee-um): that part of the vertebrate skull that contains the brain.

cretinism (cree'ti-nism): abnormal condition in humans in which from birth there is a great deficiency of thyroxin, resulting in dwarfism and idiocy; an individual having such a condition is called a **cretin**.

crop: plants (or plant products) cultivated to supply food or materials for man or domesticated animals. **Cover crops**: plants raised principally to bind the soil and prevent its loss. **Rotation of crops**: planting different crops in one field in regular order year after year so that the soil's minerals may be used up more slowly or restored. Crop is also part of the digestive tract in many animals.

cross: mating two organisms.

crossbreeding: mating two individuals that belong to the same species or even the same variety but which have no family relationship; also **outbreeding**.

crustaceans (crus-tay'shuns): members of a class within the phylum arthropoda; mostly water-living forms with firm shells, such as lobsters.

culture: the sum total of ways of living of a group of human beings handed on from one generation to another; also the growth of microorganisms or tissues for scientific study. **Culture medium**: a prepared material for raising microorganisms. **Pure culture**: a culture of only one kind of organism.

cytoplasm (sigh'toe-plasm): that part of the living matter of a cell that surrounds the nucleus.

deciduous (de-sid'you-us): shedding the leaves every year, as occurs in many trees and shrubs.

deficiency (de-fish'en-see) **disease**: illness caused by an insufficient supply of some necessary substance in the diet, such as A vitamins.

dendrites (den'drights): thickly branched projections from the body of a nerve cell which carry impulses into the cell body.

denitrifying (dee-ny'tri-fy-ing): breaking down nitrates into nitrites, ammonium compounds, or free nitrogen by microorganisms in the soil.

dentine (den'teen): a hard substance making up the greater part of the tooth in vertebrates. In the crown it is covered by enamel; in the root, by cement.

dermis: in mammals a form of epithelium lying under the thinner epidermis and containing such structures as the roots of hairs, oil glands, secreting cells of sweat glands, etc.

diabetes (dye-a-bee'teas): disease in which sugar is not used normally because of a deficiency of insulin.

diaphragm (dye'a-fram): thick sheet of muscle separating the chest from the abdominal cavity in mammals.

dicotyledons (dye-cot-e-lee'dons) or **dicots**: members of a subclass of angiosperms which have two seed leaves in the embryo, net-veined leaves, and stems which can form annual rings.

differentiation (diff'er-en-she-a'shun): processes by which embryonic cells develop the shapes and structures of specialized cells such as muscle and nerve cells.

diffusion (dif-you'shun): spreading of molecules from a region where they are more concentrated to where they are less concentrated; this may occur through a membrane.

digestion: changing larger molecules into smaller molecules; this is often necessary to enable food to diffuse through a cell membrane and to make it usable by the cell.

dihybrid (die-high'brid): an organism that is hybrid with respect to the two contrasting characters of a pair.

dinosaurs (die'no-sores): extinct dragon-like reptiles of many species that lived toward the end of the Mesozoic era; some, such as **Brontosaurus**, were of gigantic size.

diploid number: number of chromosomes normally found in each of the cells of an organism other than the sex cells; a number twice as large as the number of chromosomes in a sex cell.

disinfectant: substance that destroys all bacterial life.

dominant: in genetics, that character which, when combined with the contrasting character, shows up in the hybrid offspring; applied also to the gene of any pair of genes that produces the character that shows up.

donor: person furnishing blood for transfusions.

dorsal: in animals, applied to the back region as opposed to the under or ventral side.

ductless gland also **gland of internal secretion** or **endocrine gland**: gland that secretes a hormone directly into the blood stream.

duodenum (doo-o-dee'num): first part of the small intestine.

eardrum: membrane lying between the middle ear and the canal of the outer ear; it transmits vibrations to the small bones of the middle ear.

echinoderms (eh-kine'o-derms): members of a phylum of marine invertebrates with radial symmetry and spiny coverings; starfish group.

ecology (ee-kol'o-gee): that field of biology that deals with the relationship of organisms to their physical surroundings and to other organisms.

ectoderm (ek'toe-derm): outermost layer of cells in the hollow cup stage of an animal embryo.

effector (ef-fek'tor): an organ, tissue, or cell in an animal that responds to a stimulus, such as a muscle or gland.

egg: structure with more or less substantial covering laid by the female of many kinds of animals, containing usually a fertilized egg cell. **Egg cell:** female sex cell or ovum before fertilization in plants and animals.

electron microscope: microscope of extremely high power, using beams of electrons instead of rays of light and recording the image on a photographic plate or fluorescent screen.

element: substance of which the molecules contain one kind of atom; at present 98 elements are recognized.

embryo (em'bree-oh): animal in the early stages of its development before it is hatched or born; in a plant, before germination.

embryo sac: large cell in the plant ovule within which nuclear divisions result in the formation of the egg cell nucleus and other nuclei.

emotions (ee-moh'shuns): feelings of joy, sorrow, hate, and the like which involve important changes in the action of some internal organs and even some skeletal muscles.

emulsion (ee-mul'shun): condition of an oil in which it exists in tiny droplets, each surrounded by a thin film which gives the oil a milky appearance.

enamel: lifeless, hard, glossy outer layer of the crown of a tooth in most mammals and many other vertebrates.

end brush: branched endings of the axon through which a stimulus passes into the dendrites of another neuron or into an effector.

endoderm (en'doh-durm): innermost layer of cells in the hollow cup stage of an animal embryo.

endosperm: group of food-storing cells outside the embryo in the seeds of some kinds of plants (mostly monocots).

energy: the ability to do work.

entomology (en-toe-mol'o-jee): study of insects.

environment (en-vie'run-ment): all the surroundings of a living organism, including other organisms.

enzyme: substance made by living cells which brings about or hastens a chemical change, without being itself permanently affected; many enzymes are digestive, such as pepsin and ptyalin; others hasten oxidation, etc.

eohippus (ee-oh-hip'pus): small extinct animal believed to be the ancestor of the modern horse.

epidermis (ep-i-der'mis): outermost layer or layers of cells in an animal or plant.

epiglottis (ep-ee-glot'tis): flap of tissue that is folded down over the top of the windpipe (voice box) during swallowing.

epithelial (ep-e-thee'lee-al) **tissue:** covering tissue in plants and animals; includes lining tissues in animals.

era (ear'a): a major division of time in the history of the earth; many geologists divide time since the beginning of the earth into seven eras.

ergosterol (er-goss'ter-ohl): substance produced by and found in many plants, which can be turned into vitamin D by ultraviolet rays.

erosion (e-row'shun): wearing away the surface of the earth by agents such as water and glaciers.

essential organs: organs within a flower directly concerned with sexual reproduction; stamens and pistils.

eugenics (you-jen'ics): improvement of the human race by breeding.

Eustachian (you-stake'ee-an) **tube:** tube connecting the middle ear with the throat.

euthenics: improvement of the human race through improvement of the environment.

evolution: change or development. **Organic evolution:** theory that all living things are descended from earlier forms, that the first organisms to appear on the earth were simple, and that they gave rise throughout the ages to more and more complex forms.

excretion: giving off wastes formed in oxidation by animal or plant bodies or cells.

exoskeleton (ex-oh-skel'e-tun): a hard protective covering, as in arthropods.

family: in classification the major subdivision of an order, commonly composed of a number of genera.

fang: sharp, hollow, or grooved tooth by which venom is injected by poisonous snakes.

feeble-minded: having so low an intelligence that the person is unable to meet the conditions of life satisfactorily.

fermentation: changing of sugar by some microorganisms, especially yeasts, into alcohol and carbon dioxide; energy is released. Also changing of other organic compounds by microorganisms, with production of a gas.

ferns: plants of many species belonging to the pteridophyte group, with true leaves, roots, and horizontal stems with conducting tissue much like that in higher plants; spores borne on leaves or modified leaves.

fertilization: uniting two unlike gametes to form a fertilized egg or zygote.

fibrinogen (fye-brin'o-jen): protein in blood plasma which under certain conditions thickens and forms fibers as part of the blood clot. After hardening fibrinogen becomes **fibrin**.

filament (fill'a-ment): slender stalk-like part of a stamen; thread of an alga or fungus consisting of a row of attached cells.

filial (fill'i-al) **generations**: generations of offspring of a cross; first filial or F_1 is the first generation of offspring; second filial or F_2 is the offspring of two individuals belonging to the F_1 generation.

fishes: members of a class of vertebrates that have gills, commonly fins, and a body usually covered with slimy scales.

flagellum (fla-jell'um); pl. **flagella**: long whip-like projection from a cell.

food: any substance that can be used by a cell for oxidation, secretion, or assimilation.

food chain: series of organisms, always starting with a green plant, with each organism serving as food for the one above it in the series.

fossil: any remains, impression, or trace of an animal or plant of an earlier geological age; most often found in rock.

fraternal twins: developed from two distinct eggs, each egg fertilized by a separate sperm; distinguished from identical twins.

frond: leaf of a fern; also a leaflike part in seaweeds and other lower plants.

fruit: ripened ovary together with any other attached parts.

function (funk'shun): activity or useful action of some organ, tissue, cell, or part of a cell.

fungi (fun'jeye): plants of the thallophyte phylum which lack chlorophyll; for example, mushrooms.

gall (gawl) **bladder** or **bile sac**: sac attached to the liver in vertebrates; holds bile secreted by the liver.

gamete (gam'eat): either of the two cells that unite in sexual reproduction to form a new organism. The male gamete is the sperm; the female is the egg or ovum. In conjugation, where the gametes are similar in structure, one may be an active or supplying gamete, the other a passive or receiving gamete.

ganglion (gan'glee-on); pl. **ganglia**: small group of cell bodies of neurons. In vertebrates ganglia lie outside the brain and cord, some of them being part of the autonomic system. In invertebrates together with nerves they constitute the nervous system.

gastric juice: digestive juice of the stomach secreted by gastric glands.

gastrula (gast'roo-la): cuplike stage of the embryo in many-celled animals; at first two layered, later three layered.

gene (jean): unit of heredity; substance located in the chromosome and transmitted with it; acting with the environment and other genes it produces one or more characters in the organism.

genus (jee'nus): pl. **genera**: in classification the usual major subdivision of a family, consisting of one or more species. The name of the genus appears first in the scientific name of an organism.

geology (jee-ol'oh-jee): the study of the earth, the rocks of which it is composed, and the changes it is undergoing or has undergone.

geotropism (jee-ot'ro-pism): tropism in which the stimulus is gravity.

germ: microscopic organism that causes disease; also the beginnings of an organism.

germ cells: reproductive or sex cells of an animal or plant.

germ layers (primary): the three layers of cells in the cup stage of the development of many-celled animals; from each layer are formed particular organs and tissues.

germ plasm: protoplasm of the reproductive cells and of those cells in the early stages of development which will become reproductive cells.

germination (jer-min-ay'shun): sprouting of a seed or spore.

gestation (jes-tay'shun): in mammals the period of development of the embryo within the body of the parent.

gills: breathing organs of aquatic animals, suited to taking dissolved oxygen out of water; in fish they consist of the **arch** which holds the **filaments** containing capillaries and of **rakers** which protect by straining the water taken through the mouth.

gill slits: in fish the openings back of the head through which water leaves after it has passed over the gill filaments; also found in vertebrate embryos.

gland: any cell or group of cells that secretes a substance; the secreting cells are epithelial. There are ductless glands and glands with ducts.

glucose (gloo'cose): grape sugar; a simple sugar with the formula $C_6H_{12}O_6$.

glycogen (gly'ko-jen): "animal starch"; carbohydrate stored in the liver; found also in muscles.

goiter: enlarged thyroid gland which may be accompanied by an undersecretion of thyroxin (**endemic goiter**) or an oversecretion (**exophthalmic goiter**).

grafting: transplanting living tissue in an animal or plant from one organism to another; commonly done in plants to maintain or produce more of a desired type.

guano (gwa'no): chiefly the solid wastes of sea birds found in large deposits especially on islands off the coast of Peru and in Chile.

guard cells: two cells on either side of a leaf stoma, which regulate size of the stoma.

gullet: food pipe or oesophagus in many-celled animals; in protozoa the food tube leading into the cell.

gymnosperms (jim'no-sperms): plants of the spermatophyte group that have uncovered or "naked" seeds, such as the cone bearers.

habit: behavior that has been learned so well that it has become automatic.

haploid number: the half number of chromosomes; the number found in each sex cell as distinguished from the diploid or double number found in all other cells.

hemoglobin (he'mo-globe'in): protein containing iron in the red blood cells of vertebrates; it carries oxygen by combining loosely with it; the new substance **oxyhemoglobin** is bright red.

hemophilia (he-mo-fill'e-a): condition in which the reduced ability of the blood to clot may result in dangerous bleeding.

herb (erb): seed plant with a stem above ground which does not become woody.

heredity: passing on genes and thus characters from parents to offspring; the word is used for the resemblance as well as for the process.

hibernation (high-ber-nay'shun): a resting or "sleeping" stage occurring in some animals during the winter.

hilum (high'lum): scar left on seeds by the breaking off of the stalk which attached the seed to the fruit.

Homo sapiens (hoh'mo say'pee-enz): single species within the genus Homo which includes all mankind and some prehistoric forms.

hormone: substance secreted by the cells of an animal directly into the blood and carried to other parts of the body where it regulates and modifies activities. In plants the growth substances are often called hormones.

horsetails: perennial, herbaceous pteridophytes with hollow, jointed stems; also called scouring rushes.

hybrid (high'brid): the opposite of pure in genetics. In a hybrid the two genes of a pair are different.

hybrid vigor: the increased hardiness and size which sometimes results from outbreeding or crossbreeding.

hybridization (high'brid-iz-ay'shun): the crossing of individuals having contrasting characters.

hydrotropism (hy-dro'tro-pism): tropism in which the stimulus is moisture or water.

hypha (high'fa): a thread-like part of a mold.

hypocotyl (high-po-cot'il): that part of the plant embryo or seedling which lies between the point where the cotyledons are attached and the upper part of the undeveloped root.

identical twins: twins developed from a single fertilized egg, as distinguished from fraternal twins.

igneous (ig'nee-us) **rock**: very hard rock formed from the cooling of molten rock.

immunity: not being susceptible to a particular disease. **Natural immunity**: immunity which one has without treatment or without having had the disease. **Acquired immunity**: immunity which one gets either through recovery from the disease or by appropriate inoculation. **Active immunity**: immunity acquired after introduction of bacteria or their products. **Passive immunity**: immunity acquired by inoculation of antibodies made by some other animal.

impulse: as applied to a nerve, is that which is carried along the axon either into or out of the cell body of the nerve cell.

inbreeding: breeding of close relatives; in plants usually by self-fertilization.

incisor (in-size'er): in mammals the front teeth in both jaws used for cutting; particularly well developed in rodents.

incomplete dominance: another name for blending inheritance.

incubation (in-kew-bay'shun): keeping eggs, embryos, or young colonies of cells at an even, favorable temperature during development; eggs of wild birds are incubated by the adults; eggs of domestic fowl are usually incubated by artificial heat.

independent assortment: Mendelian law of heredity which states that genes lying in different pairs of chromosomes are segregated independently of one another; also law of unit characters.

infectious (in-fek'shus) **disease**: any disease which may be caused by the entrance of a microorganism into the body; frequently transmitted from one person to another, or contagious.

inoculation (in-oc'you-lay'shun): introduction of bacteria or viruses into the body or into media suited to their growth; also introduction of antibodies or immune serum into the body.

insects: members of a very large class of arthropods having three distinct body regions, three pairs of legs, and often wings.

instinctive behavior: complicated inherited behavior in which there is a series of reflexes, each reflex serving as a stimulus to the next, as web spinning by spiders or nest building by birds.

insulin: hormone secreted by the "islands of Langerhans" in the pancreas; regulates sugar metabolism.

intelligence quotient or **I. Q.**: number representing the score obtained on an intelligence test compared with the scores made by large numbers of people of the same age.

invertebrates: animals that have no backbone or rodlike structure (notochord) in the place of the backbone.

iris (eye'ris): diaphragm which surrounds the pupil of the eye in vertebrates; colored portion of the eye.

iron lung: apparatus for producing breathing movements in paralyzed people.

irradiation (ir-ray-dee-ay'shun) **of food**: exposing food to ultraviolet light in order to produce vitamin D in it.

irritability: ability of protoplasm to respond to stimuli.

islands of Langerhans: small groups of cells constituting a ductless gland in the pancreas that secrete insulin into the blood.

isotopes (ice'oh-topes): any of two or more forms of a chemical element which differ in the number of neutrons in the atom of that element. Some isotopes are radioactive, such as radioactive iodine or phosphorus.

lacteal (lack'tee-al): tiny lymphatic in the villus; absorbs digested fats.

larva: the form which hatches from the insect egg in complete metamorphosis; also in some animals the young when it is very different from the parent.

larynx (lar'inks): uppermost portion of the windpipe which contains the vocal chords; also called **voice box**.

layering: form of vegetative reproduction in which a twig still attached to the main plant touches the ground and takes root.

learning: changing of behavior as a direct or indirect response to the environment; also the acquiring of knowledge.

legumes (leg'youms): pod-bearing plants making up a large family; some used as food, feed, or for improving the soil.

lens (of the eye): a part lying near the front of the eyeball in the vertebrate eye that focuses the light rays on the sensitive cells of the retina.

lenticel (len'ti-sel): opening through the bark of dicot stems; permits passage of gases into and out of the stem.

leucocyte (lew'ko-site): another name for white blood cells of which there are several kinds.

lichens (lie'kens): "compound" plants consisting of an alga (or in some a species of bacteria) and a fungus living together.

life activities: activities carried on by all living things, such as food getting or food manufacture, digestion, assimilation, respiration, excretion, irritability, and reproduction.

ligament: band of fibrous tissue that connects bones.

linkage: condition in which two characters are not assorted independently of one another because the determining genes lie in the same chromosome and therefore remain together in reduction division.

lipases (lie'paces): fat-digesting enzymes.

lymph: liquid which surrounds the tissue cells in vertebrates; it is largely blood plasma which has diffused from the capillaries.

lymph node or gland: one of the glandlike structures occurring in many places along a lymphatic; it filters out certain white blood cells and makes new ones.

lymphatic (lim-fat'ick): tube which carries lymph.

lysin (lie'sin): antibody which breaks up bacterial cells or other cells which have entered the body.

macrospore (mac'roh-spore): large spore in certain ferns and seed plants; it grows into the female prothallus or, in seed plants, into the embryo sac.

maggot: larval stage of flies.

mammals: members of a class of vertebrates having hair, a diaphragm, and milk glands used in feeding the young.

marsupials (mar-soo'pee-els): "pouched" mammals; in most cases the young are born in an immature state and live in the pouch for a long time after birth.

maturation (mat-you-ray'shun): process by which eggs and sperms ready for fertilization are formed from primary sex cells; in this process the number of chromosomes is reduced to the haploid or half number.

medulla oblongata (med-dull'a ob-long-gah'ta): the hindmost part of the brain continuous with the spinal cord; the center for heartbeat, breathing, etc.

meninges (men-in'jees): three membranes covering the brain and cord of vertebrates.

mesentery (mes-en-ter'ree): one of several folds of thin membrane attached to the wall of the abdomen of a vertebrate; it holds the organs in place.

mesoderm: middle layer of cells which forms between ectoderm and endoderm in the embryo of a many-celled animal.

metabolic (met-ah-bol'ic) **disease**: disease in which there is abnormal building up or breaking down of living matter in the animal body.

metabolism (met-ab'o-lism): sum of all chemical changes that go on in a cell or in the body of an organism. **Basal metabolism**: amount of metabolism when the body is as nearly at rest as possible; a test for this is often made to diagnose thyroid activity.

metamorphic (met-e-mor'fic) **rocks**: rocks which have been changed in structure by terrific pressure or heat; marble, a metamorphic rock, is changed limestone.

metamorphosis (met-e-mor'fo-sis): in zoology, changes in an animal after its embryonic stages by which it is adapted to a different way of living, as the change from an insect larva into the adult or a tadpole into a frog. In incomplete metamorphosis in insects the form hatching from the egg bears considerable resemblance to the adult; in complete metamorphosis there is very little resemblance.

microorganism (my-cro-or'gan-ism): organism whose structure can be seen only with the aid of a microscope.

mycropyle (my'cro-pile): tiny opening in the coats of an ovule (and later of the seed); pollen tubes can enter through it.

microspore: small spore in certain ferns and in seed plants; in ferns it develops into the male prothallus and in seed plants into the pollen grain.

mitosis (mit-toe'sis): complicated nuclear division occurring in normal cell division in all animals and plants, except possibly some of the simplest; in mitosis each chromosome and gene divides longitudinally in half.

molars: grinding teeth of mammals.

molds: any of the fungi that produce a downy or furry growth on vegetable or animal matter.

molecule (moll'e-kewl): smallest particle of a substance that has the characteristics of the substance; it may consist of one atom or many thousands of atoms.

mollusks (mol'lusks): invertebrates with a soft unsegmented body, with gills, mantle, and foot, and usually covered by a shell of lime; a large phylum, including clams, snails, and octopuses.

Mongoloid: one of the three main stocks of living men; it includes, among others, Mongolians and American Indians.

monocotyledons (mono-cot-i-lee'dons) or **monocots**: members of a subclass of flowering plants which have seeds with one cotyledon, parallel-veined leaves, and scattered bundles of tubes in the stem.

mosses: plants of many species belonging to the bryophyte group, with simple leaflike, rootlike, and stemlike parts; mosses have an alternation of generations in their life cycle.

mucous (mew'kus) **membrane**: lubricating membrane that lines the alimentary canal and some other organs in higher animals.

mucus: slimy substance secreted by mucous membrane.

muscle tissue: animal tissue consisting of contractile fibers. **Striated** or **voluntary** muscle: muscle attached to parts of the skeleton; **smooth** or **involuntary** muscle: muscle found in internal organs. **Cardiac** muscle: muscle found in the heart.

mutant (mew'tant): plant or animal that shows a mutation.

mutation (mew-tay'shun): a change in a gene in the germ plasm which will at some time appear in the offspring, such as the character of white eyes among red-eyed Drosophila.

narcotic: any of a group of substances that blunt the senses.

natural selection, Darwin's theory of: theory to explain how new types of living things appear on the earth. (Darwin believed that through the operation of natural causes the fittest, in general, survive to become the parents of the next generation, thus leading to changes in types.)

nectar: sweet liquid secreted by many flowers which attracts some insects and birds; bees can make honey from it.

Negroid: one of the three main stocks of living men; it includes, among others, the Negro and Melanesian races.

nerve: a bundle of nerve fibers or axons arising in the brain, spinal cord, or ganglia and ending among other cells of the body. Each fiber in a nerve is a projection from the cell body of a nerve cell.

neuron (new'ron): a nerve cell; **afferent** or **sensory** neurons send the impulse toward the brain or cord; **efferent** or **motor** neurons carry the impulse away from brain or cord; **intermediary** neurons lie between the afferent and efferent.

New Stone or **Neolithic Age**: period in the history of civilization which followed the Old Stone Age. It ended about 6,000 years ago.

niacin (nye'a-sin): vitamin of the B complex group; niacin deficiency may cause pellagra.

nicotine: strong poison found in the tobacco plant.

nitrate (nye'trayt): compound containing nitrogen, oxygen, and at least one other element; used by plants in making proteins.

nitrifying (nye'tri-fy-ing) **bacteria**: bacteria in the soil that build up ammonium compounds into nitrates.

nitrogen cycle: passage of nitrogen atoms from the element as found in the air through more and more complex compounds into living matter and back again to the free nitrogen of the air.

nitrogen-fixing bacteria: bacteria that build up proteins from free nitrogen; some kinds are found in nodules on the roots of legumes; other kinds live free in the soil.

nodule (nod'youl): small rounded mass, as on the roots of legumes in which live nitrogen-fixing bacteria.

nuclear membrane (new'klee-er): thin living layer around the nucleus.

nucleolus (new-klee'o-lus): rounded body within the nucleus that takes stain like chromatin but is different from chromatin.

nucleus (new'klee-us): small ball of denser protoplasm, lying within the cytoplasm, containing chromatin material.

oesophagus (ee-sof'a-gus): food pipe or gullet in many animals; in man tube connecting the throat with the stomach.

Old Stone or **Paleolithic** (pay-lee-oh-lith'ic) **Age**: first period in the history of civilization; ended about 10,000 years ago.

olfactory (ohl-fac'to-ree) **lobes**: most anterior part of the vertebrate brain, containing centers of smell.

opsonin (op'soh-nin): antibody in normal or immune blood serum which makes a particular kind of invading germ more easily eaten by phagocytes.

optic lobes: in vertebrates below mammals two distinct spherical portions of the brain behind the cerebrum, containing the centers of sight; in mammals optic lobes are small and inconspicuous.

order: in classification the largest subdivision within a class.

organ: distinct part of the body of a plant or animal which consists of tissues working together to carry on some activity.

organic compound: one of a large number of complex carbon compounds; often obtained from the bodies of living things or made by man.

organic disease: disease caused by the improper working of some particular organ.

organism: any single living thing.

ornithology (or-nith-ol'o-jee): study of birds.

osmosis (oss-moh'sis): technically the diffusion of water through a membrane; also used for diffusion of dissolved substances through a membrane.

outbreeding: see **crossbreeding**.

ovary (oh'va-ree): in many-celled animals the organ in which the eggs or ova develop. In higher forms special sex hormones are also produced in the ovary. In seed plants the lowest part of the pistil in which ovules with eggs develop.

overproduction: the reproduction by animals and plants of more offspring than can survive. Darwin pointed out that this results in a struggle for existence.

oviduct (oh'vee-duct): tube from the ovary through which eggs pass toward the exterior.

ovule (oh'vule): in seed plants that structure which normally grows into the seed after fertilization; in the true flowering plants it lies within the ovary and contains the embryo sac with its egg cell.

ovum (oh'vum); pl. ova: an egg cell.

oxidation: chemical union of oxygen with some other substance; results in the release of energy.

P_1 generation: parental generation; first two individuals crossed in any given breeding experiment.

Paleolithic (pay-lee-oh-lith'ic) **Age**: see **Old Stone Age**.

paleontology (pay-lee-on-tol'o-jee): study of the organisms that lived in former ages.

palisade cells: in a green leaf the regular, upright cells just under the upper epidermis.

pancreas (pan'cree-as): digestive gland near the stomach, which pours its juice into the upper end of the small intestine; other cells in the pancreas are ductless gland cells secreting insulin into the blood.

parasite (par'a-site): plant or animal that lives in or on some other living organism (its host), taking its food from the host.

parathyroids (par-a-thy'roids): two pairs of small ductless glands lying close to the thyroid; their secretion regulates the assimilation of calcium by the body.

parenchyma (per-en'kim-ma): tissue in plants that consists of thin-walled cells with large vacuoles; it may or may not have chloroplasts.

parthenogenesis (parth-en-oh-jen'e-sis): development of an egg without fertilization, as in some insects and other animals.

pasteurization (pas-ture-iz-ay'shun): heating a liquid, such as milk, to a temperature of about 150 degrees F., followed by chilling, so as to kill nonspore-forming bacteria.

pathogenic (path-oh-jen'ik): causing disease; term applied to certain microorganisms.

peat: partly decomposed vegetable matter found in marshy regions; used as fuel when dried.

pedigree (ped'ih-gree): table or chart showing the line of ancestors of a person or some other organism; record of family history.

pellagra (peh-lah'gra): deficiency disease caused by insufficient intake of niacin.

penicillin (pen-i-sill'in): a powerful antibiotic made by the mold **Penicillium**; used in treating certain diseases.

pepsin (pep'sin): enzyme in gastric juice which in the presence of hydrochloric acid changes protein into smaller molecules such as peptones.

peptones (pep'tones): diffusible, soluble substances into which proteins are changed by enzymes such as pepsin; intermediate products of digestion.

perennial (peh-ren'ee-el): plant that normally lives more than two years.

period: geologic subdivision of time within an era.

peristalsis (perr-i-stall'sis): wavelike contractions of the rings of muscle in a tubular organ in an animal; in man food is pushed along the alimentary canal in this way.

petals (pet'els): leaflike parts of a flower, usually white or brightly colored, lying within the sepals.

petiole (pet'ee-ohl): stalk of a leaf which attaches it to the stem of the plant.

petrifaction (pet-rih-fak'shun): process by which parts of living things are turned to stone.

phagocyte (fag'o-site): one of the white blood cells that takes in and destroys bacteria and other foreign particles.

phloem (flow'em): outer portion of the vascular cylinder in the roots and stems of ferns and seed plants; contains food-conducting cells (sieve tubes) and fibers.

photosynthesis (foe-toe-sin'the-sis): manufacture of carbohydrates out of carbon dioxide and water by chlorophyll, using light energy, usually from sunlight.

phototropism (fo-tot'row-pism): tropism in which the stimulus is light.

phylum (fy'lum): used in classification; largest division within the animal or plant kingdom.

pistil (pis'till): organ in the center of a flower within which the egg cell or cells are located.

pistillate (pis'till-ate): applied to flowers having pistils but no stamens.

pith: tissue of thin-walled cells sometimes found in the center of dicot stems.

pituitary (pit-two'i-ter-ree) **body**: ductless gland at the base of the brain, secreting many hormones, one of which regulates the growth of the skeleton; often called the "master gland."

placenta (pla-sen'ta): in mammals that part of the wall of the uterus to which the embryo is attached and through which it is nourished. The placenta consists of membranes formed by the uterus and by the embryo. In the ovary of plants the placenta is the place of attachment of the ovules.

plasma (plaz'ma): liquid part of the blood, usually straw colored.

plasma membrane: see **cell membrane**.

platelet (plate'let): tiny blood cells that start the process of blood clotting; under certain conditions they break down and release a substance that aids the clotting.

pleura (ploo'ra): thin, moist membrane that covers each lung and lines the chest cavity in mammals.

plexus (plex'us): in the autonomic nervous system of the higher vertebrates it is a network of ganglia and nerves lying near or within the walls of some of the internal organs; in the central nervous system, it is a network of nerve fibers.

plumule (plume'you-l): in the embryo of a seed plant, the part that will grow into the shoot.

pollen (pol'en): tiny grains produced by the anther of the stamen of a flower (in conifers by the male cone); within each grain there is formed, besides other nuclei, the sperm nucleus which will unite with the egg nucleus. **Pollen tube**: tube that grows from the pollen grain lying on the stigma; normally, it extends to an ovule, carrying the sperm nucleus and the other nuclei toward the egg cell.

pollination (pol-in-ay'shun): transfer of pollen from anther (of stamen) to stigma (of pistil). **Self-pollination**: transfer within the same flower or between different flowers of the same plant. **Cross-pollination**: transfer between flowers of different plants.

polydactyly (polly-dak'tih-lee): condition of having more than the normal number of fingers or toes.

Porifera (pore-if'er-a): phylum of invertebrates whose bodies are pierced with many holes, such as sponges.

posterior (poss-tee'ree-or): hind end; referring to the trunk of an animal, the end opposite the head.

primates (prim-ay'tees): order of mammals including those with the best developed brains, such as monkeys, great apes, and man.

protective resemblance: see **adaptation, protective.**

proteins (pro'tee-ins): group of nitrogenous compounds needed by all living things for making protoplasm; plants make proteins from simpler substances.

prothallus (pro-thall'us): in the ferns and their relatives a tiny, flat, green plant that grows out of a spore, producing in time eggs and sperm; sexual phase in the life history of the fern.

protonema (pro-toh-nee'ma): in mosses and their relatives a tiny green, branching filament that grows out of a spore; buds forming on the filament grow into leafy plants.

protoplasm (pro'toh-plasm): living matter that makes up all plants and animals.

Protozoa (proe-toe-zoe'ah): phylum of single-celled animals.

pseudopod (siu'doe-pod): temporary projection from the body of certain kinds of cells; used in locomotion and food getting.

psychiatrist (sy-kye'a-trist): physician who is an expert on mental illness.

psychologist (sy-kol'o-jist): person trained in the science of human and animal behavior.

pteridophytes (ter'id-oh-fites): in plant classification the large group or phylum that includes the ferns, club mosses, and horsetails.

ptyalin (ty'a-lin): digestive enzyme in saliva that changes starch into one kind of sugar (maltose).

pulse: regular expansion (and relaxation) of the arteries caused by the successive contractions of the heart; can be easily felt in the wrist.

pupa (pew'pa): in the complete metamorphosis of insects, the nonfeeding stage between larva and adult.

pure: in genetics a term applied to an organism in which the two genes of a pair are alike; the organism is then pure with respect to that one pair of genes and to the character they determine; the organism as a whole would be pure only if this were true of every pair of genes.

pus: yellow-white substance that may form in an infected part of the body, consisting of dead white cells, dead and living germs, and a little plasma.

pyloric sphincter (pie-lor'ik sfink'ter): a circular band of muscle at the opening between the stomach and small intestine; when relaxed, food can go into the intestine.

quarantine (kwar'un-teen): prevention by those in authority of free movement of people, other living things, or goods in order to stop the spread of disease.

race: in the classification of man a subdivision of a stock composed of people who tend to have certain inborn physical characters in common, such as Nordic and Hindu races.

radial symmetry (ray'dee-el sim'e-tree): arrangement of parts in an animal in such a way that the parts radiate from a central point, as the arms of a starfish.

receptors: sense organs which keep an animal in touch with the environment, such as the eyes, ears, taste buds, etc.

recessive: in genetics, that character of a pair of contrasting characters that does not show in the hybrid offspring, as shortness in pea plants; applied also to the gene.

reduction division: nuclear division in which the number of chromosomes is reduced to half; reduction division in higher plants and animals occurs just before or at the time sperms and eggs develop.

reflex act: in an animal a direct response to a stimulus which is immediate, which is inborn and therefore predictable, and which may or may not be accompanied by consciousness of the act.

reflex arc: path of a nerve impulse from a receptor, along an afferent neuron, through the brain or cord, and out along an efferent neuron to the cells that respond.

regeneration (ree-jen-er-ay'shun): growing back of a part of an organism or a part of a cell which has been lost by injury, as the arm of a starfish, healing tissues, or the axon of a nerve cell.

rennin: enzyme found in our gastric juice; curdles milk.

reproduction: process by which living things make more of their own kind.

reptiles: members of a class of vertebrates with a covering of dry scales and breathing by means of lungs, such as snakes, lizards, turtles, etc.

respiration: in animals the process by which oxygen is taken into the body and used in oxidation, together with the release of the products of oxidation from the body. **Cellular respiration**: whole process in individual cells in animals. In plants respiration is the oxidation of foods in the cell.

response: behavior in living things brought about by a stimulus.

retina (ret'i-na): innermost layer of the eyeball in vertebrates, containing the cells sensitive to light.

Rh factor (R–H factor): substance in the blood of most people; persons who lack it are said to be RH negative. (Discovered in the Rhesus monkey; hence its name.)

riboflavin (rye-bo-flay'vin): vitamin in the B complex group; B_2, formerly called vitamin G.

rickets: condition in which the bones fail to develop properly, remaining soft; caused by deficiency of vitamin D or calcium or both.

rodents: members of the order of gnawing mammals with strong incisors, such as rats and beavers.

root hair: microscopic outgrowth from an epidermal cell of a root; absorbs water and minerals.

runner: slender stem growing along the ground, taking root at intervals, and producing new plants at such points, as in the strawberry.

salivary (sal'i-very) **gland**: one of three pairs of glands which empty their secretions into the mouth.

sanctuary (sank'chew-e-ree): area set aside, usually by the government, in which wildlife is protected; refuge.

saprophyte (sap'row-fite): plant that lives and feeds on dead organisms or dead organic matter.

science: organized facts and "laws" about the world and living things; also the method by which men reach understandings about the world and living things.

scion (sy'on): in grafting, the twig or bud attached to the growing plant.

sclera or **sclerotic coat**: dense fibrous membrane, forming with the cornea the outermost coat of the eyeball.

scurvy: deficiency disease caused by insufficient intake of vitamin C.

secondary sex characters: bodily characteristics, other than the sex organs themselves, which in many higher animals distinguish the male from the female, such as bright plumage in male birds.

secretin (see-cree'tin): hormone produced by the small intestine which stimulates the pancreas to secrete its digestive juice.

secretion (see-cree'shun): producing and giving off useful substances by cells or groups of cells in plants and animals; cells or groups of cells specially fitted for this are called **glands**.

sedimentary rock: rock formed from sand or mud laid down as a sediment in water and finally compressed into rock.

seed: ripened ovule containing an embryo plant.

seedling: young plant from the time it emerges from the seed until it is entirely dependent on food made by itself.

segment: one of the rings that compose the body of annelids, most arthropods, and chordates.

segregation, law of: law stating that the two members of a pair of genes separate in reduction division without having changed one another. As stated by Mendel: in the crossing of hybrids the recessive character shows up in the offspring; the ratio in the offspring being 1 pure dominant to 2 hybrids to 1 pure recessive.

selection: in breeding, the choosing of certain organisms with desirable characters to be the parents of future generations.

semicircular canals: three arches lying in different planes in the inner ear; concerned with the sense of balance.

sepals (see'pals): leaflike parts forming the outermost circle of most flowers, usually green; together they form the calyx.

serous (sear'us) **membrane**: very thin, smooth membrane lining the blood vessels and body cavities in man and other animals; also covers organs.

serum: in general any watery animal fluid; in clotting, the blood serum is the clear liquid which separates from the clot; when containing special immune substances serum is used for inoculation.

sex cells: male and female reproductive cells; eggs and sperms; contained in male and female **sex organs**. **Primary sex cells**: the cells which eventually in maturation develop into sex cells.

sexual reproduction: commonest method of reproduction among both simple and complex animals and plants in which the life of the new individual starts with the union of two cells (gametes).

sheeting: floating or steady downhill moving of a well-soaked layer of topsoil.

shrub: woody, perennial seed plant with stems branching just above the ground; usually smaller than trees.

sieve (siv) **tubes**: tubes in the phloem consisting of living cells through which manufactured foods pass. **Sieve plates**, or cell walls with holes, form at the top and bottom of each cell of a sieve tube.

slip or **cutting**: piece of a stem or leaf suitable for propagation of a new plant.

somatic (so-mat'ic) **cells**: cells in a higher animal that make up the body as distinguished from the sex cells.

somatoplasm (so-mat'oh-plasm): protoplasm of the somatic cells as distinguished from germ plasm.

spawning: releasing of eggs into the water by aquatic animals.

species (spee'shees): in classification the subdivision of a genus; often the final division. Every species has a name of at least two words, the first of which is the genus name.

spermary (sperm'a-ree): testis; male reproductive organ in animals. It produces sperm cells which pass to the exterior through sperm ducts.

spermatophytes (sperm-at'oh-fites): members of a large group (phylum) of plants that produce seeds; "highest" plant group.

spinal column: series of vertebrae in the region of the back which enclose the spinal cord.

spinal cord: nerve tissue which is the continuation of the brain and which lies within the spinal column.

spiracles (spy're-kels): in insects and some other arthropods the openings on the surface of the body leading into the breathing tubes or tracheae.

spirillum (spy-ril'lum): spiral-shaped bacterium.

spleen: an abdominal organ in higher animals; stores blood, especially red cells, makes certain white blood cells, and destroys old red blood cells.

spongy parenchyma (per-en'kim-ma): irregular cells surrounding air spaces just above the lower epidermis of a leaf.

spontaneous generation, theory of: living things can arise from dead matter; now disproved.

sporangium (spore-an'jee-um) or **spore case**: spore-forming organ in many plants.

spore: in reproduction, a one or two-celled body formed sexually or asexually in plants and some protozoa; in some cases it has a resistant wall. Also a bacterium in a stage in which it has a thick, resistant wall.

sporulation (spore'you-lay'shun): multiple division of a cell resulting in the production of spores, as in the bread mold; form of asexual reproduction.

stamen (stay'men): organ of a flower that produces the pollen; one of the essential organs.

staminate (stam'e-nate): applied to flowers which have stamens but no pistils.

sterile: free from living bacteria; also, unable to reproduce.

stigma: somewhat expanded top of a pistil of a flower to which pollen is normally transferred.

stimulant: something that temporarily quickens a process or activity of some organ or tissue of an animal or plant.

stimulus (stim'you-luss); pl. **stimuli**: anything that calls forth a response in any living thing.

stock: in grafting, a stem to which a scion is attached and which is its support. Also, a major division in the classification of mankind, such as Caucasoid, etc.

stoma (stoh-ma); pl. **stomata**: tiny opening in the epidermis of a leaf through which gases pass in and out.

strain: a variety, especially of microorganisms. Or a variety of domestic animal or cultivated plant produced by a breeder.

strata (stray'ta): parallel layers of sedimentary rock, each generally consisting of one kind of sediment deposited continuously over a long period of time.

streptomycin (strep-toh-my'sin): drug made from soil bacteria; antibiotic.

striated (stry'ay-ted) **muscle**: voluntary muscle or muscle which is under the control of the central nervous system. The fibers have cross lines.

structure: construction and arrangement of parts or organs of an organism.

style: usually slender portion found in many pistils between stigma and ovary.

sulfa drugs: large variety of compounds (sulfanilamide, etc.) in common use since the 1930's in treating various diseases and infections.

survival of the fittest: according to Darwin's theory of natural selection the survival of the best adapted organisms, which thus become the parents of the next generation.

symbiosis (sim-by-oh'sis): intimate living together of two species of organisms to the advantage of each, as the alga and fungus in a lichen.

synapse (sin'aps): region where a nerve impulse is transferred from one neuron to another; includes the end brush of one cell and the dendrites of another.

tadpole: water-living form in the life history of frogs, toads, etc.; it hatches from the egg.

tagged atoms: also called **tracers**; radioactive isotopes which, when introduced into the body, can be traced and thus help in explaining the use of various elements in body processes.

taproot: long, main root of a plant, corresponding to a main stem.

tendril (ten'dril): thin, stemlike part of many climbing plants, responsive to contact and twining around any other object.

tentacles (ten'ta-culs): slender, flexible projections of an animal; hydra and jellyfish use them for food getting and protection.

testis (tes'tis); pl. **testes:** another name for the spermary of a male animal.

thallophytes (thal'oh-fites): members of a phylum of simple plants without true stem, root, or leaf, such as algae, fungi, and lichens.

thiamin (thigh'a-min): one of the vitamins of the B complex group (B_1); needed in the diet to prevent beriberi.

thoracic (thor-as'sick) **duct:** large lymph-carrying vessel that empties lymph into a vein under the left collarbone.

thorax (thor'aks): in higher vertebrates, the part of the body between the neck and abdomen, containing heart and lungs; in insects, the part between the head and abdomen.

thoroughbred (thor'oh-bred): animal bred from parents with certain desirable traits and whose pedigrees are registered.

thymus (thigh'mus): organ in man lying behind the upper part of the breastbone; plays an important role in children; may be a ductless gland.

thyroid (thigh'royd) **gland:** ductless gland in the neck just below the voice box; secretes thyroxin.

thyroxin (thigh-rox'in): hormone secreted by the thyroid gland, containing comparatively large amounts of iodine. It speeds up oxidation in the body.

tissue (tish'you): group of cells, sometimes including cell products, which are alike in structure and do the same kind of work.

toxin (toks'in): specific poison made by pathogenic microorganisms and causing a specific disease; also, poisons produced by certain animals and plants.

toxoid (toks'oid): weakened toxin used for inoculation into people and animals against diphtheria, tetanus, etc.

trachea (tray'kee-a): in higher vertebrates the windpipe; in insects one of the tubes that branch throughout the body carrying air.

transpiration (trans-pir-ay'shun): diffusion into the surrounding air of water from the cells of a plant leaf.

trichinosis (trick-i-noh'sis): disease of men, pigs, and some other animals caused by the trichina worm which enters the digestive tract and settles in the muscles.

trilobite (try'lo-bite): any of a group of extinct arthropods that lived in great abundance in the seas during the Paleozoic era.

tropism (troh'pism): the turning of a plant or animal or one of its parts toward (**positive tropism**) or away from (**negative tropism**) the source of a stimulus.

trypsin (trip'sin): digestive enzyme in pancreatic juice that breaks down proteins and peptones into still smaller molecules.

tuber (too'ber): fleshy underground stem capable of producing new plants by vegetative reproduction, as the Irish potato.

twins: see **fraternal twins** and **identical twins.**

ultraviolet: light rays invisible to us, lying just beyond the violet end of the spectrum.

umbilical (um-bil'ick-el) **cord:** in a mammal the cord that connects the embryo with the placenta; blood vessels from the placenta to the embryo lie in it.

unit characters: see **independent assortment.**

urea (you-ree'a): nitrogen compound produced and given off as a waste in animals when proteins are oxidized or when amino acids are broken down in the liver.

ureter (you-ree'ter): in vertebrates a tube leading from the kidney to the bladder.

"use and disuse": name given to Lamarck's theory of how organisms change through the ages.

uterus (you'ter-us): in mammals the organ in which the embryo lies during its development.

vaccination (vax-i-nay'shun): process of making a person immune to smallpox; now applied to active immunization against other diseases, such as typhoid.

vaccine (vax'seen): virus of cowpox, used for preventing smallpox; nowadays any modified disease-producing material used to prevent a specific disease.

vacuole (vak'yoo-ohl): drop of liquid in the cytoplasm of plant cells particularly; **contractile vacuole:** special vacuole in protozoa used in excretion of liquid wastes; **food vacuole:** also in protozoa, particle of food surrounded by water within the cell.

vagina (va-jeye'na): in mammals the passage from the uterus to the outside of the body through which the embryo passes at birth.

variety (var-eye'e-tee): subdivision within a species based on some hereditary difference considered too small to make a new species.

vascular (vas'cue-lar) **bundle:** a group of conducting tubes and wood cells in a young dicot stem and root and leaf or in a monocot stem. In older stems they are replaced by the vascular cylinder.

vascular (vas'cue-lar) **cylinder:** the cylinder in or near the center of a dicot root and stem, holding the water-conducting tubes.

vegetative propagation (vej'a-tay'tiv prop-a-gay'-shun) or **reproduction:** asexual reproduction in higher plants from parts other than the reproductive organs, such as roots.

vein (vain): vessel that carries blood toward the heart. In a leaf the vein consists of conducting tissues and wood fibers.

venereal (ven-ee'ree-al) **disease:** disease spread commonly through the sex organs, such as syphilis and gonorrhea.

ventral: under or belly side of an animal; opposite of dorsal.

ventricle (ven'tri-k'l): in the vertebrate heart the chamber (in higher vertebrates there are two ventricles) which pumps blood into the artery or arteries.

vertebra (ver'te-bra): one of the bones composing the backbone of vertebrates.

vertebrates (ver'te-brayts): animals with backbones, making up a subphylum of the chordate phylum.

vestigial (ves-tij'ee-al) **structures:** in animals or plants imperfectly developed structures having little or no use, but which were useful in preceding organisms.

villus (vill'us): one of the many tiny projections of the lining of the small intestine into which digested foods are absorbed.

virus (vy'rus), or **filterable virus:** ultramicroscopic agents of infection, requiring living cells for multiplication; small enough to pass through a porcelain filter.

vitamin (vye'te-min): one of a group of substances in foods occurring in small amounts and necessary to keep the body in a healthy condition.

warm-blooded: applied to animals whose body temperature remains relatively constant.

weathering: breaking up of rocks or changes in their composition caused by the action of the atmosphere.

weed: a plant "out of place," that is, a plant growing where it is not wanted.

xylem (zye'lem): woody inner portion of the vascular cylinder in root and stem of ferns and seed plants.

yolk: that part of the egg of some animals, such as the fish, frog, bird, and others, which supplies food to the developing embryo.

zoologist (zoh-ol'o-jist: person who makes a special study of animals.

zygospore (zeye'go-spore): cell with a thick cell wall formed by the fusion of two similar gametes in plants.

zygote (zeye'goat): fertilized egg cell in plants and animals.

INDEX

Figures in boldface (black) indicate pages on which there are illustrations. Figures preceded by "def." indicate pages where definitions are found.

Abdomen, bird, **21**; grasshopper, **45**; insect, 41
Abdominal cavity, 229
Abscess, 210
Absorption, def., 124–**125**; def., 197; of food, 197–198
Accidents, 362–363; and alcohol, 367
Acetic acid, and wine, 323
Acne, 242–243
Acquired characters, 487–488; and evolution, 559–560; and heredity, 488–490
Acquired immunity, 316; active, 324; passive, 328
Acromegaly, 253
Active immunity, 324, 327; against tetanus, 331
Adaptations, 560–561
Adenoid, **226**
Adolescents, and mental health, 368–369
Adrenal glands, **238**, 252–253
Adrenin, 252–253
Aeration, of drinking water, 345
Afferent neuron, 278, **278**
African sleeping sickness, 349
African tribe, and disease, **320**
Agar, 75, 313; plate, **314**; slant, 313
Agaricus, **73**
Age of Mammals, 538–539; scenes of, **539**
Age of Man, 539–540
Age of Reptiles, 537; scene of, **537**
Age of Trilobites, 535–536
Agglutinins, 316
Agote, Dr. Luis, and blood banks, 212
Agricultural Experiment Stations, 391
Agriculture, U.S. Department of, 391, 402
Air, in breathing, 226–227; changes of, in breathing, 231; gases in, 231
Air conditioning, 242
Air pressure, and breathing, 229–230
Air sacs, **227**, 228, 230–231
Airplane, and insect control, 393
Albino, def., 509; **510**
Albumen, 430; and pneumonia vaccine, 339
Alcohol, 174, 366–367; and accidents, 367
Alfalfa, 87
Algae, **73**, **76**, 90, **375**
Alimentary canal, 188, **189**; absorption in, 197; digestion in, 188–198
Allergy, and skin, 243; causes, 364–365; def., 364; tests for, **365**
Alligator, 29–30; brain, **273**
Alternation of generations, def., 446; in fern, 445–446; in flowering plant, 446–447; in moss, 447
Amanita, **75**
Amber, fossils in, 528
Ameba, **40**, **62**, 63–64, 118; behavior, 265–266, **266**; reproduction, 412–413, **413**
American Tree Association, 406
Amino acids, 142, 190, 196, 199, 208; and diet, 174
Amphibians, 30–31 (see Frog)
Amylase, 196
Anaesthetic, 367
Anatomy, def., 548
Ancon, sheep, 497, **498**
Andalusian fowl, heredity in, **468**
Anemia, 209; and hookworm, 354; in malaria, 351
Anemone, sea, **59**
Angiosperms, 81, 91
Animals, classification table of, 65–66; man's use of, 382; review of, 64–66; survey of, 15–71
Annelids, 57
Annuals, def., 80
Annual rings, 156–157, **156**
Anopheles, **349**; and malaria, 349–351
Anoxia, 233–234; def., 233
Anteater, spiny, **20**
Antenna (feeler), 41; of grasshopper, **45**
Anther, **439**; def., 441
Anthills, 47
Anthrax, and immunity, 324; cause of, 321
Anthropologist, def., 575
Antibiotics, def., 334
Antibodies, 316, 324, 338–339; and typhoid, 327
Antiseptic surgery, 332
Antiseptics, 315; for wounds, 333
Antitoxin, def., 316; and diphtheria, 328–329; and diphtheria deaths, **329**; preparation, 328–329, **329**; for tetanus, 331
Antivaccination movement, 326, 336–337
Ants, 46–47, **47**; with aphids, **47**; life cycle of, **47**; tending mealy bug, **47**
Anus, 188, 198
Anvil (bone of ear), 282
Aorta, **213**, 218, **218**
Apes, 16
Aphids, 46, **47**; reproduction of, 424
Appendage, bat, **549**; cat, **549**; def., 41; insect, 41; man, **547**; monkey, **549**; seal, **549**; whale, **547**
Appendicitis, 362
Appendix, 188; in man, 550; in rabbit, 551
Apple, **444**; and codling moth, 393–394; effect of spraying, **395**
Aquarium, balanced, 378–379, **378**
Arachnids (spiders), 50–51, **50**, **51**
Archaeornis, fossil, **538**
Archaeozoic era, 533, **534**
Aristotle, 96
Arm, cells and tissues of, 129–130; of microscope, 113
Arsenic, and insects, 393; and syphilis, 332
Arteries, 206, 207, **207**, 214; and blood movement, 215; structure of, 215–216, **215**
Arthropods, 41–53; examples of, **41**
Artifacts, def., 564; Stone Age, **565**
Artificial parthenogenesis, experiments in, 424
Artificial respiration, 232–233, **232**; rocking method, 233; Schaefer method, **232**, 233
Aryan race, 576
Ascorbic acid, 180–181, 183; in common foods, 173
Aseptic surgery, 332
Asexual reproduction, 412–415; def., 417; in fern, 445–447; in flowering plant, 446–447; in moss, 447; by vegetative reproduction, 447–449
Assimilation, 143; def., 125
Asthma, 228; and adrenin, 253; and allergy, 364
Atabrine, and malaria, 351
Athlete's foot, 311
Atoms, tagged, 250
Auditory nerve, **281**, 282
Auricle, def., 213; **213**, **218**, 219, **219**, 220, **220**
Australian mammals, explanation of, 552
Autonomic nervous system, 270, 279, **279**
Autopsy, def., 251
Auxin, 303–304; "artificial," 304

Aves, 65 (see Birds)
Aviators, and breathing, 233–234
Axon, 274–275, ***274***, ***277***; nutrition of, 275–276
Azoic era, 533, 534

Baby, and learning, 288–290
Bach, Johann Sebastian, heredity of talent, 511
Bacillus, ***312***, 321; coli, ***312***; of tetanus, ***330***
Backbone, animals with, 16–39; def., 271; of man, ***226***; of snake, ***28***
Backcross, 476
Bacon, Francis, and food preservation, 384
Bacteria, 77–78, 311–316, 330, 332; and antibiotics, 334; and body's defenses, 315–316; and cheese, ***384***; colonies, ***314***; conditions of growth, 314–315; def., 311–312; digestion, ***312***; entry to body, 315; food-getting, ***312***; germ theory, 320–322; and horse, 374; methods of identifying, 314; methods of studying, 312–314; and milk supply, 345–347; and nitrogen cycle, 376–378; and pasteurization, 346; and phagocytes, ***210***; of pneumonia, ***78***; and skin disorders, 242–243; and soil restoration, 405; spores, 314–315; and surgery, 331–332; types, ***312***; typhoid, ***313***
Bacteriology, def., 312; and length of life, 359; and study of viruses, 339
Bacteriophage, 340–341
Balance, sense of, 282
Balanced aquarium, 378–379, ***378***
Bamboo stems, 157
Banana, 85
Bark, birch, ***154***, 156–157; of trees, 153–154
Barley, 84; mutation, ***480***
Barnacle, 53; rock, ***52***
Barriers, kinds of, 552
Basal metabolism, 170; apparatus, ***171***; thyroid, 247
Basic Seven, in diet, ***182***
Bathing, 242
Bathysphere, 6–7
Bats, 18, ***19***; appendages of, ***549***
BCG, vaccine for tuberculosis, 328
"Beagle," and Charles R. Darwin, 556
Bean, graph of lengths of, ***487***; seed, ***438***
Bear, black, ***99***; polar, ***99***
Beaumont, Dr. William, and gastric digestion, 193
Beaver, dam, ***264***; dam-building, 262
Beech, bark of, 153–154; purple, 137
Bees, 48–49; drone (male), ***48***; kinds of, ***48***; life cycle of, 48–49; nervous system of, ***275***; queen, ***48***; swarming, ***48***; worker, ***48***
Beeswax, 48
Beet, plant, ***141***; roots, ***149***
Beetles, 46; Colorado potato, 46, ***46***; and Dutch elm disease, 287; ladybird, 46; pine, ***390***
Behavior, 260–308, ***260***; of ameba, ***265***; complexity of, 286–289; def., 261; and emotions, 296–298; examples, 261–266, 269–282, 286–298, 301–306; learned, 287–296; of lower animals, 262–266; of man, 286–300; of mimosa, ***305***; misuse of words, 265; and nervous system, 269–270, 286; of paramecium, 266, ***266***; Pavlov's experiments, 9–10; plant and animals compared, 302–303, 305; in plants, 301–306; in protozoa, 265–266; unlearned, 262–266; of vorticella, ***269***
"Bends," 233
Benedict's solution, 116
Benzoate of soda, 384–385
Beriberi, 176–177, ***177***; 183
Bernard, Claude, and diabetes, 251
Bicuspids, 203
Biennials, def., 80
Bile, 192, ***195***, 196, 198–199; duct, ***195***; salts, 197
Binary fission (see Fission), 413
Biological Survey, Bureau of, 406
Biologists, 3
Biology, def., 3
Birch, bark, 153, ***154***; water loss, 159
Bird laws, 406
Birds, 20–26; banding, 37; bills (beaks), ***23***; brain of, ***273***; calendar, ***38***; characteristics of, 20; classification of, 20–21; "family life," 431–432; flight of, 23, 25; and insect control, 395–396; migration of, 22–23; migration routes of, ***24***; names of parts of, ***21***; nonflying, 22; perching, 22; of prey, 21; reproduction of, 430–432; scratching, 21; wading or swimming, 21–22
Bird's-foot violet, ***407***
Birth, in rabbit, 433
Bismuth, and syphilis, 332
Bison, ***99***; hybridization of, 501
Black ant, ***47***
Black body, in fruit fly, 472
Black Death, 328, 343
Blackheads, 242
Black raspberry, vegetative reproduction of, 449
"Blackout," of aviators, 217
Black widow spider, ***50***, 51
Bladder, 238; of frog, ***422***; of man, ***238***
Blade, of leaf, 137–139
Blastula, def., 425; ***425***
"Bleeders," 211; heredity of, 473
Bleeding, first aid for, 215
Blending inheritance, def., 467, 468; in fruit fly, 470
Blister rust, of pine, 386, ***386***
Blisters, 220
Blood, 206–225; and adrenin, 252; cells, 209–210, ***208***, ***210***; circulation, 206–220, ***218***, ***219***; clotting, 210–211, ***211***; composition, 208–213; and diabetes, 250–252; donations, ***212***; groups, 211–212; movement, 213–220; path, 218–220; platelets, ***208***, 209–211; sugar in, 251; table of exchange of substances in, 256; transfusions, 211–213; types, 211–212; vessels, 206–221, ***207***, ***213***, ***215***, ***217***, ***218***, ***219***, ***220***, ***221***
Blood banks, 211–212
Blood plasma, in transfusions, 212–213
Blood poisoning, 331–332
Blood pressure, ***216***, 216–217
Blood protein, in transfusions, 212–213
Blood vessels, of cat's intestine, ***215***; of earthworm, ***57***; of frog, ***207***; of skin, ***240***
Bloodhound, ***255***
Blubber, 18
Blueberry, improved by breeders, ***501***
Board of Health, and disease prevention, 343–344; inspections, 346–347; inspector in milk plant, ***347***; worker in laboratory, ***323***
Bobcat, ***17***
Body louse, 349
Body temperature, 239
Boll weevil, cotton, 389, ***390***
Bone tissue, 130, ***130***
Bones, arm, ***547***; ear, ***281***
Boston, bird calendar, 38; water supply, 345
Boston fern, 499, ***499***
Botany, def., 3
Boulder, def., 521
Boy Scouts, 233
Boyce Thompson Institute for Plant Research, 304
Brachydactyly, def., 509
Bracket fungus, ***75***

Brahman cattle, 499; bull, *500*; Hereford hybrid, *500*; Jersey hybrid, *500*
Brain, 270–274; alligator, *273*; dog, *273*; fish, *273*; frog, *273*; human, *271*; sheep, *271*; sparrow, *273*
Brain stem, 271
Braincase, of man, *226*
Bread mold, 77; *414*; reproduction of, 414–415, *414*
Breaking habits, 294
Breast bone, 229
Breathing, 226–236, *228*; air changes by, 231; and air pressure, 229–231; center, 231–232; in high altitudes, 233–234; mechanics of, 228–230; models of, *236*; movements, 228–229; rate, 232–233; regulation of, 231–232; summary of, 234
Breed, def., 495
"Breed true," def., 468
Breeders, early achievements of, 493; methods of, 493–505
Breeding, 493–505; summary of, 504–505
Bronchi, 227, *227*
Bronchial tubes, of man, *227*; 228
Brontosaurus, 537–538
Bronze Age, 573
Broomcorn, use of, 160
Broth, for raising bacteria, 313
Brown algae, 73
Brown-tail moth, 396
Bryophyllum, vegetative reproduction of, *448*
Bryophyta, 90–91
Bryophytes, classification of, *73*; 90–91 (see Moss)
Bubonic plague, 328, 343; and insect carriers, 348
Budding, def., 414; of hydra, *59*, 414
Buds, lateral, 154, *155*; terminal, 154, *155*; of yeast, *413*, 414
Bugs, 46
Bulb, def., 449; of tulip, *448*
Bull, purebred, *497*
Bumblebee, 48
Burbank, Luther, and plant breeding, 502
Burdock, 90; seeds, *445*
Burning, 119
Bush turkey, behavior of, 263–265
Butterfish, and parasites, 380
Butterfly, *41*; life cycle of, 41–42, *42*; Monarch, *42*

Cabbage butterfly, 393
Cactus, 137; barrel, *160*; water loss in, 160
Calcium, in common foods, 173; dietary experiment with, *175*; and parathyroids, 254–255
California Institute of Technology, and antibodies, 338
California redwoods, *156*
Callus, 241
Calories, def., 169: 169–174; calculation of, 171–174; in common foods, 172; need for, 170–171
Calorimeter, 169, *170*
Calyx, 439
Cambium, 156; and grafting, 502; of root, *152*, 153; of stem, 154
Cambrian period, 535–536; underwater scene of, *535*
Camel, *17*
Camomile, *89*
Camphor, and insect control, 395
Canada lynx, *17*
Cancer, 13, 360–361
Canine, tooth, 203
Canis, 98, *98*; 99; dingo, 98; familiaris, 98
Canning, of food, 385; and vitamin C, 180–181
Cannon, Dr. Walter B., 200; and adrenin, 252
Capillaries, 206–207; of frog, *207*; of lung, *227*, 228; structure of, *215*; of sweat glands, 239; of villus, *198*; and wastes, 237–238
Capillary action, in plants, 159
Carbohydrates, 110, 112; in common foods, 172; in diet, 174
Carbolic acid, and surgery, 331–332
Carbon, 108, *110*, 111; cycle, 375–*376*
Carbon dioxide, in breathing, 231; and breathing rate, 232; in photosynthesis, 140; as waste, 237
Carboniferous period, 536–537; scene of, *536*
Cardiac muscle, 224
Carnivores, def., 17–18, *19*, *99*
Carotene, 140, 183; and vitamin A, 178
Carriers, of disease, 347–348; other than man, 348
Carrot, 88; wild, 87, *88*
Cartilage (gristle), 32; tissue, *132*; of windpipe, 227
Castings, of earthworms, 57
Cat, *169*; appendage of, *549*; blood vessels of intestine of, *215*; chromosome number of, 459; continuity of germ plasm in, *489*; and heredity, *465*; and learning, 291; muscle cells of, *129*; Persian, *97*; skeleton, *548*
Catalyst, 190–191
Caterpillars, 42, *42*, *43*; codling moth, 393–394, *394*; gypsy moth, *392*, 393; tent, *393*
Cattalo, 501
Cattle, Brahman-Hereford cross, *500*; Brahman-Jersey cross, *500*; effects of selection on, 496; Texas-Brahman cross, 499–501
Caucasoid, 574
Causes of death, chart of, *360*
Cell, bacterial, *78*, 311–312, *312*, *313*, 314; body, 106, *106*, *107*, *132*; body of neuron, 274–275; def., 61, 105–135; division versus fission, 413; doctrine (theory), 125–126; functions, 118–128; and growth hormones, 303–304; membrane, 106, *106*, *107*, 111; membrane in diffusion, 123–124; parts of, 106–107; protozoan, 61–64, *62*, *64*; sap, 151; structure, 106–112, *106*, *107*; typical animal, *107*; typical plant, *107*; use of food in, *168*; wall, 106, *107*; wastes, 237
Cell division, 456–459; animal, *458*; plant, *457*
Cell wall, in cell division, *457*
Cells, 105–135, 111; activities of, 118–128; algae, 73–74, *74*, *76*; arrangement of, 129–135; blood, *208*, 209–211, *210*; in blood vessels, *215*, 216; body, *221*; cartilage, *132*; chlorophyll in, 139–140; comparison between plant and animal, 106–107; conjugation of, 415–417, *416*, *417*; def., 124–125; differentiation of, 131; and disease, 315; egg, *423*, *428*; embryo sac, *441*; epithelial, *132*, *227*; fat, *132*; fertilization of, 417–418, 422–434; germ plasm, 488–490; guard, *139*; and heredity, 454–519; and hormones, 246–258; involuntary muscle, *129*; leaf, *139*, 138–140; leaf epidermis, *139*; malaria, *350*, *351*; mucous membrane, 227; nerve, *132*, *228*, 274–276, *274*, *277*; palisade, 139; phloem, *153*; and plant tropisms, 302–304; pollen, *442*, 442; potato, *143*; reproduction of, 412–453; root, *150*, 151–153; root hair, *150*; skin, 241–242; sperm, *423*; spongy, *139*; staining, 321; stem, 153–157; stomach, 191; summary of, 111–112; sweat gland, *240*; tetanus, *330*; villus, *198*; voluntary muscle, *132*; yeast, *413*
Cellular respiration, 231
Cellulose, 106, 110, 111, 198; and pneumonia vaccine, 339
Cenozoic era, 533, *534*, 538–539
Centipede, 52; house, *52*
Central nervous system, of man, *270*, 270
Centrifuge, 209

Centrosome, *458*
Cereals, 84–85
Cerebellum, 271–273; functions of, 273; human, *271*; of vertebrates, *273*
Cerebral hemorrhage, 217
Cerebrospinal fluid, 272
Cerebrum, 271–274; functions of, 272–273; and hearing, 282; human, *271*; of sheep, *271*; of vertebrates, *273*
Chalk cliffs, 64
Chance, effect on heredity, 466–467
Chaos chaos, 64
Character (see Characteristics)
Characteristics, acquired, 487–490, 560; of amphibians, 30–31; of animals, 15–71; of arthropods, 41–53, *41*; of bacteria, 311–312; of birds, 20–26, *21*; and breeding, 493–507; and chromosome changes, 481–483, *482*; and chromosomes, 466–467; in classification, 95–103; of coelenterates, 58–60; of crustaceans, 52–53; dominant, 467–468; of early man, 566–570; of echinoderms, 55–56; and environment, 485–491, *486, 488, 490*; of ferns, 79–80; of fish, 31–34, *32*; of flowering plants, 80–90; heredity of, 454–519; heredity in fruit fly, *471*; of human races, 573–577; table, 574, *575*; inherited in man, 508–513; of insects, 41–50, *45*; of invertebrates, 39–71; and laws of heredity, 468–473; linked, 472; of mammals, 16–20; of mollusks, 53–55; of mosses, 78; of plants, 72–94; and mutation, 479–481, *480*; of protozoa, 61–64; recessive, 468; of reptiles, 26–30, *29*; secondary sexual, 421–422, *421*, 435; sex-linked, 473; of spiders, 50–51; of sponges, 61; of thallophytes, 73–78; of tissues, 129–133; and variation, 485–492; of vertebrates, 15–39; of viruses, 339–340; of worms, 57–58
Chemical, action, *110*; change, def., 189; energy, 120; "messenger," 200, 246–258; regulators, 246–258; resemblances, 550
Chemicals, and bacteria, 315
Chemistry, 108
Chemotropism, 302
Chest, 121; in breathing, *228*; change in size, 228–229; expansion, 228
Chewing, of food, 192
Chickadee, *25*
Chicken, *177*; cholera, 323–324; chromosome number of, 459
Chickenpox, 340
Chigger, 51
Children, and gonorrhea, 333; and learning, 293–294; and syphilis, 332–333; vaccination of, 331
Chilopoda, 66
Chimpanzee, *16*; and reasoning, 295–296; trained, *274*
Chinch bug, 392–393
Chitin, 41
Chlorine, 109; and water supply, 345
Chlorophyll, 106, 111, 139, 142, 143; composition of, 139–140
Chloroplasts, 106, 111, *139*, 139–141
Cholera, in chickens, 323–324; epidemic, 343; spirillum of, *312*
Cholesterol, and vitamin D, 181
Chordates, 15
Choroid coat, of eye, 280, *280*
Chromatin, 107, 111, *457*; in cell division, 456–459, *457, 458*; def., 456
Chromosome, def., 456–457
Chromosome changes, effect of, 483
Chromosome number, def., 459; significance of, 459
Chromosomes, *457, 458*; changes in, 481–482; and fertilization, 461–462; giant, *474*; and heredity, 459; map of, 470; in reduction division, *461*; and sex, 472–473; splitting of, 457–458; X, Y, 473
Chronic alcoholics, 366–367
Chrysalis, *42*
Cicada (17-year locust), 49
Cilia, *62*, 63; of epithelium, *227*; of paramecium, *62*
Cinchona, 89
Circulation, diagrams of blood, *218, 219*; in man, 206–225
Circulatory diseases, 361
Circulatory system, blood, 206–220; lymph, 206, 220–225; main, *207*; pulmonary, *219*; systemic, *218*
Circus giant, *247*, 253–254
Citric acid, and resemblances, 550
Citrus fruits, in diet, 178
Civilization, and ecology, 387 (see Culture)
Clam, 53, 54, *55*
Class, def., 15, 99
Classes, of arthropods, 41–53, *41*; of coelenterates, 60; of echinoderms, 56, *56*; of mollusks, 53–55, *75, 76, 78*; of plants, 91; of vertebrates, 16–39, *16*
Classification, 95–103; of animals, 15–66; of coins, 95–96, *96*; explanation of, 551; of gray squirrel, *100*; Linnaeus' scheme of, 97–101; of man, 564, 573–576, *574, 575*; outline of animal kingdom, 65–66; outline of plant kingdom, 90–91; of plants, 73–91, 101; principles of, 95–96, 101; and resemblances, 551; of stamps, 95
Clay, 148
Cleanliness, and health, 348
Cleavage, def., 425, *425*
Cliff dwellings, *572*
Clothes moth, 395
Clotting, of blood, 210–211; diagram, *211*
Clover, 86–87, *87*
Club mosses, 80, 91
Coal, 383; and carbon cycle, 376; formation of, 527, 536–537; fossils in, 527
Coat color, heredity in cats, *465*
Cobra, 29
Cocci, *312*
Coccyx, 548
Cochlea, of ear, 281–282, *281*
Cockroach, of Carboniferous period, *536*
Coconut palm, 85
Cocoon, def., 42; silkworm, *43*
Cod liver oil, 181
Codling moth, 393–394; control of, *395*; life history of, 394, *394*
Coelenterates, 58–60
Coffee, *88*; 89
Cohn, Professor Edwin, 212
Colchicine, and chromosome number, 482
Cold-blooded, def., 26
Colds, 340, 364
Collecting living things, *5*
Colon, 188
Colony, of bacteria, def., 313; *314*; and bacterial variation, 338
Color blindness, heredity in man, *473*
Colorado potato beetle, *46*
Community, and disease, 343–347
Companion cell, *153*
Comparative anatomy, def., 548
Composite family, of plants, 89–90, *89*
Compound leaf, *89*
Compounds, 109
Conditioned responses (reflexes), 9–10, 288–289

Conduction, in plants, 157–159
Conifers, 81–82
Conjugation, 415–417; bread mold, 416–417, ***417***; def., 417; of paramecium, ***417***; of spirogyra, 415–416, ***416***
Connective tissue, 131, 194
Conservation, forest, 399–402; soil, 403–405; summary of, 406–408
Contact poisons, 394–395
Continuity of germ plasm, ***455***, 488, ***489***
Contour planting, 405
Contractility, 269
Contrasting characters, 467–468
Convolutions, ***271***, 272
Convulsion, 255
Cooking, and vitamins, 182
Coordination, and cerebellum, 273
Copperhead, 27, ***28***
Coral reefs (islands), 60
Coral snake, 27–28
Corals, 59–60; organ-pipe, ***60***
Cork, 105, ***106***, 156; of roots, 152; of stems, 153
Corn, 84; and corn borer, 392, ***392***; chromosome number of, 459; effects of selection of, ***495***; fat in, 143; flowers of, ***440***; gene and light, ***490***; seed, ***438***; smut, 386, ***386***; stem, ***157***; water loss in, 159
Corn borer, larvae, ***392***
Cornea, of eye, 280, ***280***
Corolla, 439
Cortex, of adrenals, 253; of brain, 272, 274; of human brain, ***271***, ***276***; root, 151, 152, ***152***; stem, 153–154, ***154***
Cortin, of adrenals, 253
Cosmetics, 242
Cotton, 88–89; fats in, 143; fruits, ***383***
Cotton boll weevil, history of, 389
Cottonseed oil, 89
Cotyledons, def., 451; in plant reproduction, 443
Coughing, and disease spread, 322
Cousin marriages, ***512***
Cover crops, and soil erosion, 405
Cowpox, and smallpox, 325–326
Cows, in model farm, ***504***; muscle cells of, ***129***
Crab, ***41***, 52, ***53***
Cranium, def., 15, 271
Creosote, 385; use of against termites, 49
Cretinism, 248
Crocodiles, 29–30
Cro-Magnon, man, 570–571; art, ***571***; artist at work, ***570***
Crops, cover, 405; rotation of, 405
Crossbreeding, def., 496
Cross-pollination, def., 441
Crosses, Andalusian fowl, ***468***; in breeding, ***497***, 499–502; cat, ***465***; cattle, 499–501, ***500***; dihybrid, 470–472, ***472***; four o'clock, 464–467; fruit fly, 470, ***471***; guinea pig, 469, ***470***; pea, 467–468, ***469***; rat, ***469***; squash, ***469***
Crossing over, def., 477
Crustaceans, 41, ***41***, 52–53, ***53***, 373
Culex (mosquito), 349; life history of, ***352***
Culture, Bronze and Iron Age, 573; def., 565; of early man, 570–571; New Stone Age, 572–573; Old Stone Age, 571–572
Culturing bacteria, 312–314; medium, 313
Cutting, def., 449
Cyclotron, 250
Cylinders, root, 151–153, ***152***; stem, 153–157, ***154***
Cytoplasm, 106, ***107***, 111
Daddy longlegs, 51
Daisy, 89; Shasta, 502
Dam, beaver, ***264***
Dandelion, 89; parthenogenesis in, 449; seeds, ***445***
Darwin, Charles R., 57; theory of evolution of, 556
Darwin-Wedgwood pedigree, ***512***
Datura, and heredity, ***481***
"Daughter" cell, in reproduction, 413–414
Da Vinci, Leonardo, and fossils, 526
Daydreaming, 368–369
DDT, and insect control, 395
Death, by accident, 362; Black, 328; from bubonic plague, 343; causes of, 360, ***360***; causes of in children, 362; from diphtheria, ***329***, ***330***; infant rate, 369–370; from smallpox, 325; from tuberculosis, ***321***; and tobacco, 365–366; from typhoid, ***345***
Decay, and cycles, 376; and nitrogen cycle, 377–378; of teeth, 204
Deer, ***169***, ***421***
Deficiency diseases, def., 178
Delta, formation of, 523
Dendrites, ***274***, 274–275, 277; and nerve impulse, 276–277
Denitrifying bacteria, 377
Dermis, of skin, 241–242
De Vries, Hugo, 482; and Darwin, 559; and mutations, 482–483; and theory of evolution, 555, 561
Diabetes, 250–252, 311; use of insulin in, ***251***
Diaphragm, human, ***228***, 229, 321; microscope, 113
Diarrhea, and allergy, 364
Diatoms, 74; and food chains, 373
Dicot (dicotyledon), def., 83; 85–90, 91; seed, 438
Diet, 167–187; and calories, 170–174; carbohydrates in, 174; experiments, ***157***, ***176***, ***177***; fats in, 174–175; minerals in, 175–176; proteins in, 174; roughage in, 176; vitamins in, 176–183; water in, 175
Differentiation, 131; def., 426; in plants, 443
Diffusion, 121–124, ***122***, 188–189; of air in lungs, 231; and blood, 208–209; and capillaries, 206–207; in cells, 123; conditions of, 123–124; effect on cells, ***125***; in gases, 122; in liquids, 122; in lungs, 228; and lymph, 221; and molecules, 122–123; in root hairs, 150–151; through membrane, 122–123, ***123***
Digestion, 125, 188–205; by bacteria, ***312***; def., 189–190; diagram, ***197***; of fats, 196–197; intermediate products of, 190, 194, ***197***; in mouth, 192; in plants, 158; products of, 190, 196, 197, ***197***; of protein, 194–196; in small intestine, 196–197; of starches, 190, 192, 196; in stomach, 193–194
Digestive enzymes, 190–191
Digestive glands, 190–191, ***191***; stimulation of, 199–200
Digestive juice, 191
Digestive system, of man, 188–205, ***189***
Dihybrid, 471–472; cross, ***472***; gametes, ***471***, ***472***
Dinosaurs, 526, 537–538, ***537***; footprints of, ***527***
Diphtheria, 316, 328; and active immunity, 329; carriers, 347; death rate, ***330***; effect of antitoxin on, ***329***; and passive immunity, 328–329; susceptibility test, 330
Diploid, def., 460
Disease, advance in understanding, 338–342; communicable (see Infections); deficiency, 311; def., 311; 311–371; and drugs, 332; epidemics, 343; and future, 341; germ theory of, 320–321; heredity of, 510; infectious, 320; intestinal, 340–341; metabolic, 311; and milk supply, 345–347; organic, 311; summary of conquest, 334; venereal, 332–333; virus, 340; water-borne, 344–345
Disinfectants, 315; and surgery, 331–332
Dispersal, seed, 444–445, ***445***

Distemper, 316
Distribution, of organisms, 551–552; of races, 575
Divers, and "bends," 233
Division, ameba, 412–413, ***413***; animal nucleus, ***458***; cell, 456–459, ***457***, ***458***; embryo sac, 441, ***441***; paramecium, ***412***; of plant nucleus, ***457***; pollen grain, 442, ***442***; primary sex cells, 460–461, ***461***; yeast, 413–414, ***413***; zygospore, 416; zygote, 424–426, ***425***, 443 (see Reproduction)
Dodder, ***374***
Dog, brain, ***273***; conditioned response, 289; distemper, 316; rabies, 324–325; skull, ***193***
Dominance, in fruit fly, 470; law of, 468
Dominant, def., 467–468
Donor, of blood, 211
Double nucleus, def., 441; of ovule, ***441***
Draftees, causes of rejection, ***364***; rejection of, 362
Drawing, prehistoric, ***571***
Drinking fountains, 348
Drosophila melanogaster (see Fruit Fly)
Drugs, and disease, 332; sulfa, 333–334
Duckbill, ***20***
Duct, of gland, 192
Ductless glands, 246–258; and dog breeds, ***255***
Dust storm, 404
Dutch elm disease, 386–387
Dutrochet, Henri Joachim, 125
Dwarfism, 253
Dyeing, bacteria, 314
Dyes, 108

Eagle, American, ***22***
Ear, 281–282, ***281***; and balance, 282; of corn, ***440***, ***490***
Eardrum, ***281***, 282
Earth, changes in, 524–525; changes in surface of, 521–523; estimating age of, 525; formation of, 521; history of, 533–546; studying history of, 525; summary of history of, 540–542; table of eras of, 533
Earthworm, ***40***, 57, ***58***; and learning, 294; sex organs of, 421; structure of, ***57***
Echinoderms, 55–56, ***56***
Ecology, def., 381; 381–388
Ectoderm, 426
Edwards family, 512
Eels, life cycle of, 33–34
Effectors, 261, ***278***; in reflex arc, 277–278
Efferent neuron, 278
Egg cell, 422; hen, 422; mammal, 422
Egg nucleus, of flower, ***441***
Eggs, ant, ***47***; development of hen's, 430; development of plant, 440–441; flowering plant, 441; formation of, 460–461; frog, ***423***, ***428***; human, ***423***; hydra, ***423***; insect, 41, 42; mosquito, ***352***; used for measles vaccine, 327; for typhus vaccine, ***328***
Ehrlich, Paul, and syphilis, 332–333
Eijkman, Christiaan, and beriberi, 177
Elastic tissue, of lungs, 228
Electrical charge, in diffusion, 151
Electricity, form of energy, 120
Electron microscope, ***11***, 12; and viruses, 339
Elements, def., 108; in protoplasm, ***108***, 111
Elephant, cells, 129; fossil history, 543, ***543***
Elodea, 127, 139
Embryo, chick, ***549***; def., 425; development of bird, 430–431; of fish, 424–426; of flowering plant, 443; of frog, 428, ***549***; of human, 432; of pig, ***549***; of plant, 438, 443; of rabbit, 432–433; of turtle, ***549***
Embryo sac, of plant, 441, ***441***
Embryos, resemblances among vertebrate, ***549***
Emerson, R. A., and heredity, 490
Emotions, and behavior, 296–298; in child, ***297***; and growing up, 297–298; and habits, 294; in lower animals, 297
Emulsion, 197
End-brush, ***274***, 275; and nerve impulse, 276–277; in reflex arc, 277–279
End products, of digestion, 190
Endocrine glands, 246–258
Endoderm, 426
Endosperm, def., 438, 443, ***438***, 444
Enemies, insects, 389–398; microorganism, 311–371
Energy, in breaking log jam, ***120***; in common foods, 169–170, 172; def., 119–120; in hurdling, ***119***; measurement of heat, 168–169; measuring in food, 169–170; measuring in man, 170, ***171***; in nerve impulses, 376; in photosynthesis, 142, 145; radiant, 142; release of, 143; in respiration, 145; in resting cow, ***121***; from sun, 142; transformation of, 120
England, tuberculosis in, 321–322
English sparrow, 22
Enriched food, 180
Entomologist, def., 50
Entomology, def., 391; U.S. Bureau of, 395
Environment, 261; adaptations to, 560–561, ***560***, ***561***; and breeding, 504, ***504***; and chromosomes, 481, 482; effect on gene, 490–491; effect on organisms, 485–487, ***486***, ***488***; and human improvement, 513–516
Enzymes, def., 190–191; 194, 196; diagram of action, ***197***; where made, 191
Eoanthropus Dawsoni, 566–567, ***567***
Eohippus, 542–543; leg bones, ***542***; skeleton, ***541***
Epidemics, 343; of smallpox, 325–326; study of, 355
Epidemiology, def., 355
Epidermal cell, 138–139, ***139***, ***152***
Epidermis, of leaf, 138–139, ***139***; of root, 151, ***152***; of skin, ***240***, 241; of stem, 153
Epiglottis, of man, ***226***
Epithelial, 129; cells, ***132***, ***227***; tissue, 131
Epithelium, 194, 195; of lungs, 228; of skin, 241–242; of windpipe, 227
Eras, def., 525; described, 533–542; organisms in, ***541***; pictured, ***534***, ***535***, ***536***, ***537***, ***539***
Erepsin, 196
Ergosterol, 183; and vitamin D, 181
Erosion, def., 522; and earth's surface, 521–522; on hillside, ***403***
Esophagus (see Oesophagus)
Essential organs (flower), def., 440; ***439***
Eugenics, def., 509; 512–513
Euglena, ***64***
European corn borer (see Corn borer)
Eustachian tube, ***281***
Euthenics, def., 516; 515–516
Evaporation, from leaf, 159–160; of sweat, 240–241
Evening primrose, ***482***, 482–483; chromosome number, 459; effect of environment, ***486***; mutant, ***482***
Evergreens, 81–82, ***82***, 91
Evolution, and adaptations, 560–561; def., 553; evidences for, 540–544, 547–554, ***525***, ***526***, ***527***, ***530***, ***536***, ***538***, ***541***, ***542***, ***543***, ***547***, ***548***, ***549***, ***550***, ***551***; of man, 564–579, ***565***, ***567***, ***569***, ***570***, ***571***, ***572***; significance of fossils in, 530, 540–542, 543–544; summary of, 561; theories of, 555–563
Excavating, for fossils, ***530***, ***567***
Excretion, 125, 237–245; and typhoid, 327
Excretory organs, 238
Exercise, and blood movement, 218; and lymph movement, 221

Exhaling, 228–230, *228*
Experience, and learning, 295, 296
Exploration, 4–8, *6*, *7*, *530*, *567*
Extinct, def., 530
Extinction, of wildlife, 405–406
Eye, compound, 41; grasshopper, *45*; heredity of color, 508; heredity of color blindness, 473, *473*; human, 280–281, *280*, *281*; of white potato, 449

F_1, def., 467
F_2, def., 467
Fabre, Jean Henri, 7–8
Fainting, 217
False Solomon's seal, *407*
Families, animal, 98, *98*, 99, *99*, *100*; plant, 84–90
Family, in classification, 15, 99
Family life, animal, 434
Farming, and soil destruction, 403
Farms, inspection of milk, 346–347
Fat cells, 129, *132*
Fats, 110, 112, 196–197; absorption of, 221; in common foods, 172; composition of, 143; in diet, 174–175; diffusion of, 124; synthesis of, 143; test for, 116
Fat tissue, use in body of, 174–175
Fatty acids, 196, 198
Feathers, 20, *21*, 65; in flight, 23
Federal Food, Drug, and Cosmetic Act, 242
Feeble-minded, def., 510–511; segregation of, 512
Feeble-mindedness, heredity of, 511–513; statistics concerning, 513
Feelers, butterfly, 43; moth, 43; use of, 41
Fehling's solution, 116
Felis (cats), *97*, *98*; cougar, 98; domestica, 98; leo, 98
Female, ant, *47*; characteristics, 421–422; deer, *421*; frog, *422*; gametes, 422, *423*; malarial protozoan, *351*, 417–418; sex organs, 421, 422, *422*
Fermentation, 77; and Pasteur, 322–323
Fern, 79–80; Boston, 499, *499*; classification of, 91; Christmas, *72*; Florida, 137; mutation, *499*; prothallus, *446*; reproduction of, 445–447; spore cases, *415*; young plant, *446*
Fertilization, in bird, 430; and chromosome number, 461–462; def., 418; and development, 424; external, 423–424, 427–428; in fern, 446; in fish, 423–424; in flowering plants, 439, 442–443, *443*; and heredity, 466–467; internal, 429–430; in land-living animals, 429–430; in malarial protozoan, *351*, 417–418; in rabbit, 432
Fertilization membrane, def., 424
Fertilized egg cell, def., 418, 424, *425*, 430; of flowering plant, 443, *443*; of frog, 428, *428*
Fertilizer, and soil restoration, 405
Fever, 241; blisters, 340; and drugs, 332; malaria, 351
Fibers, root, 152; stem, 156
Fibrin, 211
Fibrinogen, 208, 211
Fibrous root, *149*
Filament, flower, *439*, 441; spirogyra, *74*, 415
Filial, def., 467
Filterable virus, 324, 339–431 (see also Virus)
Filters, for water supply, 345; porcelain, 339
Firefly, 46
First aid, 215
Fish, 31–34, *32*, *33*; in balanced aquarium, 378–379; brain, *273*; development of, 424–427, *425*, *455*; flying, 33; hatcheries, 406; and learning, 290; migration, 33–34; muscle cells, *129*; reproduction of, 423–427; sperm, *423*
Fission, in ameba, 412–413, *413*; binary, def., 413; in paramecium, 412–413, *412*
Fissure, of cerebrum, 271
Fitness (see Adaptations)
Flagellum, of bacteria, 312, *313*; of euglena, *64*
Flatfish, 33
Flatworm, *40*, 58, *58*, 66
Flax, 89, 383
Fleas, as germ carriers, 348
Fleming, Dr. Alexander, *12*
Flies, 44–45
Flight, of birds, 23–26
Floods, and forests, 399–402
Floral envelope, 439
Flounder, 33
Flower, structure, 439, *439*
Flower color, inheritance, 464–467
Flowering plant, ages, 80; characteristics, 80; classification of, 81, 83–84, 91; kinds of, 82–90; life cycle, 445; reproduction, 438–445, 446–447; saprophytic, *374*
Flowers, needing protection, *407*
Fly, and spontaneous generation, 411
Focus, of eye, 280–281; of microscope, 114
Food chains, 373; and earth history, 375
Food pipe, 229 (see Oesophagus)
Food vacuole, of paramecium, *62*
Food, absorption of, 188–189, 197–198; absorption of in villi, 206; Basic Seven, *182*; calories, 168–174, *172*; canning, 180–181, 385; choosing of (diet), 167–187; compounds, *167–168*; def., 167; diffusion into capillaries, 206–207; digestion, 188–205, *197*; energy in, 169–175; movement in canal, 188, 192–193; pushcart sales of, *347*; reasons for studying, 167–168; and reflexes, 262–263; sources of man's, 167; table of information, 172–173; and typhoid, 348; vitamins, *173*, 176–183, *183*
Forest fire, 399, *400*, *401*; fighting, *402*
Forest ranger, 402; at work, *401*
Forests, 399–402; and flood control, 399–402; and humus, *400*; and soil erosion, 402; destruction, *400*; graph of extent, *400*; uses of, 399
Fossils, def., 525, 526–530, 533–546, 564–571; diagram of relationships, *541*; early man, 564–571; elephant series, *543*; formation of, 526; how discovered, *529*; hunting, 528–530, *530*; illustrations of, *525*, *526*, *527*, *530*, *536*, *538*, *541*, *542*, *543*, *567*; insect, 528; Paleozoic, 535–537; Proterozoic, 535; reconstruction of, *530*; series of, 543; significance of, 530, 540–542, 543–544, 552–553; snail series, *543*; succession in rocks, 533; summary of, 544; and tar pool, 527; tree, *541*; types of, 526–528
4-H Club health champions, **310**
Four o'clock, blossom, *465*; heredity in, 464–467; hybrid cross of, *467*
Fox, mutation, 499; red, *98*
Fraternal twins, 514
Fringed gentian, response to light, *303*
Frog, *16*, 31; brain, *273*; capillaries, *207*; chromosome number (leopard frog), 459; classification of, 30–31, 65; development of, *428*; dissection of, 202; egg, *423*; excretory organs, *422*; metamorphosis of, 428–429; muscle cells, *129*; parthenogenesis, 424; reproduction, 427–429; reproductive organs, *422*; skeleton, *548*; sperm, *423*; spinal reflex, 279; study of tissues, 12, 134–135; and thyroxin, 247
Fronds, 79; of fern, 446
Fruit, chlorophyll in, 139; cotton, *383*; def., 444; *444*; development, 443–445, *444*
Fruit fly, 45; chromosome number of, 459; giant chromosome, *474*; heredity, 470, *471*; in milk bottles, *471*; mutations, 479–481, *480*, *481*

Fucus, 75
Function, def., 130
Fungi, ***73,*** 90, ***375***; bracket, ***75***; and disease, 311; and nitrogen cycle, 377–378; as plant parasites, 386–387
Funk, Casimir, "vitamine," 177
Fused nucleus, definition, 441

Gall (bile), 192
Gall bladder, of man, ***189,*** 192, ***195***
Game laws, 406
Gametes, active (supplying), 416; and chromosomes, 466–467, ***466***; conjugation of, 415–418; of dihybrid, 472; eggs, ***423***; def., 415; 415–418, 422–423, 429–430, 432; fertilization of, 423–424; fish, 427; formation, 460–461; frog, 427–428; and germ plasm, 455; and heredity, 466–473, ***466, 467, 469, 471, 472, 473;*** like, 417; mammalian, 432; maturation, 460–461, ***461***; passive (receiving), 416; plant, 439, 441, ***441,*** 442, ***442,*** 446–447; pure, 466; sperm, ***423***; spirogyra, ***416***; unlike, 417–418
Ganglia, 275; autonomic, 275, 279, ***279***; bee, ***275***; earthworm, ***57***; in reflex arc, 277–279, ***278***
Garden spider, ***51***
Garter snake, ***26***
Gastric glands, 191, ***191,*** 195, 199, 200; duct of, ***191***
Gastric juice, 193–194
Gastrula, def., 425; ***425,*** 426
Gene, def., 456; action of, 459; and breeding, 493–507; changes in, 479–481; and chromosome, 457; effect of environment on, 490–491; and four o'clock heredity, 466–467; and grafting, 503; and heredity, 456–481; and light, ***490***; revisions in theory, 483; theory, 456
Genus (genera, pl.), 15, 97, 98, ***98,*** 99, ***100,*** 101
Geographic distribution, of organisms, 551–552
Geologist, 521, 525
Geometrid moth caterpillar, and adaptation, ***560***
Geotropism, 301; in sunflower, ***302***
Geranium, ***72, 131***
Geranium oil, and Japanese beetle, 396
Germ cells, def., 455 (see Gametes)
Germ layers, in animal development, 426
Germ plasm, 455; and acquired characters, 488, ***489***; continuity of, ***455,*** 488, ***489***
Germ theory of disease, 320–322, 323, 332; advances in, 338–342; and Koch's postulates, 322
Germination, def., 438
Germs, def., 311; and disease, 311–371; spread of, 347–349
Gestation, def., 433
Giantism, 253
Gila monster, 29
Gill slits, in embryos, 548
Gills, fish, 32
Giraffe, ***559***
Gizzard, of earthworm, ***57***
Glacial period, 539–540
Glacier, def., 522; ***522***; and ice sheet, ***540***
Gland, def., 191; cells, 129; tissues, 131
Glands, "of Combat," 252–253; gastric, 191, ***191,*** 195, 199, 200; of internal secretion (endocrine), 246–258; intestinal, 196; oil, ***240***; salivary, ***189,*** 192, 199; sweat, 239–240, ***240***
Glasses, to correct vision, 281
Glowworm, 46
Glucose, 190, 196, 199
Glycerin, 196, 198
Glycogen, 199; and insulin, 250
Gneiss, 524
Goats, and overgrazing, 403
Gobi Desert, ***526***; and fossils, 528–530
Goblet cells, 195, ***227***
Goiter, 249; exophthalmic, 249–250; map of distribution, ***249***; treatment of, ***248***
Goldfish, 32
Gonorrhea, 333
Gooseberry, and blister rust, 386
Gooseflesh, 253
Goose pimples, 241
Gopher, 97
Gorgas, W. C., and mosquito extermination, 353
Grafting, def., 502; ***503***; and plant breeding, 502–503
Grains, 84–85
Grand Canyon, ***529***; and fossils, 528
Granite, 521, 524
Granules, 111
Graph, of bean length, ***487***; def., 487; of intelligence quotients, ***511***
Grass, extinction of blue stem, 405
Grasses, 83, ***84,*** 85
Grasshopper, ***40,*** 45–46, ***45***; mouth parts, ***68***
Gravity, and plant hormones, 303–304; and tropisms, 301
Gray matter, of brain, 272; of spinal cord, 272
Great auk, extinction of, 405
Greenland, ice cap, 540
Green plants, and food chains, 373
Gristle (see Cartilage)
Grizzly bear, California, extinction of, 405
Ground pines, 80
Ground sloth, ***528***
Grouse, hatching, ***431***; protective adaptation, ***560***
Growing point, of root, ***152***
Growing up, and emotions, 297–298
Growth, and plant behavior, 303–304
Growth hormones, synthetic, 308
Guano, def., 405; use of, 405
Guard cells, 139, ***139***
Guinea pig, ***176***; and acquired characters, 490; heredity of, 467, ***470***
Gull, ***431***
Gullet, 193; of paramecium, ***62*** (see Oesophagus)
Gustafson, Dr. F. G., and plant reproduction, 450
Gymnosperms, def., 81; 81–82, 91
Gypsy moth, caterpillar, ***392***; 393

Habits, 292–294; breaking (unlearning), 294; compared with reflexes, 292–293; formation of, 294; safety, 363
Hair, follicle, ***240***; heredity in cats, ***465***; of man, ***240***; roots, 241
Halibut liver oil, and vitamin D, 181
Hammer, bone of ear, 282
Haploid, def., 460; effect on organism, 481–482; in maturation of gametes, 460–461, ***461***
Hardwoods, 85
Harrison, Dr. Ross, and tissue culture, 340
Harvey, William, and blood circulation, 214
Hatchet foot mollusks, 53, 54, ***55***
Hawaii, 525
Hay fever, 364–365
Hay infusion, 61–63
Head louse, ***390***
Health, 311–371; and education, 369–370; laws, 344, 348; mental, 367–368; and poverty, 370; and social problems, 370; workers of Board of, ***323, 329, 374***
Health officers, and disease carriers, 347–348; and disease prevention, 343–344
Heart, 121, ***207***; beat, 214; counting beat, 215; disease, 361–362; earthworm, ***57***; in human em-

bryo, 538; muscle, 214; structure of, 213–214, *213*; valves of, *220*; work of, 213, *218*, *219*, *220*
Heart failure, and adrenin, 253
Heartwood, *156*
Heat, different from temperature, 168; form of energy, 119, 168–169; loss from body, 241; unit of, 169
Heath hen, extinction of, 405
Heidelberg man, 568
Hemlock, *82*
Hemoglobin, 209, 231; and resemblances, 550
Hemophilia, def., 473; heredity of, 473
Hemorrhage, cerebral, 217
Hemp, 89, 383
Hepatica, *407*
Herbs, def., 80; and disease, 332
Heredity, 454–519; and acquired characters, 488–490; and breeding, 493–507; diagram of simple case, *467*; in dihybrids, 470–472; and disease, 370; of disease in man, 510; and environment, 485–491; and gene theory, 464–484; and improvement of man, 508–519; in man, 508–519; mental traits in man, 511–512; and organisms studied, 470; and reproduction, 454–463; of sex, 472–473; sex-linked, 473; and variation, 485–491
Herelle, d' Felix H., and bacteriophage, 340–341
Herring, 33
Hessian fly, *44*
Hibernation, 26
Hickory, leaf, *85*
Hilum, def., 451
Himalayas, 538
Hippopotamus, and young, *461*
Hobbies, 8, *9*
Hog (see Pig)
Hog-nosed snake, *29*
Homo heidelbergensis, 568; neanderthalensis, 568–569; rhodesiensis, 568; sapiens, 569–571
Honeybee, 48–49, *48*
Honeycomb, of bees, 48, *141*
Honeydew, ant food, 47
Hooke, Robert, 105, 125
Hookworm, *40*, 57; disease, 354
Hormones, def., 200; 208, 246–258; and growth, 303–304; and plant reproduction, 450; and secondary sex characters, 422; sex, 255
Hornlessness, in cattle, 484, 497–499
Horse, and antitoxin, 328–329; and bacteria, 374; bleeding for antitoxin, *329*; breeding of, 493; and colts, *410*; fossil history, 542–543; leg bones, *542*; skeleton, *541*; skull, *193*; teeth, *193*; and tetanus, 330–331; thoroughbred, *493*; wild, *493*
Horse chestnut twig, *155*
Horsetails, 80, 91
Host, def., 311; 316, 320
Housefly, *44*, 348; chromosome number of, 459
Howard, L. O., and insect menace, 391
Human, brain, *271*; gametes, *423*; history, 564–573; races, 573–577
Humus, def., 399; 150
Hundred-legger, 41, *41*
Hunger, cause of, 280
Huntington's chorea, 510
Huxley, Thomas Henry, 126
Hybrid, def., 466; vigor, 496–497, *497*
Hybridization, def., 499; animal, 499–501; in cattle, *500*; plant, 501–502; used by breeders, 499–501
Hydra, *59*; egg, *423*; green, 380
Hydrochloric acid, 194; of stomach, 194, 196, 315
Hydrogen, 108, 109, 111; cycle, 375, *376*, *377*
Hydrophobia (see Rabies), 324
Hydrotropism, 302
Hypha, 414, *414*
Hypocotyl, 451

Ice, river of (glacier), *522*; sheets, 539–540, *540*
Ichneumon fly, and adaptation, 561
Identical twins, 514–515, *514*
Igneous rock, 521
Immune serum, and disease, 331
Immunity, acquired, 316; active, 326–327; to anthrax, 324; to chicken cholera, 323–324; to measles, 327; natural, 316; passive, acquired, 328–329; to rabies, 324–325; to scarlet fever, 327; to smallpox, 325–326; to typhoid, 326–327; to whooping cough, 327
Impetigo, 243
Impulse, in nerve, 270, 276–277
Inbreeding, def., 496
Incisor, 203, *203*
Incomplete dominance, def., 468
Incomplete metamorphosis, 42
Incubator, 313
Independent assortment, 470–472
Indians, and food preservation, 384
Indol-acetic acid, 308
Indol-butyric acid, 308
Industrial absence, 362–364
Industrial revolution, and tuberculosis, 321–322
Infant care, 369–370
Infantile paralysis, 230, 340; and carriers, 347
Infectious disease, new problems, 338–342
Influenza, 328, 340; epidemic, 343; immunity, 316; virus, 339, *339*
Inhaling, 228–230, *228*
Inheritance of variations, and evolution, 558
Inner ear, 281–282, *281*
Inoculation, for immunity, 323–325, 327–329, 331
Insanity, 368
Insect-eating plants, *306*
Insects, 41–50; as allies, 396; classification, *40*, *41*, 65; communities, 46–49; control, 391–397; cost of damage, 391; as disease carriers, 348–349; economic effects, 389–391; importations, 396–397; in insect control, 396; life cycle of, 41–42, *42*, *43*, *47*; and man, 389–398; mouth parts, 43, *43*, 45, *68*; noises, 49–50; number of, *39*; origin of problem, 389; parental care, 430; repellents, 395; scale, 46; scaly winged, 43–44; social, 46–49; stomach poisons, 393–394; structure, 41, *44*, *45*; usefulness of spraying, *395*
Insoluble substances, def., 123–124
Instinct, 263–265; shown by wasp, *263*
Instinctive behavior, def., 263; 263–265
Insulin, 250–252; injection of, *251*
Intelligence, def., 510; of identical twins, 515; tests, 510
Intelligence quotient, def., 510, 511; graph, *511*
Intercellular material, 130, *130*, *132*
Intermediary neuron, 278
Intermediate products, of digestion, 190
Internal secretions (hormones), 246–258
Intestinal, glands, 191, 196, *198*; juice, 196
Intestine, absorption in small, 197–198; digestion in small, 196–197; of earthworm, *57*; large, 188, 198; of man, *189*; small, 188, *195*
Invertebrates, def., 15; 39–71; examples of, *40*, *64*; jointed legged, 41–53; number of, *39*; soft-bodied, 53–55; spiny skinned, 55–56; table of classification, 65–66
Involuntary muscle, *129*, 131–132, *132*; of air passages, 228

Involuntary nervous system, 270, 279, ***279***
Iodine, and goiter, ***249***, 249–250; and sulfa drugs, 334; as testing agent, 110; in thyroxin, 246; radioactive, 250
Iris, of eye, 280, ***280***
Iron, 108, 111; Age, 573; in common foods, 173
Iron lung, ***230***
Irradiation, and vitamin D, 181
Irritability, 125; in neuron, 275
Islands of Langerhans, and insulin, 252
Isolation (quarantine), and disease, 343
Isotopes, and goiter, 249–250

Japanese beetle, 396, ***396***; quarantine sign, ***396***
Java ape man, 566; head, ***567***
Jellyfish, ***40***, 60, ***61***
Jenner, Edward, and smallpox, 325–326; and viruses, 340
Jewish "race," 575–576
Jimson weed, and heredity, ***481***
Juice, digestive, def., 191; 191, 192, 193, 194, 195, 196, 197, 199, 200
Jukes family, 512
Jute, 89, 383

Kallikak, Deborah, pedigree of feeble-mindedness, 511–512
Kangaroo, 552; reproduction, 433
Kanred wheat, 502
Katydid, 41, 45, 49, 50
Kelp, 75
Kernel, def., 452
Kerosene, and mosquitoes, 353
Kidneys, 238, ***238***, 256; of frog, ***422***; of sheep, ***239***
Kilogram, 169
Kingdoms, 101; animal, 15–71; animal classification, 65–66; plant, 72–94; plant classification, 90–91
Kissinger, John R., and yellow fever, 352
Knee jerk, 268
Koala, and young, ***553***
Koch, Robert, 332; and culture media, 313–314; and disease, 320–322; postulates, 322; staining bacteria, 314

Laboratory, place of work, 4, 8–9, ***109, 481***
Lacteals, of villus, 198, ***198***, 206, 221
Lactic acid, and milk, 323
Ladybird beetle, 46; in insect control, 396
Lady slipper, ***83***
Lamarck, Jean Baptiste (Chevalier de), theory of evolution, 559–560; and variation, 487–488
Landsteiner, Karl, 212
Langerhans, and diabetes, 251–252
Lanolin, 308
Larva, ant, ***47***; bee, 49; cabbage butterfly, 393; codling moth, 393–394, ***394***; corn borer, 392, ***392***; gypsy moth, 393; insect, 42; Japanese beetle, 396; mosquito, ***352***; Monarch butterfly, ***42***; potato beetle, ***391***; silkworm, ***43***; tent caterpillar, ***393***
Larynx, ***226***, 227, ***227, 247***
Lava, 524–525
Laveran, Alphonse, and malaria, 349
Law, "of dominance," 468; of independent assortment, 470–472; of segregation, 468–470; of unit characters, 470–472
Laws, to protect wildlife, 406
Layering, def., 449
Lead, 525
Lead arsenate, and apples, 394
Leaf, scar, ***155***; skeletonized, ***158***
Learned acts, def., 287–288; conditioned response, 288–289
Learning, 287–288, ***293***; and cat, 291; in children, 289–290; and experience, 295; in fish, 290; and habits, 292–294; and maze, 291; and rat, 291; by reasoning, 294–296; trial and error, ***290***
Leaves, 137–147, ***138***; color in fall, 140; compound, ***85***; differences among, 137; feathernet veining, ***83, 85***; internal structure, 138, ***139***; palmate net veining, ***83, 85***; parallel veining, ***83***; parts of, 137; stomata, 138, 139, ***139***; structure, 137–140; use to plant, 144; veining, ***83***; veins of, 157; work of, 140–145
Leech, 57
Leeuwenhoek, Anton van, 10–11; and spontaneous generation, 411
Legs, eohippus, ***542***; grasshopper, ***45***; horse, ***542***
Legumes, def., 378; 405
Lens, (eyes), 280; adaptation to distance, ***281***
Lenticels, 153, ***155***; of birch, ***154***
Lepers, and community action, 343
Leucocytes, 210
Lichen, def., 374; 77, ***375***
Liebig's beef extract, 317
Life, defined as cell activities, 124–125; length of, 359–360, ***359***
Light, and eye, 280–281, ***280, 281***; form of energy, 119; of fringed gentian, ***303***; and gene action, 490, ***490***; and plant growth, ***486***; and plant responses, 303, ***303***; response of nasturtium, ***301***; as stimulus, 261, 266; and tropisms, 301
Lightning, and nitrogen cycle, 378
Lily, flower, ***439***; flower x-ray, ***439***; water, 137, ***138***
Limestone, 60, 524
Limewater, 127
Linen, 89, 383
Linkage, 472; diagram, ***473***; sex-linked heredity, 473
Linnaeus, Carolus, scheme of classification, 99–101; work of, 4–5
Linseed oil, 89
Lipases, 196
Lister, Sir Joseph, and surgery, 331–332
Liver, ***189***, 192, 200, 256; effect of adrenin on, 252; work of, 198–199
Liver flukes, 58
Liverworts, 91
Living matter (see Protoplasm)
Living things, difference from lifeless, 118; general structure, 131
Lizard, ***16***, 29
Lobster, 52, ***53***
Lockjaw (see Tetanus)
Locomotion, 125
Locust grasshopper, 45 (see Grasshopper)
Loeb, Jacques, and parthenogenesis, 424
Los Angeles, tar pools, 527; water supply, 345
Lugol's solution, 115, 116, 420
Lumber, 383
Lumbering, 402, ***402***
Luna moth, ***43***
Lungs, 226–236, ***227***, 256; in amphibia, 31; in birds, 16, 20; and excretion, 238; blood circulation, 219–220, ***219***; in fish, 33; in mammals, 16; in reptiles, 26; structure of, 227–228, ***227***; work of, 228–234
Lymph, 206; circulation of, 221, 222; def., 220–221; ***221***, 220–222; glands (nodes), 210, 221–222, ***222***; and wastes, 237–238
Lymphatics, 206, 221, ***221***, 222, ***222***; of villus, ***198***
Lysins, 316

Macrospore, def., 446
Madder family, ***88***, 89
Maggot, 45; def., 411; and spontaneous generation, 411
Magnesium, 109, 111
Maize (corn), chromosome number, 459
Malaria, 311, 349–351; deaths from, 349; mosquito, ***349***; our success with, 353–354
Malarial protozoan, fertilization in, ***351***; life history, 350–351, ***350***; reproduction, 417–418
Male, ant, ***47***; characteristics, 421–422; deer, ***421***; frog, ***422***; gametes, 423, ***423***; malarial protozoan, ***351***, 418; sex organs, 421, 422, ***422***
Malnutrition, 364
Mammals, 16–20; Age of, 538–539; behavior, ***274***, 291, 295–296, 297; brain, ***271, 273***; characteristics, 16; embryo in uterus, ***432***; explanation of distribution, 552; family life, 434; flying, 18; gnawing, 18; with grinding teeth, 16–17; with long eyeteeth, 17–18; marine, 18; parental care, 433–434; reproduction, 432–434; simple, 18–20
Mammary (milk) glands, 16, 433
Mammoth, fossils, 528
Man, arm bones of, ***547***; as biologist, 3–13; as breeder, 493–507; behavior of, 260–300; breathing of, 226–236; cells and tissues of, 129–132; chromosome number of, 459; circulation of, 206–225; classification of, 564, 573–574; diet of, 167–187; digestion of, 188–205; and disease, 311–371; egg of, ***423***; embryo of, ***549***; endocrine glands of, 246–258; and environment, 373–409; excretion of, 237–245; heredity in, 508–519; and higher plants, 382–383; history of, 564–579; improving mankind, 512–516; and insects, 389–398; and population growth, 382; and racial classification, ***574***; skull of, ***193***; sperm of, ***423***; time clock for, ***566, 568***
Manson, Patrick, and malaria, 349
Manure, def., 405; and tetanus, 330–331
Maple, ***83***, 101, ***141***; fruits, ***445***; leaf of red, ***85***
Marble, 524
Marriage, regulation of, 512–513; and syphilis, 332
Marsupials, 18–20, ***19***, ***433***, ***552***; geographic distribution of, 552
"Master gland," 254
Maturation, def., 460; of gametes, 460–461, ***461***
Maze, 291, ***291***, ***292***
McGregor, Prof. J. H., and fossil man, 567
Mealy bug, ***47***
Measles, 340
Mechanical energy, 120
Media, for raising bacteria, 313; solid, 313–314
Mediterranean, fruit fly, 396; race, ***575***
Medulla, 271–273; and breathing, 232; human, ***271***; vertebrate, ***273***
Membranes, of blood vessels, ***215***; cell, 106, ***106***, ***107***; in diffusion, 122–124, ***123***, 150–151, 189, 198, 231; ear, 282; embryonic, ***432***, 433; fertilization, 424; of lungs, ***227***, 228; mucous, 131, 192, 195, ***195***, 197, 198, ***198***, 200, ***228***; nervous system, 271; nuclear, 107, 457, 458; plant epidermis, 133; serous, 131, 194, 216
Mendel, Gregor, and heredity, 467–472
Mendelian ratio, ***469***; explained, 466–467
Meninges, 271
Mental health, 367–368; and alcohol, 366–367; of adolescents, 368–369
Mental illness, 369
Mental traits, heredity, 510–512
Merino sheep, ***494***
Mesoderm, 426
Mesozoic era, 533, ***534***, 537–538
Metabolism, def., 170; and tagged atoms, 250; basal 170
Metamorphic rock, def., 524; examples of, 524
Metamorphosis, def., 429; of frog, 428–429, ***428***; of insect, 42
Metchnikoff, Eli, and phagocytes, 210
Microorganism, def., 63; 61–64; and man, 311–360, 383–385
Micropyle, 442, ***443***
Microscope, 11, 105, 106, ***113***; directions for use of, 114–115; effect on image, 114–115; electron, 12; Leeuwenhoek's, ***10***; modern, ***10***; parts of, 113; ultraviolet, 12
Microspore, def., 446
Midget, ***253***, 254
Migration, of birds, 22–23; of fish, 33–34; routes, ***24***
Milk, bottling of, ***346***; breeding for, 497; certified, 347; inspection of plant, ***347***; raw, 346–347
Milk supply, and public health, 345–347
Milkweed, butterfly, ***42***; fruit, ***445***
Millipedes, 52, 66
Mimosa, 304; behavior of, ***305***
Minerals, 110, 111; in diet, 175–176; movement in plants, 157–159; in protein synthesis, 142; in soil, 148–150, 151; test for, 116; use of, 175; vitamin D and bone formation, 181
Mink, mutation, ***498***
Mint family, 88
Mites, 51
Mitosis, in animal cell, ***458***; def., 458; 456–459; in plant cell, ***457***
Mixture, 110–111, 112; and compound, 111; sugar and water, 111
Mockingbird, ***21***
Moisture, and bacteria, 315
Molars, 203
Molds, 75–77; of penicillin, ***333***, 334; reproduction of, 414–415, ***414***, 416–417, ***417***; and skin disorders, 243
Molecules, 121, 122; not diffusible, 124
Mollusks, ***40***, 53–55, ***54***, ***55***, 66
Mongoloid, 574
Monkey, appendage, ***549***; chromosome number of, 459
Monocots (monocotyledons), 83, ***83***, ***84***, 91; as food, 84–85
Moran, John J., and yellow fever, 352
Morgan, Thomas Hunt, ***456***; and fruit fly, 470; and gene theory, 456
Mosaic disease, of tobacco, 340
Mosquito, ***44***; chromosome number, 459; extermination of, 352–353; ***353***; life history, ***352***; and malaria, 349–351, ***350***; sucking blood, ***349***; and yellow fever, 351–354
Moss, 78, ***78***; classification of, 90–91; pigeon-wheat, ***73***, ***447***; reproduction of, 447; Spanish, ***138***
Moth, 43–44, ***43***; life cycle, ***43***; sucking tube, ***43***
Mother cell, in reproduction, 413
Motion, of protoplasm, 125
Motor areas, of brain, 272
Motor neuron, 278
Mouth, anemone, 59; earthworm, ***57***; insect, 43, ***43***, ***44***; man, ***226***; paramecium, ***62***; tadpole, 428
Mucous membrane, def., 131; 192, 195, ***227***; of mouth, ***106***; of villus, 198
Mucus, 192, 195
Mule, and hybridization, 501
Mullein, ***385***
Muller, Hermann J., ***481***; and mutation, 481
Mumps, 340
Muscle, cardiac, 224; cells, ***129***; heart, 131–132, 214;

involuntary (smooth), 131–132, *132*, 193, 194–195; nervous control of, 279; number in body, 273; in reflex arc, 278–279; tissue, 131; voluntary (striated), 131, 132, *132*, 193
Mushrooms, *73*, 75, *75*
Musk-ox, 540
Mustard, 87
Mutant, def., 480; evening primrose, 482; fern, 499; fruit fly, *480*; mink, *498*; rye, *480*; sheep, *498*; tobacco, *498*
Mutation, barley, *480*; and breeder, 497–499; def., 479; 479–481; effect of, 480; fern, *499*; and evolution, 555; fox, 499; fruit fly, *480*; human, 509; mink, *498*; and organism studied, 480; sheep, *498*; tobacco, *498*; and x-ray, *480*
Mutation theory, of evolution, 555, 561

Naphthalene, 395
Napthalene-acetic acid, 308
Narcotic, def., 366
National Association of Audubon Societies, 406
Natural immunity, 316
Natural selection, Darwin's theory, 556–559
Neandertal man, 568–569; head of, *567*; hunting, *569*
Nebraska, in Cenozoic period, *539*
Nectar, 43, 48, 86
Needles, cedar, *82*; evergreen, 81–82, 91; hemlock, *82*; pine, *82*
Negative tropisms, def., 301; in paramecium, *266*
Negroid (stock), 574
Neolithic, def., 572
Nerve, auditory, 282; cell, *132*, *274*, *276*, *277*; def., 275; fiber, 275–276; and nerve cells, 275–276; optic, 280; tissue, 131
Nerve centers, of man, 270–273; protective, 271
Nerve impulse, 270, 276–277; path, 275, 277, *277*; in reflex arc, 277–279
Nerves, 270; earthworm, *57*; man, *270*; skin, *240*
Nervous system, autonomic, 270; central, *270*, 270–279, 279–282; involuntary, 270; of bee, *275*; of man, 269–285; and syphilis, 332
Nests, ant, 46–47; bird, *25*, 432; fish, 427, *427*; tent caterpillar, *393*; wasp, *263*
Neuron, 274–279, *274*; afferent, *278*; efferent, *278*; of human cortex, *276*; intermediary, 278; motor, *278*; sensory, *278*
Neurosis, 368
Newts, 31
New Stone Age, 572–573; artifacts from, *565*
New York City, diphtheria death rate, *330*; tuberculosis, *321*, 322; water supply, 345
New York Hospital, *369*
Niacin, 179, 183; in common foods, 173
Nicotine, and insect control, 394–395; effects of, 366
Nicotinic acid, 179, 183 (see Niacin)
Nitric acid, 116
Nitrifying bacteria, 377
Nitrogen, 108, 110, 111; and bends, 233; cycle, 376–378
Nitrogen-fixing bacteria, 377–378, *377*
Nitrogenous wastes, 237
Noctiluca, 64
Nodules, def., 378; of peanut, *377*
North America, in Paleozoic era, *534*
Nuclear division, 456–459; in animal cell, *458*; in plant cell, *457*
Nuclear membrane, 107
Nucleolus, *107*, 108
Nucleoplasm, *107*
Nucleus, 106, *106*, *107*, 107–108, 111, *132*; of egg, 422, *423*; of neuron, 275; of sperm, 423, *423*; of white corpuscle, 208
Nutrient, def., 167
Nymph, insect, 42

Oak, 101, 105; cork of, 153; leaf, *85*; seedling, *438*
Oats, 84; breeding difficulties, 502
Octopus, 53, *54*
Oesophagus, of earthworm, *57*; of man, 188, *189*, *226*
Offspring, 41–49, *352*, 411–453, 455–519
Oil glands, of skin, *240*, 241–242
Oils, 217
Old Stone Age, 571–572; artifacts from, *575*
Olfactory lobes, of vertebrates, *273*
Olive oil, 197
Olives, fats in, 143
One-celled organisms (see Algae, Bacteria, Protozoa)
Onion, chromosome number of, 459; experiment with, *465*; mitosis in root tip, 463; skin cells, *133*
Opossum, 552; reproduction, 433
Opsonins, 316
Optic lobes, of vertebrates, *273*
Optic nerve, in man, 280, *280*
Orange, seedless mutation, 499
Orchids, *83*, 148
Order, in classification, 15, 99
Organ, def., 130
Organ system, def., 131
Organic evolution (see Evolution)
Organisms, behavior of, 260–309; classification of, 95–103; def., 3; and disease, 311–371; functioning of, 137–309; heredity in, 454–519; origin of, 520–579; relationships of, 373–409; and reproduction, 411–453; structure of, 105–135; survey of, 15–94
Organs, bird, *21*; breathing, 206–236; circulatory, 206–225; digestive, 188–205; earthworm, *57*; excretory, 237–245; grasshopper, *45*; of nervous system, 269–285; origin in embryo, 426; reproductive, 421–453; structure of, 105–135; table of activities, 256
Origin, earth, 521; of species, 553–563
Ornithology, 3
Osmosis, 122 (see Diffusion)
Ostrich, 22
Outbreeding, 496–497
Ova, 421
Ovary, def., 440; 421; formation of, 460; growth of plant, 444; of flower, *439*
Overgrazing, and soil erosion, 403
Overproduction, and evolution, 557; daisy, *558*
Oviducts, 422; fish, 424; frog, *422*
Ovules, def., 440; *441*
Owls, 21, *22*
Oxidation, 118–119, 121, 125, 143–144, 168; in cells, 120–121; chemical equation, 143; compared with photosynthesis, 143–145; and excretion, 237; rapid, 118–119; slow, 118–119; and thyroid, 247
Oxide, def., 119
Oxygen, 108, 109, 111, 218, 219; and artificial respiration, 232–233; and breathing, 226, 231; cycle, 375, *376*; and high altitudes, 233–234; in oxidation, 118–119; in photosynthesis, 142
Oxyhemoglobin, 209
Oyster, 54

P_1, def., 467
Pain, and drugs, 332
Paleolithic, def., 571 (see Stone Age)
Paleontology, def., 525–526
Paleozoic era, 533, *534*, 535–537
Palisade cells, of leaves, 138, 139, *139*

Palm stems, 157
Panama Canal, and mosquito extermination, 353
Pancreas, 192; and diabetes, 251–252; stimulation of, 199–200
Pancreatic, 196; activation of juice, 197; ducts, ***195***; juice, 192, ***195***, 196
Pantothenic acid, 180
Paramecium, ***62***, 63, 118; behavior of, 266, ***266***; conjugation of, ***417***; reproduction of, 412, ***412***
Parasites, 311; causing disease, 311–358; large, 354–355; of plants, 386–387
Parasitism, 311, 373, ***374***
Parathyroid, 254–255
Paratyphoid, statistics, ***326***
Parenchyma, 133
Parental care, 430; in birds, 431–432, ***431***; in crayfish, 430; in fish, 427, ***427***; in frogs, ***430***; in insects, 430, ***430***; in mammals, 433–434
Paris green, and insects, 393
Parrot fever, 340
Parsley family, 87–88, ***88***
Parthenogenesis, def., 424; artificial, 424; in plants, 449
Passenger pigeons, extinction of, 405
Passive immunity, 328–329; for tetanus, 331
Pasteur, Louis, 332; compared with Jenner, 326; and disease, 322–325; and immunity, 323–325; and pasteurization, 345; and rabies, 324–325; and spontaneous generation, 411–412; and viruses, 340; and wine, 322–323
Pasteur Institute, and bacteriophage, 340–341
Pasteurization, of milk, 345–346; test of, 346
Pathogenic, def., 311
Pathogenic bacteria, 311, 313, 315, 316; and body's defenses, 315–316; and spores, 314; strains of, 338
Pavlov, Ivan, 9–10; and conditioned response, 288
Pea, characters studied, 468; chromosome number of, 459; heredity in, 467–472; pod, ***444***; tall × short cross, ***469***
Pearl, Raymond, and tobacco, 365–366
Peat, 78
Pecan tree, grafting, ***503***
Pedigree, def., 497, 508; of famous family, ***512***; of man, 511–512; and shortsightedness in man, ***509***; and skin condition in man, ***509***
Peking man, 566; excavating for, ***567***
Pellagra, 179, 183
Penicillin, 12, 13, 77, 334; and mold, ***333***; and syphilis, 332
Pepsin, 194
Peptone, 194
Perching birds, 22
Perennials, def., 80
Peristalsis, 193, 196, 198
Peritonitis, 362
Permeable, def., 124
Petals, 439; of lily, ***439***
Petiole, 137
Petri dish, for studying bacteria, 313; ***323***
Petrifaction, def., 526
Petrified, egg, ***526***; tree, ***526***
Phagocytes, 210, ***210***; and bacteria, 315
Pharynx, of earthworm, ***57***
Phloem, 153, 156, 157; of root, ***152***; of stem, 154
Phosphatase, in milk, 346
Phosphorus (P), 109, 111; in common foods, 173
Photosynthesis, 140–142; summarized, 145
Phototropism, 301; negative, 301; of nasturtium, ***301***; positive, 301
Phylum, annelids, 57; arthropods, 41–53; bryophytes, 78; coelenterates, 58–60; def., 15; echinoderms, 55–56; flatworms, 58; invertebrates, 39–71, ***40***; mollusks, 53–55; porifera (sponges), 61; pteridophytes, 79–80; roundworms, 57; spermatophytes, 80–90; thallophytes, 73–78; vertebrates, 16–39, ***16***
Pig, effect of environment on, ***486***; and tapeworm, 355; and trichinosis, 354–355
Pigeons, experiments on brain, 272–273
Pigeon-wheat, a moss, ***73***; ***447***
Pigment of skin, protection against ultraviolet rays, 242
Pimples, 242–243
Pine, ***72***, 81–82; beetle, ***390***; and environment, ***488***; needles, ***82***, 137; and rust, ***386***
Pineal gland, human, ***271***
Pisces, 65 (see Fish)
Pistil, 139, ***439***; after fertilization, ***443***; of flower, 440–441
Pistillate, def., 440
Pitcher plant, 305
Pith, 154; in monocots, 157
Pithecanthropus erectus, 566, ***567***
Pituitary gland, 253–254, ***271***; over-secretion, ***247***; under-secretion, ***253***
Placenta, def., 433; ***432***; of pea plant, 452
Plague, bubonic, 328, 343, 348; and quarantine, 343
Planaria, ***40***, 58, ***58***
Plant lice, 46; control of, 394; reproduction of, 424
Plants, 7–94; behavior of, 301–306; breeding, 493–507; classification of, 90–91; competition among, ***385***; families, 72–94; food-making, 137–165, ***142***; and growth hormones, 303–304; importance of green, 144–145; insect-eating, 304–305, ***306***; movement of water in, 158–159; organs, ***131***, 133; phyla, ***72***; reproduction of, 438–453; structure of, 137–165; tissues, 133; unusual behavior of, 304–305; useful, 88; uses of, 382–383
Plasma, 211, 220, 221; membrane, 106; of blood, 208–209
Platelets, ***208***, 209; and clotting, 210–211
Pleura, ***227***, 230
Plexus, of autonomic system, 279, ***279***
Plumule, 451
Pneumococcus, 338
Pneumonia, 338; and sulfa drugs, 334; vaccine, 339
Poison hemlock, 88
Poisons, contact, 394–395; stomach, 393–394
Polar bear, ***99***
Poliomyelitis, 230, 340
Polled (cattle), def., 497
Pollen, and allergy, 365; def., 441; development of grain, 442, ***442***; grain, 442, ***442***; tube, ***442***, ***443***
Pollination, 441
Pollution, of water supply, 344–345
Pollywog, 428
Polydactyly, def., 509
Polynesian, ***575***
Polyneuritis, ***177***
Poplar leaf, ***85***
Pores, of skin, 239
Pork, and parasites, 354–355
Positive tropism, ***266***, 301, ***301***, 302, ***302***, 303–304
Postulates, of Koch, 322
Potassium, 109, 111; chlorate, 127; oxalate, 224
Potato, ***87***, ***141***; beetle, 390–391, ***391***, 397; cells, ***143***; economics of, 390–391; vegetative reproduction of, ***448***
Poverty, and health, 370
Pouched mammals, 18–20, ***19***, 433, ***433***
Praying mantis, 45, ***45***
Prehistoric, ages, 564–573, 577; men, 564–573, 577

Prejudice, def., 576
Preservation, of food, 384–385
Prevention, of disease, 322–334, 338–342, 343–358, 359–371
Primary germ layers, 426
Primary sex cells. 460–461, ***461***; dihybrid, ***472***
Prolific, def., 385
Protective resemblance, 560–561
Proteins, 110, 112; in common foods, 172; in diet, 174; diffusion of, 124; digestion of, 194; synthesis of, 142–143; test for, 116
Proterozoic era, 533, ***534***, 535
Prothallus, of fern, ***446***, 445–446; of flowering plant, 446
Protococcus, 74
Protoplasm, 105, 111, 125, 126; composition of, 108–109; compounds in, 109–110; contractility of, 269; elements in, 108, 109, ***108***; irritability of, 269; structure of, 108; summary of, 111–112
Protozoa, 15, 61–64, ***62***, ***64***, 66; behavior of, 265–266, ***266***, 269, ***269***; of malaria, 349–351, ***350***, ***351***; and symbiosis, 374; tropisms of, ***266***, 301
Pseudopod, 63
Psittacosis, 340
Psychiatrist, def., 368; 369
Psychologist, def., 286; 368
Psychozoic era, 533, ***534***, 539–540
Pteridophytes, ***72***, 79–80, 91
Ptyalin, 190, 191
Public health, 343–371; disposal of sewage, 344–345
Pulmonary, artery, ***213***, 219; circulation, ***219***, 219–220; tuberculosis, 322; vein, 220
Pulse, 215
Puma, ***97***
Pupa, 42; of ant, ***47***; of mosquito, ***352***
Pupil, of eye, 280
Pupillary reflex, exercise, 267
Pure, bacterial culture, 314; gamete, 466
Pure Food and Drug Act, 385
Pus, 210; in skin, 242–243
Pustules, of cowpox, 325
Puzzle box, and cat, 291; and man, 294–295
Pyloric sphincter, 195–196
Pylorus, ***195***
Pyramidal cells, of brain, ***276***
Pyridoxin, 180
Pythons, 28, 29

Quail, ***264***
Quarantine, def., 343
Queen Anne's lace, ***88***
Quinine, 89; and malaria, 332–351

Rabbit, 18; and web of life, 381; reproduction of, 432–433
Rabies, 324–325
Races, def., 573; blood groups in, 575; classification of, 573–574; of man, ***575***; misuse of term, 575–576; prejudice, 576–577; table of human, 574
Radiation, of heat, 241
Radioactive elements, 250
Radium, and cancer, 361
Ragweed, 90, ***366***; and hay fever, 364–365
Ratios, Mendelian, 466–467, ***467***, ***469***, 471, 508; dihybrid, ***472***
Rats, 18; dietary experiments on, ***175***; extermination of, 347; as germ carriers, 348; and learning, 291
Rattlesnake, 27, ***27***; head, ***27***
Ray flowers, 89–90, ***89***
Reasoning, and learning, 294–295; and lower animals, 295–296; tools for, 296
Receiving gamete, 416, ***416***
Receptors, 261, ***278***, 279–282; of ear, 281–282; of eye, 280–281; internal, 280; in reflex arc, 277–278
Recessive characters, 468, ***469***, ***470***, ***471***, 473; def., 268; in man, 509; mutations, 478–480
Recombination, and variation, 474
Rectum, 188, ***189***
Red corpuscles, ***208***, 209–210; and malaria, 350–351
Red Cross, 233
"Red snow," 74
Redi, and spontaneous generation, 411
Reduction, of chromosome number, 460–461
Reduction division, def., 460; female primary sex cell, ***461***; and heredity, 466; and independent assortment, 471–472; male primary sex cell, ***461***
Redwoods, giant, ***156***
Reed, Walter, and yellow fever, 352
Reflex arc, 277–279, ***278***
Reflexes, 262–263, 287, 288, 298; in frog, 279; and habits, 292–293; in protozoa, 265
Reforestation, 402; chart, ***400***
Regeneration, in starfish, 56; of nerve, 275–276
"Reindeer moss," 77
Relationships, of living things (ecology), 373–409
Rennin, 194
Repellents, def., 395
Reproduction, 125, 411–453; ameba, ***413***, 412–413; of aphids (plant lice), 424; bird, 430–432; fern, 445–447; fern versus flowering plant, 446–447; fish, 423–427; frog, 427–429; in land-living animals, 429; and insect life histories, 41–42; malarial protozoan, 350–351; mammal, 432–434; moss, 447; organs of, 421; paramecium, ***412***, 412; parental care in fish, 427, 430; rabbit, 432–433; spirogyra, 415–416; by spore formation, 414–415; and survival, 434; vegetative, 447–449; yeast, 413–414; ***413***
Reproductive organs, 421, 442; bird, 430; flowering plant, 439–442, ***439***, ***440***, ***441***, ***442***; frog, ***422***; origin in embryo, 426–427; rabbit, 432–433
Reptiles, 26–30, ***26***, ***27***, ***28***, ***29***, ***30***; Age of, 537–538; brain, ***273***; embryo, ***549***; fossil, ***537***; skeleton, ***28***, ***548***
Resemblances, among vertebrates, 547; and classification, 551; chemical, 550, ***550***; in embryos, 548–550, ***549***; explanation of embryonic, 550; explanation of structural, 548; protective, 560–561, ***560***, ***561***; in skeleton, ***547***, ***548***, ***549***
Reservoirs, and water supply, 345
Resin, 82
Respiration, 119, 125, 226–236; animal compared with plant, 144; and breathing, 231; cellular, 231; compared with photosynthesis, 143–145; plant, 143–144; summarized, 145
Response, 260–308; ameba, ***265***; conditioned, 288–289; learned, 289–290; paramecium, ***266***; plant, 301–306; to stimulus, 261; types, 261–262; unlearned, 262–263; vorticella, ***269***
Retina, of eye, 280–281, ***280***
Retted, def., 384
Rh factor, 212
Rhizopus, 77, ***414***; reproduction of, 414–415, ***414***
Rhodesian man, 568
Riboflavin, 180, 183; in common foods, 173
Ribs, ***228***, 231
Rice, 84, ***141***; and beriberi, 177
Rickets, ***180***, 181, ***181***, 183, 311
Ringer's solution, 135
Ringworm, 243, 311

Ritchie, Walter S., 109
Robin, ***16***
Rockefeller Institute for Medical Research, and pneumonia vaccine, 339
Rocks, 521–525; age of, 525; and earth history, 525–544; formation of, 521; formation of sedimentary, 523; how exposed, ***529***; kinds of, 521, 523, 524; strata of, ***523***; tilted strata of, ***524***
Rockweed, ***74***, 75
Rodents, 18
Rooster, ***254***
Roots, 148–153, ***152***, 157; cap, ***152***; as food, 148; growing point, 152, ***152***; hairs, ***150***, 150–151; ivy, 148; length in rye, 148; orchids, 148; and plant responses, 303–304; structure of, 151–153; sugar beet, ***149***; tap, ***149***; use to plant, 148; wheat, ***149***
Rose, 86; wild, ***86***
Ross, Ronald, and malaria, 349–350
Roughage, 176, 198
Roundworms, ***40***, 57, 66
Rubber, 88, 383
Runner, of strawberry, ***448***, 449
Rusts, 118, 386
Rye, ***141***

Saber-toothed tiger, ***528***
Safety, home check list for, 363
St. Martin, Alexis, and gastric digestion, 194
Salamanders, 31
Saliva, 190, 192, 194, 196
Salivary glands, of mosquito, ***44***; of man, ***189***, 192, 199
Salivary juice, 194
Salmon, life cycle, 34
Salt, 109, 111
Sanctuaries, def., 406
Sand dollar, 56
Sandstone, 523, ***529***
Sanitation, def., 343–344
Saprophyte, def., 374; ***374***
Sapwood, ***156***
Scale insects, 46; control of, 394
Scales, bird, 20, ***21***; fish, 32, ***32***; of insect wings, 43; reptile, 26
Scallop, 55
Scarlet fever, and carriers, 347; immunity, 316
Scavengers, def., 21; 210
Schaefer respiration method, ***232***, 233
Schick, Bela, and diphtheria, 329; test, 330
Schleiden, Matthias, 125
Schwann, Theodor, 125
Science, and improvement of man, 516
Scion, def., 502; ***503***
Sclerotic coat, of eye, 280, ***280***
Scorpion, 51, ***53***
Scouring rush, ***79***
Scurvy, 176, ***176***, 178, 180–181, 183, 311
Sea, anemones, 58–59, ***59***; lettuce, 75; lily, 56; lion, 18, ***19***; urchin, ***46***
Sea urchin, ***46***; and parthenogenesis, 424
Seal, 18; appendage, ***549***
Seaweeds, 74–75
Secondary growth, of stems, 157
Secondary sexual characteristics, 421–422; in birds, 421; in deer, ***421***; in frog, 435; and hormones, 422; in mammals, 421–422; in man, 422; in spiders, 422
Secretin, 200, 246
Secretion, def., 125; as conditioned response, 288; as reflex, 262
Secretions, 9–10; digestive, 190–197; internal, 246–258
Sediment, 523; and fossil formation, 526, 527
Sedimentary rock, formation of, 523; strata of, 523, ***523***, 524, 528, ***529***; tilted, ***524***
Seedless, fruits, 449–450; vegetables, 450
Seeds, def., 438, 444; agents of dispersal, 445; bean, ***438***; coats, 438; corn, ***438***; development of pea, ***444***; dispersal, 445, ***445***; formation, 438–439, 442–443; in plant life cycle, 445; sprouting, ***150***, ***438***
Segments, abdominal, 41; worm, 57
Segregation, in four o'clock, 464–467, ***466***, ***467***; in fruit fly, 470, ***471***; in garden pea, 468–469, ***469***; in guinea pigs, ***470***; in squash, ***469***; in rats, ***469***; law of, 468–470
Selection, animals, 496; in breeding, 493–496; in corn, ***495***; def., 494; effects explained, 495; natural, 556–559, 561; in plants, 493–494; procedure, 494–495; of strawberry, ***494***
Self-pollination, def., 441–442
Semicircular canals, ***281***, 282
Semmelweis, and blood poisoning, 331, 332
Sensation, and brain, 272; and receptors, 279–282; and reflex arc, 278–279; and skin, 242
Sense organs, 261
Sensitive plant, 304, ***305***
Sensory neuron, 278, ***278***
Sensory region, of brain, 272
Sepals, 439, ***439***
Serous membrane, of artery, 216; def., 131; 194
Serum, blood, 211; experiment in resemblances, ***550***; immune, 331
Seventeen-year locust, 49
Sewage, and bacteriophage, 340; disposal, ***344***; and water supply, 344–345
Sex, chromosomes, 472–473; heredity of, 472–473; organs, 255, 422; effect of removal of, ***254***
Sex-linked heredity, 473, ***473***
Sexual reproduction, animal, 421–437; def., 417–418; plant, 438–453; simplest, 351, ***351***, 415–418, ***416***, ***417***
Shale, 523, 524, ***529***
Shapiro, H. L., and races of man, ***575***
Sheath, of neuron, ***274***
Sheep, 16, 99, ***104***, ***382***; Ancon mutation, ***498***; and anthrax, 324; bighorn mountain, ***99***; brain, ***271***; merino, 493, ***494***; and overgrazing, 403
Sheeting, def., 405; and soil erosion, 405
Shellfish, and typhoid, 348
Shells, 30, ***30***, 53, 54, ***54***, 56, ***56***, 59, 60, ***60***, 64, ***64***, 526, ***543***
"Shipworm," 55
Shortfingeredness, 509
Shrubs, def., 80
Siamese cat, heredity, ***465***
Siberia, fossils in, 528
Sieve plate, ***153***
Sieve tubes, 156, 157; of roots, 153
Silkworms, and disease, 321; life cycle, ***43***
Silt, def., 523
Sinanthropus pekinensis, 566
Sinuses, ***226***, 364
Sinusitis, def., 364
Sire, def., 497
606, a drug, 332
Sixfingeredness, 509
Skeleton, cat, ***548***; eohippus, ***541***; fossil fish, ***525***; frog, ***548***; horse, ***541***; porpoise, ***551***; snake, ***28***; turtle, ***548***
"Skeleton," arthropod, 41; invertebrate, 39
Skin, 129, 238, 239–243, ***240***, 256; and body tem-

perature, 239–241; care of, 242; as receptor, 280; and ventilation, 242
Skull, 15, 271, ***567***; anteater, ***193***; armadillo, ***193***; dog, ***193***; horse, ***193***; man, ***193***, 226
Slime molds, 127
Slip, def., 449; 447–449
Slugs, 54, ***55***
Small intestine, 256
Smallpox, 325–326; cases in U.S., 325–326; epidemic, 325–326, 343; immunity, 316; and culture, 340
Smell, 280
Smooth (involuntary) muscle, ***129***, 131, ***132***, 193, 194, 216
Snails, ***40***, 53, 54, ***54***; fossil series, ***543***; in balanced aquarium, 378–379
Snakes, 27, 29; poisonous, 27–28; shedding skin, 28, ***29***; sperm, ***423***; x-ray, ***28***
Snapping turtle, ***30***; hatching, ***429***
Soaring, of birds, 21
Social insects, 46–49, ***47***, ***48***
Sodium, 109; chloride, 109
Soil, 148–150, ***149***, bacteria, 376, 377–378; conservation of, 403–405; destruction of, 402–403, ***404***; erosion, ***403***; experiment, 137; formation of, 521–523; minerals, 148–150; particles, ***150***; and tetanus, 330–331; top, 402, ***403***; and transpiration, 159–160; water in, 150–151
Soldiers, variation in, 487
Soluble, 123–124
Somatic, def., 455
Somatoplasm, and acquired characters, 487–490; def., 455
Sore throat, and milk supply, 345
Sorghum, 476
Sound and hearing, 282
Soviet Union, and conservation, 405–406
Soybean, and selection, 494; uses of, 494
Spanish moss, 137, ***138***
Spawning, 34; def., 424
Species, causes of variation, 473–474; chromosome number, 459; def., 15, 495–496; 97; origin of, 521–579; and variety, 495–496
Specific antibodies, 316
Speech, aid to learning, 396
Sperm, 421, 422, 423; ducts, 422; in fertilization, 424, 428, 429–430, 432, 442–443, 446, 447, 461–462; fish, ***423***; flowering plant, 442, ***442***; frog, ***423***; human, ***423***; maturation, 460–461, ***461***; snake, ***423***; worm, ***423***
Spermary, 421; frog, ***422***; formation of, 460
Spermatophytes, ***72***, 80–90, ***81***; classification of, 91
Sphagnum, 78
Spiders, 41, ***41***, 50–51; instinctive, 263–264; trap-door, 51; webs, ***51***
Spinal column, 271
Spinal cord, 270–272; in man, ***226***, ***270***, ***271***; in reflex arc, 277–279; in sheep, ***271***; in vertebrates, ***273***
Spiracles, of grasshopper, ***45***
Spirilla, ***312***
Spirogyra, 73, ***73***, ***74***; conjugation in, ***416***; reproduction of, 415–416
Spleen, 209–210, 222
"Splints," of horse's leg, 542
Sponge, ***61***, freshwater, ***40***; muscle cells, ***129***
Spongy cells, of leaves, 138, 139, ***139***
Spontaneous generation, def., 411; experiments, 411–412
Sporangium, bread mold, 415; moss, 447
Spores, bacteria, 314–315, ***330***; bread mold, ***414***; def., 414; malarial protozoan, 350–351, ***350***; moss, ***447***; puffball, ***557***; reproduction by, 414–415, 407; tetanus, 330–331
Spore cases, fern, ***415***; mold, ***414***, ***415***; moss, ***447***
Sporulation, def., 414; 414–415, 417; in various organisms, 415
Spraying, and apples, ***395***; and germs, 348
Sprouting seeds, ***150***, ***438***
Squash, heredity of shape, ***469***; tendrils, ***302***
Squid, 55
Squirrel, gray, classification of, ***100***
Staining, bacteria, 314, 321; cells, 458–459
Stamens, 439, ***439***, 441–442, 445, 464
Staminate, def., 440; flower, ***440***
Stanley, W. M., and viruses, 340
Starch grains, ***143***
Starches, 110, 112; chemical formula of, 141; in diet, 174; in diffusion, 124; digestion in plants, 158; plant sources of, ***141***; production in plants, 140–142; test for, 116
Starfish, ***40***, 56, ***56***; chromosome number, 459
Statistics, def., 343
Stems, 153–160, ***154***, ***155***, ***156***, ***157***; bamboo, 157; chlorophyll in, 139; conducting cells, ***155***; corn, ***157***; diagram, ***163***; growth of, 154–157; monocot, 157; palm, 157; structure of, 153–154; unequal growth in, 303–304; variations in, 157; white potato, 449
Sterile, def., 313, 501
Sterilization, methods, 313; and surgery, 331–332
Sterilization of human being, 513
Stickleback, male at nest, ***427***
Stigma, ***437***, 440, 441, 442, 443, ***443***, ***444***
Stimulant, 367
Stimulus, def., 261; 263, 265, 266, 269, 270; plant responses, 301–306, ***301***, ***302***, ***303***, ***305***, ***306***; in reflex arc, 277–278, ***278***; responses of protozoa, 265–266, ***266***, ***269***; varies responses, 287
Stock, in grafting, 502, ***503***; races of man, 573–***575***
Stomach, 188, ***189***, ***195***, 197; digestion in, 193–196; function, 130; glands, ***191***; lining, ***191***; movements, 195–196; muscles, ***195***; structure, 194–195, ***195***; tissues, 194–195
Stomach poisons, for insects, 393–394
Stomata, 138–139; ***139***, 140, 159; number, 139; of stems, 153
Stone Age, artifacts from, ***595***; history of, 565–573
Strain, def., 495; bacteria, 338; plus and minus in reproduction, 417
Strata, rock, def., 523, ***523***, ***524***, ***529***
Strawberry, ***86***; and selection, ***494***; vegetative reproduction, ***448***, 449
Streptococcus, of pus, 312; and sulfa drugs, 333, 334
Streptomycin, 334
Striated muscle, 131, ***132***, 193 (see Voluntary muscle)
Structure, def., 3
Struggle for existence, and evolution, 557
Style, ***439***, 440
Successful reproduction, 434
Sugars, 110, 112, 208; in diet, 174; and diffusion, 121–124, ***122***, ***123***; and insulin, 250–252; in photosynthesis, 141–142; and metabolism, 143–144, 145, 190, 196, 199; movement in plants, 158; sources of, ***141***; test for simple, 116
Sugar cane, ***84***, 85; breeding of, 501
Sulfa drugs, 333–334
Sulfur, 108, 110, 111; "showers," 441
Sulphuric acid, ***110***
Sun, and gene action, ***490***; and photosynthesis, 142
Sunburn, 242
Sundew, 304–305, ***306***

Sunflower, ***302***; mutation, 499
Surface, earth, 521–525
Surgeon General, 344
Surgery, appendicitis, 362; and cancer, 361; and infection, 331–332; and sulfa drugs, 334
Survival of the fittest, and evolution, 558
Susceptible, to disease, 324
Suspension, 108
Swallowing, 192–193
Swarming, of bees, ***48***, 49
Sweat, 239–241; glands, 239–240, ***240***
Swiss cheese, ***384***
Symbiosis, 374–375
Symbols, of elements, 108–109
Symmetry, bilateral, 55; radial, 55
Synapse, def., 276; ***276***, ***277***; in reflex arc, ***278***
Syphilis, 332–333

Tables of food values, 172–193
Tadpoles, ***30***, 428; changing to frog, ***428***; and thyroxin, 247–248
Tail, in embryos, 548
Tapeworm, 58, 355, ***355***
Taproot, beet, 148, ***149***
Tar pool, 527, ***528***
Tarantula, ***51***
Taste buds, 280
Teeth, 192, ***203***; armadillo, ***193***; dog, ***193***; horse, ***193***; human, ***193***; infected, 364
Temperature, and bacterial growth, 314; body, 239; def., 168; regulation, 239–241
Tenderizing, of meat, 383–384
Tendrils, plant, 301–302; squash, ***302***
Tent caterpillar, nest, ***393***
Tentacles, jellyfish, ***61***; octopus, ***54***
Terminal branches, of neuron, 275
Termites, 49; and symbiosis, 374; damage by, ***49***
Testis, 421
Tests for compounds, 110, 116
Tetanus, 330, 331; bacilli, ***320***
Texas cattle, 499
Thallophytes, classification of, 90
Thiamin, 179, 180, 183; in common foods, 173
Thigmotropism, 301–302
Thistle tube, 122, 123; in diffusion experiment, ***123***
Thoracic duct, 221
Thorax, of grasshopper, ***45***; of insect, 41
Thorndike, E. L., and behavior, 291
Thoroughbred, horse, ***493***
Thousand-leggers, 41, ***41***
Throwback, def., 474
Thunder lizard, 537–538
Thymus gland, 255
Thyroid gland, ***226***, 246–250, ***247***
Thyroxin, 246, 247, 248–249; effect of, ***248***
Ticks, 51
Time clock, for man, ***566***, ***568***
Timothy, ***84***
Tissues, 129–133, ***215***, ***221***, ***227***, ***240***, ***276***; culture of, 339–340; origin in embryo, 426; plant, 133, ***133***, 139, ***139***, 151–153, ***152***, ***153***, 153–154, ***154***; relation to lymph, ***221***; stomach, 194–195; types, ***129***, ***130***, ***132***
Toads, 31, ***31***; midwife and eggs, ***430***
Tobacco, 87; and health, 365–366; mammoth mutation of, ***498***; mosaic disease of, 340
Tongue, man, ***226***; as taste organ, 202–203
Tonsils, ***226***; and infection, 364
Toothache, 204
Topsoil, 402, ***403***
Tourniquet, 215
Toxin-antitoxin, and diphtheria, 329
Toxins, bacteria, 316; diphtheria, 328; and diphtheria susceptibility, 330; malaria, 350–351; tetanus, 331
Toxoid, 328–329; for tetanus, 331
Tracer atoms, 250
Trachea, ***189***, ***226***, ***227***, 227, ***247***
Tracheids, ***155***
Trachoma (eye infection) and sulfa drugs, 334
Transfusions, and blood banks, 211–212
Translucent, 116
Transpiration, 159–160
Transplantation, of bacteria, 314
Transportation system; earthworm, ***57***; human, 206–225; plant, 148–165
Trapdoor spider, 51
Trees, def., 80; cross-section, ***156***
Trial and error learning, 290–291
Trichinosis, 354–355
Trilobite, 535–536, ***535***, ***536***
Tropisms, 301–304, 305; animal, 265–266, ***266***
Trudeau, E. L., and tuberculosis, 337
Trunk, ***154***; cross-section of, ***156***; of tree, 154–155
Trypsin, 196
Tsetse fly, 349
Tube feet, of starfish, 56
Tube nucleus, 442, ***442***
Tuber, def., 449
Tuberculosis, 321–322; death rate graph, ***321***; following hookworm, 354; and milk supply, 345; statistics of death by, 321–322; vaccine for, 328; and x-ray, 322, ***323***
Tubes, in roots, 152; water-conducting, ***155***
Tulips, response to temperature, 302; "sleep" movements of, 305; structure of flower, 439; vegetative reproduction of, ***448***
Tumor, 360–361
Turgidity, and plant behavior, 304
Turkey, behavior of bush, 263–265
Turtles, 30; babies hatching, ***429***; skeleton, ***548***
Twig, horse chestnut, ***155***
Twins, fraternal, 514; identical, 514
2-4-D, 308
Twort, and bacteriophage, 340
Tyndall, John, and spontaneous generation, 411–412
Typhoid, bacteria, ***313***; and carriers, 347; death rate, ***345***; fever, 326–327; statistics, ***326***; and water supply, 344–345
Typhus, vaccine preparation, ***327***
Tyrannosaurus, ***537***, 538

Ultramicroscopic, def., 456; genes, 456
Ultra-violet light, and germs, 348; and microscopes, 12; and sunburn, 242; and vitamin D, 181
Umbilical cord, ***432***
Undulant fever, and milk supply, 345
Unequal division, in yeast, 413–414, ***413***
United Nations, and World Health Organization, 370
United States, Department of Agriculture, 501–502; Fish and Wildlife Service, 406; Forest Service, 402; Public Health Service, 328, 344, 362–364; tuberculosis death rate, ***321***
Unlearned behavior, 262–266
Uranium, 525
Urea, 199; as waste, 237
Ureter, 238, ***238***; of frog, ***422***
Urine, 238; and diabetes, 251
"Use and disuse," theory of evolution, 560
Uterus, 432, ***432***

Vaccination, reasons for, 325–326
Vaccination, smallpox, 325 (see Inoculation, Immunity)
Vaccine, 325–326, 327, 339; influenza, 340; preparation of, 326, ***327***; smallpox, 325; yellow fever, 340
Vacuoles, 106, 111; cell, ***107***; root hair, 150
Vacuum, 229
Vagina, def., 433
Valves, heart, ***213***, 220, ***220***; lymphatic, 221; vein, 217–218, ***217***
Van Helmont, Jan, plant experimenter, 137
Variation, in bean length, ***487***; caused by environment, 485; environmental, 485–492; in evening primrose, ***486***; and evolution, 557–558; hereditary, 479–485; in man, 573–577; measurement of, 485–487; partly explained, 473–474; in pig, ***486***; in soldiers, 487
Varieties, def., 495; in classification, 101
Vascular bundles, in corn, ***157***
Vascular cylinder, 153; root, 152, ***152***; stem, 154
Vegetables, seedless, 450
Vegetative propagation (see Vegetative reproduction)
Vegetative reproduction, 447–449; in African violets, 449; in bryophyllum, ***448***; and plant breeding, 502; in potato, ***448***; in strawberry, ***448***; in sweet potato, 449; in tulip, ***448***; in white potato, 449
Veins, 206, 207, ***207***, ***213***, 214, ***215***, 216, 217–218, ***218***, 219, ***219***, 220, ***221***; leaf, 137, 138, ***138***, 154; of leaves, 138, ***138***, ***139***, 154, 157, ***158***; structure of, ***215***; valves, ***217***
Vena cava, inferior, 219; superior, ***213***, 219
Venereal disease, 332–333
Ventilation, 242
Ventral, def., 202
Ventricles, 213, ***213***, 214, 215, 218, ***218***, 219, ***219***, 220, ***220***
Venus's flytrap, 304–305, ***306***
Vertebrae, 15, 271
Vertebral column, 271
Vertebrates, def., 15; brain, ***273***, 273–274; classes, ***16***; kinds, 15–39; number, ***39***; structural resemblances, 547; table of classification, 65
Vestigial structures, 550–551; in porpoise, ***551***
Vestigial wing, in fruit fly, 472; and temperature, 490
Villus, 198, ***198***, 206, 221
Virulence, of germs, 338
Virus, 339–342; common virus diseases, 340; influenza, 339; measles, 327; and rabies, 324; smallpox, 340; tobacco mosaic, 340
Vision, 280–281; and cerebrum, 272
Visual purple, and vitamin A, 179
Vitamins, 176–183; A, 177–179, 181–183; and cooking, 182; B, 177; B_1, 179, 183; B_2, 183; experiment, ***179***; B complex, 179–180; C, 178, 180–183; experiments, ***176***; D, 181–183; experiments, ***180***, ***181***; E, 182, 183; G, 183; in common foods, 173; K, 183, 211; pills, 182–183; review table, 183
Volcanic eruption, 524
Voluntary muscle, 131–132, ***132*** (see Muscle)
Von Behring, Emil, 328–329
Von Mohl, Hugo, 126
Vorticella, ***62***, ***269***
Vultures, 21

Walking stick, and protective adaptation, ***461***
Wallace, Alfred Russell, and evolution, 556
Warm-blooded, def., 16
Wasp, nest, ***263***
Wassermann test, for syphilis, 333
Wastes, def., 199, 206, 208, 237; diagram, ***237***; diffusion, 206–207; and kidney, 238; removal, 237–240; and sweat glands, 239
Water, in the diet, 175–176; in diffusion, 121–124; distilled, 123; excretion, 230, 238, 241; movement in plants, 151, 157–160; in photosynthesis, 140–142, 145; in protoplasm, 108, 109; in soil, 150–151; test for, 116; as waste, 237, ***237***
Water, birds, 21–22, ***23***; fleas, 373; moccasin, 27–28; ocean life, ***74***
Water-living animals, 18, ***19***, 30–34, 53–56, 58–61, ***74***; plants, 73–75, ***74***, ***76***
Watershed, after fire, ***401***; def., 345
Water supply, and public health, 344–345; and typhoid deaths, ***345***
Weathering, def., 522, ***522***
Web of life, 381
Web, spinning of, 263–264
Wedgwood-Darwin, pedigree, ***512***
Weeds, 385, ***385***
Weight, and calories, 170–174; reducing, 171; relation to diet, 174–175
Weismann, August, and acquired characters, 488–489; experiment with mice, 489
Whale, 18; flipper bones, ***547***
Wheat, 84–85, ***141***, ***149***; Kanred, 502
White ant (termites) 49
White corpuscles, blood cells, ***208***, 209, 210, ***210***; of lymph nodes, 222
White matter, of brain, 272; of spinal cord, 272
"White plague," tuberculosis, 321–322
Whooping cough, immunity, 316
Wildlife, conservation of, 405–406
Willow, 86
Wilting, of plants, 160
Windpipe, of man, ***189***, 227, 228 (see Trachea)
Wisdom teeth, 203
Wood, heart, ***156***, 157; pulp, 383; root fibers of, 152; sap, ***156***
Worker, ants, 47, ***47***; bees, 48–49, ***48***
World War II, and malaria, 349
Worms, 57–58; sperm, ***423***
Wounds, puncture, 331; and sulfa drugs, 333–334; and tetanus, 331
Wriggler, of mosquito, 352
Wyoming, fossils, 530

X-rays, and cancer, 361; and fruit flies, ***481***; of lily, ***439***; and tuberculosis, 322, ***323***
Xylem, 152, 153, 156, 157; of root, ***152***; of stem, 154, ***154***

Yale University, study of behavior, 296
Yeast, 77; reproduction, 413–414; ***413***
Yellow fever, 340, 351–354
"Yellow Jack" (see Yellow fever), 351
Yolk, 422, 425–426, 430, 431, ***432***, 461
Yolk sac, of fish, 425–426
Young (see Offspring)

Zebra, ***14***
Zoologist, 3
Zygospore, of bread mold, ***417***; def., 416; of spirogyra, ***416***
Zygote, def., 418; ***425***, ***428***; of flowering plant, 443, ***443***