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LIFE SCIENCE

Benedict, Ralph Curtiss

LIFE SCIENCE

BASED ON

High School Biology

THE MACMILLAN COMPANY · NEW YORK

1941

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Preface

Learning in science has become an integral part of the modern educational program at both the elementary and secondary school levels. With the advent of elementary science and general science in the elementary and lower secondary school grades, a general course in biology has become well established in the sequence of science courses for the high school grades. Biology merits the general approval it has received from science teachers and administrators alike. Emphasizing as it does fundamental biological principles and related physical science material, this life science has proved its worth as one of the most popular and valuable offerings in the secondary school program.

The authors of this biology textbook have had a varied science teaching experience ranging from the elementary school grades to the liberal arts college. They have served as members of many local, state, and regional curriculum committees. To this background of professional work, gained in New York, Texas, and Ohio, may be added years of research in both pure science and educational fields together with such practical experience as has been contributed by camp, farm, and industrial work carried on from New England and New York in the North to Texas in the South, and Ohio, Iowa, Nebraska, and Wyoming in the Middle West and Northwest.

On the basis of their experience in the organization of curriculum materials and with the construction of science textbooks, the authors have planned this book as a series of flexible units. The general framework of content is carefully designed to meet the needs and serve the interests of the thousands of American boys and girls who are found in our high schools today. Although the organization of materials in this book is not dominated by any one syllabus, it has been carefully checked against many city and state courses. With the emphasis upon biologic principles and with hundreds of experiments described or suggested in the text, *Life Science* should appeal to normal pupil interests and should find ready adaptation to school requirements in various sections of the country. The illustrations have been selected from various sources and represent various habitats that may be found in this country and in the world at large.

In the selection and arrangement of materials, the authors have kept in mind the usual criteria of pupil interests and larger social values, have endeavored to arrange the material in a natural learning sequence, and have employed a simple and direct style of writing in the treatment of the topics. The many experiments that have been described should facilitate real learning and promote classroom and laboratory experiments. The reporting of experiments and experimental results is indeed the very method of science itself. In every possible way an effort has been made to develop and apply principles and generalizations in such a way that pupils will respect and habitually use the scientific method. Finally it may be said that the book was planned in relation to a wide range of individual and social problems, including leisure-time and vocational opportunities, personal and mental hygiene, plant and animal breeding, and conservation.

The authors cannot express their full indebtedness to all who have contributed, but feel that special mention of indebtedness should be made to the following: Dr. Ernest Edward Dale, Union College, who reviewed and made valuable suggestions on the sections relating to genetics; Dr. A. F. Blakeslee and Dr. Oscar Riddle, Carnegie Institution of Washington; Dr. H. L. Shapiro, American Museum of Natural History; Dr. Harry Laughlin, Director, Eugenics Record Office; Dr. George M. Reed, Brooklyn Botanical Garden; Sister Mary Lourdes, Vincentian Institute; Drs. B. R. Coonfield, Paul R. Orr, Priscilla F. Pollister, and

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Contents

LIFE SCIENCE

Photo by Walter J. Shoonmaker

Animal photography is an interesting hobby. The man who took this picture spends his vacations photographing animals at night.

Everyday Use of Biology

Most people who study biology do so because they are interested in the living things around them. Biology is the science of plants and animals. It includes the study of food, diseases, fossils, and hundreds of other topics that relate to living things.

If you are the kind of person who believes that a subject should be useful, biology should fill your requirements exactly. Since plants and animals make up such an important part of your surroundings, you certainly ought to learn all you can about them. No matter where you live or what you do, you can put biological knowledge to use every day of your life. Whether you expect sometime to be a nurse, a housewife, a lawyer, a physician, a farmer, an aviator, a stenographer, a secretary, a teacher, a chemist, a writer, a dietician, or just a well-informed citizen, you cannot afford to omit the study of biology.

What is more, in order to achieve success in any line of work, it is usually necessary to lay careful plans and to carry out these plans in an orderly way. Such a procedure is sometimes referred to as the *scientific method.* There is nothing mysterious about the scientific method; it is merely the application of common sense. The scientific method can be used by anyone to solve everyday problems in exactly the same way that it is used by scientists to solve scientific problems. Scientists simply base their work upon the belief that this is an orderly world and that everything is the result of definite causes. Their ideas are drawn from carefully observed and tested facts. Successful businessmen, successful baseball players, and successful automobile mechanics use the scientific method just as consistently as successful scientists do. The study of biology should familiarize the student with the scientific method and provide valuable practice in its use.

Sitting under a ladder, holding an open umbrella, and breaking a mirror, this girl is using the scientific method to test three superstitions.

Someone has said, "Curiosity is always very noticeable in idiots, gossips, and scientists." A person who is especially curious about living things, curious enough to get all excited about studying them, often becomes a biologist. Biologists are usually not so concerned with the practical use of their discoveries as you may imagine. They are biologists because it is fun. It is thrilling to find a new kind of bug, to go on expeditions into unknown lands, or to discover a new kind of germ under a microscope.

One thing that makes biology especially interesting is that there are still so many discoveries to be made. For instance, there is a common insect called the "silver fish," or "starch bug," whose life history has never been studied. This insect is found in almost every house and is espe-

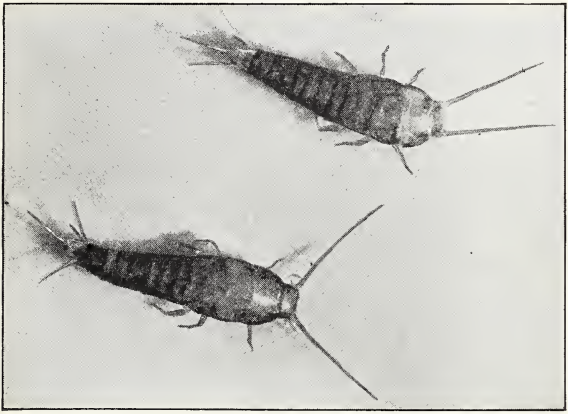


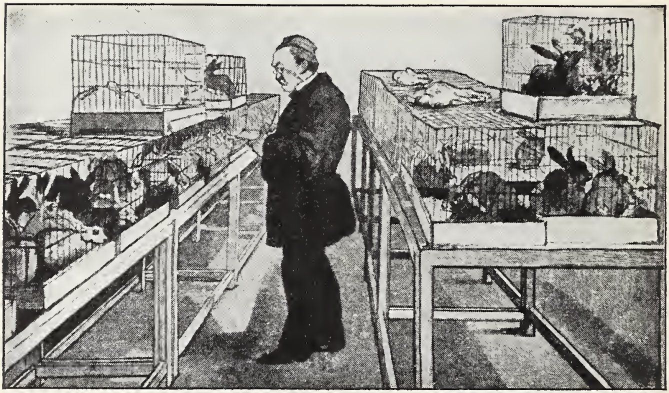
Photo by Hugh Spencer

Silver fish are sometimes called *bookworms*.

cially numerous in damp places. No one knows where its eggs are laid, how many eggs are laid and what they look like, how long it takes for the eggs to hatch, or what growth stages take place. The reason why these things are unknown is because no one has yet taken the trouble to discover them. Any high-school boy or girl could do the experimental work and make an original contribution to biologic knowledge. It would probably be as interesting as a trip to the ocean bottom or exploring a new country.

Of course, many of the things that biologists discover while they are having fun turn out to be very useful.

Think of what the world would be like if there had never been any biologists. The causes of disease would still be unknown. There would be cures for only a few diseases. We would not know very much about how our bodies are built or how they work. We would not know anything



From the Bettmann Collection

Louis Pasteur's curiosity led to his patient scientific experiments with disease germs. As a result of his discoveries many thousands of lives and many millions of dollars have been saved.

about germs. Improvement in plants and animals would be very slow.

Experiment stations, museums, government agencies, and research departments of large companies employ many people with biological training in an effort to increase our knowledge of plants and animals. Many other vocations such as agriculture, animal breeding, the food industries, pharmacy, and dentistry are closely related to the field of biology. It is more than likely that, no matter what you do, your own vocation will have something to do with biology.

Whether or not your lifework is directly concerned with living things, you will meet many questions about plants and animals. You will read about them in newspapers and magazines, you will meet them in television,

Photo from Ewing Galloway

Why does this nurse wear a mask and avoid touching the gauze and the instruments she is laying out in a hospital operating room?

in the movies, at the zoo, and on your vacations. You will wish to know the answers. It is hoped that you will find many of the answers in this book.

Review and Thought Questions

1. What is biology?
2. Illustrate by an everyday instance how the average citizen profits from applying the scientific method.
3. List several practical motives for studying biology.

4. How do biologists' discoveries make our lives easier and safer?

5. Name as many vocations as you can in which biological training is useful.

Activities

1. Look through newspapers and magazines for articles and illustrations on everyday uses of biology. Nominate a bulletin-

Photo by R. C. Benedict

These boys are unwise to drink from a stream close to a farm building. Why?

board committee-for-the-week to select and post on a biology bulletin board interesting pictures and clippings contributed by members of the class.

2. After conferring with your friends and classmates, list twenty superstitions most common in your neighborhood. Can you find the source or explanation for any of them?

3. Begin to collect periodicals, pamphlets, and books for a biology class library. Reference books for the various units you will study are listed at the end of each unit. You will need these and other books in carrying out the activities suggested at the end of each chapter. Your school or public library may be able to let you keep some of these books in your class library for the duration of your study of the unit in which they are especially useful.

Biological topics fill the pages of many periodicals and pamphlets issued by various organizations, to which members of your family may belong, or whose publications may be in your school or public library. You will find useful material in such periodicals as *Hygeia,* the magazine published by the American Medical Association, Chicago; *The National Geographic Magazine,* published by The National Geographic Society, Washington, D. C.; *Nature Magazine,* published by the American Nature Association, Washington, D. C.; *Natural History,* the magazine published by the American Museum of Natural History, New York; and *Frontiers,* the magazine issued by the Academy of Natural Sciences, Philadelphia; *The Science News Letter* published by Science News Service, Inc., Washington, D. C.; and *The Science Digest* published by Munn & Company, Inc., New York, N. Y.

Government bulletins are issued free or at low cost by various departments of your state and national governments. Write for a price list to the Superintendent of Documents, United States Government Printing Office, Washington, D. C.

4. In many hobbies, such as that of animal photography suggested by the illustration on page 2, a knowledge of biology adds to your skill and enjoyment. Make a list of hobbies in which biology will be helpful. Find out if your school or city library has any books, magazines, or newspapers giving biological ma-

terial of use in the hobby that particularly interests you, and begin collecting a hobby library of your own.

5. Appoint a committee to write to the United States Department of Agriculture, Washington, D. C. for the following free government bulletins on animal pests which are likely to cause problems at some time or other in any average family household. Select one of the problems represented and give a report on it before the class, using the government bulletin as one of your references.

Bedbugs
Carpet Beetles
Clothes Moths
Cockroaches and Their Control
House Ants
Housefly Control
Silverfish

6. Perhaps you have bought some "antiseptic" to apply to a sore throat or to an infected finger, because you heard over the radio that scientific laboratory experiments prove its germ-killing powers. Find out what reliable scientific experiments, such as those reported by the American Medical Association in *Hygeia,* prove regarding the effects of antiseptics on the germs that cause colds and other infections.

Unit 1

LIFE ON THE EARTH

The great variety of life on earth is amazing. At zoos, aquariums, museums, and botanical gardens, we marvel over the curious differences in living things. All over the world scientists are constantly discovering more about the various races of men, the most interesting of all animals, and about the varieties of plants and animals on which man depends. In Unit One, as the following outline shows, we will find out how many different kinds of living things have been discovered and how they are classified from the scientific point of view.

LIVING THINGS

- Forms
- Kinds
- Habitats

MAN

- Human Physical Traits
- Kinds of Men
- Types of Culture

USEFUL PLANTS AND ANIMALS

- Uses of Plants
- Uses of Animals

CLASSIFICATION

- The Oldest Branch of Biology
- Classification Is Fun
- The General Scheme of Classification

1. Living Things

Living things have not always existed on the earth. According to present estimates, the earth is about five billion years old. After this planet was formed, it was two or three billion years before conditions were such that life could exist. When living things finally made their appearance, it took many millions of years for them to develop and spread over the earth's surface. All living things are really a part of the earth, depending upon the water, the air, and the soil for their food and upon a distant sun for energy.

Forms

Living things exist in a great variety of forms. Some are round, some are flat, others are triangular, and still others are spiral. The shapes of most of them are very complicated. In fact, it is almost impossible to think of a shape which does not remind us of some living thing. While nearly all our decorative designs are based on the shapes of plants and animals, only a few of the existing life forms have been used for this purpose. There are still millions of living things whose shapes have not yet been recorded.

The largest living things. A banyan tree growing near Calcutta, India, is probably the largest living thing on earth at the present time. The heaviest living thing is almost certainly one of the sequoias growing in California.

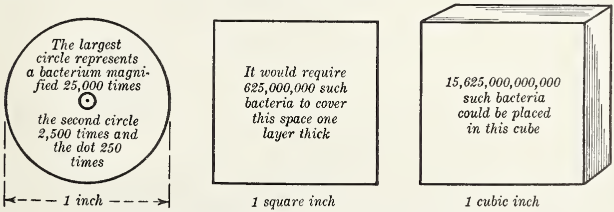
The tallest is either a sugar pine or a eucalyptus tree, while the longest is a seaweed somewhere in the Pacific Ocean.

Some trees are as tall as a thirty-story building.

Blue whales are the largest animals on earth. Even a newborn baby whale is about 25 feet long and weighs 8 tons. When full grown, blue whales may be as much as 80 feet long and weigh as much as 80 tons. Even the great dinosaurs of ancient times never grew that large.

Among land animals, elephants are the largest living forms. They are not the tallest or the longest, but no other land animal approaches them in weight.

The smallest living things. The plant kingdom includes the smallest kinds of living things as well as the largest kinds. The yeast plants used in breadmaking are



Do you realize how small bacteria are?

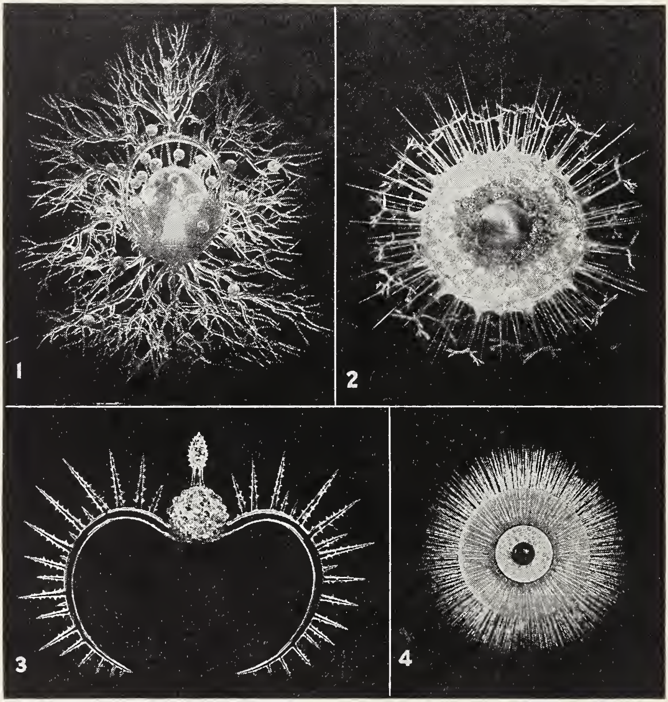
so small that they cannot be seen without a microscope. But bacteria are still smaller than yeast plants. The largest bacteria known are only about 1/2000 of an inch long. The bacteria that cause typhoid fever are about 3/25,000 of an inch long, while those that cause influenza are only 1/50,000 of an inch in length.

Some kinds of animals are also very small. A full-grown ameba is usually about 1/100 of an inch long and is about the smallest animal that can be seen with the naked eye. In a drop of stagnant water there may be thousands of animals much smaller than amebas. But no kinds of animals are as small as bacteria.

Kinds

About 1,000,000 different kinds of living things have been discovered and named. Of these, approximately

800,000 are animals, and 200,000 are plants. It has been estimated that at least 3,000,000 more kinds remain to be discovered. Scientists all over the world are constantly



Photos from American Museum of Natural History

These are the decorative shapes of four kinds of minute sea animals called protozoa (Radiolaria).

exploring new regions and adding to the number of known kinds of plants and animals.

Kinds of animals. No list of the total number of the known kinds of animals can ever be up-to-date. So many kinds of animals are already known that each newly discovered kind has to be checked very carefully to be sure that it has not been discovered before. The following

© Field Museum of Natural History

The giant Panda, a rare animal from Tibet, is one of the many kinds of mammals.

numbers of the known kinds belonging to various animal groups are very conservative:

Mammals	4,500
Birds	13,000
Fishes	15,000
Oysters, etc.	50,000
Worms	7,000
Crabs, etc.	8,000
Reptiles, etc.	5,000
Spiders, etc.	5,000
Insects	400,000
Microscopic forms	5,000

One circumstance that helps to make the total number of animals so enormous is that almost every animal has at least one kind of parasite.

Great fleas have little fleas upon their backs to bite 'em,
And little fleas have lesser fleas, and so *ad infinitum*.
And the great fleas themselves, in turn, have greater fleas to go on;
While these again have greater still, and greater still, and so on.

DeMorgan

Kinds of plants. The collection of mounted plant specimens in the American Museum of Natural History

Wheat rust, a fungus parasite on wheat stems, destroys uncounted millions of wheat plants every year.

in New York City includes over 150,000 species. In the New York Botanical Garden, at least 14,000 different kinds of living plants may be seen.

It would be impossible for anyone to learn the names of all the different kinds of plants or animals. Today it is necessary for scientists to specialize. One becomes an expert on ferns, another on grasses, another on a certain group of bacteria. By the work of the specialists, our knowledge of plants and animals increases very rapidly.

Habitats

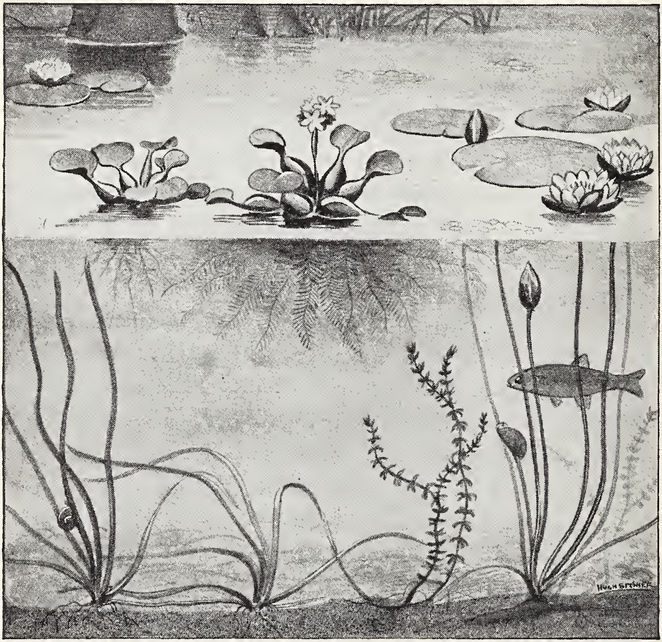
The habitat of a plant or animal is the place where it lives. Each species has a fairly definite habitat, although man and a few other species have come to be rather widely distributed.

The ocean. A great deal more life exists in the ocean than exists on the land. About five sevenths of the earth's surface is ocean. On the land, plant and animal habitats are confined chiefly to a thin layer of surface. In the ocean, there are living things at all depths.

The ocean inhabitants may be said to represent three general types of habitat: the shore dwellers, the surface dwellers, and the dwellers of the ocean depths. Along the shores of the ocean live countless numbers of clams, crabs, barnacles, starfish, squids, and other animals, as well as many kinds of plants. These living forms prefer the shallow water near the land and are seldom found far from the shore.

On the ocean surface are many floating forms of life: tiny plants that may give the ocean color and small animals that eat the plants. Larger swimming forms are also very numerous, such as sea turtles, sharks, fish, and whales.

In the ocean depths various fish, barnacles, crinoids, and sponges live in a region of permanent darkness, low temperature, and great pressure. These animals live mostly on the dead bodies of surface forms that sink down to them. There are no green plants in this region, due to the absence of sunlight.



How many of these plants growing in a Florida swamp can you name?

Fresh water. Swamps, ponds, streams, and rivers provide homes for great numbers of plants and animals. Fresh-water animals include snakes, fish, leeches, crayfish, and many others. Some animals, such as toads, frogs, and mosquitoes, spend part of their lives in fresh water and part on the land.

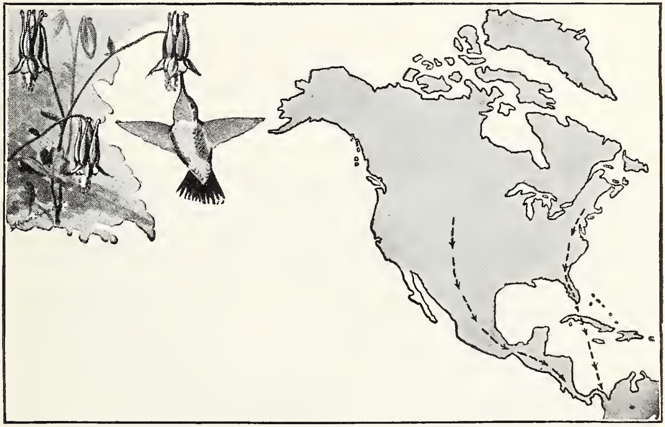
Plate I. More life exists in the ocean than on land.

SALT-WATER ORGANISMS

The shallow waters of the oceans, in temperate and tropical regions, swarm with color, both in the plant and animal kingdoms. Green animals and red plants, red animals and green plants, and a great variety of other colors are common. Starting at the top, the plate shows the following organisms:

The jellyfish, Aurelia, a pale, whitish dome; the egg case of a skate with its clasping hooks; a periwinkle, a small, edible snail introduced from Europe, on the rock above (two others below); small mussels of the edible type; sea grapes (upper right): brownish, rounded animals with two openings, of special interest because, as chordates, they belong in the same phylum as man; delicate, star-like hydroids, in a tuft; sea vases, another kind of chordate (on rock); a branching red seaweed, and to the left, a pale, delicate sea anemone; to the right, tufts of sea lettuce, with more sea anemones; on the rock, in front of the red seaweed, the brilliantly colored small starfish; on the rock, to the right of the starfish, eight acorn barnacles; to the right of the rock, three edible mussels, one with hairlike, attaching threads; growing from one of the mussels, a tuft of the brown seaweed, Fucus; below the edible mussels, a single, corrugated, inedible mussel; above this, the shell of a bloody clam; below the corrugated mussel, a green, edible sea urchin; each side of the sea urchin, several red sea anemones; to the left, below the starfish, a knobbed whelk, extending its velvety black foot; below, as if bowing to the whelk, three tentacled annelid worms, projecting from their woven cases; lower right, an oyster which is harboring the red-beard sponge; above and below, several limpets, a patch of coral, and holes made by the boring sponge.

Plants such as water lilies grow under water except for the upper surfaces of their leaves. Long stalks connect these leaves with the roots which are embedded in the soil at the bottom of the lake or pond. Water hyacinths are examples of floating plants. They have air bladders



Where do the humming birds of our temperate region migrate in winter?

which keep them afloat. Other fresh-water plants, such as Elodea, are entirely submerged.

The arctic regions. For a few weeks each year the arctic *tundra* is teeming with life. Buttercups, forget-me-nots, lichens, poppies, and mosses grow luxuriantly in the few inches of soil which have been thawed out by the continuous sunlight. In a short time they are covered again with snow which protects them from the long, cold winter.

On high mountains the plants and animals often resemble those of arctic regions. The plants are small, but flowers are numerous and colorful.

The temperate regions. The plants and animals of temperate regions are characterized by their adaptations to the change of seasons. Many of the plants live only one year and produce seeds which are not injured by the

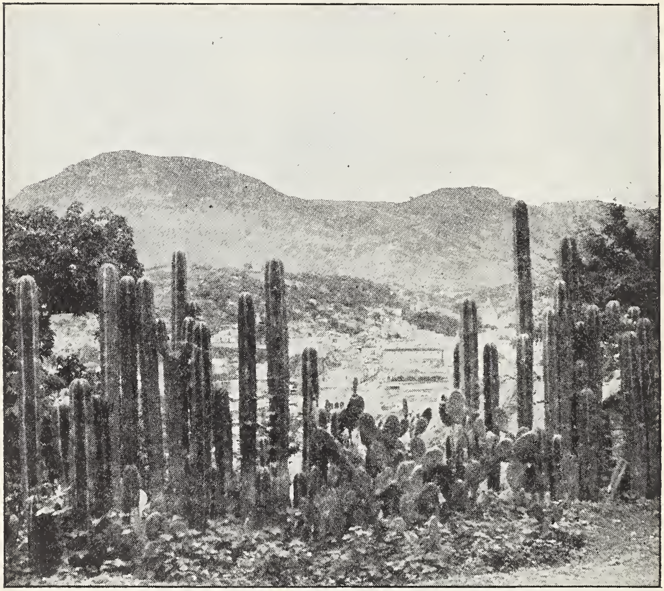


Photo by James Sawders

Where rain is scarce, plants take strange forms.

low winter temperature. Others shed their leaves, store up food in their roots and remain dormant during the winter. Some animals grow thick coats of fur, some hibernate, and some migrate south in winter.

The tropical regions. The greatest variety of life that exists anywhere is found in the tropics. In the jungle the thick mass of intertwined vegetation provides food and shelter for animals of every description. In the tropical rain forest, the vegetation forms a thick canopy above the ground through which almost no sunlight can penetrate. This canopy is green throughout the year, and in the dark, warm, and humid space underneath, live many of the strangest creatures on earth.

Deserts. Although water is extremely scarce in deserts, there is no desert too dry for living things to exist in it. An interesting fact about desert plants is that they resemble each other very closely, no matter in what desert they live. Desert plants conserve water by developing thick leaves or, like the cactus, by substituting stems for leaves. Since without some protection such fleshy plant growths would be in great danger of being eaten by animals, many desert plants, such as the aloes and spurges of Asia, are protected by their poisonous sap. Others, such as cacti in America, grow spines of a very efficient sort. In spite of these defenses, desert plants are often eaten by desert animals, since wherever food is available there is usually some animal to eat it.

Review and Thought Questions

1. Where can we find the basis for many new decorative designs?
2. What are the largest animals living today?
3. What are the largest plants of today?
4. Are the smallest living things plants or animals?
5. About how long is an influenza germ?
6. About how big is the smallest animal you can see with the naked eye?
7. Of the different known kinds of animals, which kinds are the most numerous?
8. What is a mammal? (Make use of the glossary of biologic terms in the Appendix of this text.)

9. Give two reasons to account for the fact that life is more abundant in water than on land.

10. What important environmental factor is present in tropical but not in desert regions?

Activities

1. Make a list of the animal pets that you know.

2. Make a list of all the wild animals you have seen in the city or country.

3. Measure the circumference and determine the diameter of the largest tree you can find in your neighborhood.

4. Put a drop of stagnant water on a microscope slide. Count the one-celled plants and animals you can see through the microscope.

5. Make a labeled collection of all the plant seeds you can find.

6. Set up and maintain an aquarium. A large glass jar will do. Stock this jar with water and living things from a pond or stream.

7. Remove a block of earth from a forest floor or from a vacant lot. Put this material in a small covered glass jar and place in the light. Keep a diary of what grows.

8. Start building a scientific library of your own by collecting and filing magazine and newspaper clippings.

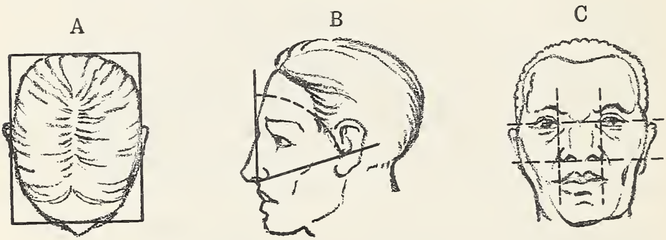
2. Man

Of all the living things on earth, the most interesting is a two-legged animal called man. His scientific name is *Homo sapiens,* the Latin for "Man the Wise." This species of animal is very widely distributed and is able to exist even in the coldest and driest regions. For protection against unpleasant weather, man builds houses of various sorts. Some of these houses are made of grass and sticks and are not much more elaborate than those made by birds. Others are made of hardened mud, stone, steel, and wood. Frequently the houses are built close together in cities and are connected with each other by streets, sidewalks, gas pipes, water pipes, and telephone lines.

The animal called man considers himself much superior to the other animals. It is true that he is able to stand erect, can grasp things with his hands, and has a well-developed brain. But many other animals are superior to man in speed, physical strength, keenness of vision, and in other ways. Man has, however, the ability to study himself and the world around him from a scientific point of view—something no other animal has learned how to do.

Human Physical Traits

Of the two billion human beings now living on earth, no two, not even twins, are exactly alike. Men differ from each other in thousands of ways. Some of these differences, such as weight, temperament, and language, are not constant and are therefore unsatisfactory for the purpose of comparing men with each other. In order to study man scientifically, it is necessary to select traits that are relatively constant and that can be measured, so as to have a satisfactory basis for comparison. Among the traits which have been found most satisfactory for this purpose are the following: hair texture, head form, skin color, stature, and some other characteristics.



These indexes are used in the scientific study of man: (A) cephalic index: width of head divided by length of head; (B) facial angle: determined by finding the number of degrees in this angle; (C) nasal index: width of nose divided by length of nose.

Hair texture. The form of the hair is perhaps the most commonly used trait in the scientific comparison of human types. Hair is either straight, wavy, or kinky. The real difference is in the shape of the hair as seen in cross section. Straight hair is round; wavy hair is slightly oval; kinky hair is flattened.

Head form. The form of the head lends itself easily to fairly objective measurement. The width of the head measured above the ears divided by the length of the head is known as the *cephalic index*. The cephalic index is expressed as a decimal fraction and is usually less than 1.00 because heads are usually longer than they are wide.

If the cephalic index is .75 or below, the individual is said to be long headed; if between .75 and .80, he is regarded as medium; if above .80, he is regarded as wide headed.

Skin color. Skin color is due principally to the presence of the brown pigment, *melanin.* Differences in the amount of this pigment result in many shades of skin color. But, since exposure to the sun also affects skin color, the color factor is a less satisfactory basis for comparison than are more fixed traits.

Polynesian 5′-9⅓″ | *Scot* 5′-8¾″ | *American Negro* 5′-6⅝″ | *Chinese* 5′-4⅛″ | *Japanese* 5′-3⅛″ | *Blackfellow* 4′-4¾″

The average heights of various racial groups have been scientifically determined. The wall represents the average stature of all men.

Stature and other traits. Height, when the individual is standing, can be very easily and accurately measured. The length of the upper part of the body, or the "sitting height," is also a useful basis for comparison. Additional comparisons are made on the basis of the *nasal index* (ratio of width to length of nose), the *skull capacity* (cubical content), the shape of the lips and ears, and the eye folds.

Kinds of Men

All men now living belong to the same species. In prehistoric times, other species of men existed, but probably

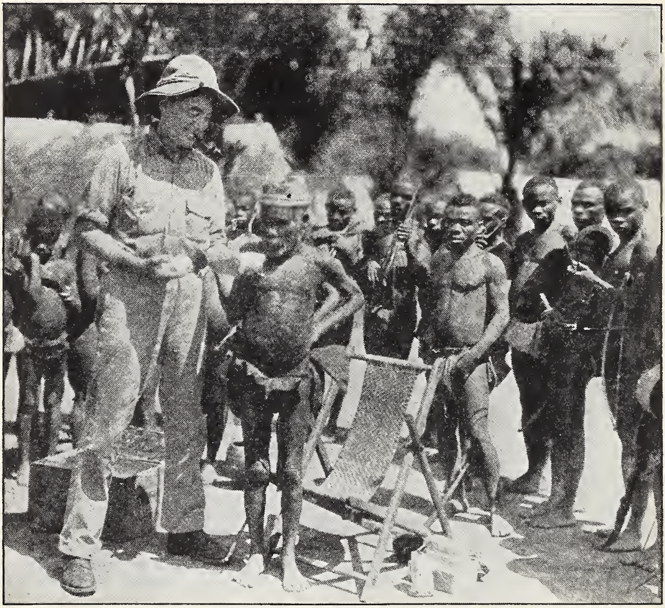
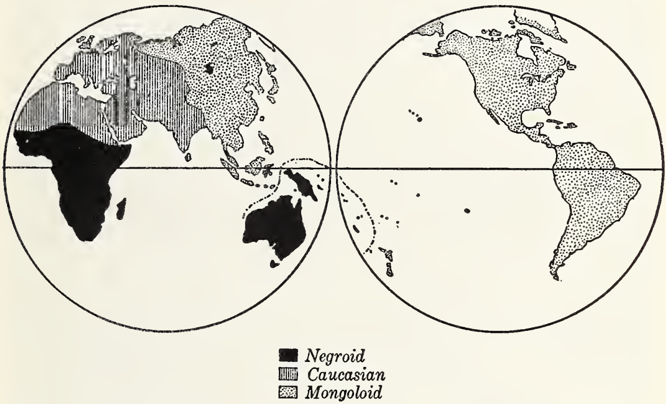


Photo from Ewing Galloway

Pygmies are the smallest human beings. This pygmy group from the African Congo belongs to the same species as all other men now living.

no representatives of these other kinds of men are alive today.

Races. The human species may be divided into three large groups called *races*. Even in very early times it was customary to associate the races of men with the continents on which they lived. Europe was considered the home of the white race, Asia of the yellow race, and Africa of the black race. When Columbus discovered America, it was believed that a new kind of men, the red race, had been found. But it is now believed that the American Indians are members of the yellow race and that their ancestors came over from Asia in prehistoric



The distribution of races before the time of Columbus was less mixed than it is today.

times. Today we recognize only three principal races: the white or Caucasian race, the yellow or Mongolian race, and the black or Negroid race.

Subraces. The classification of mankind on a racial basis can never be a very accurate one, because there is great variation of physical traits within each race. However, within each race certain natural groups occur, which are referred to as subraces. In the case of the white race, four of the subraces are: (1) the *Nordics,* whose ancestral home was northern Europe, (2) the *Alpines* in central Europe, (3) the *Mediterraneans* in southern Europe, and

(4) the *Hindus* in India. The following table presents a summary of the principal subraces and of the characteristic physical traits of each.

Racial Classification

Subraces	Hair Texture	Head Form	Color Skin	Stature	Principal Races
Bushmen (South Africa)	tufted	long	brown	short	Negroid
Negritos (New Guinea, Philippines, Malay Peninsula, Equatorial Africa)	kinky	medium	black	very short	Negroid
African Negroes	kinky	long	black	tall	Negroid
Oceanic Negroes	kinky	long	black	tall	Negroid
Australians (Australia)	wavy	long	black	above average	Negroid, Caucasian
Mediterraneans (Around Mediterranean Sea)	wavy	long	dark white	average	Caucasian
Nordics (Northern Europe)	wavy to straight	long	white	tall	Caucasian
Alpines (Central Europe)	wavy to straight	short	white	above average	Caucasian
Hindus (India)	straight	long	dark white	medium	Caucasian
Ainus (Northern Japan)	wavy	medium to long	light brown	average	Caucasian, Mongolian
Malaysians (Java and Philippines)	straight	short to medium	brown	below average	Mongolian, Caucasian, Negroid
American Indians (North and South America etc.)	straight	short to long	brown	average to tall	Mongolian
Eskimos (North America)	straight	long	yellow	short	Mongolian
East Asiatics (Eastern Asia)	straight	short	yellow	below average	Mongolian

Throughout the Pacific islands there is evidence of mass movements of peoples, resulting in mixtures of yellows, of blacks, and of whites. The Polynesians are an example of such a mixture. Evidence has been found to indicate that the islands of Japan were once settled by a bearded people, probably part of the Caucasian race. Remnants of these people, the so-called "hairy Ainus," still remain. In other words, the present Japanese was an immigrant and was probably chiefly Mongolian.

Photo from Ewing Galloway

The American Indians belong to the yellow or Mongolian race.

With modern methods of communication and transportation, man is probably moving about today more than ever before in human history. North America is now occupied chiefly by the white or Caucasian race. In this country there are many members of the yellow race, including the American Indians, and there are also many members of the black race, or Negroes. Such a city as New York is indeed a melting pot of peoples from all over the world.

Photo from Ewing Galloway

The Ainus, a remnant of bearded Caucasians, still live among the beardless Mongolians on the island of Hakaido, Japan.

Types of Culture

It is possible to study man from the viewpoint of his ways of living as well as of his physical characteristics. In fact, both the way of living and the type of environment have much to do with physical appearance.

Stages of culture. The superiority of man over the other animals is principally due to the fact that man has developed various types of culture.

Culture includes the common customs and ways of doing things that are associated with any stage of civilization. The earliest men probably lived in a warm climate where there was an abundance of food, all of which was eaten raw. Then, after tools and weapons had been invented, man probably migrated from place to place in

Photo from Ewing Galloway

These wandering Arabs encamped by the Dead Sea are in the herdsman stage of culture, depending for a living largely upon domesticated animals.

search of wild animals; this was the hunting and fishing stage of culture. In the next stage, man became a herdsman. When plants were domesticated, agriculture and permanent communities became elements of man's culture. At present, a large part of the human race has passed into the industrial stage of civilization.

However, within quite recent times, practically all the culture stages of the past were represented in the Western Hemisphere. In the arctic regions of North America, the Eskimo is still a hunter and fisherman, with a diet consisting almost entirely of animal material. Until recently the Indians of the north-temperate forests and plains depended largely upon hunting and fishing but also made use of the more abundant plant products and carried on some hoe culture as well. The greater abundance and variety of more easily obtainable food in these regions supported a relatively greater population than was possible in the arctic regions. Other Indian tribes, farther

Photo from American Museum of Natural History

In the arctic regions of North America, the Eskimo is still a hunter and fisherman, with a diet consisting almost entirely of animal material.

south, such as the Aztecs of Mexico and the Incas of Peru, represented a comparatively high stage of culture. Their domestication of plants and animals had proceeded far enough to supply food for a dense population. The Indians of the deserts in the southwestern portion of North America were, on the other hand, wandering tribes. Still other Indians in tropical South America lived very much as did their most primitive ancestors. Even today, they subsist largely on berries, fruits, nuts, and roots, in a manner which represents the lowest stage of civilization.

The environment and culture. It is evident that certain environments are more favorable to the development

Photo from Publishers' Photo Service

The rice crop of India supports a dense population of dark-skinned Caucasians.

of higher stages of civilization than are others. The most advanced civilizations of the world, along with the thickest populations, are found in the temperate zones. In the cold arctic regions, and in the hot, damp tropics, conditions are not suitable for the support of a large population nor for the development of a high type of culture.

Man's search and struggle for food have been partly responsible for his migrations and for the degree of civilization which he has attained. In his migrations, man usually carried with him the domesticated plants and animals with which he was familiar. Some of these plant and animal introductions have been more successful than others; some have exerted a tremendous influence on human life. The introduction of rice as a food crop in Java, for example, has resulted in the establishment of one of the most densely populated areas in the world. Similar areas with almost identical climatic conditions are quite sparsely settled because of the lack of suitable food crops. While the North American continent probably supported as large a population as was possible with the ways of living practiced by the various Indian tribes, the intensive agriculture introduced by the white race made it possible to support many times the original hunting and fishing population.

Review and Thought Questions

1. In what, if any, physical characteristics is man superior to other animals?
2. In what ways are some animals physically superior to man?
3. In using the scientific method to determine race, what traits furnish the best basis for comparison? Why?
4. Name three racial groups recognized today.
5. Name the principal subdivisions of each of these races.
6. The American Indians belong to what race?
7. Africa is occupied chiefly by what race?

8. Pygmies belong to what race?

9. Why are blue eyes, light hair, and tall stature more common in northern Italy than in southern Italy (study the table, page 30)?

10. Explain why it is often difficult to distinguish between the individuals of one racial group and another.

11. Why do we say that the United States is a melting pot?

12. Why is language often a poor guide in distinguishing races?

13. Why is man more widely distributed than other animals?

14. How does man affect the distribution of plants and animals?

Activities

1. Construct a rule for measuring the length and width of the head. Fasten a piece of wood at right angles to the end of a meter stick and another similar piece so that it will slide along the stick at right angles with it. Use this device for measuring and determining the cephalic index of the members of the class. Make your readings in millimeters.

2. Study and list your racial characteristics including the following: hair color and form; skin color; stature; cephalic index (divide width of head by length); eye color. What is your racial stock?

3. Report to the class on the mixed character of the white race in some nation in Europe. Consult the reference list for Unit I (see pages 77–78), and the catalog of your library for helpful books. If your library has Coon, Carleton S., *The Races of Europe,* a study of the excellent photograph section, following page 399, will give you fine material on the mixture of subraces in the various national groups.

4. Find out as much as you can about your own racial history, where your ancestors came from, etc., and report your findings to the class.

5. Make a study of the history of civilization and describe man's life in the different stages of culture through which he has passed.

6. Visit a museum where there are relics and exhibits on the life of primitive man.

7. Make a list of the reasons why man migrates. Account for the present large population of the United States as compared to the sparse population before Columbus' discovery of America.

3. Useful Plants and Animals

Primitive man depended upon materials he secured from plants and animals that lived near him. He could not have survived without them. The vegetable part of his diet consisted of such things as roots, nuts, seeds, wild fruits, mushrooms, leaves, and the bark of certain trees. His animal foods included raw meat, snails, birds' eggs, young birds, and frogs. Instead of sugar he used the honey of wild bees. People who lived near the seashore also had fish, shellfish, and seaweed. Primitive man's clothing consisted almost entirely of animal skins.

Civilized man is fully as dependent upon plant and animal materials as was primitive man. Many new uses for plants and animals have been developed. In fact, it was largely due to the discovery of new ways of growing and using plants and animals that the human race became civilized.

Uses of Plants

We still find plants very useful for food, just as primitive man did. No matter what article of food we eat, some plant directly or indirectly produced it. The animals we use for food either get their food directly from plants or from other animals that eat plants.

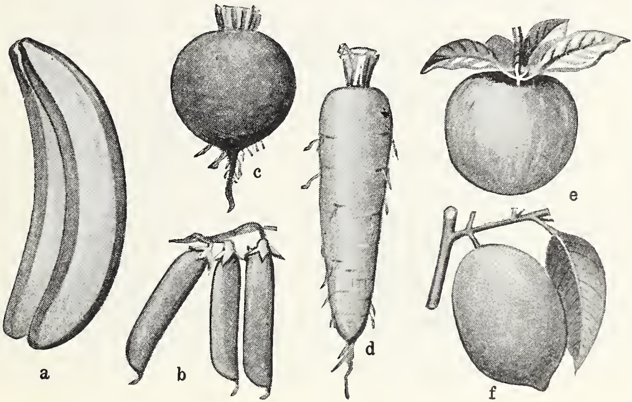
Food plants. The cereals were among the first plants to be cultivated and are still the most important group of food plants. Chinese writings record the cultivation of rice in China more than four thousand years ago. Barley was used in the religious rites of the Greeks many centuries before Christian times. Grains of wheat have

We depend upon these useful plants: (a) timothy, (b) red clover, (c) wheat, (d) rice, (e) red top.

been found embedded in a sun-dried brick taken from an Egyptian pyramid tomb built over five thousand years ago.

The principal cereals are wheat, rye, rice, barley, sorghum, oats, buckwheat, and corn. The first seven are natives of the Old World, corn alone belonging to the New. All except buckwheat belong to the grass family of plants.

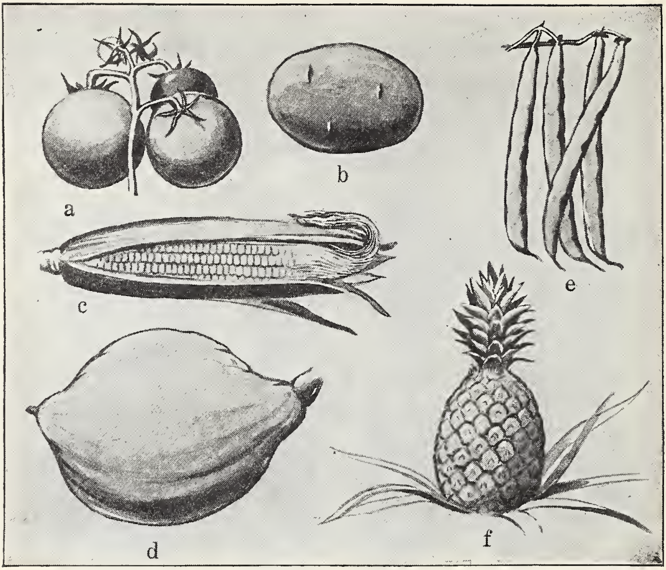
Among our other food plants, very few are natives of the area that is now the United States. We are indebted to our native plants only for fruits and berries, such as grapes, strawberries, raspberries, cranberries, and blackberries. The early settlers of America brought nearly all their food plants with them: cabbage, beets, carrots, spinach, sugar cane, and many others. It is generally believed that most of these crop plants were first cultivated



These foods are immigrants from the Eastern Hemisphere: (a) banana, (b) peas, (c) beet, (d) carrot, (e) apple, (f) lemon.

in western Asia. Many of them were grown long before man began to keep written records.

In the region south of what is now the United States, a number of basic food plants had been developed long before the time of Columbus. The corn of the Mexican Indians is perhaps the most valuable plant native to America. Potatoes, originally from the mountains of South America, are now widely grown in the Old World as well as in the New. Other American plants such as pineapples, chocolate, sweet potatoes, tomatoes, and tobacco are today important crop plants in various parts of the world.



These plant foods come from South America: (a) tomato, (b) potato, (c) corn, (d) squash, (e) beans, (f) pineapple.

Industrial plants. Plants supply many of the raw materials used in industry. Industrial chemists are constantly at work finding ways to make new products from plant materials. Next to plants used primarily for food, those that produce fibers have proved most useful.

As civilization developed, man solved the problem of finding some sort of material for clothing and cordage which would be easier to procure than the skins of animals by learning to spin plant fibers into yarn. The yarn was then woven into cloth or twisted together into rope. The most important fiber plant is cotton, of which there are two main kinds. Upland cotton, a native of the Old World, has been grown for at least 2,600 years. Sea

Island cotton, an American plant, has longer fibers but a smaller yield. The seeds on which the cotton fibers grow are important sources of oils, fertilizer, and animal foods.

Flax, jute, and hemp, too, are important fiber plants. The stems of these plants contain long strands of almost pure cellulose. The fibers are obtained by first allowing the stems to rot. Then after being dried they are beaten and the softer parts are combed away.

Wood ranks next to vegetable fibers in economic importance. From prehistoric times it has been the most widely used material for building and furnishing dwellings and for other kinds of construction. Within recent times wood has been used so extensively that it is becoming rather scarce. Better management of our timber supply is essential to prevent a serious shortage of wood and other forest products.

The knowledge of rubber first came to Europe in the report of Columbus' second voyage, which described the Indians' playing with elastic balls. For a long time the only use found for this new material was to rub out pencil marks. This is how it got the name of "rubber." The demand for rubber has greatly increased within recent years. At present most of the supply comes from the sap of a rubber tree native to Brazil but now cultivated largely in the Orient.

Another important industrial development within recent years is the greatly increased production of oils. Oils are derived from a great variety of plants. They are used widely in industry, as a base for paints and for food. Some of the important sources of oils are the *tung* tree of China; copra, which is the dried fruit of the coconut palm; and the seeds of soya bean, cotton, flax, and peanut plants.

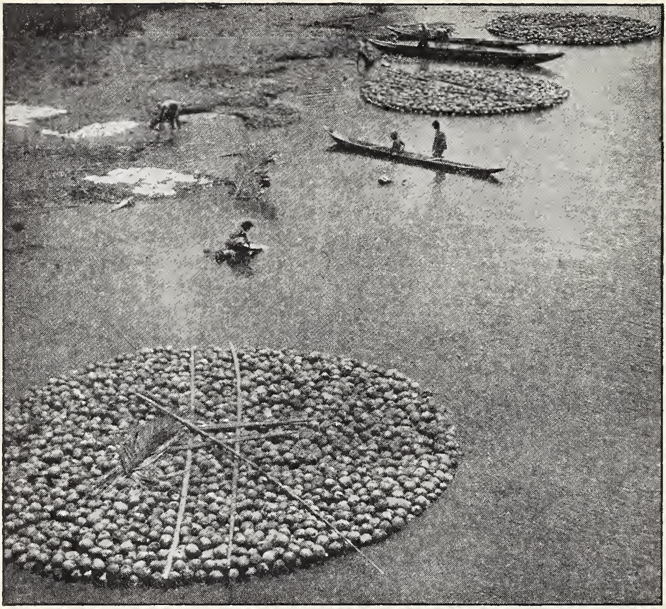


Photo from Ewing Galloway

A raft of coconuts, formed to be floated down a river in the Philippines. Copra, dried coconut meat, is an important commercial source of oil. Perhaps the soap you used to wash your hands with today was made with oil from such a raft.

Other uses of plants. Food, clothing, and shelter are still the three main purposes for which man uses plants. But ever since prehistoric times man has been discovering additional uses for plants. Various substances which man puts into his mouth or stomach, such as horse-radish, pepper, tobacco, alcohol, and tea are not taken primarily for their food value but for their stimulating effects. Others, such as camphor, perfumes, and lampblack, are used for purposes other than clothing and shelter.

Spices are plant substances which contain pleasantsmelling oils. Cinnamon is the bark of a tree; ginger is a root; mustard and nutmeg are seeds; sage and thyme are leaves; cloves are dried flower buds; and pepper is a berry-like fruit.

Drugstores as well as grocery stores sell many kinds of plant materials. Castor oil is obtained from the seeds of the castor bean. Digitalis, which is used in the treatment of heart trouble, is obtained from the common garden foxglove. Camphor is a gum obtained by distilling the wood of the camphor tree. Peppermint camphor, or menthol, comes from the peppermint plant. Most of our other medicines are also derived from plants.

Some plants are used not only to make us well but also to make us sick. A great many plants contain substances called *alkaloids,* some of which are powerful poisons. *Marijuana,* which consists of the dried leaves or flower clusters of the Indian hemp plant, contains one of the most dangerous alkaloids. Opium is the dried juice which flows from wounds made in the seed pods of the opium poppy. It contains over twenty different alkaloids, the principal one being *morphine.* The coca shrub which grows in South America is the source of the alkaloid *cocaine.* Coca leaves mixed with lime are chewed by the Indians to lessen their hunger. The dried leaves of the tobacco plant contain the alkaloid *nicotine.* Many alkaloids are habit forming and are especially dangerous when taken in too large doses.

Primitive man knew and used thousands of kinds of plants. As men became civilized, the uses of many plants were forgotten. Now some of these useful plants are being rediscovered. It has been found only within recent years that a Chinese drug, *ma juang,* contains a powerful and useful medicine, *ephedrine.* The Rockefeller Foundation has a commission in Asia which is investigating other ancient remedies. The United States Department of Agriculture has been interested in studying native cultivated

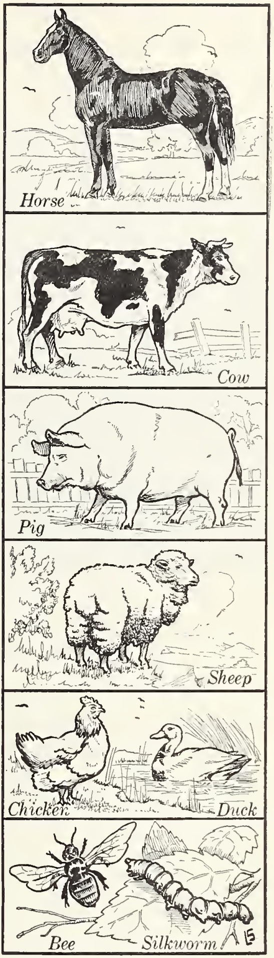
Photo from Keystone View Company

The Indian hemp plant, marijuana, supplies a dangerous, habit-forming alkaloid drug. Here police discover it being grown in a New York backyard.

plants over the whole earth. In a little over thirty years, they have made more than 90,000 separate introductions for experimental tryout in this country, and their agents are widely scattered in the field all the time.

Uses of Animals

Primitive man probably considered most other animals as enemies and competitors. Possessing only crude weapons to defend himself, early man was in constant danger of attack by large beasts of prey and must have lived in constant fear of them. Yet, ever since there has been a human race, man has depended upon animals for much of his food and clothing. Without the help of other animals, the human race would perhaps never have survived, and the development of civilization would certainly have been impossible.



These useful animals came from abroad. What others might have been included?

Mammals. Long before the historic period, man began the domestication of animals. Certain *mammals* were domesticated very early. The horse and the dog were probably domesticated first and cattle next. The earliest known remains of domestic cattle date from about 10,000 B.C. Pigs are believed to have been domesticated in China about 5,000 years ago. Camels, sheep, goats and various other animals have been kept in captivity for thousands of years. Other kinds of mammals, such as guinea pigs and rabbits, have been domesticated more recently.

Of all the animal groups, mammals are by far the most useful to man, and of all their uses the most important is as a source of food. The average American eats the equivalent of his own weight in meat annually. Cattle and pigs furnish about equal amounts of the meat supply of this country; the number of sheep and other mammals used for food is small in comparison. In Britain and France, mutton is relatively much more important in the menu. In other countries the amount of meat consumed depends upon food habits and other factors, but mammals are important sources of food everywhere. In Africa, the natives have always used the meat of buffaloes, antelopes, and other large mammals. In Asia, the camel is a food animal and in South America the llama and alpaca are valued for the food they supply.

Domesticated mammals supply not only most of the world's meat but all the dairy products as well. The value of dairy products in the United States amounts to about three billion dollars annually. Domesticated cattle furnish most of the dairy products. But in various parts of the world other mammals, such as goats, water buffaloes, yaks, camels, horses, and sheep, are important sources of milk, butter, and cheese.

Mammals are of use to us in supplying many other important products besides food. Chief among these are fibers suitable for clothing. Sheep's wool, over two billion pounds of which are produced annually, is the most widely used animal fiber. Other important animal fibers are mohair, which comes from the angora goat, and the woolly hair of the camel, of the alpaca, of the vicuña, and of the llama. Deer antlers are used extensively in the manufacture of handles for knives and forks. Bones of land animals and wastes from meat-packing plants are important sources of fertilizer. For centuries many useful products have been obtained from whales, but the supply of whales is now nearly exhausted. Elephants yield most of the

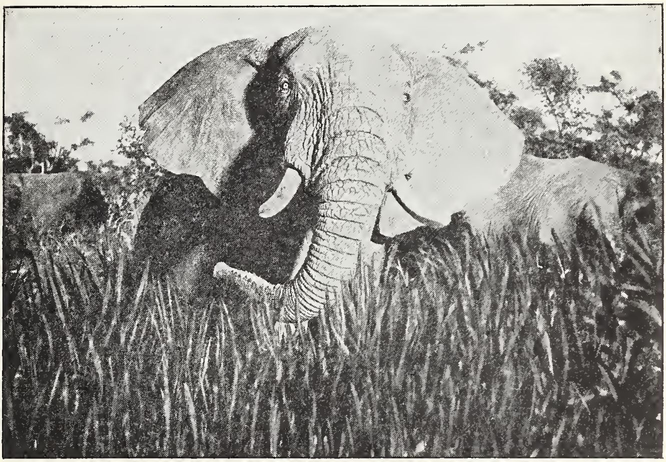


Photo from Ewing Galloway

Elephants furnish most of the ivory of commerce and are used as working animals in their native lands.

ivory of commerce, though walrus ivory is also much used. The whitest and hardest ivory comes from hippopotamus teeth.

Much of the world's work is done in the present, as it was in the past, with the aid of animals. The horse is still the chief draft animal but by no means the only important one. The water buffalo is widely used in India, the Philippines, and the Hawaiian Islands. In India the humped oxen pull all sorts of vehicles. Camels still plod across the sands of Asia and Africa. Elephants, yaks, llamas, alpacas, and dogs are draft animals or beasts of burden in other parts of the world.

Birds. Although most birds are of great value as destroyers of insects, the only kinds from which man secures important useful materials are the domesticated varieties. The most useful bird from the economic point of view is the chicken, which was domesticated thousands of years ago. Its ancestor was a native of India known as

Courtesy State Institute of Applied Agriculture, Farmingdale, Long Island

Each hen in this picture lays about 24 dozen eggs per year.

the jungle fowl. Every year the chickens in the United States alone produce more than three billion dozen eggs as well as large quantities of meat.

Ducks, geese, and guinea fowl have also been raised in captivity for a very long time. The turkey is the latest food bird to be domesticated and is the only domestic animal that is a native of North America.

Reptiles and amphibians. Though many reptiles and amphibians are still used as food in some parts of the world, civilized man secures few useful materials from these animal groups. Alligator skin, turtle soup, and frogs' legs are almost the only exceptions. Many reptiles and amphibians, however, destroy insect pests.

Photo by Walter J. Shoonmaker

The salamander is a harmless amphibian which helps to destroy such insect pests as plant lice.

Fish. Man has been eating fish since prehistoric times. Of the 13,000 species, over 5,000 kinds are important sources of food. At present, salmon and herring are the most extensively used food fishes. Cod, halibut, mackerel, tuna, shad, perch, and bass are also widely consumed.

While fish are valuable chiefly as food, they have many other uses. Menhaden and some other kinds are rarely used for food but are caught for the oil they contain. After the oil has been extracted, the remainder of their bodies is dried and made into fish meal which is fed to domestic animals or used as fertilizer. Glue is an important by-product. The oil extracted from the livers of halibut, cod, menhaden, salmon, and tuna is a good source of vitamins A and D, for use in nutrition. The air bladders of sturgeon, cod, and other fish furnish isinglass and gelatin.

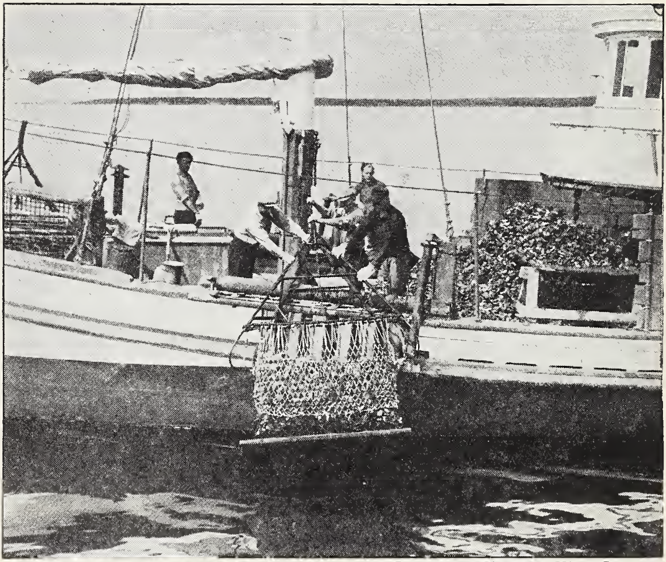


Photo from Keystone View Company

Today oyster farming is an important industry. Here after four years of maturing, these mollusks are being gathered by pulling them up in nets dragged over the oyster beds.

Mollusks. No one knows who ate the first oyster, but it is certain that the eating of many kinds of mollusks began a long time ago. Great mounds of shells found in Denmark and in our own central states testify to ancient man's fondness for shellfish. Today oyster farming is an important industry, and large quantities of clams, mussels, and scallops are taken from the ocean.

In addition to supplying food, mollusks also furnish great quantities of mother-of-pearl used in the manufacture of knife handles and similar articles. Buttons are made from the shells of fresh-water clams, oyster shells are ground up and fed to chickens, and sometimes mollusk shells are used to build roads.

Insects. Though most insects are harmful instead of useful, grasshoppers, locusts, and other insects are widely used for food by primitive people, and certain insects are put to modern industrial uses.

Four insects which provide materials of considerable commercial value are the lac, the cochineal bug, the silkworm, and the honeybee. Lac culture is an important industry in India. Certain plants are artificially infested with lac insects. These insects secrete around the young twigs of the host plant a waxy substance which is the source of shellac. Cochineal bugs are grown in Mexico as a source for the carmine used in the manufacture of lipstick. The silkworm is cultivated in various places in Europe and Asia. It feeds upon the leaves of the mulberry tree and after reaching maturity spins a cocoon. The cocoons are collected and heated to kill the pupae. They are then unwound and spun into silk. Honeybees provide both honey and beeswax. The bee industry in the United States alone does a business which amounts to over thirty million dollars per year.

Other products derived from animals. Animals produce many additional materials which are not usually associated with the animals that produce them. Limestone and all the products made from it would be absent from the earth if there had been no shell-forming animals.

Chalk is an animal product, as are also bath sponges, coral jewelry, and most scouring powders. Leeches, long used in medicine, are now the source of a drug which prevents

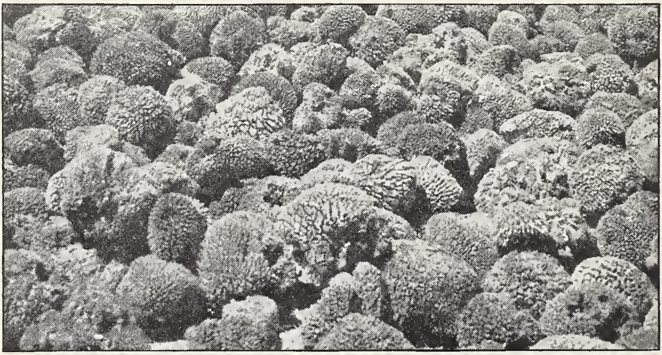


Photo from Philip Gendreau

Sponges are marine animals.

the clotting of blood. Tannic acid comes from plant galls caused by gall insects. Animals also supply thousands of interesting food delicacies such as trepang, which comes from the sea cucumber; caviar, the salted roe of the sturgeon; and escargot, commonly known as snails.

Review and Thought Questions

1. How does our food differ from that of primitive man?
2. From what continent did corn originally come?
3. Name three berries native to the United States.
4. Where did potatoes originate?
5. Where were many of our important food crops first cultivated?
6. From what country did we get ephedrine?
7. Mention three uses of plants to us other than their use as foods.

8. What important industrial product is made from the sap of a tropical tree?

9. What dangerous drugs are obtained from plants?

10. What government department is interested in studying and introducing new plants into this country?

11. Name three important plant fibers and three important animal fibers.

12. Name three insects that are economically important.

Activities

1. Make a collection of common grains, mount them on a chart, and tell the country of origin of each.

2. Make a collection of five different kinds of fibers. Mount them and tell on the chart the country of origin and use of each.

3. Make a collection to show the products from several important domestic animals. Mount the products and tell in each case the animal from which it is derived and the use for it.

4. Make a study of the dietary habits of some primitive people; write a report of your study.

5. Make a report on the development of some new plant product.

6. Make a study of the characteristic foods of the people of five different countries.

4. Classification

Everyone has to be able to identify things. The savage in the tropical jungle needs to have a particularly keen knowledge of the kinds of animals and plants of his surroundings. He must know what kinds are safe to eat, what kinds furnish fibers, and what kinds contain the poisons that he uses on his arrow tips. In fact, the primitive savage of the most remote wilderness often knows things about plants which scientists would like to discover.

But, in general, people are not much interested in a thing unless it affects them directly, unless they can use it, or unless it entertains them as a curiosity.

To the scientist, the value of a particular animal or plant is determined by its biological significance, not by its practical or commercial use. His scientific classification includes all kinds of living things. He wants to discover, compare, and describe every different species to be found on the earth's surface.

The Oldest Branch of Biology

The practice of classification, or *taxonomy,* is probably the oldest branch of biology. The progress of this branch of science may be shown by reference to a few different workers in the field.

Some two thousand years ago, Alexander the Great, one of the world's greatest soldiers, had a still greater

Photo by Lynwood M. Chace

To what groups do these animals belong?

Greek teacher named Aristotle. The young conqueror, Alexander, had a quality rarer than military genius, because he recognized the greatness of Aristotle and made it possible for him to carry on scientific studies by sending him specimens from different parts of the world. In the field of classification, Aristotle recognized some five hundred different kinds of plants and about the same number of animal species. Those were the days before widespread invasions and the mixing of peoples had broadened geographic knowledge. For Aristotle, the known world was a few hundred miles in diameter.

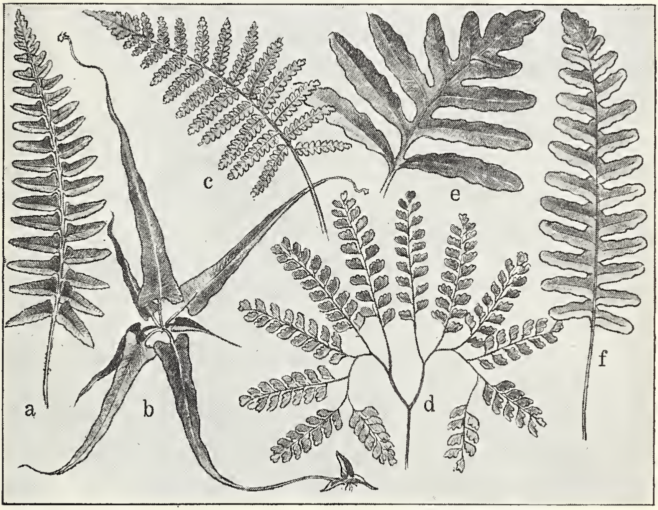
With the military conquests and expansion of the Roman Empire a few hundred years later, a Roman writer, Pliny, seems to have known many more plant and animal species. But knowledge of plants and animals grew slowly for a long period.

The most important milestone in the whole history of taxonomy was reached in the eighteenth century, about the time of the American Revolution, when Linnaeus in Sweden proposed an organized system of classification of plants and animals, which in its general plan holds good today. Linnaeus listed and described in a series of books more than 5,000 species of animals and about the same number of plants.

Today the described species are numbered in hundreds of thousands for both plants and animals, and some scientists estimate the total number of living things as probably in the millions. The field of taxonomy has become so vast that no one man attempts to know thoroughly more than a small part of the field. Some scientists specialize in the study of snakes, turtles, butterflies, or birds. Others confine their studies to the investigation of special kinds of disease germs, or even to the study of a single kind of germ.

Classification Is Fun

In addition to being the earliest branch of biology to be developed, classification is also one of the simplest and most easily understood. There are thousands of amateur classifiers who find this study a hobby which takes them



Some common ferns found in the eastern states are: (a) Christmas fern, (b) walking fern, (c) marsh fern, (d) maidenhair fern, (e) sensitive fern, (f) polypody.

out into the fields and woods throughout the year, and which, in bad weather, keeps them occupied in studying material already collected.

If you have ever started to make a collection of stamps or coins, you have already something of the taxonomist's point of view. A stamp collector gets together stamps representing every denomination and issue he can obtain from all the countries of the earth. He knows them and can identify and describe their differences. In biology, the amateur or professional classifier collects and studies some group of plants or animals in the same way. For example, the American Fern Society is composed largely of people who are engaged in other occupations but who like to get into the woods, along streams and cliffs, where ferns grow best. They often exchange pressed specimens with each other, so that they gradually acquire a collection of all the species in their particular state, in the United States, or even in a wider field.

We may summarize the taxonomist's method of work as follows:

1. Collect a wide range of specimens, or visit them in their natural habitats, if possible.

2. Compare these specimens, point by point, to note similarities and differences. Usually they fall rather easily into groups.

How we classify apples. Suppose we apply this method to apples. If you make a collection of apples and examine them carefully, you will find that they are not alike. You will be able to separate them into groups according to color, shape, size, and striping. There will be differences in taste and texture. If you cut the apples into pieces to study the internal structure, you will find more differences. All these characteristics and others form the basis for classifying the group of apples.

Since all apples belong to a single species, you are classifying them into what the taxonomist calls *varieties*. Cultivated species of plants and animals commonly include a great many different varieties.

What is a species? Let us see what the biologist means by the word *species*, which is the most important term in the classification of plants and animals.

Oak trees may be found in almost any part of the United States, either growing wild or planted in the yards or parks. The different kinds of oaks are little changed in cultivation, so that even those planted in cities are just about as they are in their wild habitat. To classify the oaks growing in your locality, secure specimens of as many kinds of leaves and acorns as are easily obtainable. As a guide for classifying them, you may use the illustration on page 62, in which are represented six species common in the eastern part of the United States. A similar outline chart for other groups of oaks in most sections of the country can easily be found in reference books on the subject.

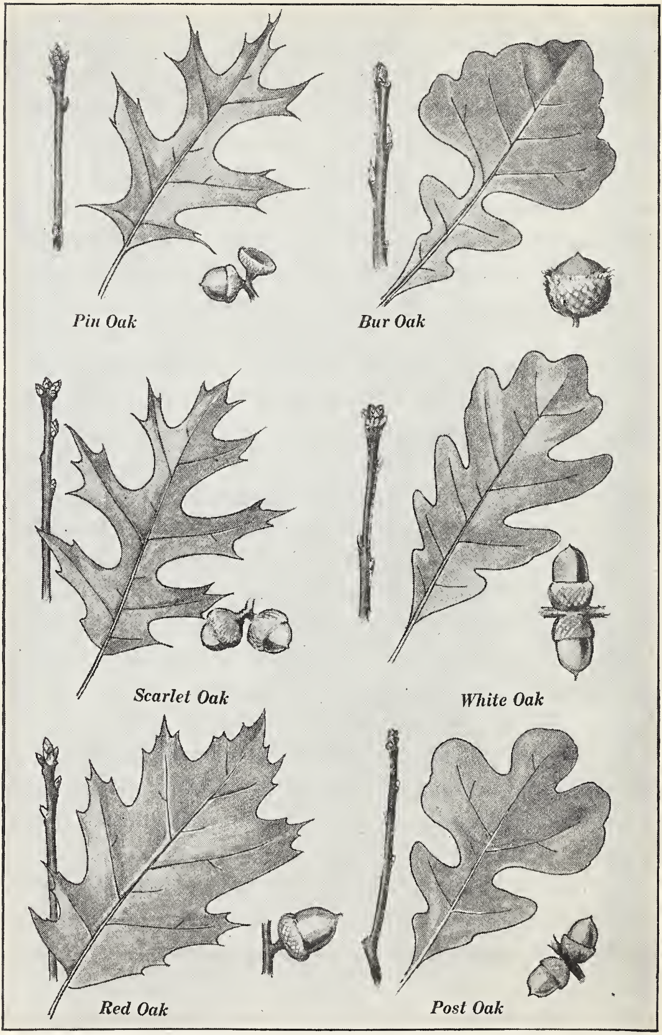
Try to classify the leaves you have collected according to the species. Notice that some of the leaves have sharp bristles at the end of the divisions or lobes, while others never show these bristles. These bristles help to determine two main divisions of the whole group of oaks. Also, the round-lobed oaks have sweet acorns, which develop from the flower in one season. Of the bristle-tipped or *black-oak* group illustrated, three easily distinguished species are shown:

1. Pin oak (*Quercus palustris*)—Small leaves, with few lobes, somewhat irregular; the acorns small, with flat "saucers"; trunk usually straight, with many lower branches drooping and dead.

2. Scarlet oak (*Quercus coccinea*)—Larger leaves, with thin blades, shiny on both sides, the middle lobes often much larger than the others; the acorns with deep saucers.

3. Red oak (*Quercus rubra*)—Leaves rather dull, with lobes alike in size; the acorns large with flat saucers.

In the round-lobed group, called the *white-oak* group,



Note the differences in the leaves and acorns of each of these six common species of oaks.

three species are also shown. Notice some of their distinguishing features:

1. Bur oak (*Quercus macrocarpa*)—Leaves large and leathery, with deep lobes, the terminal lobes larger than the lateral, dark green above and somewhat glossy, dull and paler below; acorns oval-shaped with mossy cups.

2. White oak (*Quercus alba*)—Leaves large, with much the same number and shaped lobes, medium green above, but paler below; a large tree, with its lower branches usually horizontal; the acorns egg-shaped.

3. Post oak (*Quercus stellata*)—Leaves with two middle lobes much enlarged, so that the leaf is cross-shaped; acorns with cup-shaped saucers.

Each of these *species* consists of all the individuals which conform to a common pattern without too wide a variation from it. The white-oak species includes all the trees which resemble each other closely, more closely than they resemble the individuals of the post-oak group, for example, or the bur oak, and still more than they resemble species of the bristle-tip, or black-oak, group. Another characteristic of any given species is that usually it will not interbreed with the individuals of another species. Furthermore, the acorns of any given species will always grow into the same kind. In other words, the group name for all similar individuals, which reproduce their own kind, and which usually will not cross or hybridize with individuals of another kind is *species.*

Species are the basic unit groups in the scheme of classification, although there are several higher groups in a complete system.

What is a genus? The six different oak species together with all other oak species constitute the oak *genus,* (plural, *genera*), or group of similar species.

Since scientists long ago found it necessary in dealing with species internationally to have a common language

Photo from J. Horace McFarland Company

Would you place the horse-chestnut tree in the oak genus?

to name them, Greek or Latin names are used. Each species has two names, with the genus name first. The white oak, for instance, is written *Quercus alba L.*, with *Quercus* meaning oak, *alba* white, and the *L.* standing for Linnaeus, who founded this system of international names. The apple is *Pyrus malus,* in which *Pyrus* means the pear genus, as the apple and pear are closely related, while the word *malus* is an old word for apple.

Among animals, the common dog, the wolf, the coyote, and other doglike species belong in one genus, to which the scientist gives the name of *Canis,* the Latin word for dog, from which we get the English word *canine.* The common dog is *Canis familiaris;* the wolf is *Canis lupus.* Man has his place in the scheme of classification, as *Homo sapiens.* The genus name *Homo* means a manlike animal; the species name *sapiens* means "the wise."

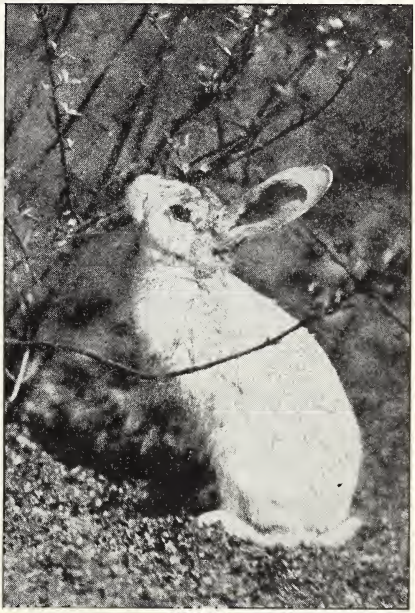


Photo from Black Star

Look up the scientific name of this animal in a dictionary.

The General Scheme of Classification

Living things may be grouped into larger classes than genera and species. We are accustomed to distinguishing between *plants* and *animals.* Animals may be characterized as being generally active and having the capacity for making rapid responses. Plants are more passive and lack muscular and nervous systems.

Kingdoms and their subdivisions. All living things may be classified either in the plant or the animal kingdom.

Photo by Lynwood M. Chace

To what phylum does this ant, feeding on plant lice, belong?

Since the plant kingdom and the animal kingdom both include extremely diverse kinds of organisms, it is clear that the kingdoms may be conveniently divided into smaller and more restricted groups. The seed plants form a natural group, and one-celled animals form another. Animals that have their skeletons on the outside are grouped together as well as those that have inside skeletons. Such a subdivision of the kingdom is called a *phylum* (plural *phyla*). Ten animal phyla and five plant phyla are generally recognized by biologists. Under this plan the species included within any given phylum do not resemble each other very closely.

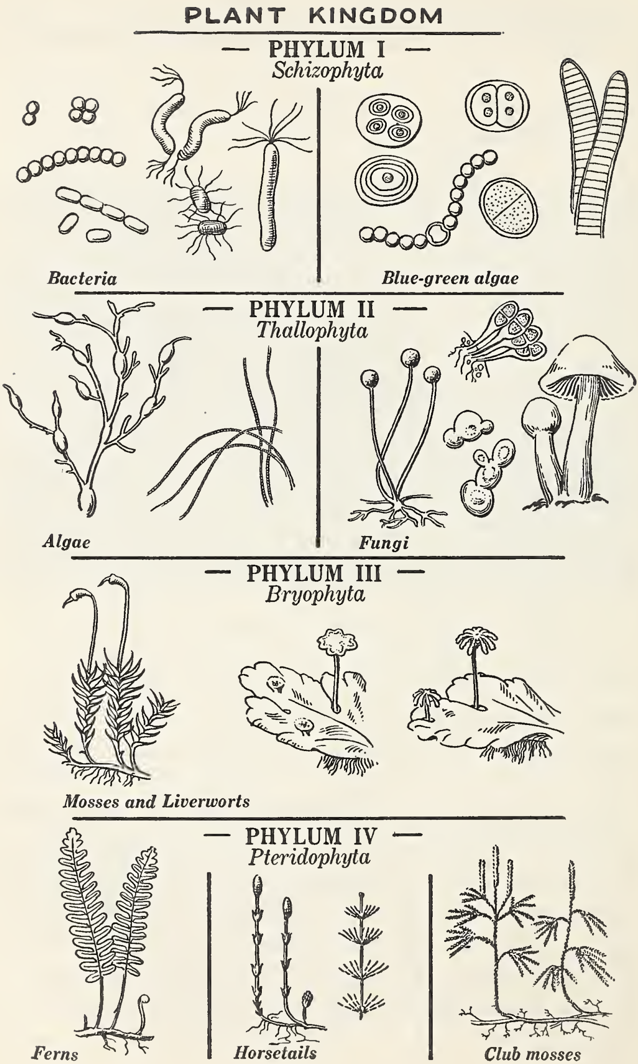
Beginning with the most general distinctions, biologists have agreed on the following grouping of living things.

Kingdom
Phylum
Class
Order
Family
Genus
Species
Variety or race

The following table illustrates how some of our common plants and animals fit into this general scheme.

Kingdom	Phylum	Class	Order	Family	Latin Scientific Name, Genus and Species	English Common Name
Plant	Spermatophyta	Angiospermae	Rosales	Leguminosae	Medicago sativa	alfalfa
Plant	Spermatophyta	Gymnospermae	Coniferales	Pinaceae	Pinus ponderosa	yellow pine
Plant	Spermatophyta	Angiospermae	Rosales	Rosaceae	Pyrus malus	apple
Animal	Chordata	Mammalia	Carnivora	Felidae	Felis domestica	cat
Animal	Chordata	Mammalia	Carnivora	Canidae	Canis familiaris	dog
Animal	Chordata	Mammalia	Primates	Hominidae	Homo sapiens	man

The main groups of living things. It is evident that *structure* is the principal basis for the modern system of classification. The following diagrams of the main divisions of living things will give you a good idea of how the system works and will be useful to you in your study of biology throughout the year. (An outline of the principal groups of plants and animals will be found in the Appendix.)

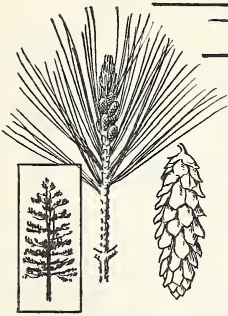

PLANT KINGDOM
— PHYLUM I —
Schizophyta
Bacteria
Blue-green algae
— PHYLUM II —
Thallophyta
Algae
Fungi
— PHYLUM III —
Bryophyta
Mosses and Liverworts
— PHYLUM IV —
Pteridophyta
Ferns
Horsetails
Club mosses

PLANT KINGDOM

— PHYLUM V —

Spermatophyta

1 - Gymnosperms



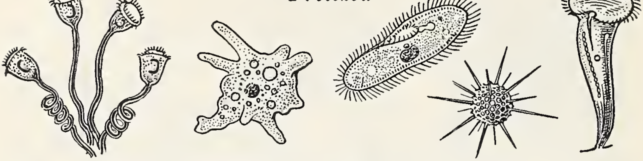
2 - Angiosperms

Monocotyledons

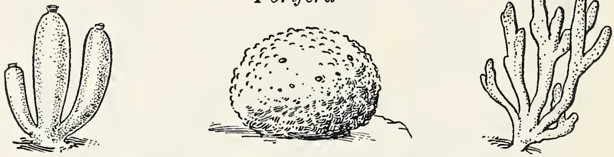
Dicotyledons

ANIMAL KINGDOM

— PHYLUM I —
Protozoa

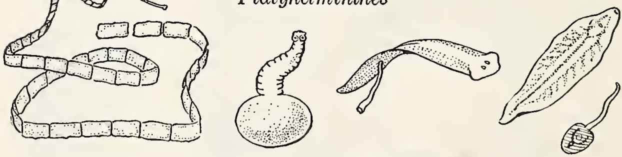


— PHYLUM II —
Porifera

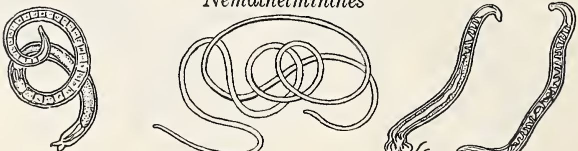


— PHYLUM III —
Coelenterata

— PHYLUM IV —
Platyhelminthes

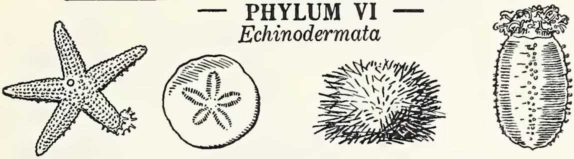


— PHYLUM V —
Nemathelminthes



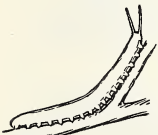
ANIMAL KINGDOM

— PHYLUM VI —
Echinodermata



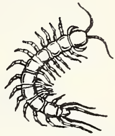
— PHYLUM VII —
Annelida

— PHYLUM VIII —
Arthropoda

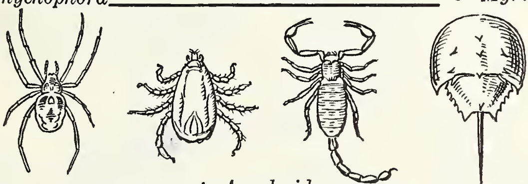


1 - Onychophora

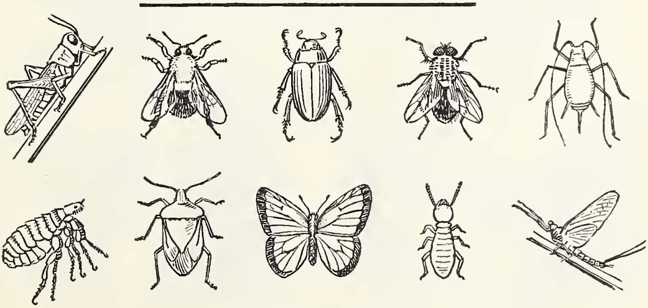
2 - Crustacea



3 Myriapoda



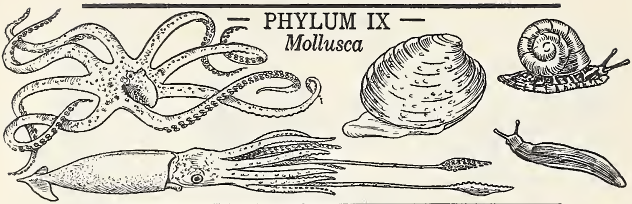
4 - Arachnida



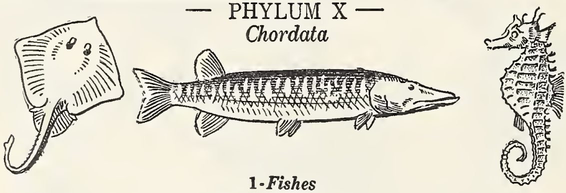
5 - Insecta

ANIMAL KINGDOM

— PHYLUM IX —
Mollusca

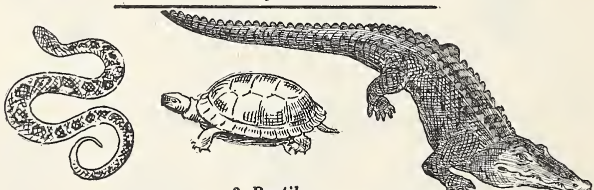


— PHYLUM X —
Chordata

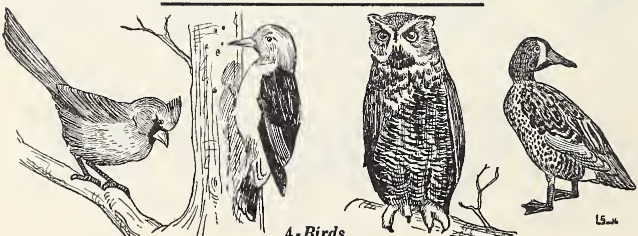


1-*Fishes*

2-*Amphibians*



3-*Reptiles*

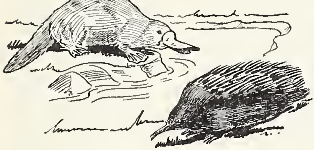


4-*Birds*

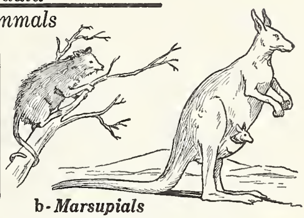
ANIMAL KINGDOM

— PHYLUM X —
Chordata

5-Mammals



a-*Monotremes*

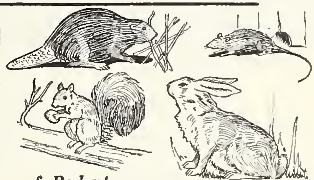


b-*Marsupials*

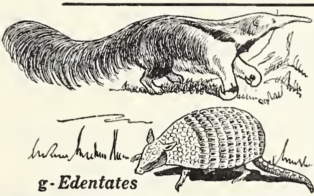
c-*Insectivora*

d-*Chiroptera*

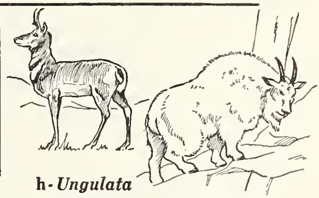
e-*Carnivores*



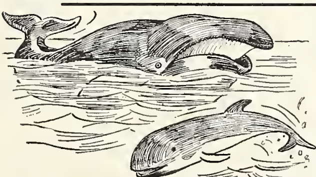
f-*Rodents*



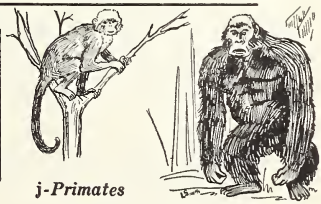
g-*Edentates*



h-*Ungulata*



i-*Cetacea*



j-*Primates*

Review and Thought Questions

1. What is the scientific classification of living things called?
2. Who was the earliest known taxonomist?
3. Name five kinds of oaks.
4. List five characteristics used in classifying oaks.
5. What is a species?
6. What is a genus?
7. Name five kinds of dogs.
8. How are plants and animals named scientifically?
9. Who founded the present system of classification of plants and animals?
10. Give the scientific names of an oak species, of man, of an animal species.
11. Compare the values of the scientific naming of plants with the popular methods of doing so.
12. What practical values has taxonomy?
13. How would you go about classifying a plant or an animal that you had never seen before?
14. How is it possible for scientists to classify prehistoric and extinct animals?
15. Name in order the subdivisions of a phylum.
16. Starting with the simplest of animals, trace the developments of structure from one phylum to the next.

Activities

1. Make a "nature trail" near the school building. Identify as many living species as you can and label each with its scientific name. The trail may lead through unused land, through a piece of woodland, around a pond or lake, or along a city street.
2. Make a collection of the leaves, twigs, fruits, etc., of trees in the neighborhood. After drying them, mount them, and identify and label each one.

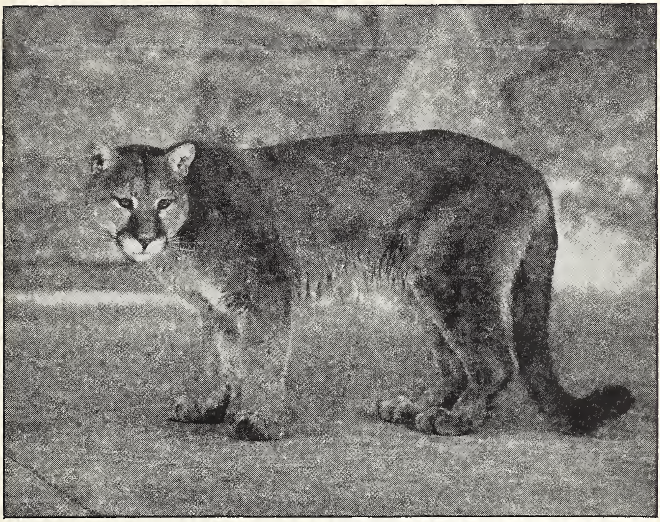


Photo from New York Zoological Society

In what biological class does the puma belong?

3. Visit a local fish store. List and describe the various fish that are on sale. Later classify them and learn their scientific names.

4. Make a collection of mollusk shells. If you live on the coast, you can readily obtain the shells of clams, oysters, scallops, etc. Inland, the shells of numerous snails may be obtained. Mount, classify, and name them scientifically.

5. Make a field trip to a place nearby where there are many kinds of living things. List the different phyla represented with the plant or animal example that you find. Refer to guides and manuals on classification to identify individual specimens.

6. If possible, visit a museum. Study the exhibits related to classification. For any family of plants or animals, describe and name the individuals represented in the exhibit.

7. Collect the different grasses growing in the neighborhood of your school. Dry them (by pressing), mount them and identify them with the help of a guide or manual.

8. For three oak species, collect a twig to show the buds, an acorn, a typical leaf, a piece of bark. Mount them. Compare them as to structure. Name the species.

9. Make a collection of weeds that grow in your community. Find out whether they are native to this country or are plant immigrants from abroad. Learn the scientific name of each weed. Mount and label them.

10. Make a list of the insects injurious to the households of your neighborhood. Classify them with the help of a guide or manual for the classification of insects.

References for Unit One

The lists of books at the end of this and of later units are suggested to aid you in assembling a class library for the unit and in finding books that will be helpful in your individual activities. In securing information for class discussions, in carrying out the activities at the ends of the various chapters, and in reading on topics that especially interest you, you may need to look through the lists given in other biologies, as well as through the following list, to discover useful references you can find in your school, home, or public library. For information on your special part of the country, look through local newspapers and periodicals, find local publications in your library, and write for material to state institutions and to the Superintendent of Documents, Washington, D. C.

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Unit 2

SIMILARITIES IN LIVING THINGS

You may be surprised to find that living things are actually as much alike as they are different. The bark of trees corresponds to the skeletons of animals. The sap of trees corresponds to the blood of animals. General likenesses of this kind have long been evident, but the most striking likenesses were not discovered until scientists began to use the microscope. As this plan of study for Unit Two suggests, not only is all living matter constructed on a similar plan for similar purposes, but it is made of the same stuff, *protoplasm,* with the same unit of structure, *cells.*

LIVING MATTER

RESEMBLANCES IN STRUCTURE AND FUNCTION

Invertebrates and vertebrates
Similarities in the dog genus
Similarities among plants
Similarities between plants and animals

PROTOPLASM

The chemical nature of protoplasm
The physical nature of protoplasm

CELLS

THE CELL THEORY

Pioneers with lenses
Discoveries with microscopes
Early ideas about cells
Spontaneous generation disproved
The structure of cells

CELL DIVISION

Prophase
Metaphase
Anaphase
Telophase

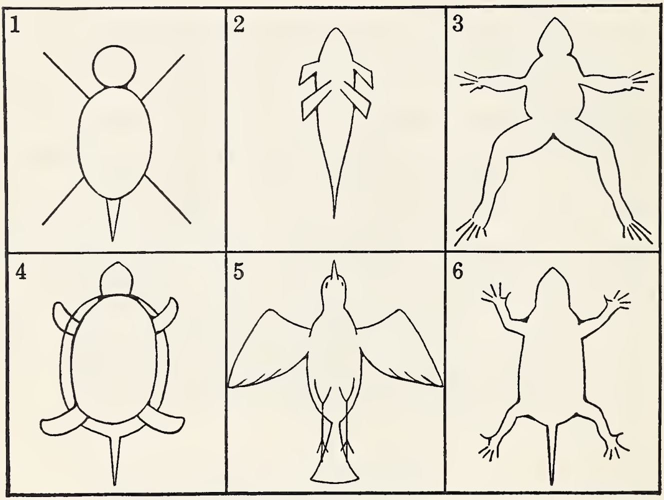
5. Living Matter

Children who have the same father and mother resemble each other in many ways. Even among first cousins the resemblances are often very marked. Where the relationship between people is less close, the resemblances are not so striking, but frequently certain likenesses are still strong among second, third, or fourth cousins. Most people cannot trace their ancestry back more than a few generations but, if they could, they would discover a great many relatives. Among members of the same nationality, the relationships are comparatively close. Between members of different nationalities or different races, they are more distant.

Resemblances in Structure and Function

Long ago, man began to notice that people not only resembled each other but that they also resembled certain animals. The arrangement of the eyes and mouth is the same on a man's face as it is on the face of a bear, horse, dog, frog, or fish. When individual organs such as eyes, teeth, tongues, and ears are compared, the resemblances are even more striking.

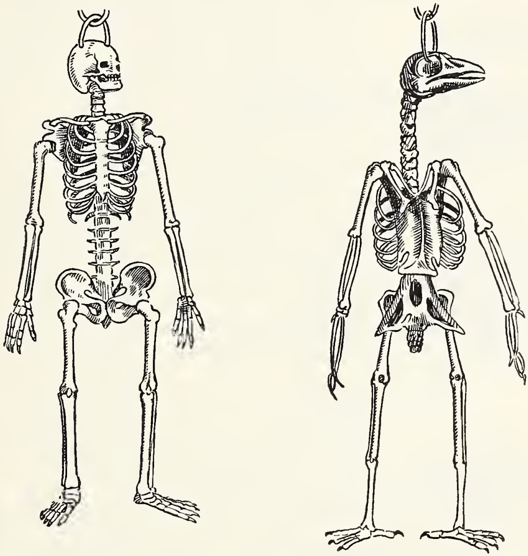
Invertebrates and vertebrates. It is sometimes convenient to divide animals into two large groups: *invertebrates* and *vertebrates*. All the animals that lack backbones are invertebrates and those that have backbones are vertebrates. Many of the invertebrates have some kind of protective covering. This protective covering serves as a skeleton, since no invertebrate has any bones on the inside of its body. Some vertebrates, such as turtles, armadillos, and porcupines, also have body coverings which



Many different kinds of animals have the same body plan. With this body plan (1), compare the diagrams of fish (2), frog (3), turtle (4), bird (5), and mammal (6). What are the chief differences?

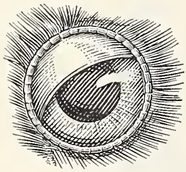
protect them well, but their real skeletons consist of bones on the inside of their bodies.

Many resemblances exist among the different kinds of invertebrates. There are about 800 kinds of fleas, for instance, all quite closely related. Every flea has six legs, grouped near the front part of its body. If you look at a flea's leg under a microscope, you will notice that it is jointed, with the skeleton on the outside and the muscles on the inside. All of the other 400,000 kinds of insects have legs that are similar to those of fleas. Even lobsters, spiders, and crabs, though not close relatives of fleas, have the same kinds of legs. Other remarkable similarities among these animals may be discovered by examining their eyes, breathing organs, and feelers or horns.

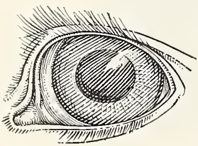


One of the earliest to notice man's resemblance to other animals was Pierre Belon (1517–1564). He published this picture.

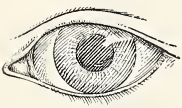
Among vertebrate animals, there are also many resemblances. Beside being alike in having backbones, all vertebrates are built on essentially the same body plan. Each has a head region and a trunk region. Extending outward from the trunk region there are always four appendages and usually also a tail. Some vertebrates use all four appendages for walking. Man walks on two legs, leaving the hands and arms free to perform other functions. Birds fly with their front limbs, while fish use the tail and all four limbs for swimming. Horses and cows find their tails useful for swatting flies; birds and squirrels use their tails as balancing organs; while some monkeys use their tails for grasping. Man gets along very well without using a tail, but a rudimentary one is present at the base of the backbone.



Owl



Horse



Man

From Romanes, Darwin and after Darwin

Vertebrate animals have similar eyes.

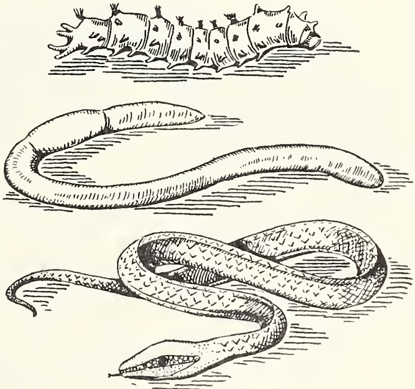
What is true of external appearance is also true of internal structure. It has been said that there is not a single organ of man, not even the smallest muscle, that does not have its counterpart in the ape. Digestive systems, livers, lungs, kidneys, hearts, and various glands are all very similar in higher animals. Parts of organs have been taken from certain animals and transplanted into other animals, where they have continued to function.

While it is easy to point out similarities between various kinds of animals, it is also easy to make serious mistakes. Superficial resemblances are not always good guides in determining how close the relationship is. Snakes, angleworms, and caterpillars are somewhat similar in shape but are not closely related. Careful examination of these animals, especially of their internal structure, shows that they are really quite different. Although they are related to each other, the relationship is somewhat remote.

Similarities in the dog genus. Dogs have been interbred with wolves, foxes, jackals, and coyotes many times.

This indicates a rather close relationship among these animals. It is an interesting fact that when wolves are domesticated they sometimes learn to bark like dogs. If they are allowed to escape and become wild, they begin howling again. The relationship is not so close, however, as it is between the hundreds of varieties of domestic dogs.

While the ancestors of dogs were wolflike animals, they were probably quite different from the wolves of today. Dogs were domesticated in prehistoric times, but most of our common breeds originated rather recently. The bulldog was not known before the year 1600, and the Newfoundland dog originated less than three centuries ago. Toy terriers, toy bulldogs, and various other breeds have been developed only recently.



With surface likenesses, why are the caterpillar, night crawler or angleworm, and snake placed in different phyla?

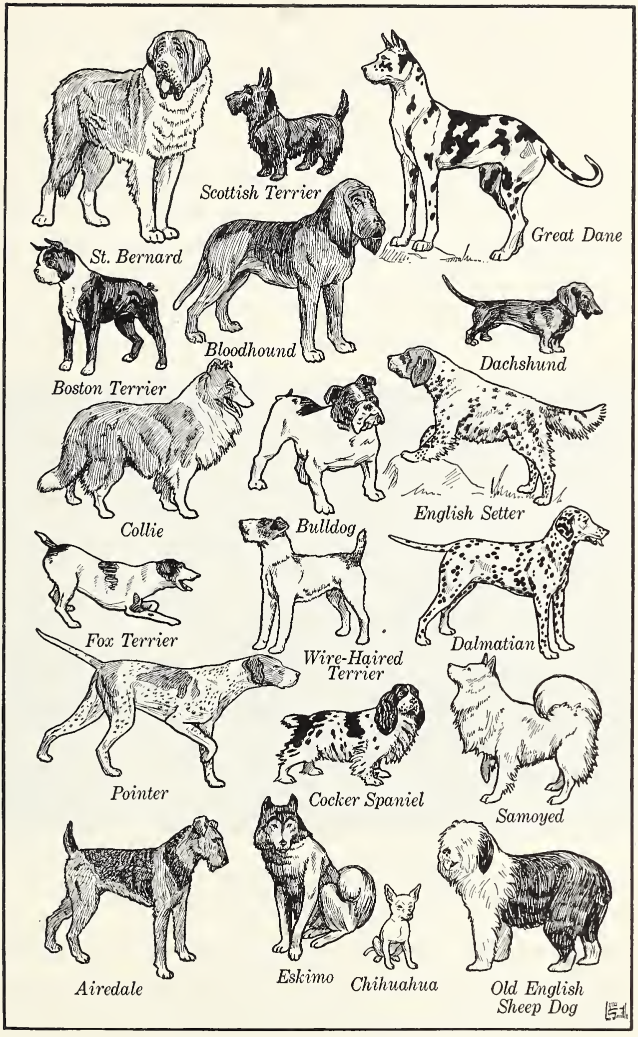
Similarities among plants. Just as higher animals resemble each other in many ways, so do higher plants. The body plan of seed plants consists of three general regions: roots, stems, and leaves. In most plants, roots help the plant to secure water and serve to hold it in place; stems hold up the leaves and transport liquids; leaves exchange gases with the air and are green in color.

Among the various families of seed plants, there are still closer similarities. The members of the sunflower family may be distinguished by the form of their flowers, which consist of a head of tiny individual flowers sur-

Why are all these placed in the same genus?

rounded by a fringe of petal-like parts, as in daisies, dahlias, and asters. This family includes at least one tenth of all the kinds of seed plants and is the largest plant family. All its members contain a special kind of starch called *inulin*.

The members of the grass family have similar leaves and



Most common varieties of dogs have developed only recently.

similar habits of growth. All the species constituting the family contain a glasslike substance called *silica,* which aids in the support of the long, slender stems. Oranges, limes, lemons, and grapefruit all contain *citric acid.* Besides having this chemical compound in common, these fruits have a similar structure, which is further evidence of their relationship. In other plant groups, such as the mint family, the gourd family, and the pine family, the similarities are obvious.

Similarities between plants and animals. Not long ago sponges were believed to be plants. Today we know

Photo by Hugh Spencer

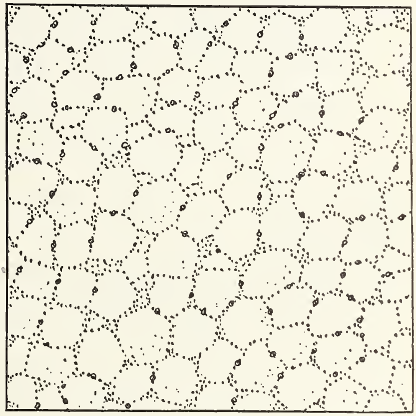
You must be careful to distinguish poison ivy with its three leaflets from woodbine with its five leaflets.

they are animals. But there is still a question as to whether certain other lower forms of life are really animals or plants. Both plant characteristics and animal characteristics are sometimes present in the same organism (see discussion of Euglena, page 161). In the higher forms of life it is usually easy to distinguish between plants and animals, but there are basic resemblances among them.

Protoplasm

Since ancient times it has been common practice to classify all natural objects simply as belonging to three groups: animal, vegetable, and mineral. It was believed that "minerals grow; plants grow and live; animals grow, live, and feel."

About one hundred years ago, when scientists became seriously interested in the study of living things, they needed a word which meant "living matter." Purkinje, the physiologist, suggested the word *protoplasm*, which is a compound of two Greek words, *protos* meaning *first*, and *plasm* meaning *form*. A German botanist, Hugo Von Mohl, popularized this word in his writings and it has been used ever since.



Redrawn from Wilson, The Cell

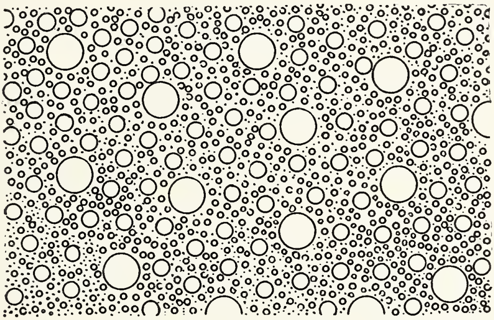
The stuff of life, protoplasm, is here magnified about 2000 times. Note its granular nature as shown in a bit of starfish egg.

At first it was thought that protoplasm was entirely different from nonliving matter, but today scientists are not so sure about this. Certain plants and animals may be frozen or dried and lose all signs of life but when favorable conditions return they live again. Still, no physical or chemical test has yet revealed any special difference between living and lifeless matter.

The chemical nature of protoplasm. When living things are analyzed chemically, they are found to contain chiefly the elements *carbon, hydrogen, oxygen,* and *nitrogen.* In protoplasm these elements do not exist singly; they are always combined with each other in the form of chemical compounds. The element carbon combines to form more different chemical compounds than all the other elements put together. In its diamond form it is the hardest substance known. The element hydrogen is the lightest substance known and requires a very low temperature to change it into a liquid. Oxygen is remarkable for the ease with which it combines with other elements and in the stability of its compounds. Nitrogen, on the other hand, is among the most inactive elements and forms relatively unstable compounds. From the interaction of these and a few other widely different elements, all protoplasm is built.

Besides carbon, hydrogen, oxygen, and nitrogen, living things with few exceptions also contain smaller amounts of phosphorus, sulphur, calcium, potassium, sodium, iron, magnesium, and chlorine. It makes no difference if the sample of protoplasm analyzed is taken from a plant or an animal, a man or a mouse, these twelve elements will be present. This is additional evidence that important similarities exist between all living things.

The physical nature of protoplasm. When oxygen combines with hydrogen, the resulting compound is water. Water is the chief compound found in protoplasm. Thousands of other compounds formed by chemical combinations of hydrogen, oxygen, and the other elements are also present. They are mixed with the water in various ways. Some are completely dissolved whereas others are suspended in the water. The result is a mixture that is neither completely solid nor completely liquid. The protoplasm of a



Redrawn from Shull, Principles of Animal Biology

Protoplasm resembles the emulsion shown in this diagram. It is neither completely liquid nor completely solid.

jellyfish is nearly all water; in man, less water is present, and the protoplasm is thicker. An emulsion made of soap and water resembles protoplasm in some ways, but no one has ever succeeded in making a mixture of anything that resulted in living matter.

Review and Thought Questions

1. Describe the general body plan of vertebrates.
2. Do you know of any animals that have more than one pair of eyes?
3. In what respect is a flea similar to a spider?
4. For what purposes do different animals use their tails?
5. What internal organs are common to all the higher animals?

6. Describe the general body plan of seed plants.

7. A kind of starch called inulin is found in all members of what plant family?

8. What chemical material is common to all members of the grass family?

9. What characteristics do plants and animals have in common?

10. Who established the word *protoplasm?*

11. Name the four most common elements found in protoplasm.

12. What is the chief compound found in protoplasm?

Activities

1. Make an inventory of those physical traits that are characteristic of members of your own family.

2. Compare the shape and composition of some animal teeth with those of human beings.

3. Visit a meat market and compare the structure of a leg of lamb with that of veal.

4. Buy a beef heart and compare its shape and structure with drawings of the human heart.

5. Make a collection of flowers of members of the sunflower family. Compare the structure of these flowers.

6. Test the acidity of lime juice, lemon juice, and grapefruit juice with litmus paper. An acid turns blue litmus paper red.

6. Cells

Of all the similarities among living things, none is more striking than the fact that all living things are composed of *cells.* The smallest plants and animals have a single cell. The largest have many millions of cells. The number of cells in the human body has been estimated at about twenty-nine trillions. The work of the body is divided among these cells with different kinds of cells doing different kinds of work. In many ways, however, each cell leads an independent life. It takes in food and gives off wastes. It carries on chemical changes within its protoplasm. These same activities are carried on by the cells of all plants and animals. That is to say, the cell is the unit of structure and function in all living things.

The Cell Theory

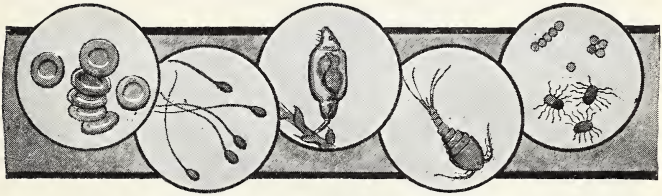
Little was known about cells until about one hundred years ago. The reason for this is that most cells are too small to be seen without a good microscope. The improvement of the microscope enabled scientists to study cells and brought about the development of modern biology. Without the microscope we would know very little about hygiene, medicine, surgery, and the working of our bodies.

Pioneers with lenses. Galileo (1564–1642) was one of the first to appreciate the magnifying powers of two lenses placed in a series. When he made an instrument with a concave lens at one end and a convex lens at the other, he found that by looking through in one direction he got a telescopic effect and by looking through the other way he got an enlarged view of small things near at hand. Galileo does not seem to have made any extensive use of the microscopic effect of his instrument, although he did describe the appearance of small animals as early as 1610.

Photo from Bettmann

Anton van Leeuwenhoek (1632–1723) grinding his own single lenses, some of which magnified as much as 250 times, discovered new worlds of living things.

Leeuwenhoek, the man who popularized the use of lenses in studying living things, reported his first discovery in 1678. The three-hundredth anniversary of his birth was widely celebrated among biologists in 1932. He was a Dutch lens-grinder who became interested in the magnifying effect of single lenses. He ground and polished between four and five hundred of them, and tried their enlarging effect on all kinds of materials, just as any boy with a magnifying glass is interested in looking at anything he comes across. Leeuwenhoek was a careful observer and he made extensive examinations of living materials. From him we date the first recognition of the corpuscles in the human blood, of minute animals in drinking water, and many other things never before seen by man. Considering that the best of his lenses could magnify no more than 260 times, and considering the difficulty of working with such high-powered single lenses, it is more than remark-

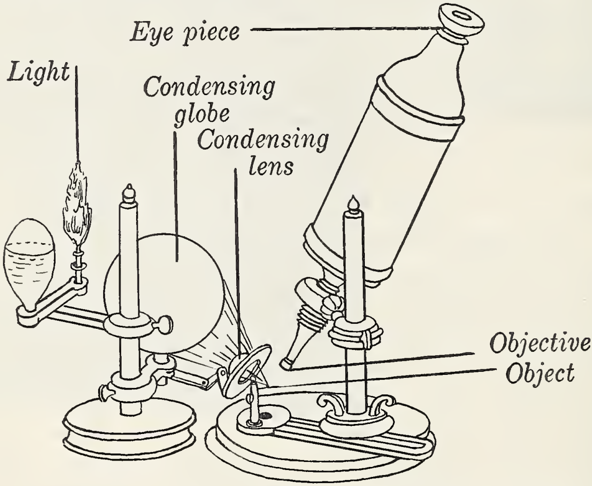


Leeuwenhoek was the first to see minute living things such as these.

able that he was able to see as many things as he did.

Discoveries with microscopes. Another milestone in the use of the microscope in biology was marked by the Englishman, Robert Hooke in 1665. Hooke's microscope had two lenses instead of one. The compound microscopes made today have more than two lenses but are similar in principle to that used by Hooke. Compound microscopes have two or more lenses in a series while Leeuwenhoek's simple microscope had only a single lens. Hooke, examining a very thin slice of cork, found that it was not really a solid structure but was composed of numerous tiny cavities, somewhat like a honeycomb. To these little holes, Hooke gave the name "cells," a term which has persisted in biology, although with changed meaning, as we have noted.

During the latter half of the seventeenth century, along with Hooke and Leeuwenhoek, there were several other notable workers with the microscope whose names may be merely mentioned: Grew, an Englishman; Swammerdam, a Dutchman; Malpighi, an Italian. These men worked as biologists, studying living things intensively. They dissected small insects, examined the minute parts of plants and animals, and left records in the form of drawings which for accuracy cannot be improved upon today. For nearly one hundred and fifty years, no one improved upon Hooke's microscope, but even with the imperfect instruments of those times, facts regarding the structure of living things were gradually accumulated.



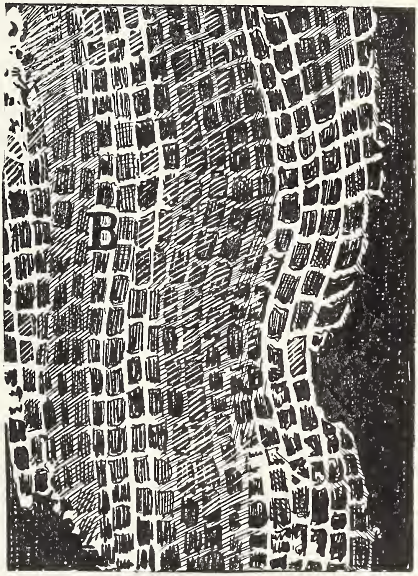
From Mavor, General Biology, after Carpenter

Robert Hooke (1665) advocated the use of the compound microscope, against the simple lenses used by Leeuwenhoek. In demonstrating the advantages, he showed a thin section of bark, and named the small spaces *cells.*

Early ideas about cells. About 1830, Robert Brown, an English botanist, had noted in some plant material that all parts were made of cells. Within each cell he discovered a central, denser body, which he named the *nucleus.*

In the latter part of the eighteenth century, a French physician, Bichat, because he thought of living substance as something "woven," had called it *tissue,* from the French word for a kind of cloth. We still use this term in biology. Tissues are groups of similar cells.

In 1838, Schleiden suggested the idea that the cell is the essential unit in the bodies of plants. "Each cell leads a double life: one independent, pertaining to its own development alone, the other incidental, as an integral part of a plant. The vital process of the individual cells, however, forms the first indispensable and fundamental basis for both vegetable physiology and comparative physiology in general." In other words, every plant is built of cells as units, and carries on its functions through the activities of its individual cells working together.



After Smith, Overton, et al., A Textbook of General Botany

What Hooke's microscope showed. A thin section of the cork bark of a tree showing the empty spaces which Hooke called cells. Now we know that these are only the walls within which the living cells had once lived.

A year later, Schwann, a neighbor and co-worker with Schleiden, published the results of his researches on animal tissues. His problem was more difficult. Cells are harder

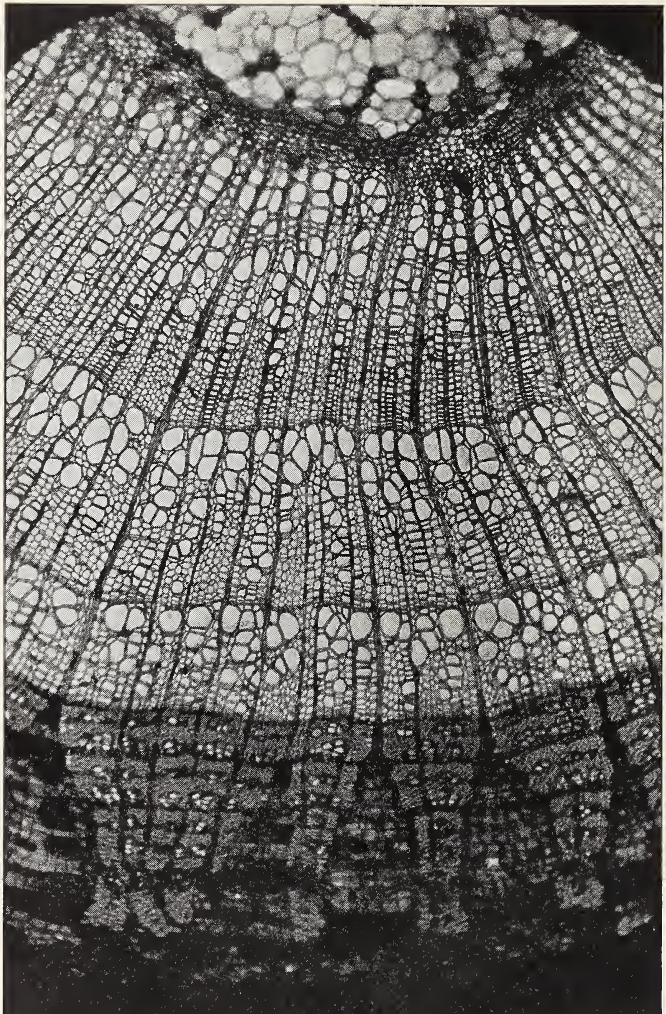
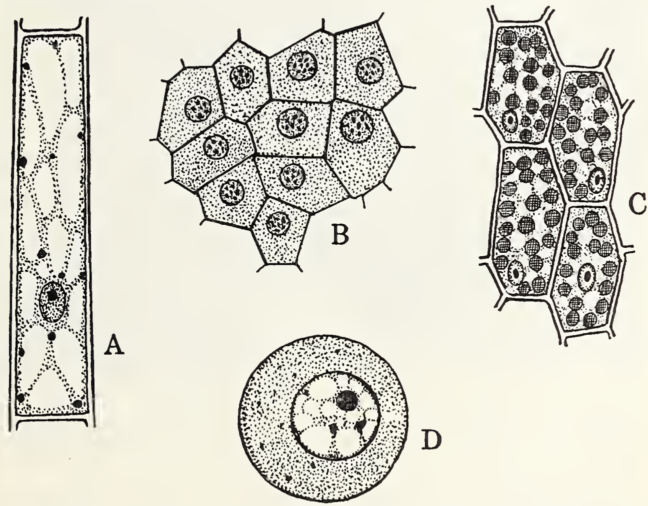


Photo by Hugh Spencer

This section of a three-year stem of the linden tree shows many cells united and working together.

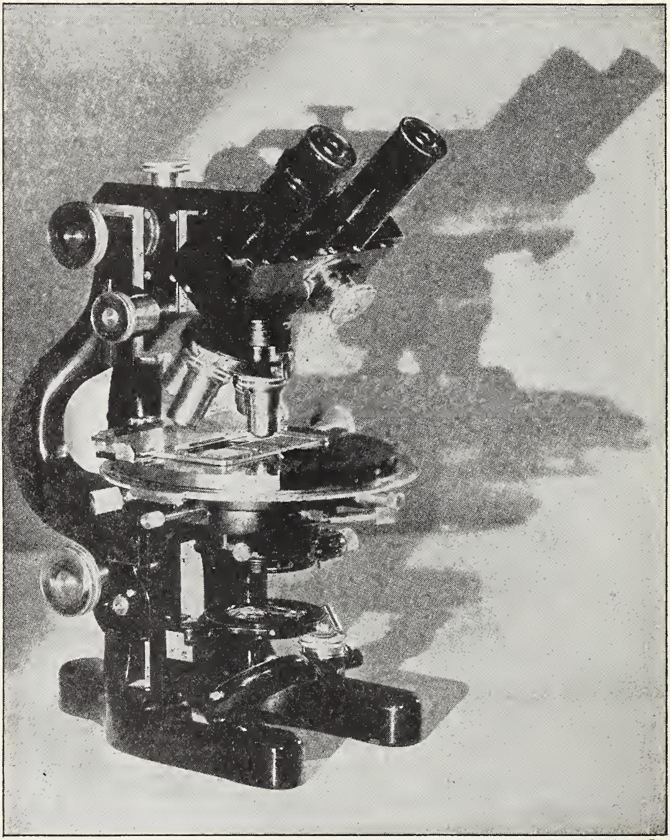
to see in animals than in most plant material. Schwann was a more thorough worker than Schleiden. His studies showed that for animals, as for plants, the cell is the unit both of structure and of function, and that for both plants and animals, these cell units have essentially the same basic structure. With this discovery, he pointed out, "The great barrier between the animal and vegetable kingdoms, viz., diversity of ultimate structure, vanishes." Schwann summarized his findings in three statements which are still valid:

1. The entire animal or plant is composed of cells or of substances thrown off by cells.
2. The cells have a life that is to some extent their own.
3. This individual life of all cells is subject to that of the organism as a whole.



Redrawn from Haupt, Fundamentals of Biology

Compare these typical plant and animal cells and nuclei: (A) Squash hair, (B) outer skin of salamander, (C) moss leaf, (D) unfertilized starfish egg.



Courtesy of Bausch and Lomb Optical Co.

A modern research microscope is built on the same plan as that of Hooke but with great improvements in lenses and mechanical parts.

In 1861 Schultze defined the cell as "a particle of protoplasm with a nucleus." A little later he referred to protoplasm as "the physical basis of life." Meanwhile, Virchow, who worked at the same time as Schultze, pointed out that disease as well as health depends upon cell condition. The body may be considered as "a state in which every cell is a citizen." Disease is a kind of civil war between cells caused by some harmful agency.

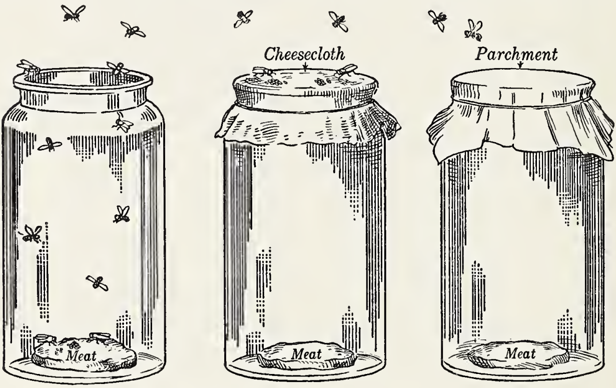
Following the period of Virchow and Schultze, further study of the cell has followed two main lines: (1) microscopical study seeking to disclose what the smallest details of protoplasm may be; and (2) chemical study of its composition to determine of what compounds it is made. Through these two methods, a vast amount has been learned about cells since the 1860's, but nothing has been found out which takes away anything from the essential truths recognized by the men of that time.

About 1880, microscope lenses were considerably improved. A clearer vision of the smaller structure of protoplasm was consequently obtained. Furthermore, during the latter half of the nineteenth century there were great advances in the methods of preparing cells for study, and in the methods of staining protoplasm to bring out its minute details more clearly.

Spontaneous generation disproved. Until the middle of the nineteenth century, most people believed that living matter could come from nonliving matter. A few people still believe this to be true. It is well known that spoiled foods become covered with mold and that dead animal bodies become alive with maggots. According to the theory of spontaneous generation of life, dirty cloth may produce mice, worms may come from mud, and other living things may be produced in similar miraculous ways.

In 1668 Redi, an Italian, disproved the spontaneous generation of maggots from bad meat. He showed that if the meat is covered with netting so that flies cannot reach it to lay their eggs, no maggots will appear. "The dead flesh of animals cannot engender worms unless the eggs of the living be deposited therein." It might be interesting for you to repeat Redi's experiment with meat and maggots, provided that such scientific but somewhat odorous work is not banned by members of your family.

About one hundred years later, another Italian worker, Spallanzani, went farther than Redi. He foreshadowed



In a significant experiment in the 17th century, Redi (1626–1699) showed that rotting meat does not become directly transformed into maggots, the larvae of flies. How does this experiment prove that it does not do so?

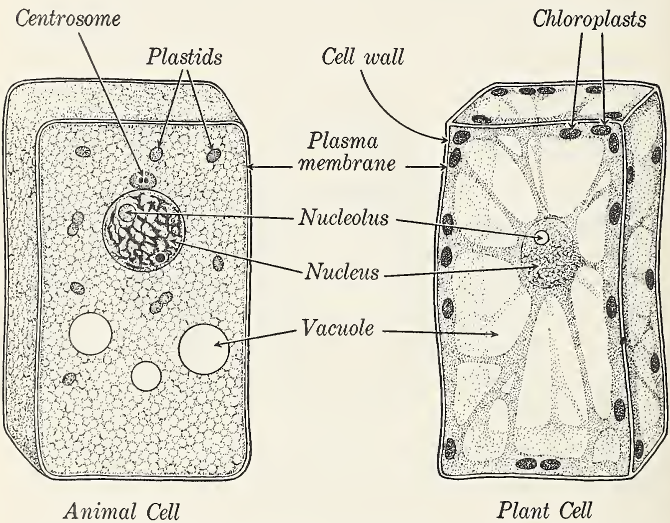
Pasteur's work by demonstrating experimentally that broth does not ferment or decay if air, and consequently the germs in the air, is excluded. Other men of the same time carried on similar experiments, but with contrary results which aroused much controversy. Many men continued to believe in the spontaneous formation of various kinds of microscopic life from dead matter until Pasteur's experiments about 1860. The great French scientist demonstrated conclusively that if all contamination by live cells of bacteria or fungi is prevented, foods do not ferment or spoil. Modern canning methods are based upon the discoveries of these experimenters.

The structure of cells. Since the time of Leeuwenhoek's pioneering with the microscope, thousands of scientists have been observing cells and making discoveries about them. Gradually, the cell theory became an established fact. Among the more recent investigators, Professor E. B. Wilson of Columbia University, who spent over fifty years studying cells, is recognized as having made many important additions to our knowledge of cell structure.

Each cell consists of two forms of protoplasm, (1) the *cytoplasm,* and (2) the *nucleus,* the former usually more liquid than the latter. A cell may have a wall surrounding the cytoplasm. In plants, this wall is commonly *cellulose,* a nonliving substance secreted by the cytoplasm as a sort of shell. In animal cells, there may be no wall, or the wall may be made of some special substance or of hardened cytoplasm.

The cytoplasm in the cell appears as a clear liquid, containing various kinds of granules, of different sizes and appearance. In a typical plant cell, there are rather large bodies, called *chloroplasts,* which contain the green pigment, *chlorophyll.* In the cytoplasm of animal cells there are smaller bodies called *plastids.* In animal cells and in the cells of some plants, there is usually a small double body, the *centrosome,* located near the nucleus. Other kinds of granules have been recognized and given names, but we need not go into further detail here.

The nucleus, like the cytoplasm, is far from being a simple solid structure. As it seems to be the most important part of most cells, and to be responsible for the general direction of the cell's activities, we may hope to find in its minute structure something which explains its importance. Its surface layer, the *nuclear membrane*, is distinct. It often contains one or more smaller bodies, which stain densely, and which have been given the name *nucleolus*, or "little nucleus." However, since these are not always



The various structures of both animal and plant cells can be identified as two forms of protoplasm: (1) the nucleus and (2) the cytoplasm.

present in nuclei, they are obviously not essential. Through the mass of the nucleus which is a clear liquid, there appears to be a fine, clear network of a substance called *linin*. Scattered along this linin are many particles of *chromatin*. This is so named because it tends to take up stains readily. During cell division, the chromatin collects to form thread-like structures called *chromosomes*, which are very important in cell division.

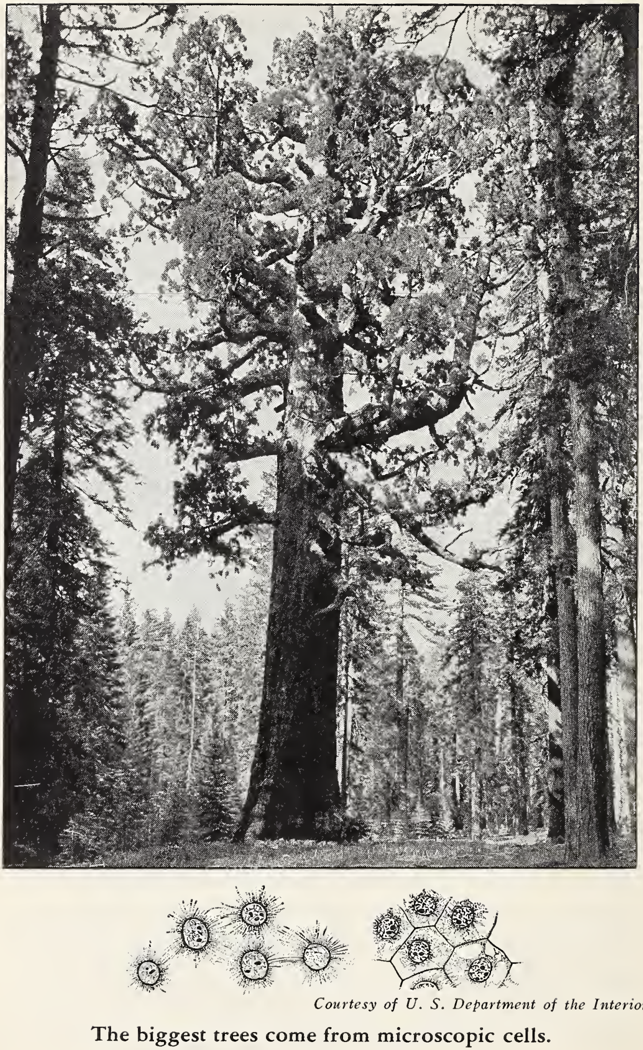
Cell Division

Plants and animals grow by adding new cells to their bodies. Older cells divide to form new cells. In most plants, this dividing and adding of new cells continues as long as the plant is alive. In animals, the total number of cells does not usually increase after adulthood is reached, but cell division continues, because new cells are needed to take the places of those that are destroyed or worn out.

The protoplasm of a cell must go through a series of gradual changes before a single cell can become two cells. The process is known as *mitosis*, or indirect cell division. There is, it may be noted, a method of direct cell division which occurs in the development of some diseases.

The nucleus is the center of the cell reproductive process, which may be described through four stages or phases as follows: (1) *prophase*, (2) *metaphase*, (3) *anaphase*, (4) *telophase*. While it has been found convenient to describe mitosis in terms of phases, it should be remembered that it is a continuous process. The different diagrams employed to represent the successive changes may stand as snapshots taken as the changes progress.

Prophase. During the earlier stage of the prophase, the chromatin granules in the nucleus become more prominent, enlarging and elongating until they appear to meet and form a continuous thread. Each thread next appears as a double thread, apparently having split lengthwise. Then it breaks crosswise into sections, the chromosomes, each comprising a number of the originally separate granules. The number of these chromosomes in the cells of any given individual, and in the individuals of that species, is constant. The numbers range from as few as two in the

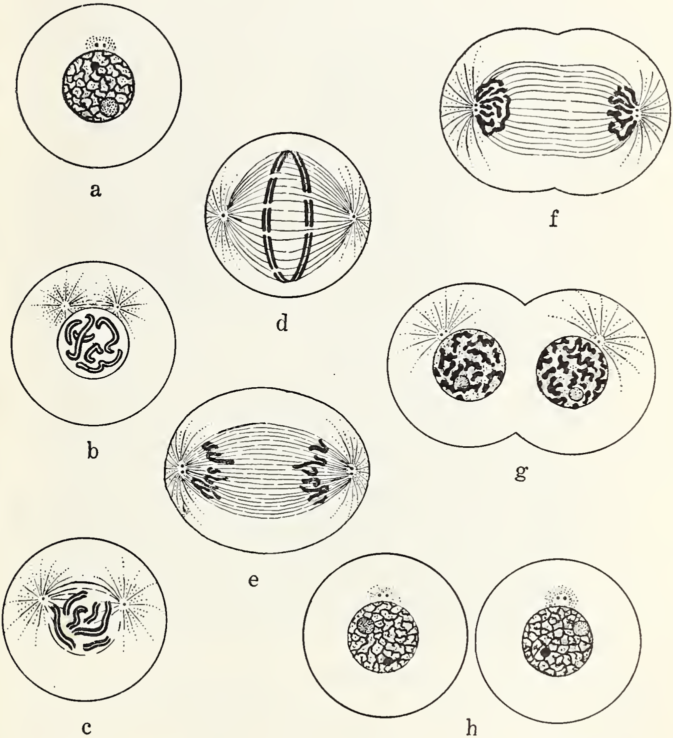


Courtesy of U. S. Department of the Interior

The biggest trees come from microscopic cells.

cells of a parasitic worm to two hundred or more in other forms.

During the next stage of the prophase, changes take place both in the cytoplasm and in the nucleus. Two radiating cones of lines form on opposite sides of the nucleus. These gradually extend until they penetrate the nuclear mem-



After Hegner

Stages in the division of an animal cell. (a) Resting stage, (b) middle prophase, (c) later prophase, (d) metaphase, (e) anaphase, (f) early telophase, (g) later telophase, (h) resting stages again.

brane, which disappears. At the same time the double chromosomes move toward the middle of the nucleus, becoming arranged in a plane at right angles to the axis of the cones of lines. The lines extend further and meet in the region where the chromosomes have taken position. The whole figure is now spindle shaped, with points called *poles* and a middle portion called the *equator*. When this spindle shape is complete, the prophase has been completed. Making a crude figure of such a spindle, using some soft wire that can be arranged to form two hollow cones meeting at the center, will help you to understand what happens.

Metaphase. This second phase of mitosis accomplishes what is perhaps the purpose of the whole process. The chromosomes have come into the equator divided into two equal halves. It appears probable that some of the spindle fibers or lines from the poles were attached to the chromosome halves, and are responsible for pulling them apart. At any rate, the double chromosomes are gradually split apart, half of each being pulled toward opposite poles of the spindle. As soon as the halves are separated, the metaphase has been completed.

Anaphase. The positions of the poles of the spindle are the points at which the two new or daughter nuclei are to be organized. During the anaphase, the new chromosomes move apart along the spindle lines until they reach the poles. Some spindle lines remain between the two groups of new chromosomes, often forming a barrel-shaped figure. Across the equatorial region of these lines, in plant cells, thickenings begin to form on the spindle lines. No such thickenings occur in animal cells.

Telophase. In order that the original cell may become two complete new cells, the chromosome groups form two new nuclei, each with a complete nuclear membrane. Next the cell mass as a whole divides, and the cytoplasm separates into two parts.

In plant cells, a cellulose wall is laid down between the two new protoplasm masses, completing the final separa-

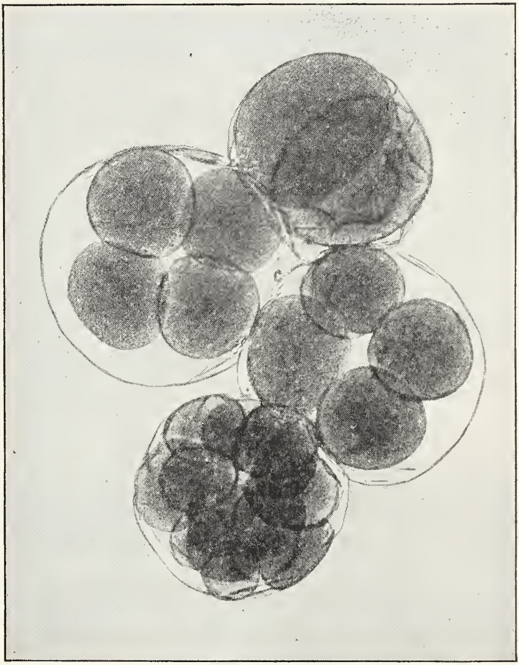


Photo by Hugh Spencer

Some early stages in the development of a starfish. A microphotograph of 2-, 4-, and 8-celled stages in the division of the fertilized egg.

tion. In animal cells, the cytoplasm is divided somewhat differently. Ordinarily, as the anaphase proceeds, a crease appears around the middle of the old cell. This crease tightens inwardly, as if a belt were being drawn more and more tightly around it, until the cell masses have separated.

One other difference between animal cells and most typical plant cells may be cited. In animals the centers of the spindle fibers are formed around two small bodies in the cytoplasm, the centrosomes. After division, the centrosomes may persist and themselves divide in preparation for the next mitosis. Although centrosomes are present in the simpler kinds of plants, none are known in higher plants.

After cell division, the two daughter cells enlarge, due to assimilation of food. They grow until they reach the size characteristic of the particular kind of tissue. Then they are ready to divide in their turn. Thus, starting from a single cell, two cells, then four, eight, and so on, are formed until the billions of cells of the adult individual have been gradually produced.

Review and Thought Questions

1. Who gave the greatest impetus to the development and use of the microscope for the study of living things?
2. Who first named the cell?
3. Who discovered the nucleus in the cell?
4. Who formulated the cell theory?
5. How did Schultze define a cell?
6. What modern American scientist has added greatly to our information about cell structure?
7. Of what is a plant cell wall composed?
8. In what cells are centrosomes normally and usually found?
9. What is the material in the nucleus that stains readily?
10. What is meant by "spontaneous generation?"

11. Name two early scientists whose experiments helped disprove the idea of spontaneous generation.

12. Whose work conclusively disproved the idea that living things may come from lifeless matter?

13. How did Pasteur's work contribute to modern methods of preserving food?

14. Name the four stages in cell division and tell the most significant changes that occur in each stage.

15. Why is cell division necessary for growth?

Activities

1. Bore a small hole through a sheet of tin or copper. Then fix the metal in a horizontal position and allow a small drop of balsam to fall directly on the hole. Do not disturb for several days. After the balsam has dried, you will have a simple microscope which will work like those made by Leeuwenhoek.

2. Find a labeled diagram of a compound microscope in some reference book. Study the diagram and learn the names and uses of the various parts.

3. Repeat Hooke's experiment by cutting a very thin slice of cork with a razor blade and looking at it with a compound microscope.

4. Look at prepared slides of various plant and animal tissues.

5. Practice describing the positions of objects as seen in the field of a microscope. Position in the microscope field may be indicated by reference to the field of a clock. If an object is to the left of the center of the field, it is said to be at nine o'clock. If it is at the top, it is at twelve o'clock. If it is slightly to the right of the top, it is at one o'clock, and so on.

6. Examine sections of root tips. Note the different shapes and sizes of cells. Locate the region of cell multiplication and observe that these cells later become specialized.

7. Make three-dimensional models of the four stages in mitosis. Use clay, soap, paraffin, wire, or any other material that seems convenient.

8. Examine the cross sections of stems of various ages. Observe tissues undergoing mitosis.

9. Report on one of the scientists mentioned in this chapter.

References for Unit Two

Of course, some of the books listed for Unit One (see pages 77–78), along with others you may find listed in the catalog of your library, will be helpful.

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Unit 3

CHANGES IN LIVING THINGS

Did you know that fossils embedded in rocks show that the plants and animals of long ago differed greatly from those of today? What other evidences are there that living things have changed and are still changing? How do biologists explain these changes? Use the following outline as your guide in finding answers to the last two questions.

RECORDS IN ROCKS

Fossils

- How fossils are formed
- Kinds of fossils
- Series of fossils

Changes Through the Ages

- Azoic time
- The Archeozoic era
- The Proterozoic era
- The Paleozoic era
- The Mesozoic era
- The Cenozoic era

CHANGES IN SPECIES

Evidences of Past Changes in Living Things

- Structural similarities
- Vestigial structures
- Evidences in embryos
- Geographic distribution

Changes in Living Things of the Present

- New varieties
- New species
- Variations produced by breeding
- Changes in species population
- The relation of human migration to species population

7. Records in Rocks

Living things of the past not only resembled each other as do the living things today but were similar in many ways to modern forms. For a long time biologists have been interested in the meaning of these similarities and have made careful studies of the plants and the animals of long ago. Through these studies many forms of life now no longer in existence are actually better known than some living things of today.

Fossils

Our knowledge of the living things of the past has been gained through the study of *fossils.* The term fossil comes from the Latin word *fossilis,* which means something dug out of the earth. At one time any object that came out of the earth and had an interesting shape or color was called a fossil. At present, the term is usually applied only to the remains or imprints of plants or animals found in rocks.

How fossils are formed. Only the smallest fraction of the plants and animals of the past are preserved as fossils.

The most favorable conditions for the formation of fossils exist near the shores of shallow seas. When rivers pour out their muddy waters into these seas, or storms churn up the mud from the bottom, a great many fine rock particles are left suspended in the water. These suspended particles gradually settle and cover living and dead plants and animals with a layer of mud and other sedimentary materials. Similar layers are deposited on top by later storms and floods. Time and pressure change the layers

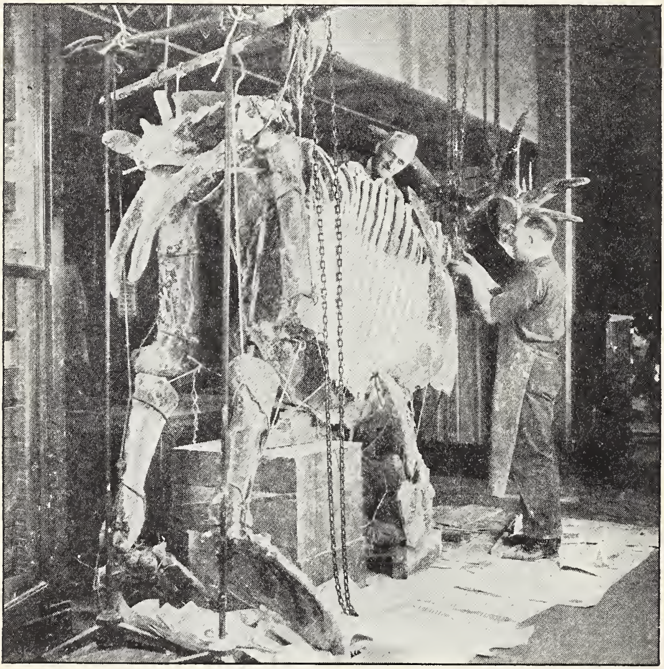


Photo from American Museum of Natural History

When bones of an extinct animal are found, scientists are often able to put them together as they originally were, and to add flesh and skin to show us what the animal looked like. Here museum experts are reconstructing a great plant-eating animal which lived near Alberta, Canada.

of sediment to rock. Then the movements of the earth's crust may push this layered rock upward, so that the fossils of sea-living organisms are often found embedded in rocks far above sea level.

On the land, the most favorable situations for the formation of fossils are lakes, marshes, and bogs. Plants and animals are usually numerous in these places, and others may be carried in by streams. Many become permanently entombed and are preserved as fossils.

In deserts, the windblown sands often aid in the formation of fossils. The nests of dinosaur eggs which were

From a painting by Charles R. Knight *© Field Museum*

From bones and even from bodies frozen in the ice, scientists reconstruct many extinct animals. Here are early camels (left), pigs (center), and a huge animal of the horse family (right).

discovered in the Gobi desert were preserved in this way. Drifting sand dunes also cover up standing trees, which may then petrify, that is, turn to stone.

In arctic regions, animals are sometimes preserved by refrigeration. Whole bodies of a kind of mammoth that lived 25,000 years ago have been found in northern Russia. The mammoths were in such excellent state of preservation that the meat was used for food. Although they were merely frozen, they were just as truly fossils as animals preserved by other means.

Great numbers of fossils have been found in tar pits, such as those at Rancho La Brea, near Los Angeles. These tar pits were originally petroleum springs, which gradually evaporated, forming pools of thick, sticky tar. Rains left water floating on top of the tar, and animals came to drink the water. Naturally, some of the animals became mired in the sticky stuff. Other animals came to prey on them with the result that they, too, were unable to get out of the pool. The tar prevented their bones from decaying, and many of the specimens we now see in museums were preserved in this way.

Some of the most perfect fossils ever found were embedded in amber. Amber is the resinous sap which exudes from trees, and is dried and hardened by time. It is not uncommon to find insects in pieces of amber. Although some of these insects lived millions of years ago, they can be studied just as easily and thoroughly as the insects living today.

Kinds of fossils. Most fossils of higher animals consist only of the harder parts, such as teeth and skeleton. Usually, because they are embedded in rock, other mineral matter is added to the parts which are preserved. The process is known as being *petrified,* or turned to stone. Parts of plants are similarly petrified. The petrification of ancient plants or animals is sometimes so perfect that it is possible to study the structure of the cells under the microscope.

Not all fossils are of the petrified variety, however. Sometimes, instead of being replaced by mineral matter, the original fossil is completely dissolved away by ground water, leaving holes in the rock. These holes are called *molds.* Later the holes may be completely filled again with mineral matter, sand, or mud. They are then called *casts.*

Tracks made by extinct animals walking in the mud are called *imprints.* Imprints of leaves, of insects, and even of raindrops are fairly common. They are preserved only

Photo from American Museum of Natural History

Fossils of horseshoe crabs are found in Europe, America, and India. They belong to a group of animals called trilobites, a large group of Paleozoic arthropods.

where another layer of rock-forming material covers the original imprint very soon after it is made.

All of the kinds of fossils mentioned have been forming ever since there have been living things on earth. They are still being formed today.

Photo from American Museum of Natural History

The Irish elk, a giant deer, is known only from its bones. This is how scientists think the great animal looked.

Series of fossils. Through the study of fossils, the ancient history of many plants and animals is now fairly well known. Fossils found in the deeper layers of rock are naturally older than those found in layers above them. Where fossil remains of a certain type of organism are numerous, it is possible to arrange them in a series beginning with the earliest and to trace their development through long periods of time.

The ancient history of the horse is so completely known as to be practically beyond question. The earliest known ancestor of the horse family lived at least 40,000,000 years ago. It was an animal about the size of a fox with four

Photo from American Museum of Natural History

The four-toed Eohippus, an animal about the size of the fox, is the earliest known ancestor of the horse. These primitive horses once lived in the western part of the United States.

toes on its front feet and three toes on its hind feet. In later strata of rock, a larger horse was found. It was the size of a sheep with three toes on each of its feet. Still later, fossils show the three toes remaining but with the middle toe more highly developed than the others. The next horse was about the size of a donkey, with only one toe on each foot but with traces of two others. Finally, the modern horse emerged. Along with the changes in the size and the number of toes, there were corresponding changes in the teeth, the skull, and other body parts.

Another animal that has been studied intensively in fossil form is the elephant. The earliest known ancestor of the elephant showed no indication of a trunk. Fossil remains of later types indicate a gradual change in the shape of the skull and in the increasing length of the trunk.

Camels originated in North America and migrated to the Old World within comparatively recent times. They have since become extinct in North America, but their fossils are plentiful. The earliest camels were about the size of jack rabbits and had forty-four teeth. Later fossils show larger skeletons and fewer teeth. It is not known whether any fossil camels had humps, as a camel's hump has no bony framework whatever.

Changes Through the Ages

The story that fossils tell could never have been well understood without the help of the *geologists*, who study the layered structure of the earth. For more than one hundred years, biologists and geologists have been working together, getting material for the story recorded in the rocks.

The work was begun about 1800 by the Scottish geologist, James Hutton, who suggested that a knowledge of the everyday processes such as rainfall, erosion, waves, and wind were all that were needed to understand the past history of the earth. About the same time William (nicknamed *Strata*) Smith, an English surveyor, noticed that the same organic remains were present in rocks which were widely separated. He concluded that layers of rocks having the same fossils were similar in age.

With this as a beginning, geologists have constructed a chronological table of both fossils and rocks and have divided the history of the earth into long chapters called geologic eras.

PRINCIPAL DIVISIONS OF GEOLOGIC TIME

ERAS	MAXIMUM THICKNESS OF DEPOSITS	DOMINANT LIFE
Cenozoic 60 million years	37,000 feet of clay, sand, gravel, limestone, sandstone, and coal	Mammals and flowering plants
Mesozoic 135 million years	65,000 feet of sandstone, shale, limestone, and coal	Reptiles, cycads, conifers, and primitive flowering plants
Paleozoic 355 million years	70,000 feet of shale, limestone, and coal	Amphibians, fishes, shelled invertebrates, ferns, lycopods, calamites
Proterozoic 650 million years	74,000 feet of conglomerate, lava, sandstone, slate, schist, quartzite, and limestone	Primitive marine invertebrates, algae, bacteria
Archeozoic 850 million years	100,000 feet of sedimentary schist, gneiss, lava, slate, and limestone	Simple unicellular organisms

Azoic time. The history of the earth begins about two billion years ago. According to the most widely accepted theory, the earth was originally a globe of intensely hot gases which gradually contracted and cooled sufficiently to form a crust of rock. For a long time this crust was unstable; great cracks appeared in it, and sinkings of the heavier portions made depressions in it. As the steamy atmosphere began to cool, the condensed water ran into the larger depressions forming the oceans. The elevated portions of the earth's crust then became the continents.

The term *azoic* means without life, for certainly no living thing could have existed on the earth while such tremendous changes were occurring.

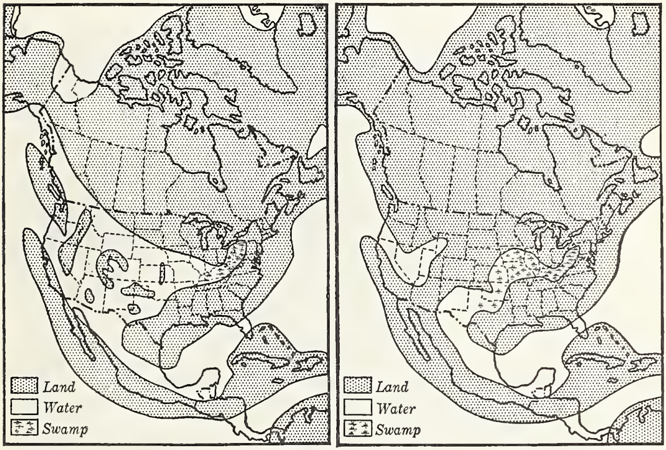
Courtesy of Brooklyn Botanic Garden

A landscape of 500 million years ago. The earliest land plants were small with forked branching like many algae of today. There were no flowering plants until the late Paleozoic Era.

The Archeozoic era. *Archeozoic* means primitive life. Minute traces of carbon are present in the rocks formed during this era. During the early stages of the earth's history, there was much more carbon dioxide in the atmosphere than there is now. The presence of so much carbon dioxide in the air provided one of the conditions favorable for the development of plant life.

Living things during this era must have been confined to the ocean. Minute plants, probably one celled, may have lived near the ocean surface with lime-secreting algae on the bottom of the shallower seas.

During Archeozoic times much of the old land was worn down by erosion, so that the oceans spread over areas that had previously been dry land. Sediments were deposited



Redrawn from Schuchert and Dunbar, Historical Geology, Part III

During these two periods in the Paleozoic Era, the coal beds of Pennsylvania and neighboring states were probably formed in the swamps and shallow water that covered a large part of the region which is now the United States.

over these areas. Later in the era, some of these areas were uplifted, and today their fossil-bearing rocks are exposed in many places. Between eras there is always a break in the record of living things, caused by tremendous geological happenings such as the uplift of the continents at the end of the Archeozoic era.

The Proterozoic era. The fossils of the next great age, the *Proterozoic* (former life) era, are all water forms. No land forms have been discovered in any of the rocks.

The secretions of limestone-forming *algae* indicate that these plants were most abundant. Simple, many-celled animals such as sponges, worms, and small mollusks also existed.

The Paleozoic era. During the early part of the succeeding *Paleozoic* (ancient life) era, the land was again

Courtesy of Brooklyn Botanic Garden

Coal was formed from plants like these of the late Paleozoic Era.

worn down. Most of what is now North America was at or below sea level during the greater part of this era, with the ocean first advancing and then retreating.

The rocks deposited in Paleozoic times show an abundance of fossils, especially in North America. Representatives of all plant and animal phyla, except in their higher forms, are to be found. There are no birds, mammals, or flowering plants, however, and only the simplest reptiles existed. During the Early Paleozoic, there was a great abundance of marine invertebrates. We therefore call it the *Age of Invertebrates* in contrast with the Middle Paleozoic which is known as the *Age of Fishes*. The Later Paleozoic is known as the *Age of Amphibians* or the *Age of Coal-making Plants*.

The Paleozoic era ended with a prolonged period of cold weather. The coal-making plants that had flourished in the warm lowlands perished and were replaced by hardier plants. Many groups of animals were reduced in numbers or became extinct. There was world-wide uplift, mountain building, and glacier action.

The Mesozoic era. The wholesale destruction of life that occurred at the end of the Paleozoic era prepared the way for new types of living things in the next period. During the *Mesozoic* (middle life) era, reptiles became the dominant animals. This was the age of the great dinosaurs, and other reptiles of many kinds inhabited the land, sea, and air. But long before the end of the era, the larger reptiles had already disappeared, and mammals had appeared upon the scene.

The end of the Mesozoic era was marked by world-wide continental uplift, the birth of the Rockies and the Andes, coal and chalk deposits, and the widespread flooding of lands.

The Cenozoic era. We are now living in the *Cenozoic* (modern life) era. This era began about sixty million years ago. No widespread submerging of continents has occurred during this era, and modern types of plants and animals have existed since its beginning.

Perhaps the most important geological event of Cenozoic times was the coming of the glaciers. The climate had been mild in the early part of the era but about one million years ago it began to get cold. Snow and ice piled up in arctic regions and moved slowly southward. At one time

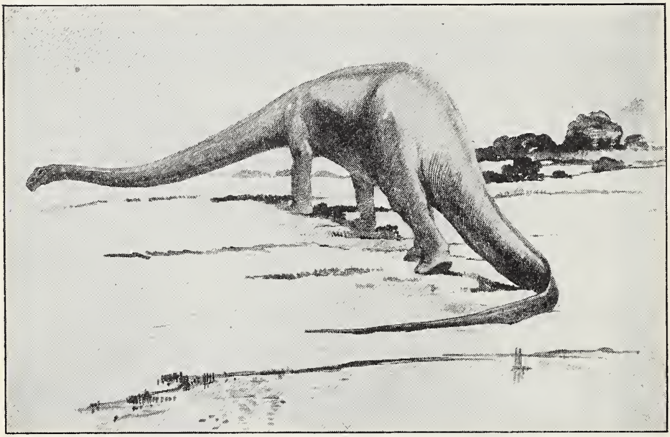
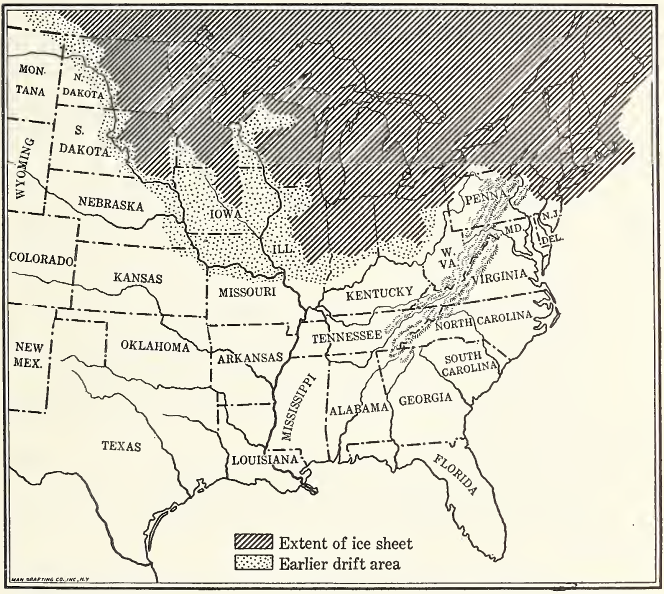


Photo from American Museum of Natural History

In the Mesozoic, the age of great reptiles, the diplodocus, ninety feet long, was only one of many strange animals. All of them and their thousands of species have become extinct.

the ice sheet extended as far south as the Ohio River. In most glaciated regions, there is evidence of more than one glaciation. Cold and warm periods alternated, with the ice sheet advancing and retreating. At least four major glacial advances are known to have taken place, the most recent not more than 25,000 years ago.

As the glaciers advanced, plant life was destroyed, and most animals migrated southward. During the interglacial periods, living things spread northward again. Fossil remains of both arctic and tropical life are found close together in many places. Admiral Byrd has reported the discovery of coal in the Antarctic, and fossil palm trees



In North America many thousands of species were wiped out or driven southward when glaciers moved down from the north and dropped icebergs in New York harbor.

have been found within the Arctic Circle. Fossils of such arctic animals as the musk ox and the woolly mammoth have also been discovered as far south as Arkansas.

The most important biological event that has taken place in Cenozoic times was the appearance of man on the earth. Some authorities date a new geologic era, the *Psychozoic* (mental life), from this event. It is possible that the fossil remains of man may sometime be added to those of the dinosaur, dodo, and other extinct creatures.

In any event, it must not be supposed that geologic and biologic changes are confined to the past. Today continents are still rising and falling. The water level of the ocean is rising. New varieties of living things are appearing, and others are disappearing. Shore lines are sinking in some places and rising in others. Glaciers are receding but may advance southward again. Changes are probably taking place now as rapidly as at any time in the past.

Review and Thought Questions

1. What are fossils?
2. Describe three ways in which fossils may be preserved.
3. How are molds, casts, and imprints formed?
4. How can the relative ages of fossils be determined?
5. The development of what animal has been clearly traced through fossil evidence?
6. How many estimated millions of years ago did the first known ancestor of the horse exist on this earth?
7. Why is it believed that camels originated in North America?
8. Briefly describe characteristic life forms that are believed to have existed during the Archeozoic, Proterozoic, Paleozoic, and Mesozoic eras.
9. What was the most important biological event of the Cenozoic era?
10. What is the estimated length of the Cenozoic era?

Activities

1. Observe the surface features of your vicinity and account for their present state. Find examples of changes that are now taking place.

2. Look up the geological history of your locality.

3. Find out where there are good hunting grounds for fossils in your locality. Determine the age of any fossils discovered by relating them to the geological formation in which they are found.

4. Make a study of any fossils that are to be found in the school collection.

5. Visit a museum and study the reconstructions of plants and animals that existed long ago.

6. Find a piece of soft coal which shows the structure of the stems or leaves that compose it.

7. Make a special study of the evolution of some common domestic plant or animal.

8. Changes in Species

Before man began examining the record of the rocks, it was commonly believed that species did not change. Most people thought that the first horses on earth were just like the horses of today and that all other living things were descended from a long line of ancestors which were all practically alike. The scientists' study of rock layers and of the fossils found in them presents very strong evidence that this is not so. The enormous thickness of the fossil-bearing rocks indicates that the earth is very old and that there has been plenty of time for changes in living things to take place. The fossils show that living things tend to change from simple forms of life to more complex forms. Furthermore, the change from simple to complex forms of life is indicated by several lines of evidence in addition to the testimony of fossils.

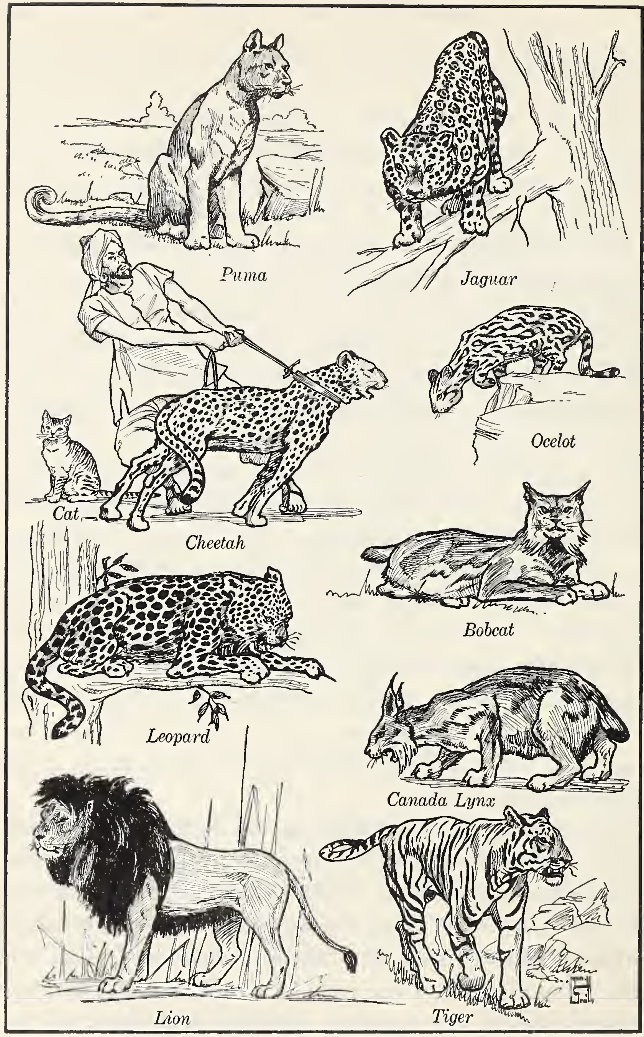
Evidences of Past Changes in Living Things

Though the evidence presented by fossils is probably the most conclusive and direct, there are other reasons why biologists believe species change. Examination of these additional lines of evidence provides both a check against the fossil evidence and aid in understanding how changes in species take place.

Structural similarities. Living things are classified on the basis of structure. Similar individuals are included in the same species. When there is any question as to what species a given individual belongs, the internal structure as well as the external structure of the individual must be taken into account. Mere external resemblances are not enough to determine finally how an organism should be classified. Sometimes the classification of a plant or animal is changed as a result of a more complete study.

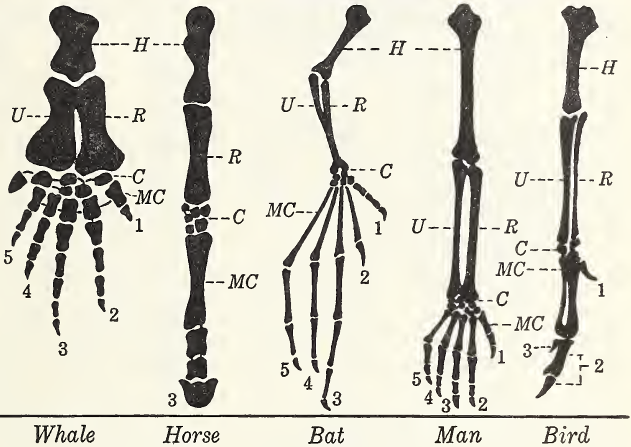
The individuals that make up a single species have a large number of structural similarities and few marked differences. Their similarities are due to the fact that they are descended from common ancestors and thus are closely related. Among the various species that make up a genus, there are also similarities; but these are fewer and the differences are greater than those within a species. This is evidence of more remote common ancestry and more remote relationship. Among different genera the relationship is still more remote. For instance, the house cat, the tiger, the leopard, and the lion each belongs to a separate species. These species are all included in the genus *Felis.* The cheetah also belongs to the cat family but is sufficiently different from other cats to warrant its being placed in the genus *Acinonyx* instead of the genus Felis. In the broader classification groups, the similarities become still fewer and the differences more numerous, but relationships still exist.

When the skeletons of different animals are placed side by side and compared with each other, some very interesting observations may be made. General similarities will be noticed at once. Even among species which are almost totally unrelated, such as frogs and elephants, there are striking similarities in the parts of the skeleton. There are resemblances in the number, position, and shape of the bones. Skulls, backbones, and leg bones all follow the same general plan.



All these members of the cat family are more or less distantly related.

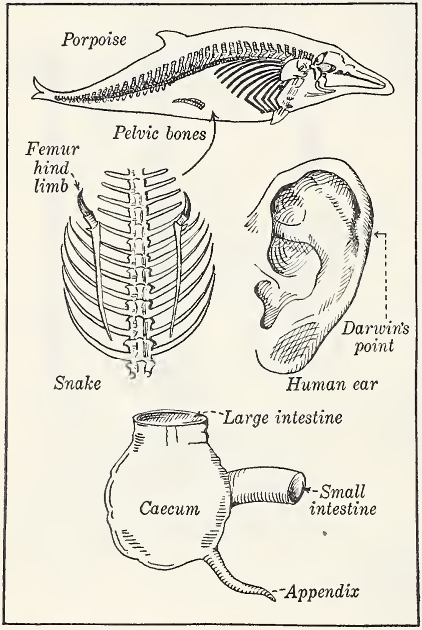
Among the higher vertebrates, the bones of the forearm are of special interest. In different animals the forearm is modified for running, digging, swimming, grasping, walking, or flying. The result is a great variety of shapes



Even in very different animals the same bones can be found. Note "finger" and "wrist" bones in five very different vertebrates. H — humerus; U — ulna; R — radius; C — carpals; MC — metacarpals; 1, 2, 3, 4, 5 — phalanges.

and sizes of bones; yet these are clearly recognizable as the same structures. The neck bones are also good illustrations of similarities revealing relationships. Mammals, with one or two exceptions, have exactly seven vertebrae in their necks. The giraffe has not one more than the apparently neckless whale or the tiniest mouse.

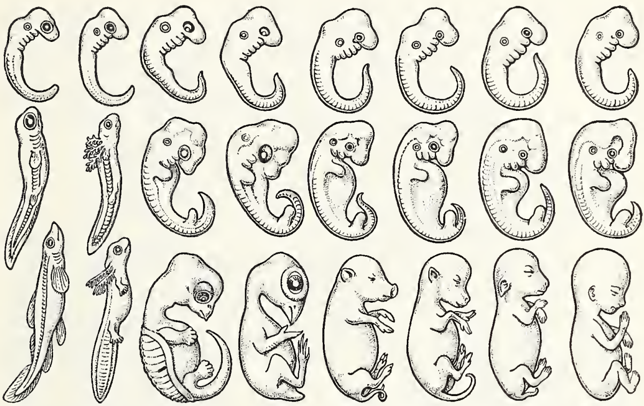
Vestigial structures. On each side of a horse's foot, there is an utterly useless small bone. These bones are the remains of formerly useful toes. Also, in the python and other related snakes there is a pair of small leg bones toward the back of the body. These bones occupy the position that hind legs do in other animals but are entirely useless to snakes. Such useless vestiges of once-useful parts of the body are called *vestigial* structures.



Vestigial structures show how living things change. The porpoise and the python do not have hind legs. Man does not prick up his ears, and his appendix is no longer of any use.

Man has no fewer than seventy vestigial structures. Some are muscles connected with the scalp and ears. These muscles correspond closely with those used to twitch the skin and move the ears in other animals. The facial muscles, however, have become modified so that their present function is to express the emotions, but most muscles attached to the skin are useless. There are other useless muscles attached to the base of the backbone. The last five vertebrae of the backbone have grown together to form the coccyx, also a vestigial structure. Most familiar of all human vestigial structures is the appendix. In lower animals the appendix is a useful organ but in man it has no present function. It persists only because of heredity.

Evidences in embryos. All living things start out as single cells. In the one-celled stage, most organisms resemble each other so closely that it is almost impossible to identify them. A one-celled elephant looks approxi-



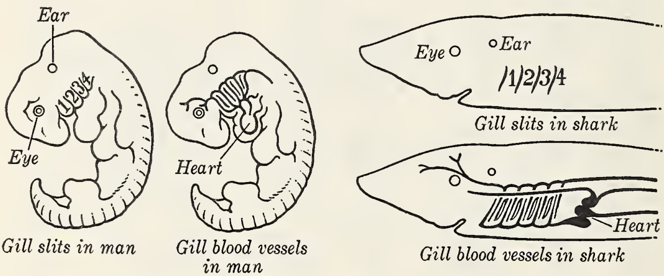
Fish *Salamander* *Tortoise* *Chick* *Hog* *Calf* *Rabbit* *Man*

The embryos of all vertebrates look alike in their earliest stages. They gradually differentiate as they become older. (Redrawn from Romanes, *Darwin and after Darwin.*)

mately like a one-celled mouse. A one-celled rabbit looks like a one-celled sheep.

As cell division proceeds, the developing organism is known as an *embryo*. During the early stages of their development, the embryos of fish, frogs, pigs, horses, and all other vertebrates show similarities which are almost as remarkable as those that occur in the one-celled stage.

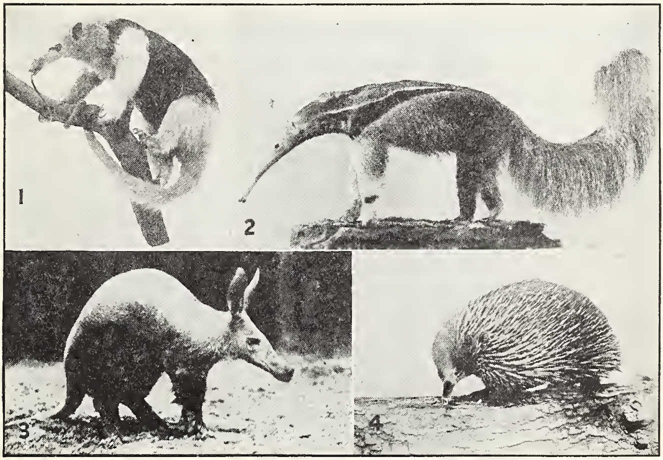
At some stages, the embryo of an advanced species often resembles the adult of a lower species. Thus, in one stage, the human embryo has gill slits. These disappear as development advances but leave traces which persist even in the adult body. The Eustachian tube, which leads from the throat to the ear, is a remnant of a gill slit. At another stage, the human embryo has a well-developed tail, but this disappears long before birth, leaving only a short remnant at the base of the spine. In the development of one kind of parrot, teeth are present in the embryo. They serve no purpose to the growing bird in the egg and are entirely absent in adult parrots. Before birth young whales are covered with hair, but adult whales are hairless.



Embryo structures which become gills in fish develop into entirely different structures in other vertebrates.

The biologist finds no difficulty in accounting for such occurrences. He explains the young parrot's teeth as indicating a relationship to some ancestral reptilelike form. Similarly, the hair of the unborn whale indicates that whales have probably descended from some earlier hairy mammal. Thus, the development of the individual seems to repeat the history of the race. This principle is not always true in a restricted sense, but in a broad sense there is considerable evidence to support it.

Geographic distribution. Studies of the present distribution of plant and animal groups furnish an additional line of evidence to explain changes in species. Animals that live near each other or along natural migration routes are similar, because of descent from common ancestors. But where there are natural barriers, such as oceans, large rivers, or mountains, the types found on either side tend to be different rather than similar.



Photos from American Museum of Natural History, William Thompson, New York Zoological Society

(1) The lesser anteater from South America, (2) the great anteater from Venezuela, (3) the aard-vark or ant bear from Africa, (4) the spiny anteater from Australia. All of these animals eat ants and have similar mouth parts. The first three belong to the order Edentata, but the spiny anteater is an egg-laying mammal and is not closely related to the others.

The animal types living in North America, Europe, and northern Asia resemble each other quite closely because these areas are believed to have been once joined by land bridges. On the other hand, the animal types living in South America are quite unlike those of North America because of difficulties of travel between the two continents. Only a few animals are common to both continents, the outstanding example being the puma, or mountain lion, which found no difficulty traveling up and down the twelve-thousand-mile range of mountains that connects the two continents.

The Tasmanian tigers, koala bears, kangaroos, egg-laying mammals, and spiny anteaters of Australia have no close relatives anywhere in the world. It is unknown whether Australia was ever connected with the mainland of Asia. If it was, the separation occurred a very long time ago, and both migration and interbreeding have since been impossible because of ocean barriers.

The life forms that exist on islands depend mainly upon accidents of distribution. Usually they tend to resemble the life forms of the nearest mainland. Few immigrants, however, find their way to oceanic islands, and consequently the life found on them consists of a relatively small number of species. Frogs are never present, because they cannot endure salt water. Occasionally a new plant arrives as a seed in the mud clinging to the foot of a migrating bird or as an undigested bit of fruit eaten by the bird.

Changes in Living Things of the Present

In 1923 a yellow sweet-potato plant growing in Delaware produced three red sweet potatoes in addition to some yellow sweet potatoes. So far as known, these were the first red sweet potatoes that ever appeared on earth. They have since been widely propagated.

In one of the greenhouses of the Brooklyn Botanic Garden there is a specimen of the Cuban thatch palm which for years was considered the only known representative of its kind. Very recently, a few other representatives of this species have been found in Cuba. If these plants were to die, the species would be extinct.

Since life began on the earth, species have been changing. New kinds of living things appear, undergo many changes and perhaps endure for ages. But when all the individuals of a species die, the species disappears forever.

Courtesy of Brooklyn Botanic Garden

This Cuban thatch palm is one of the last plants of its species.

New varieties. Newspaper and magazine articles frequently report the introduction of new varieties of plants or animals. Within recent years, growers have been given the opportunity to claim patents for any distinctive new plant. The first plant to be patented was a new variety of rose. Several hundred plant patents have since been granted. It is thus obvious that we can find plenty of evidence that changes and variations are taking place among our common plants and animals.

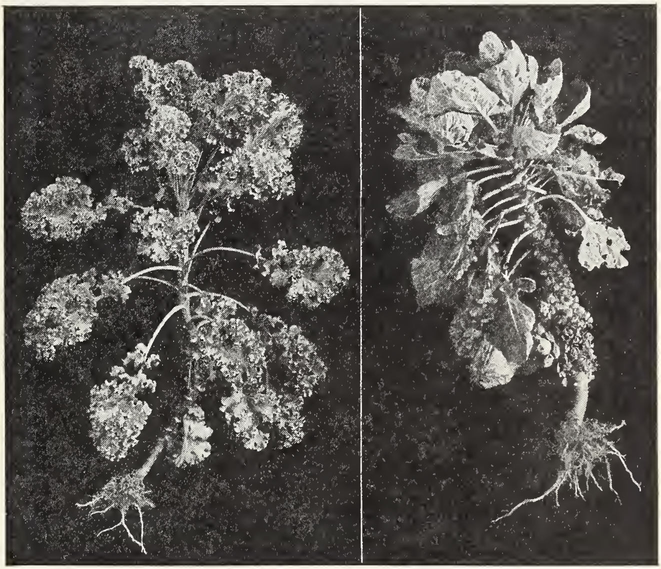
Usually these new forms differ too little from the parent forms to be regarded as new species. New roses may have a slightly different shade of color or odor; some differ in the shape and carriage of their stems and leaves. Furthermore, most of such new types among flowering and fruiting plants cannot reproduce themselves naturally. New varieties of flowers and fruits often do not breed true to seed. The offspring raised from their seeds are not the same as the parent plant. That is why such varieties must

Photo from American Museum of Natural History

These distinctive shapes of white gourds belong to one species. Other gourds of the same species show wide differences in color as well.

be raised by grafting, or by dividing the plant at the roots. Apples and other fruits are generally reproduced by grafting, which does not really produce a distinct new individual. It only subdivides the parent plant by making branches of it grow on stems of a different kind. Thus, all seedless oranges have been reproduced by repeated division of the stems of the original tree discovered in Brazil in the 1870's. Many new varieties do not, therefore, fit our definition of a species, although they do give evidence of a great tendency among living things to change.

However, there are cases of variation in which the differences among the varieties of a domesticated species are every bit as great as the differences which distinguish species. Consider the cabbage and its relatives: cauliflower, broccoli, kohlrabi, Brussels sprouts, and a multitude of dif-



Courtesy of Brooklyn Botanic Garden

Kale and Brussels sprouts are varieties of the cabbage species.

ferent kales. All these are classified as one species, *Brassica oleracea.* The differences between the varieties of the cabbage family are due to the long period of cultivation which this vegetable has enjoyed. The Greeks had several of the main types of cabbage; likewise, the Romans. We do not know when the first wild cabbage type was first raised by man. We do know that the wild type, closely similar to some of the kales, is found growing naturally today along the western coast of Europe, and it is believed to have been the starting point from which, through careful selection, the wide differences in the varieties of this species have been brought about. Since these varieties breed true to seed, unlike those of roses and many other plants, their development represents a process similar to the origin of new species.

New species. A case of great variation among plants occurred only recently. From a wild species, the sword fern, there arose in 1895 a new variety which was called the Boston fern. This fern proved very successful as a house plant and was grown in increasing numbers. Before 1900 several new sorts were developed from variation in the Boston fern. One, the Pierson fern, had leaves that were twice divided, as compared with one division for the Boston fern. Another, Scott's fern, had leaves only about half as long. Since that time florists have found about 240 additional variations, many of which showed differences much wider than those distinguishing species. Forms with leaves three, four, and even five times divided were introduced, some with leaves less than six inches long in contrast to six-foot leaves in the Boston fern.

Such variations are not at all infrequent, both among domesticated and among wild forms. White robins, white sparrows, even white crows, are known; likewise, white trout, white blackberries, and white-blossomed flowers occur among colored sorts. Differences in size, variations in details of shape, and a great variety of new features may appear, as in the Boston fern, without any known cause.

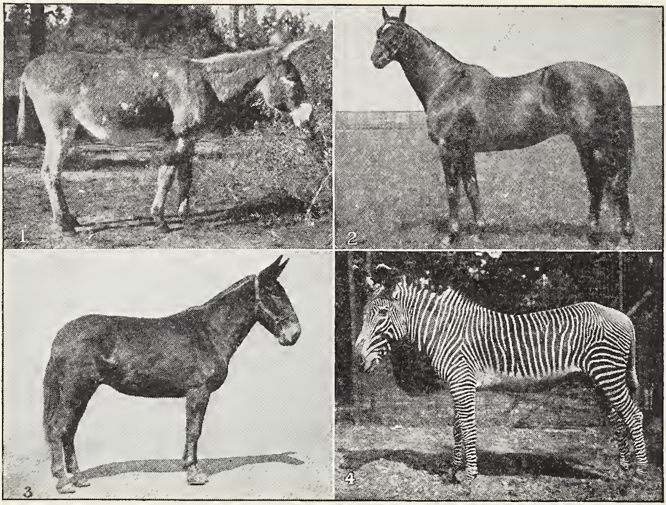
Variations produced by breeding. Practical growers are able to bring about variation of another sort from which new varieties may result. If two distinct varieties,

Courtesy of Brooklyn Botanic Garden

Race crossing in the cabbage species, of kohlrabi (left) and broccoli (right), produced two good-for-nothing grandchildren.

or even two species, are crossed and any offspring is raised and examined, many differences are usually found among the grandchildren. Some of the offspring are intermediate between the original types, and some show various combinations of the ancestral characteristics. Sometimes individuals with entirely new characteristics appear. Some of these may be selected and grown as new varieties.

Men have been changing plants and animals by breeding for about as long as they have been cultivating plants. Some dogs, like the bloodhounds, are bred because of their ability to follow a trail. Others are raised exclusively because of their desirability as pets. Some horses are bred for work, others for speed, still others for ranching, riding, or polo. At first men probably used the method of simple selection almost exclusively, but they must have



Photos from Ewing Galloway, U. S. Dept of Agric., N. Y. Zoological Society

Breeding has produced great diversity in the horse family.

brought about the accidental crossing of different desired varieties even before they realized what was happening.

The result of all the methods of selecting and breeding carried on through thousands of years is the immense diversity of variety which we see among domesticated forms today. They show differences far exceeding those which separate wild species. Many of them breed true to type. They differ chiefly from wild species in the fact that their differences are of the sort that are favorable to man's use, and are usually more or less unfavorable to their existence in the wild. Domesticated fowl, for example, seldom survive on return to the wild. Turkeys, not having been domesticated long, thrive when they escape to their wild kin; and even dogs and house cats are as fierce as wolves and bobcats after a generation in the wild.

Changes in species population. The total number of individuals in any given species, that is, the total population of the species, is subject to change.

We have already referred to the species of Cuban thatch palm whose numbers seem to have been reduced to a few plants. The American buffalo or bison has been reduced from herds of millions of animals to a few thousand individuals preserved in parks. The passenger pigeon, which formerly flew in flocks of millions through the Middle-Western states, is completely extinct now. Fifty species of birds have died out in North America within the past seventy-five years. Some idea of the extent of this extinction may be gained from the following article from *Time*, April 8, 1935, although since it was written a few Carolina parakeets have been reported still at large.

The last survivor of the race of heath hens died in 1932 on Martha's Vineyard (*Time*, April 11, 1932). Cause: overshooting, grass fires. The Eskimo curlew was extinct by 1925. Cause: overshooting during migration. The passenger pigeon disappeared just after the turn of the century. Cause: market hunters killing nesting birds. The petrel and flicker of Guadalupe Island vanished about 1906. Cause: cats, goats. The Carolina and Louisiana parakeets were never seen after 1904. Cause: demand for caged birds. Great auks have been extinct since 1844 (*Time*, November 26). Last week specimens of all these unfortunates were included in an exhibition of extinct birds by Chicago's Field Museum of Natural History, coupled with a warning that, without rigid safeguards, three more North American birds are threatened with imminent annihilation; the trumpeter swan, the whooping crane, the ivory-billed woodpecker.

About 1905, some American chestnut trees in the neighborhood of New York City were found to have a new fungus disease. Within a few years, all the hundreds of thousands of this species in the Eastern states had been almost completely wiped out and there seems no way to

Photo from American Museum of Natural History

The last of the once numerous heath hens died a few years ago on Martha's Vineyard.

save any of the trees remaining in the South. In more recent years the American elm species has been threatened similarly by a newly introduced disease. The white pine, America's most important lumber tree, is fighting another fungus enemy, the blister rust.

The surface of the earth seems to be almost completely utilized by living things. In general, if any species spreads out, one or more species must decline. However, there is an exception to this rule where a particular disease causes

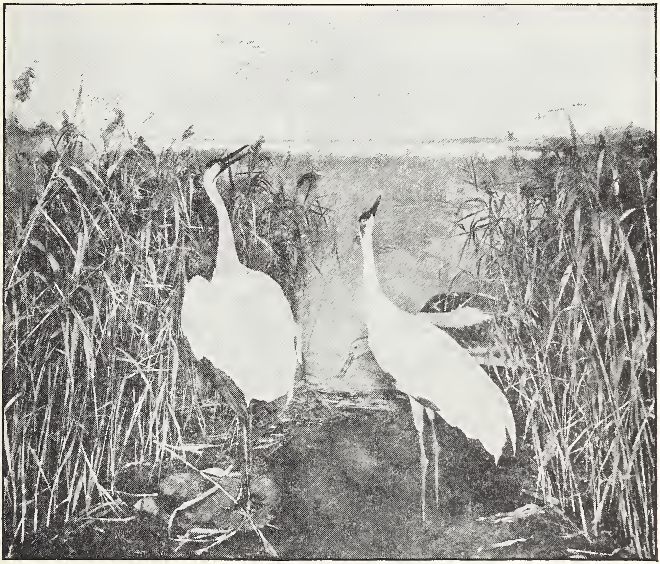
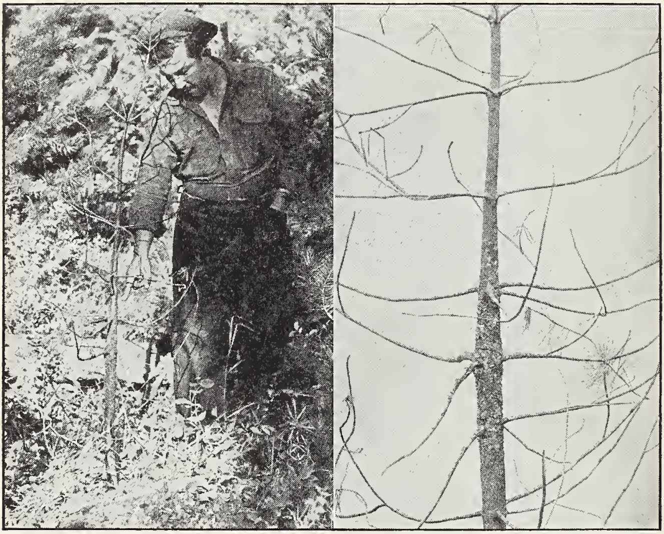


Photo from American Museum of Natural History

The whooping crane is fast disappearing.

death to its host. It is true that at first the white-pine blister-rust fungus increases as the pine trees decrease, because the fungus spreads into wider and wider territory. But if it kills the pine trees rapidly, as the chestnut blight did the chestnut, there are fewer and fewer trees after a while on which the fungus disease can spread. It kills off its own source of food. That is exactly what this chestnut blight has done. With chestnut trees all killed off, the fungus must also disappear.

Relation of human migration to species population. The migrations of men have brought about great changes in the biological relations of different parts of the world. Think of the millions of acres in America which now grow wheat, oats, and rye from Asia, as well as fruits,



Courtesy of the Scientific American

White pine blister rust, a fungus disease, threatens to wipe out the white pine, the most important of American timber trees.

vegetables, and domesticated animals from Europe and Asia. Consider also the changes in man's population over the past three hundred years. For the year 1600 A.D., the total human population of the earth is estimated at just about 400,000,000. Since then it has grown to a total nearly five times greater, or nearly 2,000,000,000.

Together with man's increase, there has gone forward a corresponding increase in the populations of the various species man favors and cultivates, as well as in those species which seem always to accompany man without his permission, such as rats, mice, clothes moths, disease germs, and other undesirable species.

Increases in population seem usually to be related to migrations. The species which seem to have shown the

These undesirable plant immigrants are far too numerous in many parts of the United States: (a) dandelion, (b) plantain, (c) oxeye daisy, (d) Canada thistle, (e) crab grass.

greatest increase in numbers are those which have spread from their original habitats into new ones. This is just as true for many lower animals and for many plants as it is for man. The house sparrow, when brought to America, increased greatly, and largely at the expense of American bird species. Weeds are, almost without exception, species from other continents. In the United States our weeds are chiefly immigrants from Europe, Asia, Africa, and South

America, but America has sent to those continents a series of its native plants which have become as troublesome weeds for them as any in our fields.

Review and Thought Questions

1. Individuals in the same species are much more alike in structure than species in the same genus. Explain.

2. Mammals have seven vertebrae in their necks. The giraffe is a mammal. How many vertebrae does a giraffe have in its neck?

3. Vestigial structures are found in both plants and animals. Name two vestigial structures found in man.

4. The embryo of an advanced species often resembles the adult of a lower species. Why is this a significant statement?

5. What possible explanation is there for the gill slits found in the embryos of some land animals?

6. What explanation do biologists offer for the peculiar plant and animal species of Australia?

7. What evidence do we have that changes are taking place in living things today?

8. How do biologists account for the existence of different varieties of cabbage or of cats?

9. How is the fact that living things vary, or may be made to vary, of use to man?

10. Name one animal that has only recently been domesticated.

11. Name two animals that have become extinct in recent times.

12. Name a plant in the United States that is threatened with extinction.

13. The total human population of the earth has greatly increased during the past 400 years. What plant and animal species has man caused to increase during this time? What plant and animal species has man caused to decrease?

Activities

1. Count the vertebrae in the neck of a skeleton of some mammal.

2. Ask a surgeon why it is sometimes necessary to remove by operation the human appendix, a vestigial structure found in man.

3. Try to locate a pupil in your school who can wiggle his ears.

4. Make a report on the different kinds of horses raised by man.

5. Look up the work of Burbank and other breeders and report upon how they made use of the fact that living things vary.

6. Make a report on the conservation laws of your state that are designed to prevent the extinction of wild animal life.

7. Prepare a picture exhibit of wild plants that are in danger of extinction.

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Unit 4

PROBLEMS OF LIVING THINGS

If we fail to solve the everyday problems of living satisfactorily, we have trouble. If we fail to solve them at all, we die. We need to understand what is happening inside us to live well. While the human body is the most complicated mechanism on earth, our life problems resemble those of all other living things. Even from the simplest plants and animals, we can learn a great deal about ourselves. For this reason it is a good plan to begin, as we do in this unit, by considering the life problems of the simplest living things, proceeding gradually to the study of more and more complex living things.

9. The Simplest Plants

The total amount of plant life on the earth is much greater than the total amount of animal life. Most of this plant life consists of minute organisms which are distributed everywhere over land and sea. In some lakes there are as many as thirty million tiny plants in every quart of water. Although such plants are too small to be seen without a microscope and for this reason most people are not aware that they exist, problems common to all living things are solved by these microscopic bits of life.

Representative Types of Plant Cells

Since many small plants are remarkable for their beauty and coloring, you will find it interesting to collect some of the common kinds and study the activities by which they keep themselves alive.

Spirogyra. This is one genus of the group of simple plants called *algae*. Its common name is *pond scum* or *water silk*. It grows in the form of long threads, each thread consisting of a row of cylinder-shaped cells joined end to end. The filaments have a slippery feeling, due to a layer of gelatinelike material which covers the walls of the cells.

Spirogyra is a widely distributed genus and is present in nearly every still pool or slow brook. The plants have large cells with large internal parts, which may be seen clearly under the microscope. Usually some species of

Spirogyra can be found at any time of the year, floating on pools in warmer weather, under the ice in the same pools in winter, or in springs at any season of the year. Its one disadvantage is that, despite its commonness and its use by thousands of students over many years in laboratories, no one has so far succeeded in cultivating it. Although it grows luxuriantly in the stagnant water of outside pools, it will not grow regularly in culture jars, due to some peculiar need that has so far baffled scientists who study it.

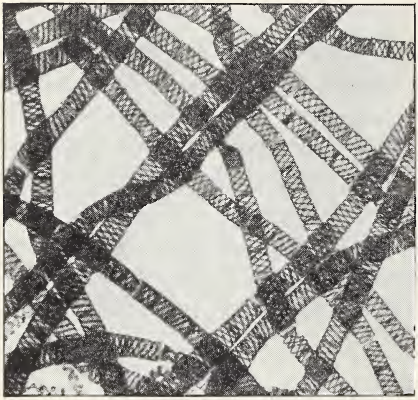


Photo by Hugh Spencer

Spirogyra filaments look like this under the lense of the microscope.

Closterium. This is a good example of the family of green algae known as *desmids.* The cells are large, bright green, and crescent shaped. Unlike Spirogyra, Closterium is a genus that thrives under laboratory conditions and may sometimes be found in the same culture jar several years in succession.

A group of young biology students in Brooklyn once carried on a study to find out whether Closterium could be collected at all times of the year. Once a week some mud was collected from the bottom of an artificial pond at the Brooklyn Botanic Garden and examined under the microscope for these sickle-shaped cells. The collections were continued during the winter, even when the

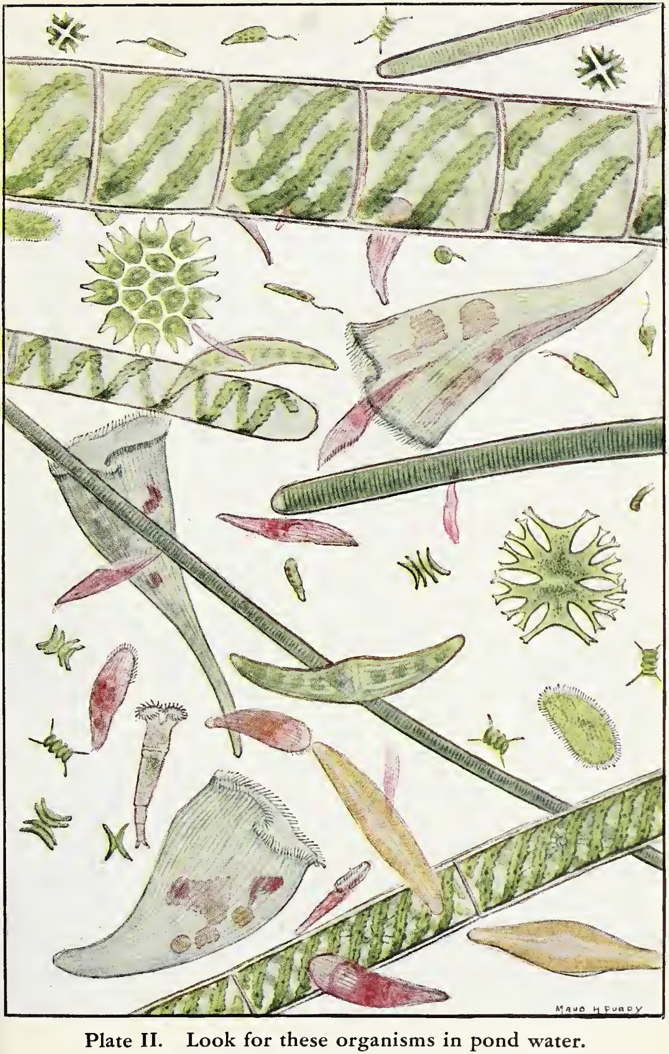


Plate II. Look for these organisms in pond water.

MICROSCOPIC LIFE IN FRESH WATER

Among fresh-water organisms, the chief color is the green of the plants as seen in the single cells and in the filaments of various algae. These are often characterized by beautiful shapes and designs. A few fresh-water Protozoa show considerable color. Starting at the top, left, and noting each form only once, the organisms represented are as follows:

Pediastrum tetras, a four-celled, colonial alga; Euglena viridis, a green flagellate, with a reddish eyespot; Scenedesmus, another four-celled colonial alga; Oscillatoria, a filamentous, blue-green alga, which waves back and forth through the water; Spirogyra, a broad, short-celled species; Paramecium Bursaria, the paramecium which is green because of the algae living symbiotically inside of it; another specimen is shown more plainly lower down at the right; Pediastrum duplex, a sixteen-celled platelike species; Blepharisma, the reddish, ciliate protozoan, of which a dozen specimens are shown; Closterium, the crescent Desmid; Stentor, the trumpet-shaped, bluish green protozoon, making a meal of Blepharisma; Oscillatoria, two more filaments; Spirogyra, a species with only one plastid in each cell; the star-shaped Desmid, Micrasterias (middle, right); a rotifer, a multicellular animal which is smaller than many single protozoan cells: this is the only colorless organism on the plate, near lowest Stentor; Diatoms, two boat-shaped cells, with a golden-brown pigment; Spirogyra, a third species; near rotifer, a two- and a four-celled colony of a second species of Scenedesmus.

ice had to be broken to get at the mud underneath. Not once was Closterium absent from the collections. Other

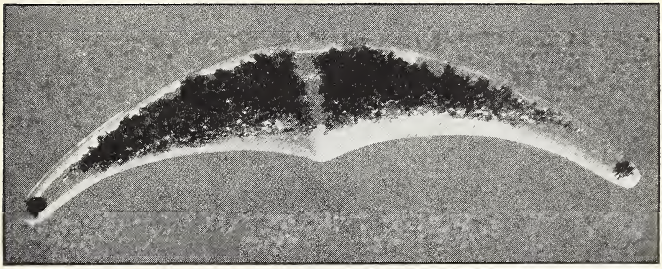
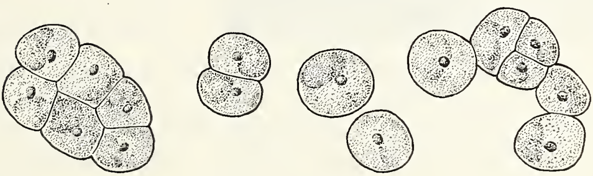


Photo from American Museum of Natural History

Closterium, a single-celled alga, is common and easy to grow. The dark spots at the end are small vacuoles with tiny jiggling granules.

desmids, as well as various other algae, were also found. Some of the desmids were most beautifully shaped and designed.

Protococcus. The green covering that is often found on the shaded sides of trees, old buildings, rocks, and fences usually consists of masses of Protococcus. Unlike



The common bark alga, Protococcus, is single-celled, but is often found in groups of indefinite numbers of cells. It grows on the damp side of tree trunks, and, as this is usually the north side, it may serve as direction finder.

most algae, this genus lives very well out of water, but it requires damp places for its growth and is greenest just after a rain. When not crowded by its neighbors, a

Protococcus cell is spherical and contains a nucleus and a single irregular chlorophyll body, or *chloroplast*. As cell division adds cells, small, platelike colonies are formed, the adjacent sides of the daughter cells remaining in close contact.

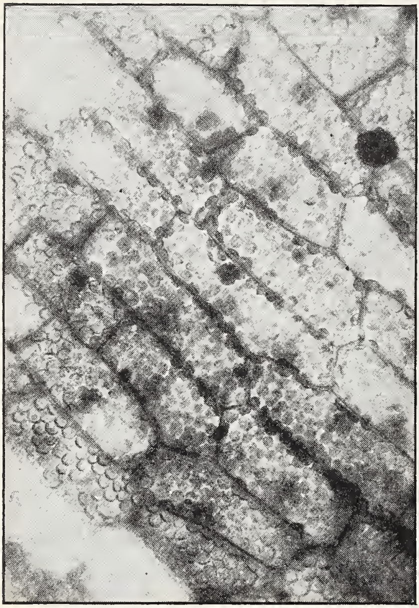


Photo by Hugh Spencer

In this portion of an Elodea leaf you see chloroplasts, cell walls, and nuclei. Since all parts of the protoplasm contain proteins, this picture is evidence that proteins were produced in the growth of the leaf. Note the larger round spot outside the cells. You can see this much more clearly in an actual specimen.

Elodea. Although Elodea, the common aquarium plant, is not really a simple plant, certain characteristics make it very suitable for study. The margin of an Elodea leaf is only one cell in thickness, whereas most of the rest of the leaf is but two cells in thickness. Under the microscope the cells are roughly rectangular and their contents may be seen very clearly. Elodea grows in sluggish streams and ponds throughout the continent of North America, except in the extreme North. In winter it is obtainable from any dealer in aquarium supplies, and it grows well in the laboratory.

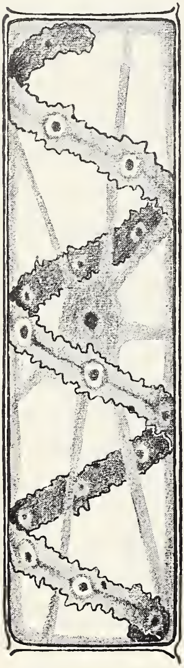
Euglena. This organism is found almost everywhere in pools, lakes, and small puddles of water, sometimes so abundantly that the whole surface "blooms." Euglena is an organism about which there is a difference of opinion. Zoologists often regard it as belonging to the phyla of one-celled animals called *protozoa,* while botanists place it among the algae. In its free-swimming form, it moves about by means of its long, whiplike flagellum. Because it has no cellulose wall in this stage, it may bend and twist about in all directions. At other times, it may settle on the sides of the jar, lose its flagellum, and develop a cellulose wall.

Activities of Simple Plants

It is possible to find out a great deal about how animals solve their problems by watching their activities, but watching the activities of plants in the same way is not very exciting. Most plants are either motionless or move so slowly that it is unprofitable merely to sit and watch them in the hope that they may do something interesting. In order to find out what plants do, it is necessary to apply the scientific method in carefully planned experiments. Suppose we start with specimens of the simple plants discussed in the foregoing pages.

Photosynthesis. The production of starch by green cells exposed to the light is called *photosynthesis.* The presence of starch can be detected by the use of iodine, since iodine turns starch blue. The amount of light that reaches our specimens can easily be controlled, and it is easy to plan experiments that show the relation of light to starch formation.

Starting with Spirogyra, Closterium, or Elodea, divide some material into two cultures and place one in the dark for an hour or more. Place the other in bright light for the same length of time. Then mount a sample of each on a slide and observe it under a microscope. Next, place a drop of diluted iodine on each specimen and examine them again.



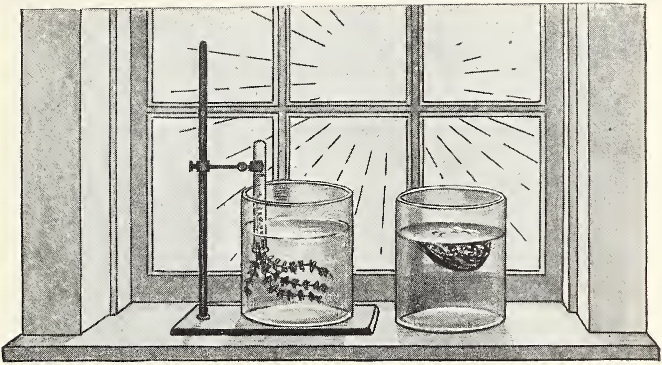
This Spirogyra cell has a single, coiled chloroplast.

In the specimen which was kept in the light, if you have used Spirogyra or Closterium, you will see dark, blue spots scattered along the chloroplasts. If Elodea has been used, the cells will appear rather solid blue. The specimens kept in the dark will be stained brownish or yellowish from the iodine, but not blue.

Oxygen as a waste product of photosynthesis. Starch is not the only product formed when photosynthesis takes place, as you may discover by another experiment.

Using Spirogyra, divide the material into two portions and place each portion in a jar of water. Set one jar in a dark place and the other jar in a light place for several hours. In the jar standing in the light, the mass of Spirogyra filaments will be found floating at the top of the culture, while the Spirogyra that was kept in the dark will be found at the bottom. The lighted mass floats because numerous bubbles of gas caught in the tangled threads buoy it up. If these gas bubbles are collected in a test tube, and a glowing splinter is thrust into the tube, the splinter will burn brightly, showing the gas to be oxygen.

If cut stems of Elodea or some other aquarium plant are placed in a jar of water and exposed to bright sunlight, bubbles of oxygen can be seen coming from the cut stems in regular streams. Place your hand so as to shade the



The oxygen being given off by Elodea and by Spirogyra is a sign of photosynthesis. In Elodea, the oxygen given off by the leaves passes into air channels to the stem and is collected under water in the test tube. It ceases to collect when the plant is shaded.

plants, and the bubbles stop almost instantly, only to start anew when the plants are again exposed to the sun.

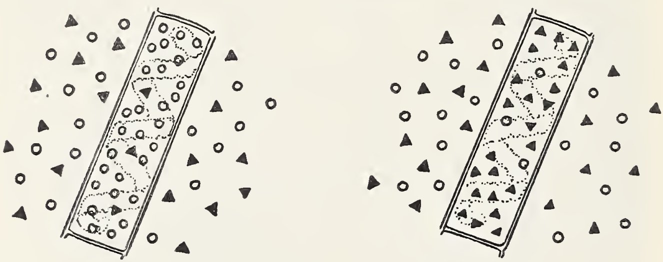
Digestion of starch in plant cells. When plant cells make starch in the daytime, they are storing up food.

If you try to mix some starch with water, you will find that starch is insoluble. In order to use the starch that they make, plant cells must digest it. The digestion of starch consists in changing it to sugar, which is soluble.

After the experiment in which you find evidence that green plants produce starch in the light, put some of the lighted material in a dark place for several hours and test it again. If iodine causes no blue reaction, you may safely conclude that the starch has been digested.

Respiration. After starch has been changed to sugar by digestion, the next process that takes place in plant cells is respiration.

In respiration the sugar is combined with oxygen, and carbon dioxide is given off. In the daytime, simple plants



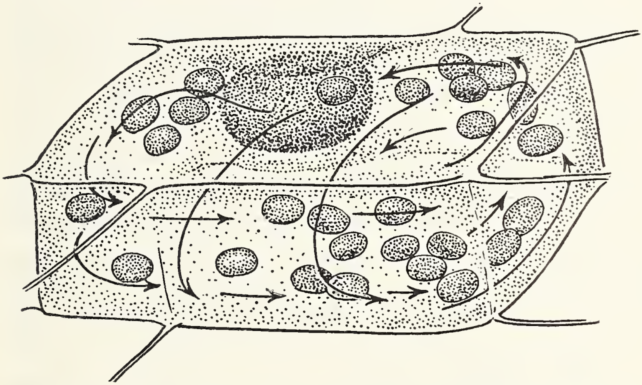
○ = *Oxygen molecules*
▲ = *Carbon dioxide molecules*

Photosynthesis and respiration in a Spirogyra cell are carried on by osmosis through the plasma membrane. Which cell was in the light and which in the dark?

have plenty of oxygen within their cells for respiration, because oxygen is constantly being produced as a result of photosynthesis. At night, or in the dark, plants must take in oxygen from the surroundings. As a result of respiration, carbon dioxide is given off.

Because carbon dioxide dissolves in water quite readily, we never find bubbles of carbon dioxide tangled among the threads of Spirogyra or coming from the cut stems of Elodea. Since carbon dioxide turns lime water milky, we can easily detect its presence by shaking up a little clear lime water with the water in which plants have been kept in the dark. If the mixture turns milky, we can be sure that respiration has taken place and that carbon dioxide is present.

Motion in plant protoplasm. Remove a young Elodea leaf from a plant which has been kept in a good light. Place it in a drop of water on a slide and focus the microscope on some of the larger cells of the upper surface.



This diagram of a single Elodea cell shows the course taken by the streaming motion of the chloroplasts. Do the chloroplasts swim or are they carried?

Look for the small, rounded chlorophyll bodies within the cells. Motion within the cell is immediately apparent.

Normally you will find that the green plastids are traveling rather rapidly around the cell walls. At first, it may seem that they are moving along by their own action, but a longer observation will show that they are being carried in streams of cytoplasm. The movement might be described as a sort of cell circulation, but it is better to reserve this word for its more appropriate use with higher animals and to call this protoplasmic motion *streaming*, or *cyclosis*, which means "circling." There is without doubt a current in the cytoplasm of each cell. Sometimes the motion stops, and the chlorophyll bodies remain motionless; then it starts again.

While Elodea cells are especially favorable for the observation of cyclosis, this movement can be seen in many other kinds of plant cells. In Spirogyra and Closterium, by careful focusing of the microscope, a thin current of cytoplasm granules may be seen while the chloroplasts remain stationary. Extensive studies of a wide variety of living plant cells have led to the conclusion that cyclosis is characteristic of all plant cells.

A number of other types of motion may be observed in plant protoplasm. You may recall that in mitosis the various parts of the nucleus, particularly the chromosomes, did a great deal of moving about. Also sometimes whole cells and groups of cells of lower plants may move. *Diatoms* are a kind of single-celled algae which glide through the water like little boats. Closterium is known at times to change its position, bending upward or gliding along a surface. Whole filaments of the blue-green alga, *Oscillatoria,* maintain an incessant waving motion, back and forth through the water. In Euglena we have a definite organ of motion, the *flagellum*, which pushes the cell along rapidly. Furthermore, these and other similar green cells may bend and twist with a freedom of motion which is more animal-like than plantlike. Take from an aquarium water that has become green in color, and you will find many microscopic plants which show movement.

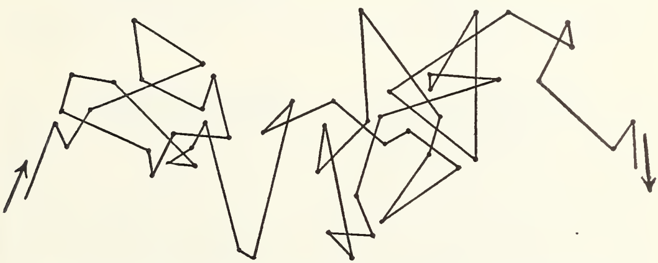
Although movement is characteristic of many one-celled plants, not very much is known about the methods whereby some of these movements are produced. In general these movements serve to place the plants in a better position to carry on photosynthesis.

Physical Processes in Plant Cells

Plant cells are surrounded by a continuous wall or *membrane* of cellulose. Inside this *cellulose wall* there is another membrane, the outer surface of the cytoplasm, called the *plasma membrane*. All materials that enter or leave the cell must pass through these two membranes. None of our experiments so far have given us any information about how materials get into and out of plant cells.

In order to understand how this exchange of materials occurs, it is necessary to consider a few common physical processes that take place throughout all nature. All matter, living and nonliving, is subject to the same general laws regarding these common processes.

The motion of molecules. All matter is in motion. Every substance consists of molecules of some kind, and these are in constant motion among themselves. The



The Brownian motion of a single particle of carmine shows how it is knocked about by the constant motion of the invisible water molecules in a drop of water. In plant cells small granules are similarly in constant motion.

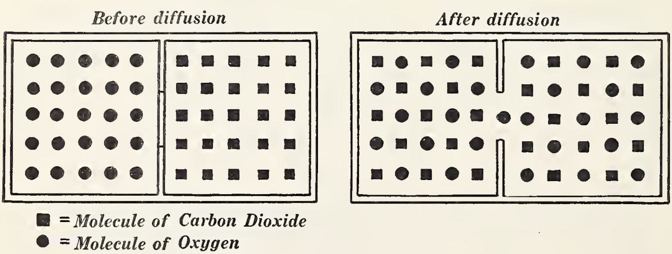
motion is one of vibration. It is greatest in gases, less active in liquids, and still less in solids.

Evidence of this can easily be discovered through an experiment with what is known as *Brownian motion*: If carmine or some other finely powdered material is placed in water and examined under a microscope, the particles may be seen jiggling back and forth. The carmine particles cannot move of themselves, but are small enough so that they are knocked about by the molecular motion of the invisible water molecules.

Diffusion. *Diffusion* is the process by which two or more substances tend to mix together as a result of the motion of their molecules. Two or three simple experiments will serve to demonstrate diffusion.

If a container of some strong-smelling substance such as camphor, ammonia, or a perfume is opened in a closed room in which there are no drafts, the odor will soon be noticed in all parts of the room. What happens is that the molecules of the substance have spread among the molecules of air and some of them have come into contact with the sense organs of the nose.

In diffusion, the molecules spread in among each other until there is an even distribution in the space available.

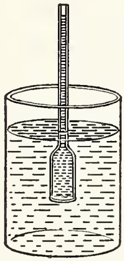


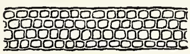
This diagram shows how two gases mix by means of diffusion.

Thus, if two adjoining chambers of equal size containing carbon dioxide and oxygen are connected by an opening, one half of the oxygen molecules will move into the carbon chamber and one half of the carbon dioxide molecules will move into the chamber which originally contained pure oxygen.

Liquids do not diffuse as rapidly as gases, because their molecules do not move as fast or as far, but they do diffuse. Two liquids brought into contact will often diffuse together until there is a complete mixture of both. Some liquids, such as oil and water, which cannot be mixed together, also cannot diffuse together.

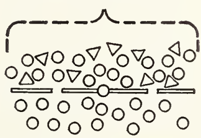
Solids, also, may be able to diffuse. For example, when a solid dissolves in a liquid, it becomes diffused in the





Dry wood

Wood in contact with damp surface



Here are two demonstrations of diffusion through membranes. Water molecules push among the cellulose molecules of the wood cells and cause the wet surface to expand. A glass cylinder with a parchment membrane over one end placed in a mixed solution may admit some substances and exclude others.

liquid. Put a crystal of copper sulphate at the bottom of a glass of water. As it dissolves, it forms a blue solution which gradually diffuses upward to color all the water in the glass. Try adding, in the same glass, a crystal of common salt, a lump of sugar, and many other substances. The added materials may dissolve and diffuse and form a solution containing many different substances. If any two of the diffusing substances tend to react chemically with each other, however, the process of diffusion leads to a process of chemical change. In cells this is happening all the time.

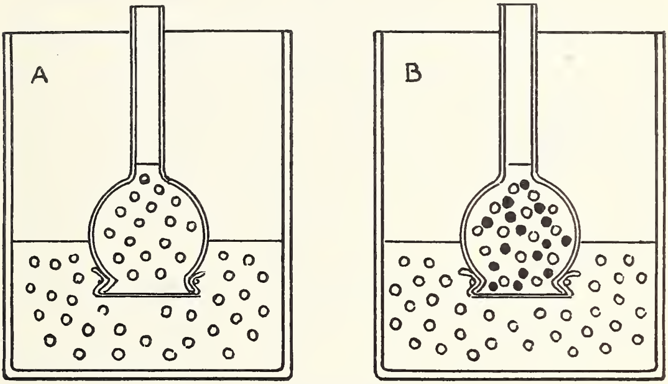
A liquid sometimes diffuses into a solid without causing the latter to dissolve. For example, if a piece of dry wood is placed in water, a good deal of water will pass into the substance of the wood by diffusion. If measured after it has soaked thoroughly, the piece of wood will be found to have become longer and heavier. Some of the water will have gone into the cavities of the wood cells, but much of it will have penetrated into the actual substance of the cell walls. As the water molecules spread in among the cellulose molecules of the walls, the latter are forced further apart, and the wood swells.

Some membranes will allow one kind of liquid to penetrate but not another. Thus, rubber does not allow water to diffuse into it but does allow gasoline to enter. Such a membrane is called a *selective membrane*.

Osmosis. Let us see how the presence of a membrane affects the process of diffusion, first in a nonliving situation, then in a plant cell.

Fill a thistle tube with sugar solution and tie an ordinary sausage skin over the funnel end. Invert the tube in a glass of water, being careful to mark the level of the sugar solution in the tube. Observe that, after thirty minutes or more, the level of the liquid in the tube rises noticeably higher.

The process is this: The water in the glass diffuses into the substance of the sausage-skin membrane, and is then in contact with the sugar solution. The water molecules then tend to diffuse among the molecules in the tube. At the same time, but at a slower rate, sugar molecules penetrate the membrane and then diffuse out into the water. The sugar and water molecules continue to mix until

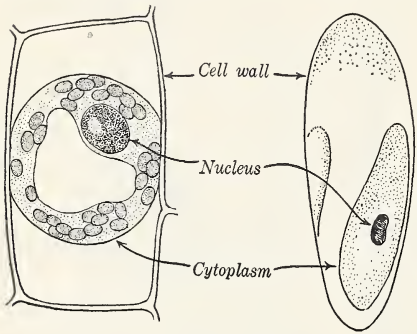


In these two thistle tubes with sausage skin membranes over the funnel ends, water molecules are represented by o, sugar molecules by •. What will happen in each tube and why?

there is an even distribution on both sides of the membrane. The explanation for the rise of the liquid lies in the fact that more water goes inwardly than sugar goes outwardly. This process is called *osmosis.* The two substances are going through the same membrane in opposite directions at the same time, but one goes through in greater quantity. This produces what is called *osmotic pressure.*

The conditions necessary for osmosis require two liquids separated by a suitable membrane. How does a simple plant, such as Spirogyra, provide these conditions? What constitutes the osmotic membrane? What are the liquids?

A few simple experiments will help to answer these questions. Mount a few filaments of Spirogyra, or leaves of Elodea, on four slides and to each add a different liquid: (1) distilled water, (2) 3 to 5 per cent salt solution, (3) water solution of eosin, (4) water with a trace of iodine. Each of the four slides now presents differences from the normal condition of the plant cells in ordinary pond water.



The pictures show the appearance of an Elodea cell and a one-celled animal, respectively, after immersion in 4% salt solution. The process is called *plasmolysis*. Can you explain what happened to bring about this result?

Slide 1. Not much change will occur, but the filaments are likely to become slightly larger because the distilled water, having nothing dissolved in it, will exert more osmotic pressure than ordinary pond water.

Slide 2. The cellulose walls will remain about the same, but the cytoplasm will contract away from the walls into a rounded mass. The cell sap from within exerts osmotic pressure outwardly. We call this condition *plasmolysis*. If continued too long, the cell will not live, but if returned to fresh water quickly enough, it will resume its normal appearance.

Slide 3. The cellulose wall will become pink, but the cell sap within the cytoplasm will remain uncolored. In other words, by diffusion, the eosin can penetrate the cellulose but not the plasma membrane.

Slide 4. As the iodine, which is poisonous to protoplasm, will penetrate both cellulose wall and protoplasm, turning the latter brownish, the cell will be destroyed.

From such experiments as these and many others, the conclusion has been reached that in a plant cell the osmotic membrane is the outer surface of the cytoplasm, the plasma membrane. The plasma membrane is able to exert some control over the interchange of material with environment outside. It can restrict the outgo of substances which are important to the cell, and it can prevent the entrance of other substances although it cannot keep out a violent poison like iodine.

Review and Thought Questions

1. What simple plant has not been successfully cultivated in the laboratory?
2. Name an organism that has both plant and animal characteristics.
3. What compound is usually identified by the use of iodine?
4. What important gas is released during photosynthesis?
5. Contrast photosynthesis and respiration.
6. Is movement characteristic of plant or animal protoplasm? Explain.
7. Molecules are the smallest possible particles of any compound. Are water molecules more active in gas, in liquid or in a solid state?
8. Some substances diffiuse through plant and animal membranes and other substances do not. Explain the significance of this statement.
9. Under what circumstances does osmotic pressure occur?
10. Why do dried prunes swell when soaked in water?
11. Why do cucumbers and some other vegetables shrink when placed in salt water?

Activities

1. Collect different kinds of water plants from nearby ponds or pools. Bring them to the laboratory with some of the pond water and place them in battery jars or aquaria for study.

2. Scrape some mud from the bottom of a pond or pool. Place it in water near a sunny window and examine it from time to time to see what organisms develop.

3. Try to identify some of the kinds of algae growing in your cultures by referring to some reference book.

4. Using glassware of different sorts and green clay, paper, or cloth, construct a model of a Spirogyra cell.

5. Repeat the experiment in which it was observed that oxygen was given off by Spirogyra in the presence of light, but place the Spirogyra in distilled water which has had no opportunity to absorb carbon dioxide. Use Spirogyra in aquarium water as a control.

6. Repeat the foregoing activity with the same control, this time passing carbon dioxide into the distilled water from a generator.

7. Mix one drop of India ink with 15 cc. of distilled water. Put a drop of the mixture on a microscope slide, cover with a cover glass, and observe under high power.

8. Cut two short pieces of rubber tubing. Place one in water and the other in gasoline over night. Explain what happens.

9. Secure an egg without a shell or carefully remove the entire shell from a fresh egg. Place the egg in distilled water for several hours and observe.

10. Pour chloroform into a bottle to a depth of about one inch. On top of this carefully pour about one inch of water. Now add the same amount of ether. Observe from time to time without disturbing the bottle.

11. Place Spirogyra in varying concentrations of sugar solution. Observe the plasmolysis of the cells.

10. The Simplest Animals

In general, the problems of animals are similar to those of plants. In order to remain alive, both plants and animals must obtain certain materials from their surroundings and carry on various physical and chemical processes within their bodies. They must also get rid of the waste products that form within their bodies.

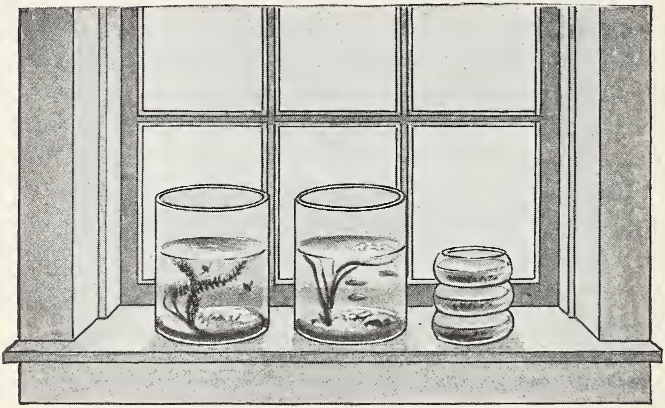
Green plants are unique, however, in being able to absorb energy from the sun and to use it to carry on photosynthesis. Since animals are unable to absorb energy from the sun, they must find ways of getting their food from plants.

If we are to obtain a clear understanding of how animals solve their problems, it will be a good plan to observe some of the simplest animals. The simplest animals are the *protozoa* (singular, *protozoon*), which are composed of only one cell.

Miniature Zoological Gardens

Animals having a single cell can be observed much more easily than animals of many cells. They are so small that we can look through them with a microscope and see what is inside their cells. They are just as interesting to watch as the big animals of the zoo, and most of them are far more active. Protozoa are almost no trouble to care for and require little space. Furthermore, a quart of water from a stagnant pool may contain as many different animal species as a whole zoo, and there are likely to be a thousand times as many individuals. Let us prepare a few miniature zoological gardens so that we will have plenty of specimens for study.

Preparing mixed cultures of protozoa. Set up a number of glass jars, five to ten or more. Use ordinary glass



Miniature zoological collections can be set up in battery jars and finger bowls. The finger bowls nest together. What would you have to do to keep the battery-jar cultures for a length of time?

battery jars, eight to nine inches high, and some shallow, open finger bowls. In each, place a small quantity of material collected from a pond or lake, such as (1) dead leaves; (2) mud from the bottom; (3) stems and leaves of water plants. Do not use much material—just enough to cover the bottoms of the vessels.

Add water to fill each vessel about half full. It is desirable to avoid city water supplies that may have been treated with chlorine. Spring water or water from a pond or brook is good. Later, as the water evaporates from the cultures, it may be replaced with distilled water.

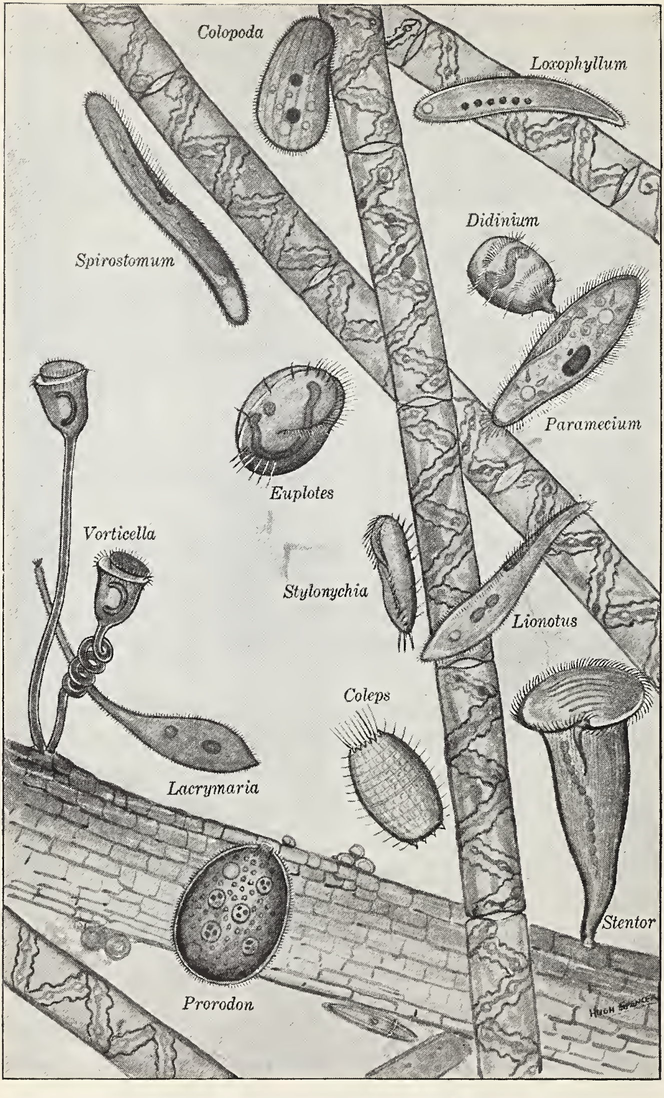
Set up two or three jars of each collection and then place each kind of material under different conditions. Some jars may be given the brightest light in front of a window, and others placed on a dark shelf. Some may be covered with glass plates, but most of them should be left open for best growth.

In some or all such cultures which are left undisturbed for a week or so, a large number of different types of microscopic animals will be found. From these original mixed cultures, special types may be selected for further culture and study. The general method of preparing such cultures is as follows.

Pure-culture methods for protozoa. The paramecium is one of the easiest protozoa to find and one of the easiest to grow in the laboratory. You are likely to find it in most of your mixed-culture jars. Its special culture is simple, and the same method, with slight variations, may be used for a number of other one-celled animals.

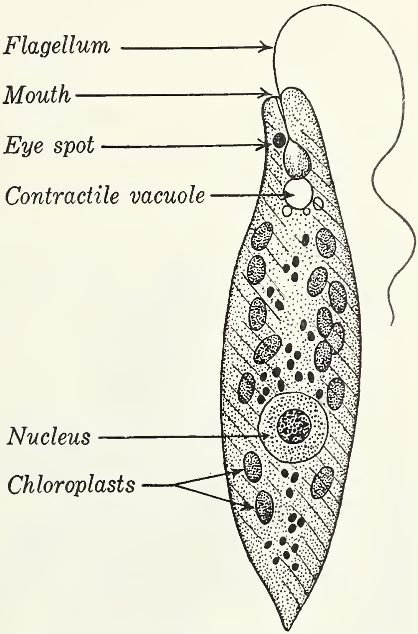
Into an eight-inch battery jar pour about six inches of distilled water. Rain water or spring water will do. Add forty grains of boiled wheat and let stand. In about a week the surface will be found to be covered with a scum which consists almost entirely of bacteria. How did these get in, and why have they developed so abundantly?

A few days after the scum forms, introduce a few paramecia into the culture, either from a purchased culture or by selection from one of the mixed cultures. It is better to start with large-sized specimens. There are eight or ten common wild species of paramecia which vary considerably in size and availability for class study. A good-sized specimen will measure as much as half a millimeter in length. In this size it is possible without



The fourteen different protozoa shown here all have hairlike cilia to drive them through the water.

magnification to see individual paramecia as tiny whitish specks. A culture should produce an abundance of paramecia within a week after inoculation, and it should remain good for a few weeks more. After three weeks, the number of paramecia will gradually grow less. Other kinds of protozoa will increase in number, and finally paramecia will almost disappear. For best results, new cultures of paramecia should be started every few weeks.

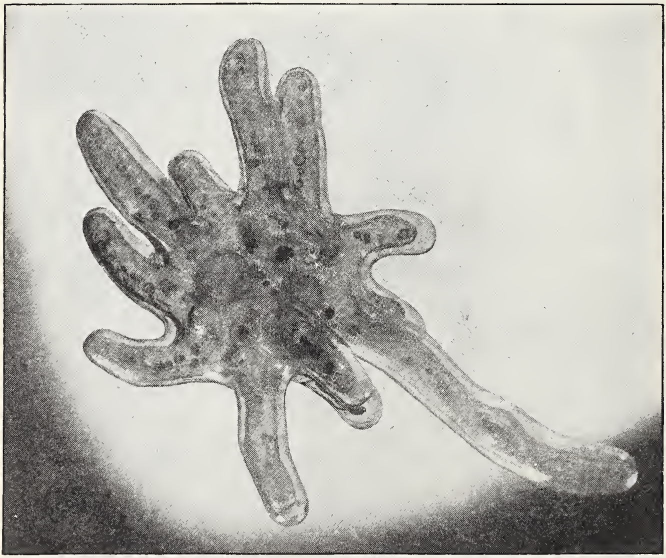


The structure of Euglena is simple. The small dark granules are a sort of starch, and there may be several contractile vacuoles opening into the reservoir into which the mouth leads.

The cultivation of some kinds of protozoa requires modifications of the method used for paramecia. The plantlike Euglena (see diagram at right) grows best if rice is used instead of wheat, and the cultures must be kept in the light so that photosynthesis can take place. Amebas require very careful attention, constant watchfulness, and special methods. It is usually more satisfactory to use purchased ameba cultures than to try to grow them. The ameba not only does not like all kinds of foods, but cannot live unless it gets things which are appropriate. Even with appropriate foods available, it often does not thrive or even continue to live, because of various other unsatisfactory conditions.

Two Famous Animals

Fame is seldom secured by simply carrying on one's daily life in a normal and ordinary manner. But in this way two species of protozoa, the ameba and the para-

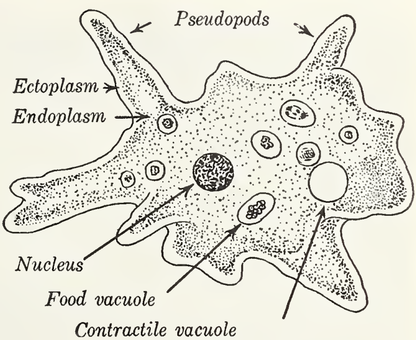


Courtesy, Bausch and Lomb Optical Company

Ameba, the simplest animal, is greatly magnified in this picture.

mecium, have become very well known indeed. Almost everybody who has studied biology has had occasion to become acquainted with them. They are so widely known and studied, not because they have done anything especially noteworthy, but because they represent certain features of animal cells that are typical. The ameba is a type of animal cell that is about as simple as could be imagined. The paramecium, on the other hand, is an example of an animal cell of great complexity. Both of these organisms will repay our careful study.

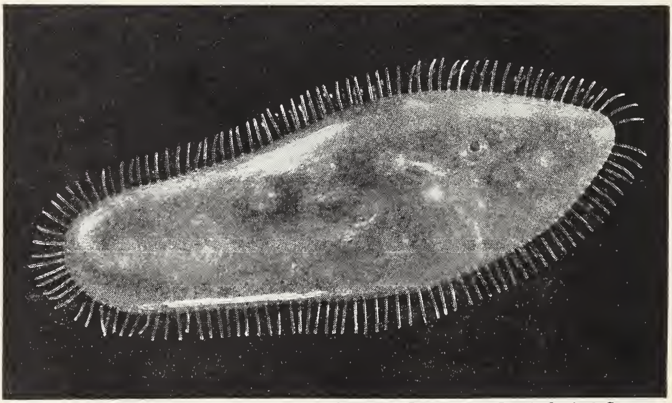
Let us observe them under both the high and the low power of a compound microscope and get acquainted with them ourselves. With the ameba this will not present any difficulties, as it is a slow-moving animal and we can follow it across the slide with ease. A paramecium, however, usually seems to be in a hurry and travels across the slide so rapidly that it is difficult to get a good look at it. A piece of lens paper placed between the slide and the cover slip will remedy that by trapping the paramecium among the fibers.



This diagram shows the structure of an ameba. Find each of these labeled structures in the preceding illustration.

The structure of an ameba. An ameba has no definite or fixed shape. Sometimes it contracts into a rounded drop; sometimes it elongates. Sometimes it is smooth, without projections, but usually it shows a number of fingerlike projections, the *pseudopodia.*

Sometimes ameba cells are large enough to be seen without magnification, appearing as tiny whitish specks. Under a microscope, an ameba appears to be an irregular drop of liquid, clear around the margin but densely granular through most of its mass. The outer clear margin is called *ectoplasm.* The inner granular part is the *endoplasm.* Together these constitute the *cytoplasm.* There is also a rounded nucleus, usually about in the center, which seems to have a finer granular structure than the endoplasm. Within the endoplasm will be seen an indefinite number of *food vacuoles,* clear spots containing bits of food, such as the one-celled plants called *diatoms.* At intervals another kind of vacuole will appear and disappear, the *contractile vacuole.* The granules in the endoplasm are variable in size, some large and somewhat crystalline in appearance, many much smaller and less distinct.



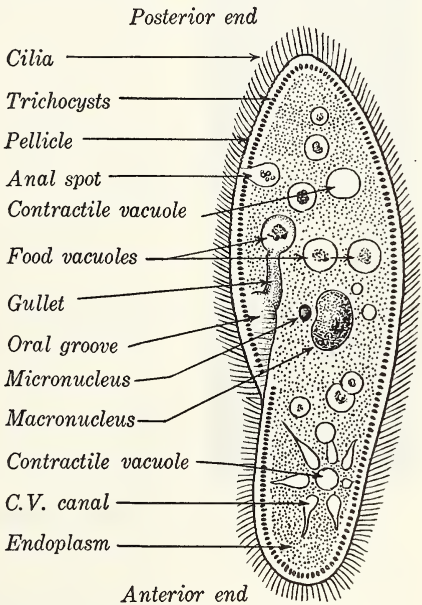
Courtesy, Bausch and Lomb Optical Company

The Paramecium, here greatly magnified, is one of the commonest and best known of the protozoa.

The structure of a paramecium. A paramecium shows a higher degree of complexity in its structure than the ameba. To begin with, we find a definite shape, slender and streamlined, appropriate for its rapid motion. The shape has been compared to the outline of a slipper, with the rounded heel at the front.

The shape is changeable to a limited extent. If an animal gets caught in a tight place, it can bend double to turn around, or squeeze through an opening much narrower than its normal dimensions. On a microscope slide, the weight of the cover glass usually flattens the paramecium cell so that it spreads out much wider than it naturally is.

The surface layer of the paramecium is differentiated into a number of parts, or little organs. The outer part of the ectoplasm is hardened into a stiffened layer, the *pellicle*. From this there project in regular arrangement hundreds of hairlike *cilia* (singular, *cilium*). The beating of the cilia serves to drive the animal through the water. Near the forward end, one side of the animal is depressed in a shallow *oral groove,* which leads backward, and dips down near the middle into a funnel-shaped *gullet.* The



How many of the structures of the paramecium labeled here can you find in the preceding illustration?

outer opening of this gullet is called the mouth. Under the pellicle there is a layer of little sacs, called *trichocysts.* Each one of these consists of a bag containing a coiled hair which can be discharged in defense.

Photo from American Museum of Natural History

This simple radiolarian is a shell-forming protozoa.

Within the cell, the endoplasm is finely granular. There are usually a number of food vacuoles, and generally two contractile vacuoles, one near each end. Research workers have reported two kinds of fibers in the endoplasm. One kind is believed to act as nerves do in a multicellular animal. The other kind act as muscles.

The paramecium is further complicated by having two nuclei instead of one as in ameba. One of these is much larger than the other and is believed to be concerned with the ordinary processes of the cell. The small nucleus is the chromatin nucleus which is active in cell division and reproduction.

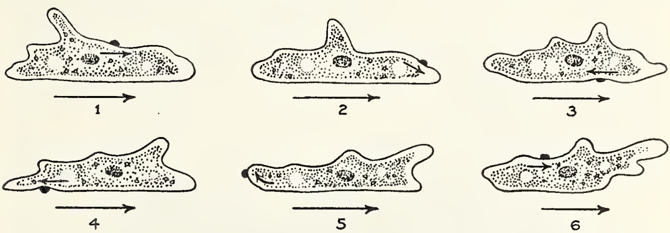
Other types of protozoan cells. Euglena is an organism possessing contractile vacuoles, a surface pellicle, and a whiplike flagellum, all of which are animal-like features. But Euglena also has chlorophyll bodies scattered through its cytoplasm and at times a wall of cellulose, both of which are plantlike features.

Some other kinds of protozoa form shells of different kinds. Some form a shell of a horny substance called chitin, the same substance of which fingernails are made. Others make lime shells. Others form shells of silica. Many common kinds form a shell by collecting and cementing together numerous minute grains of sand.

Shell-forming protozoa live in such abundance in parts of the oceans that the discarded shells form layers of ooze on the bottom many feet in thickness. Some kinds of rock consist largely of protozoan ooze hardened into layers of stone. The shells of some protozoa are beautiful in shape, sometimes very complex, not unlike miniature mollusk shells.

The Activities of Protozoa

Motion and locomotion in amebas. Think of an ameba as a tiny drop of a thick liquid, within which streaming currents of cytoplasm may start out in any

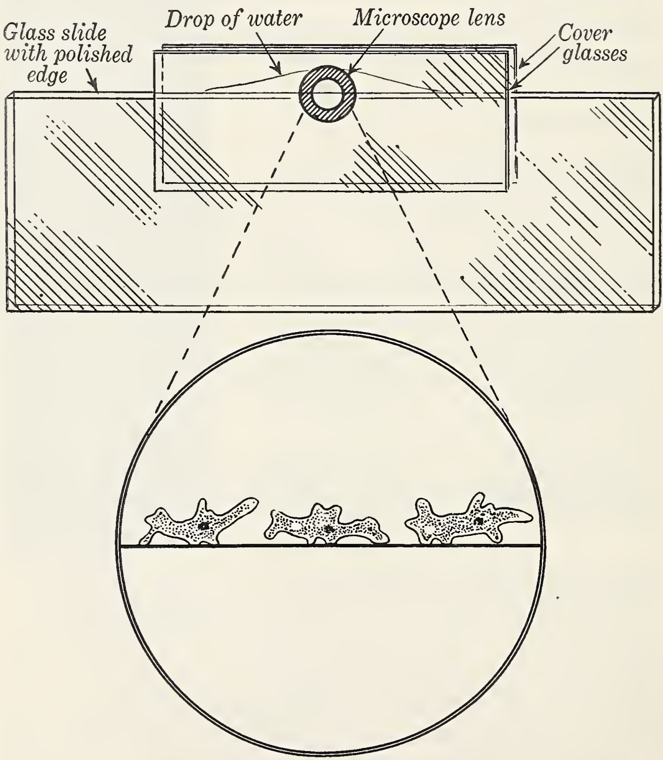


After Newman

Note the changes in the position of the particle of lampblack, showing that ameba moves with a sort of rolling motion.

direction. As a stream flows outward, it pushes out in the form of a pseudopodium. When the streaming of cytoplasm continues long in one direction, the whole mass of the ameba moves along, and what started as a slender projection widens out as the entire drop flows into it. The direction of such streaming may be reversed at any time. The ameba is seen to reach some obstruction with a projected pseudopodium and stop; then the current which was going into the pseudopodium starts back into the main part of the cell.

The streaming may take place in several directions at once. Numerous pseudopodia may often be seen, project-



With a slide prepared as shown in the upper part of this drawing and with the microscope horizontal, it can be observed that ameba often "walks" on the ends of pseudopodia.

ing in all directions, upward and downward, as well as along the surface on which the animal is resting. According to some textbook pictures, and as the animal appears when flattened under a cover glass, the common impression is that an ameba is usually flattened in form, like a drop of water on a glass plate. Actually an ameba "walks" on the ends of pseudopodia.

Motion and locomotion in paramecia. In an ameba, motion and locomotion are one and the same thing; streaming motions in the cytoplasm cause the ameba to move from place to place. In the paramecium, motion and locomotion are not the same. If a paramecium that is stationary is watched, a general streaming of the cytoplasm inside may be observed. The food vacuoles move around the cell, although the contractile vacuoles remain fixed in place. Apparently such streaming is a sort of cyclosis, like that in Elodea cells.

At the same time, even in quiet cells, another kind of protoplasmic motion may be seen in a paramecium, that of the cilia. In a motionless animal, this ciliary motion will cause currents of water to eddy around the animal, bringing food particles into the oral groove and gullet.

The hundreds of cilia of a paramecium move in a series of waves along the length of the animal.

In the gullet the cilia move so as to push food material into the animal.

A single cilium seems to have a motion something like that which the human being uses when doing the crawl stroke. When carried forward, it is bent so as to lessen water resistance, but in the effective stroke, it straightens out and pushes against as much water as possible. The direction of the stroke may be instantly reversed, so that it beats against the water in the opposite direction. In swimming, the motion of several hundred cilia must be co-ordinated so that they do not interfere with each other. This seems to be brought about by having them move in a series of wavelike actions along the length of the animal. If you have ever seen the effect of wind sweeping across a field of standing grain or a meadow, you have an idea of the way in which waves of bending cilia propel a paramecium through the water.

Redrawn from Jennings

In which direction, up or down, is this paramecium moving? The position of the oral groove will tell. The whole path is a spiral.

A paramecium generally moves with the same end forward. If you watch one on a slide, you will shortly discover that it can easily go into reverse, but that it backs up only for short distances. As it backs, it usually changes the angle of its body slightly so that when it starts forward again, it tends to miss the obstruction.

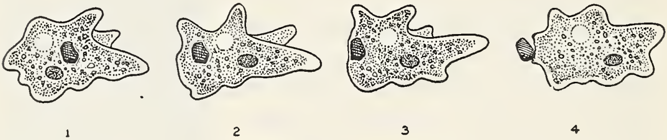
You will not really understand the normal swimming motion of a paramecium if you study it only under a cover glass. In a deeper drop of water, you will find that with the forward motion two other motions are associated. The animal tends constantly to rotate as it swims ahead, sometimes twisting to the right, sometimes to the left. With this twisting, the path of the animal follows a spiral course.

Ingestion. Protozoa must eat and the process of food-taking, or *ingestion,* may be easily observed. When an ameba extends a pseudopod into contact with a bit of food material, it tends to concentrate its flow in that direction. The first pseudopod extends further, and others are projected toward the food particle, passing around and beyond it. Eventually the ameba as a whole has flowed over the food and enclosed it in the protoplasm.

In a paramecium, the eating process differs in accordance with its different structure and locomotion. The food particles are smaller, and even bits of useless materials are taken in. This may be shown by a simple experiment. Into a small portion of a paramecium culture, introduce a pinch of powdered carmine and stir. Then mount a drop and examine it under the microscope. You will be able to see that carmine particles are driven into the gullet by currents created by the motion of the cilia. The formation of a food vacuole may also be watched easily. A little mass of carmine particles begins to accumulate at the end of the gullet.

Digestion. If an ameba is watched constantly over a period of hours, it will be discovered that the contents of the food vacuoles, the bodies of the algae or protozoa, are getting gradually smaller; that is, they are being digested. The protoplasm of an ameba or a paramecium secretes chemical substances which act on the proteins, fats, and carbohydrates and reduce these compounds to simpler forms, suitable for use by the protoplasm surrounding the food vacuoles.

Elimination. In an ameba, the process of eliminating indigestible material is very simple. It is merely a reversal of the process of food-taking. The ameba flows along and leaves the indigestible waste behind. In a paramecium, there is a definite *anal spot,* a weak place in one side of the animal through which such waste materials are squeezed out from time to time. The process may be ob-



The ameba crawls past the undigested particle until it can be pushed out through the surface.

served sometimes in a stationary paramecium. A little cloud of small granules will be seen oozing out.

Absorption and assimilation. These processes of absorbing outside materials through cell membranes and of changing them into protoplasm must be inferred in protozoa, since they cannot actually be seen in their details. We can say with certainty that ameba and paramecium cells grow larger, and that means that they make more protoplasm which must have been formed from food materials absorbed from food vacuoles.

Respiration. If an ameba or a paramecium is placed in water from which all the oxygen has been removed, its activities will slow down. In a few hours it will become entirely motionless. If the animal is then placed in water which contains oxygen it will begin to move and ingest food again. This indicates that the ameba and the paramecium require oxygen for breathing, or *respiration.*

Excretion. Most of the waste products that have actually played a part in the life of the protozoa are excreted in the same way as in plant cells (see pages 170–173). As a result of respiration, carbon dioxide is constantly being formed in a greater concentration within the protoplasm than in the water outside. Consequently it is continually passing through the plasma membrane by osmosis. The same is true of the wastes which result from the breaking down of proteins.

Unlike plant cells, protozoa possess a special organ of excretion, the *contractile vacuole*. The chief function of this organ is to excrete water. Since there is a greater concentration of water outside the cells than inside, water tends to enter continuously. If some protective device were not provided, the osmotic pressure of this water would either burst the cells or dilute the contents to too great an extent. Accordingly the contractile vacuoles open from time to time, allowing the excess water to escape. These vacuoles also aid in the excretion of carbon dioxide and other wastes, since the liquid from the protoplasm always contains some of these materials.

Review and Thought Questions

1. In what respect are green plants unique in their ability to absorb energy?
2. Name two advantages in studying protozoa in animal physiology.
3. Why should distilled or rain water rather than tap water be added to protozoan cultures?
4. What one-celled animal may be seen with the naked eye?
5. Why should Euglena cultures be kept in the light?
6. Why are the ameba and the paramecium so popular in the biology laboratory?
7. Distinguish between ectoplasm, endoplasm, cytoplasm, and protoplasm.

8. What specialized structures in higher animals compare in function with food vacuoles and contractile vacuoles in the ameba?

9. How does a paramecium propel itself through the water?

10. Why is the paramecium considered more advanced in type than the ameba?

11. Name four common groups of protozoa.

12. Why do many students have the impression that an ameba is flat in shape?

13. Describe the forward motion of a paramecium in the water.

14. How would you prove that amebas and paramecia require oxygen for respiration?

Activities

1. Paramecia have been raised in many different kinds of cultures. Try the effect of putting portions of a good culture, rich in paramecia, in several different liquids (*a*) distilled water, (*b*) Knop's solution, (*c*) distilled water and thyroid extract, (*d*) a culture full of small green alga cells. What happens after a few days to the numbers of paramecia and to the size of the cells?

2. Observe streaming in amebas and paramecia under the high power of your microscope.

3. Look up special culture methods for different protozoa and try them out.

4. Some biologists believe that some protozoa may persist in dried form and that when ponds dry up they are blown about as dust. How would you set up an experiment to test the truth of this idea?

5. Place some timothy hay in a bottle and fill the bottle with distilled water. Let this stand two or three weeks and then examine specimens of the water with a microscope to see what organisms are present.

6. Take a microscope slide and scrape along the side of an aquarium at the surface of the water. Try to get a few particles of algae in the drop of water that adheres to the slide. Transfer this to another slide and place a cover glass over it. Usually several species of protozoa will be found, as well as other simple animals. These will be around the masses of algae and may be observed on the slide under conditions similar to those that obtain in their natural habitat.

7. Secure reference books containing illustrations of various protozoa and try to identify the various forms found in your cultures.

8. Draw a diagram six inches long of a paramecium. Label all important structures.

9. Look up in the library kinds of protozoa which may cause water to develop an unpleasant fishy taste.

11. Multicellular Organisms

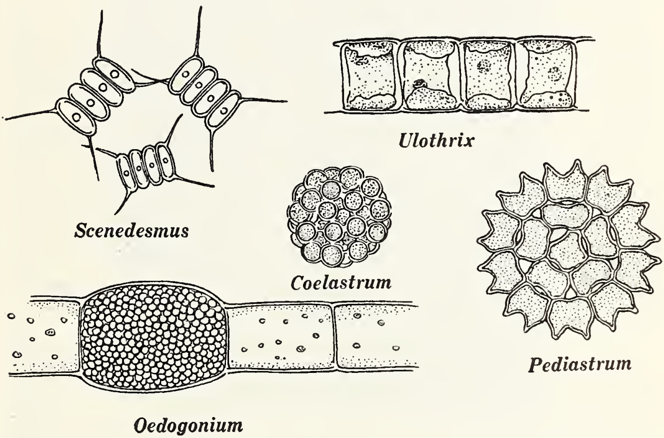
When a potato is cut into several pieces, the surface exposed to the air is greatly increased. Likewise, an animal that contains several cells has a greater cell surface than it would if it contained only one cell. Experiments with one-celled plants and animals show how necessary the cell surface, or plasma membrane, is for taking in food and oxygen and giving off wastes. For this reason, it is not surprising that the larger plants and animals are composed of many cells.

Plants and animals that contain more than one cell are called *multicellular organisms.* When cell division takes place in one-celled, or unicellular, organisms, the cells separate completely after division. When cell division takes place in multicellular organisms, the new cells remain in contact and the organism merely grows larger.

Types of Multicellular Organisms

Among the simplest multicellular organisms, cell groupings are of three different kinds: (1) *Cell associations* include all cases in which the association between the cells is purely accidental. There is no necessary attachment or relationship between the cells of such a group. They exist together because they grew in such crowded conditions that they had no means of becoming separated. (2) *Colonial organisms* include all kinds in which associations of some definite number of cells regularly occur, although there is little or no co-operation between the cells themselves. Colonial organisms usually take some definite shape; there are four-celled forms, eight-celled forms, sixteen-celled forms, and forms containing hundreds of cells. (3) In *true multicellular organisms*, the cells show definite differences in structure, and certain cells are specialized for carrying on particular functions.

Cell associations among the algae. Protococcus is an excellent example of this type of multicellular organism. As it grows on the bark of trees, its cells occur both singly



After Smith, Overton, et al.

In colonial organisms among the green algae, the cells are normally found grouped in a definite arrangement.

and in groups varying in number and arrangement. This grouping is due to the fact that as cells reproduce by cell division there is no way by which they may separate. Hence they remain in crowded masses. Where they are in contact, they are so pressed together that their naturally spherical shape becomes much distorted. However, each cell is completely independent in its activities.

Some types of algae, naturally entirely unicellular, may grow so crowded together that they form sheets of cells which become attached to each other. These form frequently in laboratory cultures and occur both in fresh water and in salt water.

Bacteria often form similar dense masses, apparently as a normal form of growth. Such masses are known as *zoogloea* and may occur in water cultures where the cells are apparently free to separate. They stay together because the cells secrete a gluey covering.

Colonial types of algae. Some of the commonest types of colonial algae are already familiar. Any kind in which the cells are attached regularly in filaments is an example. In Spirogyra the cells grow attached at the ends, but there seems to be no co-operation between adjoining cells in their ordinary daily activities. This connection offers one advantage in that the cells are less likely to be carried away during floods. Long filaments are more likely to become fastened to stationary objects in streams than are single cells.

It is very difficult to show clearly how a filamentous alga differs from a completely unicellular alga. There are, however, some filamentous types in which there is a real approach to multicellular conditions. *Ulothrix* is usually cited as an example of this sort. Starting as a single cell, it becomes attached to some solid object in the water. Then it lengthens and divides crosswise. The attached cell forms projections which penetrate any depressions in the supporting object and is known as a *holdfast cell.* It has less chlorophyll than the other cells which continue the growth of the filament. Later the whole thread may break away from its mooring.

Scenedesmus is another very common kind of colonial alga and is usually abundant in culture jars. There are several species, which differ in the number, shape, and

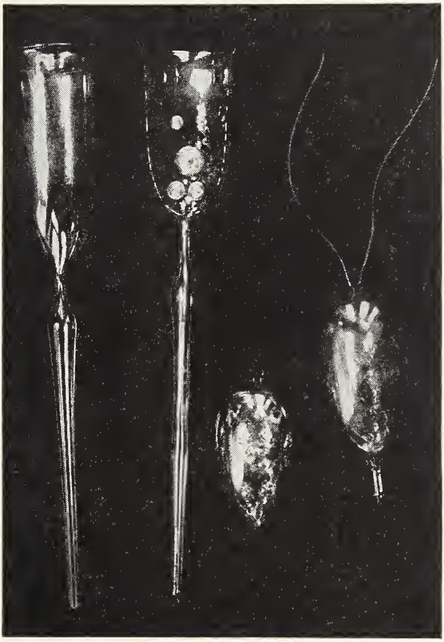
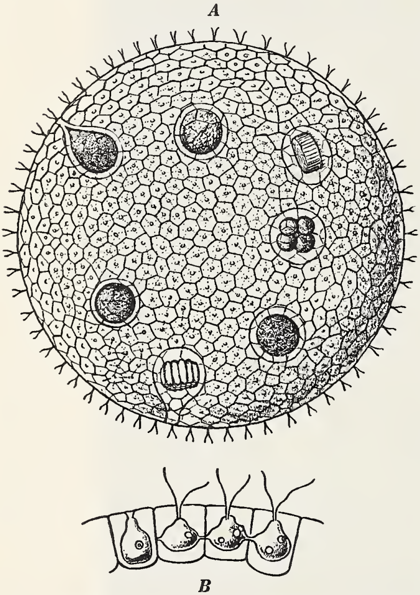


Photo from American Museum of Natural History

Cells of Gonium, here modeled in glass, are one of the simplest kinds of colonial flagellates. Note the two whiplike flagella.

arrangement of cells in the colony. The commonest species has four cells fastened together side by side; but eight-celled colonies are common, and sometimes only two cells occur together. In one species of four cells the two end cells each have two tail-like projections. This form is known as the "four-tailed" Scenedesmus.

There are many other kinds of colonial algae, often with very attractive colors and patterns. If they were large enough to be seen without a microscope, they would probably be ranked among the most beautiful plants we have. Some have the cells arranged in a line or row, while others are arranged in a flat plate. The *water net* has elongated cells fastened at the ends so as to form a definite net-like arrangement.



Volvox is a colonial organism consisting of hundreds of cells, each with two flagella. Imagine a boat with hundreds of oarsmen! Volvox cells are connected with each other by strands of protoplasm.

There is considerable disagreement regarding the classification of the colonial flagellates, and some forms are claimed by both botanists and zoologists. All are composed of green cells like Euglena, but each cell has two whiplike flagella instead of one. These flagella project through a gelatinous layer which surrounds the colony. One of the simplest forms is *Gonium,* which grows in plate-like colonies usually consisting of sixteen cells. The cells of these colonies seem to be entirely independent save in one respect. In order for them to accomplish locomotion, it is obvious that some co-ordination between the large number of flagella is necessary. Pandorina, for instance, rolls along in the water like an animated green berry, the thirty-two "oars" of its sixteen cells all working in harmony. Microscopic examination of these forms reveals tiny threads connecting the cells.

In reproduction Volvox goes a step further than the other flagellates in cell differentiation. A few of its cells become much enlarged at the expense of others. Some of these enlarged cells become differentiated as egg cells, or female reproductive cells. Others subdivide into numerous sperm cells, or male reproductive cells. This differentiation of cells to perform different work is an important principle in the life of multicellular organisms.

Division of labor in true multicellular organisms. When men live alone as some trappers do in the Far North, they have to do practically everything for themselves. When they live in communities, they can divide up the tasks. Even in the smallest villages people follow different occupations. In small towns there is likely to be at least one storekeeper, a doctor, and one automobile mechanic. In larger towns the number of kinds of workers increases. There is greater division of labor. A somewhat similar division of work occurs among the cells of a multicellular organism.

Whenever cells occur in large numbers to form a single organism, they tend to become adapted for special tasks, some doing one kind of work, some another kind. They also tend to become modified in structure, depending upon the kind of work that they do. In the plant kingdom, there is a gradual series of larger and larger kinds showing increasing division of labor among the cells. First, the differentiation occurs as in Volvox, between reproductive cells and nutritive cells. Later, we find increasing differentiation between different kinds of nutritive cells. Some of the simpler plants become very large. The brown algae of the Pacific Ocean are probably the largest organisms in existence, sometimes reaching a length of five hundred feet.

Photo by Hugh Spencer

Rockweed, or Fucus is a multicellular plant, with forked branching, and with growing points at the end of each branch.

Among the algae the differentiation between the cells is never very great in degree. One kind, *Fucus*, consists first of a basal holdfast region by means of which it maintains a firm hold on rocks and other submerged or partly submerged objects. From this it branches out into a flattened, fanlike form with a fibrous ridge running along the center of each division. Scattered along its ribbon-like parts are occasional air bladders which buoy it up toward the light. Aside from the holdfast parts, all of its surface cells may take in food materials from the sea water. Chlorophyll is present in all cells except toward the center of the structure. Some of these central cells are long and fibrous and are fitted for strengthening and conduction. In other words, the daily functions of a fucus plant are divided into food-taking, photosynthesis, holdfast, support, and conduction. In the higher plants we shall see that this list of plant functions is greatly extended.

Photo by R. C. Benedict

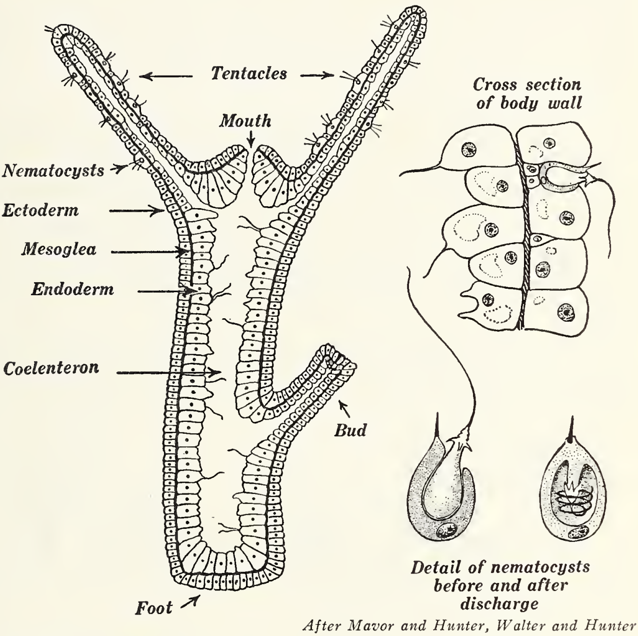
Fucus grows firmly fixed to rocks or piles, and can stand strong waves without injury. Below, some spread-out plants show their fanlike branching at low tide on the Atlantic coast.

Animals with Two Layers of Cells

In the pools of many streams and in small ponds there lives a little animal called the *Hydra.* This animal has been studied by thousands of biology students and has become very well known because it is the simplest example of a typical multicellular animal. It is not very large, most specimens being barely visible to the naked eye while the largest ones rarely exceed half an inch in length. On seeing a Hydra for the first time, one is reminded of an octopus. The Hydra has long, waving tentacles which are probably as dangerous to its prey as the tentacles of the octopus are supposed to be to us. Its food consists chiefly of small crustacea, especially *Daphnia,* which live in the same situations. In catching these active animals, the Hydra tentacles come into play. If a swimming Daphnia happens to hit against a tentacle, you will see it suddenly stop as if stunned. Then the tentacles draw the Daphnia to the mouth of the Hydra and so into the body cavity. Altogether the Hydra is a very interesting animal to observe. Watching it solve its problems will teach us a great deal about how other animals solve their problems.

The cell structure of Hydra. A Hydra is essentially a hollow bag with hollow arms, or tentacles. The wall of the body and of the tentacles is made of two layers of cells, an outer *ectoderm* and an inner *endoderm.* Each layer is really a general sort of tissue made of several different kinds of cells.

Even in a living animal some of the differences in the cells may be seen. Scattered along the tentacles and body will be found small projecting cells, the *nettle cells,* or *stinging cells.* Each nettle cell is really a tiny sac containing a coiled barb which is discharged when a certain point on the cell is touched. It is the discharge of these barbs which stuns the Daphnia and renders them temporarily



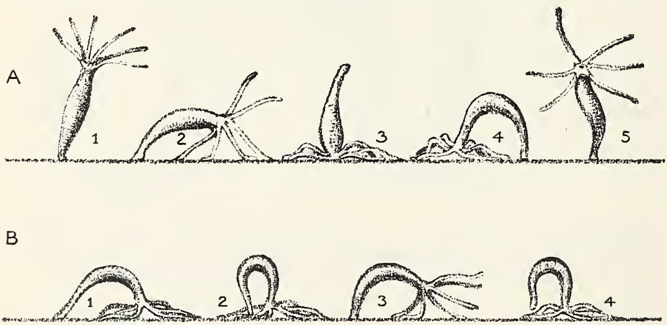
The body plan of Hydra is a hollow bag, with a wall two cells in thickness. Note the stinging cells on its tentacles.

powerless to swim away. It is also the presence of this kind of cell in some jellyfish that makes these such uncomfortable things to come into contact with when swimming in salt water. All species of the phylum called *Coelenterates* possess nettle cells, technically known as *nematocysts.*

To get a clear picture of the cell structure of the Hydra, examine some cross sections of specimens that have been carefully stained. As the accompanying illustration shows, the ectoderm consists of four different kinds of cells: nettle cells, sensory cells, body-muscular cells, and nerve cells. In addition there are small undifferentiated cells which are able to develop into the other types, or into reproductive cells.

The endoderm contains some of the same kinds of cells and some that are different. Undifferentiated and body-muscular cells are present, also gland cells and cells which resemble amebas. In both the endoderm and ectoderm, the nerve cells form branching nets of fibers. Let us see how these various kinds of cells of the Hydra operate.

If you have been observing the Hydra, you will have noticed that its motions are rather slow. Its tentacles wave



After L. Jammes

Here you see a Hydra, the simplest typical multicellular animal. It moves by (A) turning somersaults, or (B) by "inching," or by gliding along on its base.

slowly about in the water as the animal remains attached to some underwater plant. It can glide slowly along on the base of its body or it can turn somersaults, end over end. If touched suddenly, it contracts to a ball-like shape with the tentacles appearing as short stubs.

In accomplishing these motions the body-muscular cells are the ones that are acting. These cells have projections which extend in different directions. Those in the ectoderm extend lengthwise and those in the endoderm extend crosswise around the body. The contraction of the body-muscular cells in the ectoderm shortens the animal, while the contraction of the body-muscular cells in the endoderm reduces the diameter, thereby causing the animal to increase in length.

Life processes of Hydra. Digestion takes place in two ways. The gland cells pour out digestive juices which act on the larger food particles in the central cavity and reduce these partly to soluble form. Smaller particles may be picked up by the cells which can send out pseudopodia as amebas do. They are taken into these cells and digested there. Indigestible materials are discharged through the mouth opening by a contraction of the body. For this reason this opening is sometimes called the *mouth-anus.*

When digestion has occurred, food materials are in soluble form within the body cavity. Absorption then takes place exactly as it would if the surrounding cells were unicellular organisms. The conditions necessary for osmosis are provided, and the soluble materials pass into the endoderm cells. The ectoderm cells have to get their food from the endoderm cells by the same process. Every cell of a Hydra is either in contact with available food material or is only one cell removed from its food. No circulation is necessary.

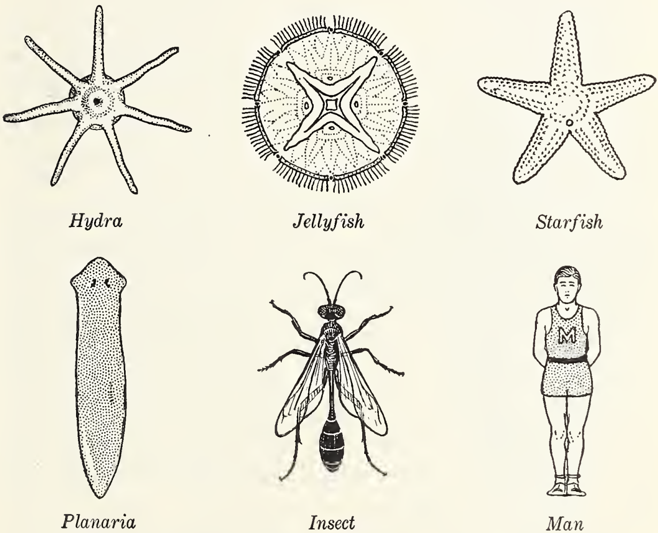
Every cell of the animal is directly in contact with water containing dissolved oxygen. The ectoderm is in contact with the water outside the digestive cavity and

The Portuguese Man-of-War, a Coelenterate of the jellyfish group, is a highly specialized animal, with a part that serves as a sail and with tentacles for different purposes.

the endoderm is in contact with the water inside. Therefore every cell can act for itself in taking in oxygen and in getting rid of carbon dioxide. In this function of respiration there is no co-operation between cells and no division of labor is necessary.

As with carbon dioxide, so with other cell wastes, each cell discharges its waste products directly into the adjacent water.

Other similar animals. The Hydra is the simplest animal possessing both a digestive cavity and external organs. Like the rest of its phylum, the Coelenterates, it is built of two layers of cells. Other members of the phylum, such as sea anemones, are often much more com-



Multicellular animals are either *radially symmetrical* (Coelenterates and Echinoderms) or *bilaterally symmetrical* (all other phyla) in body plan. Man is a bilaterally symmetrical animal.

plicated in the development of their body plan, but their basic similarity is plain. Jellyfish have the same general structure as Hydras but are inverted so that they float with the mouth opening downward.

All Coelenterates are built on a circular plan with radiating tentacles. There is no right and left side to such animals. This body plan is known as *radial symmetry.* It seems always to be associated with animals that are slow in motion, if not completely fixed in place. Contrasted with this type of body plan is that of *bilateral symmetry* characteristic of the next animal to be described, as well as of man.

Animals with Three Layers of Cells

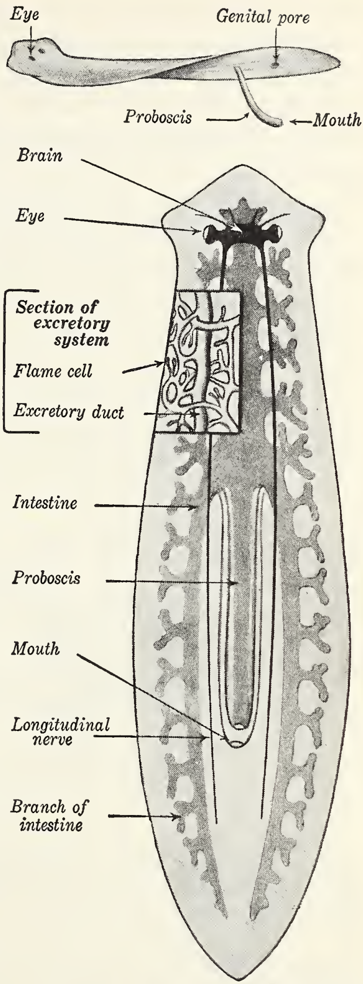
The simplest bilaterally symmetrical animal is the fresh-water flatworm, *Planaria,* another of the biologist's favorites. It looks like a small leech and is found in similar situations. Planaria is harmless to man, although some of its relatives are serious intestinal parasites.

General structure of Planaria. About half an inch in length, brownish or blackish, with a broadened front end containing two earlike lobes, the Planaria is far from being an interesting-looking animal. Its bilateral symmetry is shown by the fact that it has a right and left side and can be divided into two equal parts through the midline. Its front end is characterized by the presence of two definite eyes, and there are numerous nerve endings in this region. It moves with a slow, gliding motion and can contract and squirm.

The food-taking organ is near the middle of the under side of the body. This consists of a long, muscular tube, or proboscis, with a mouth at the end. This can be drawn into the body, or protruded and waved around like an elephant's trunk. From it the food tube, or *enteron,* leads into three main branches within the body, one leading forward and two leading backward. Each main branch has many small branches which penetrate to all parts of the body.

The body of the Planaria consists of three layers of cells, *ectoderm, endoderm,* and *mesoderm.* The ectoderm is the outside surface layer and the endoderm is the lining of the digestive cavity. The mesoderm is many cells thick, consisting of longitudinal and circular muscles and of other kinds of tissues.

Life processes. The food of Planaria consists of small particles of organic matter. They are very fond of fresh meat, and their feeding may be watched in the labora-

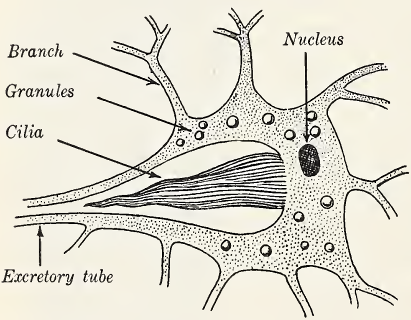


Planaria is an animal with three layers of cells, ectoderm, endoderm, and mesoderm.

tory if a bit of chopped beef is placed in a dish with a few of them. The food material is passed into the branching digestive tube, the *enteron,* and is digested by enzymes which are secreted by cells in the lining of the digestive cavity. Indigestible matter is passed out by way of the mouth.

Osmosis comes into action when the food has been made soluble. While the Planaria is many cells thick, there is no circulatory system, so that osmosis is the means by which digested food is distributed through the body. Distribution is greatly aided by the fact that the branches of the enteron extend through all parts of the body.

There are no special organs and tissues for respiration. The surface layers of the animal absorb the oxygen, which is distributed throughout the body by osmosis, and the carbon dioxide is excreted by reversing this process.



The flame cell is a type of cell found only in Planaria and other Coelenterates. Each flame cell is hollow, with flickering cilia which draw in waste matter.

The Planaria and all other flatworms have a peculiar type of excretory system. This consists of a series of fine tubes penetrating the body and opening through pores on the upper surface. At the inner ends of these branching tubes are specialized cells called *flame cells.* A single flame cell is hollow with a group of flickering cilia inside. The motion of these draws liquid into the tube system from the intercellular spaces in the mesoderm. The liquid then passes gradually toward the external pores.

Compared to the Volvox, even the Hydra is a rather complex animal, with its various types of cells all working co-operatively to carry on ingestion, digestion, egestion, and locomotion. But in relation to the Planaria and all higher animals, the Hydra is about as simple a type of animal as can be imagined. Its tentacles are the nearest approach to definite organs. While the body has two layers of cells, there are no tissues in the sense that we recognize tissues in higher animals. Planaria, on the other hand, shows a definite development of tissues and of a few organs. The eyes are special organs. The mouth, proboscis, and enteron make up an organ system. The system of excretory tubes makes up another organ system, and these worms have a rather complex set of reproductive organs. As we study the solution of life problems by animals higher in the scale than Planaria, we may expect to find still greater complexity of structure and an increasing degree of cell specialization.

Review and Thought Questions

1. Give one explanation to account for the limited size of a one-celled organism.
2. Name at least three types of simple multicellular organisms and give one example of each.
3. What is the chief difference between colonial organisms and true multicellular organisms?
4. What characteristic of protoplasm is suggested by the fact that most living things are multicellular organisms?
5. What is the difference between a cell association and a colonial organism? Illustrate by referring to a four-celled aggregate of Protococcus and a four-celled Scenedesmus.

6. Why is a Ulothrix filament counted higher in the scale than a Spirogyra filament?

7. In what respect must the cells of a swimming colony work together? How is the co-operation between cells provided for?

8. A true multicellular organism always has several different kinds of cells for its nutritive functions. How does this condition compare with that in colonial organisms?

9. Considering radial and bilateral symmetry, to which type does each of the following belong: starfish, grasshopper, bird, sea urchin, cat?

10. Describe Planaria and tell in what principal points it differs from Hydra.

11. Compare the specialization of structure in Hydra and Planaria.

12. Why is the biologist as much interested in the activities of simple multicellular forms as in those of large organisms?

Activities

1. Study prepared slides of simple multicellular organisms such as Volvox, Pandorina, and Gonium.

2. Hydra can sometimes be found along the sides of an aquarium. With a pipette try to catch some specimens and study them under the microscope.

3. Observe the reactions of Hydra when they are touched with a needle or when the vessel that contains them is given a sudden jar.

4. Look up culture methods of Hydra and Planaria and grow some cultures of them.

5. Is Hydra useful or harmful to man? By visit or library reference, find out how it is regarded at fish hatcheries.

12. Higher Plants

The largest tree is like the smallest alga in that it carries on the same general life processes. But there are great differences in the ways in which the great mass of the tree with its innumerable cells solves its problems as compared with the one-celled alga.

Let us look at the body plan of some typical seed plants, of which trees are large examples. We shall understand the plan most easily if we start with the earliest stage, the seedlings of any common garden vegetable, weed, or young tree.

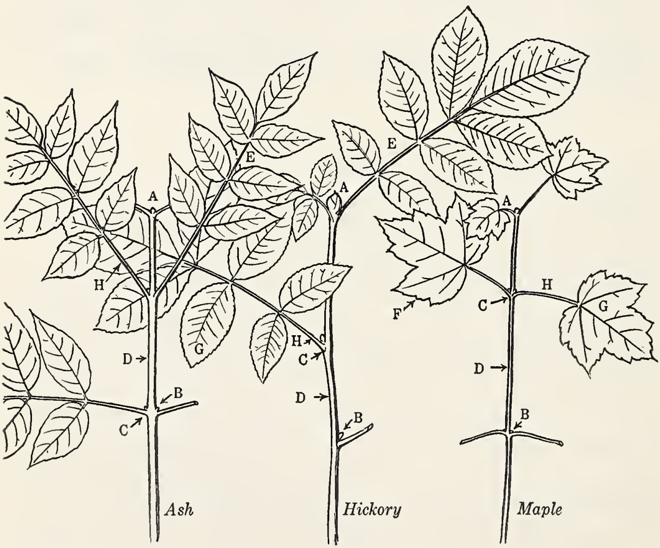
Plant Organs and Tissues

The fact that the ordinary plant consists externally of three organs—*roots, stems,* and *leaves*—is familiar to everyone. The seedling shows a single stem bearing one or more leaves. The root part starts at the base of the stem and is branched except at the very beginning, where a single *primary root* is all that has had time to develop.

As the young plant grows older, the stem usually branches. Keeping pace with the stem branching is the development of the root system. The number of leaves is indefinite. In some low-growing plants there may never be more than five or ten leaves, while a large tree may have hundreds of thousands. The number for a large maple has been estimated at 200,000, while an oak may develop as many as 700,000 leaves in a single season.

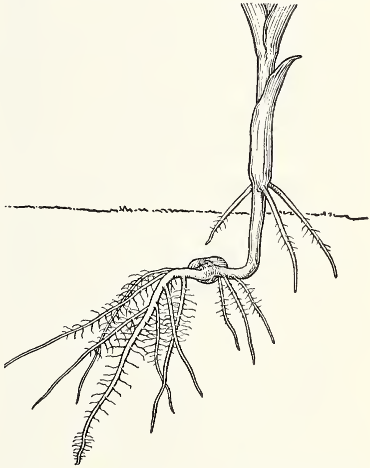
This indefiniteness in the number of leaves and in the extent of the branching of stem and root systems is part of the body plan of a seed plant. Leaves are short-lived organs and must continually be replaced by new leaves on new branches. Similarly, in the root system, only the youngest rootlets can function by taking in soil water. New absorbing portions must be constantly formed to replace the parts that have become too old to do their work.

The development of new organs. An examination of the seedlings of different ages will show that new stems and new leaves are formed almost always at definite



Leaf arrangements vary (note compound leaves of ash and hickory). A, terminal buds; B, axillary buds; C, nodes; D, internodes; E, midrib of compound leaves; F, lobe of maple leaf; G, blade in maple, leaflet in hickory; H, petiole or leaf or stalk.

places on the stem. At the tip of each stem there is usually a *terminal bud* which contains cells undergoing mitosis. Internally, the bud consists of young leaves in various stages of development. New stems and leaves may also develop from *lateral buds* which usually arise in the upper angles formed by a leaf base and its stem. This angle is called the *axil* of the leaf, and buds formed in it are called *axillary buds.* Lateral buds may sometimes arise from other places on the stem. These are called *adventitious buds.*



The *primary* root is the first one from the seed. Branches of this are called *secondary* roots. Roots arising from stems are called *adventitious.* A corn plant has all three kinds.

The arrangement of organs. The arrangement of leaves on stems follows several different plans. That portion of a stem to which a leaf is attached is called a *node;* the space between two nodes is the *internode.* Internodes may be short and the leaves consequently crowded, as in carrots and in dandelions. In other plants the internodes may be long and the leaves widely separated.

Another variation in the leaf-stem arrangement lies in the number of leaves at a single node. In the *alternate* type of arrangement leaves occur singly, one at each node. When two leaves occur at a node, the arrangement is said to be *opposite.* In some plants, three or more leaves spring from every node; this is called a *whorled* arrangement. The alternate plan is the most common, and the whorled is the least common.

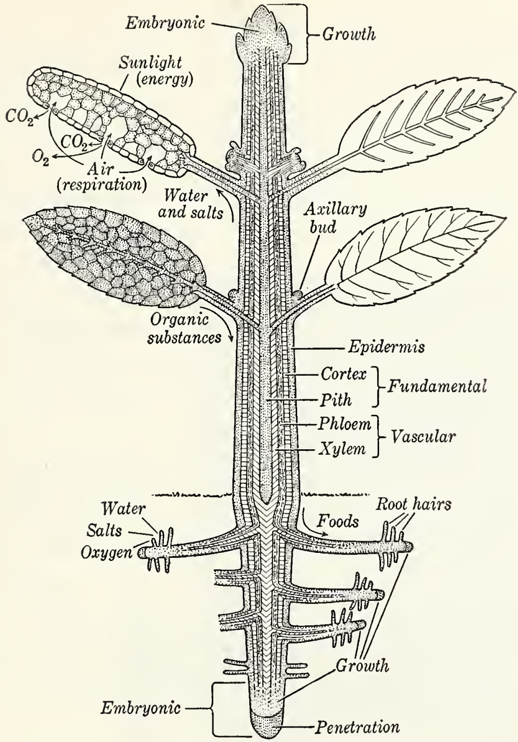
The root system follows a branching plan much like that of the stem system, but the plan is not so evident. The first root is called the *primary root.* In many plants the primary root grows straight down as deep as the soil allows. The branch roots from the primary root are called *secondary roots.* Since there are no axils on roots, secondary roots do not arise at definite points but appear in a definite number of vertical lines. In carrots there are four rows of secondary roots, as may be seen by noting the vertical rows of creases.

In some plants roots may arise from stems, usually at the nodes. These are called *adventitious roots.* They are common in plants such as corn and are important not only as food-absorbing organs but also as props for the stems.

The plant tissues. The internal tissue systems of various kinds of seed plants are of many different varieties, but all can be reduced to a common plan, which we can understand most easily in a seedling.

The seedling contains three main tissues: (1) the *epidermis,* a layer usually one cell thick, which covers the entire plant; (2) the *vascular* tissue, extending as a connected system of fibers from the root tips through the stem to the leaves where it appears as veins; and (3) the *fundamental* tissue, mostly soft, thin-walled cells surrounding the vascular fibers and enclosed by the epidermis.

One other sort of tissue, the *undifferentiated* or *embryonic,* is found in buds and at the tips of roots. It cannot be classified with any of the three kinds of tissues



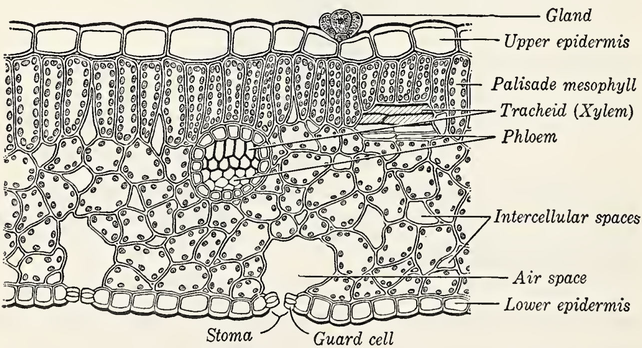
The internal structure of a growing plant shows three organs, root, stem, and leaf, and three main differentiated tissues, *epidermis*, *vascular*, and *fundamental*. Besides these, there are *buds*, which consist of *undifferentiated* tissue.

just mentioned, because new vascular tissues, new epidermal tissues, and new fundamental tissues arise from it. Embryonic tissue, called *cambium*, is present as a continuous sheath within the vascular tissue in many kinds of stems. Cambium is responsible for the ability of plants such as trees to grow in thickness.

The Functioning of the Whole Plant

When we think of the plant as a whole, it is easy to recognize how the form and position of the different organs are fitted for the performance of the various activities carried on in the plant. It is obvious that the leaves are primarily formed and placed so as to expose chlorophyll to the best advantage in order to promote the function of photosynthesis. Likewise, the form and position of the roots enable them to take in soil water and anchor the plant firmly in place. Between the roots and the leaves is the stem. The stem connects roots and leaves, distributes liquids throughout the plant, and exposes the leaves to the light and air.

The structure and functions of leaves. Examine a prepared slide of a cross section of some typical leaf, such as the lilac. The thin sheet of green tissue is usually from six to eight cells thick, although there are masses of much



This section through a lilac leaf is less than half a millimeter long, and about a quarter millimeter thick. Note: the upper epidermis, thickened for protection and with gland cells for excretion; vascular tissue, one vein in cross section and one cut lengthwise; fundamental tissue, with chloroplasts and air spaces; and lower epidermis, with openings or stomata.

smaller cells in the veins. The upper and lower layers of epidermis are easy to distinguish. Filling most of the space between the upper and lower epidermis is the *mesophyll.* In leaves such as lilac, the mesophyll has two layers, with the cells differently arranged. Under the upper epidermis is the *palisade mesophyll,* consisting of one or more rows of cells. Although they are closely packed, there are narrow air spaces between them. Below the palisade cells and next to the lower epidermis lies the *spongy mesophyll,* a layer of very loosely packed cells.

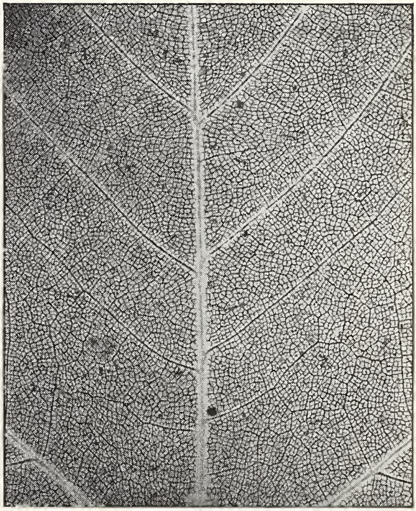
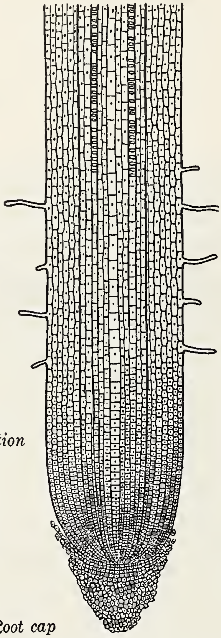


Photo by Lynwood M. Chace

The vascular tissue of a leaf is shown by its veins. Every portion of the leaf is reached by the smaller veinlets.

The epidermis of the leaf deserves careful study. It is made up of broad, interlocking cells, with occasional smaller cells. The latter are of two sorts, the *guard cells,* which mark the air pores, or *stomata* (singular *stoma*), and the *gland cells.* Guard cells occur in pairs, like two kidney beans placed with their concave sides together, thus leaving a slitlike opening. Stomata occur chiefly on the lower surface of leaves. The gland cells occur in little groups set in depressions of the leaf surface (see illustration, page 218).

The structure of the vascular tissue of a leaf should be carefully examined. Notice in a whole leaf how the vein system spreads throughout the leaf, forming a network of smaller and still smaller veins, running in all directions through the mesophyll until it reaches every part.



Note the different zones of activity in a short length of young root. The total surface exposed by all such roots on a large plant, especially by the root-hairs, is enormous.

A vein contains two special kinds of conducting cells, the *xylem*, or wood cells, and the *phloem*. Xylem cells are pointed, and some have the wall strengthened by a spiral thickening. Phloem in leaf veins consists chiefly of thinner-walled cells.

The structure and functions of roots. To understand root structure as related to the root functions, we need to remember that in any root system there are several different parts: (1) the growing tips; (2) the absorbing portions; (3) the older portions in which conduction and support are the main functions. We may well take them up in the order just given.

1. The *root tip* is an interesting and surprising structure. It is the portion where cell division and elongation

take place. Each of these little masses of growing cells drives the root tip farther and farther into the soil. This force results from the increased amount of tissue and from the water pressure which osmosis forces into them. The extreme end of a root is usually covered and protected by the thimblelike *root cap,* a cone of soft cells which are continually being worn off on the outside and renewed from within.

2. The *root hairs,* or absorbing parts of a root are only a short distance above the tip.

Each root hair is a projection of a single epidermal cell. Scores of root hairs start out in

Courtesy of Brooklyn Botanic Garden

A mustard seedling has root hairs.

every direction, like little cobwebby threads. They bend and twist between particles of soil to which they often become firmly attached. In most plants they exist in enormous numbers and thus expose a very large area of absorbing surface to direct contact with the soil. A root hair lives but a brief period. The older ones die and are replaced by new ones which push out just back of the extending root tip.

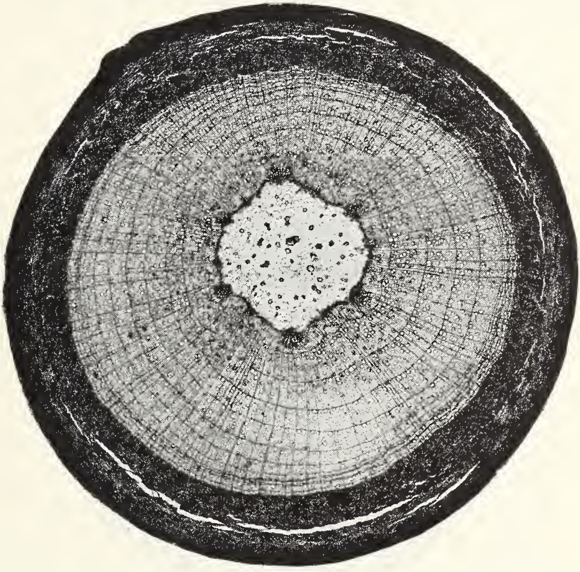
Under the epidermis lies a layer of fundamental tissue which is called the *cortex.* In the center of the root is a core of vascular tissue consisting of ridged strands of xylem alternating with threads of phloem.

3. To see the cellular details of a root, a prepared cross section, such as that of the root of a buttercup should be studied. However, we can get a good idea of the arrangement of tissues by examining such roots as the carrot and the parsnip, which are primary roots that have been greatly thickened with stored food. The carrot has a thick outer cortex surrounding its fleshy central cylinder of vascular tissue. If a carrot is split and allowed to dry for a few hours, the cortex may be pulled away from the central cylinder, from which vertical rows of vascular fibers may be seen projecting. These are branches that led to the secondary roots as the carrot grew in the soil.

The structure and functions of stems. Stems perform no peculiar, primary function for the plant as a whole. Their work is to support and to display the leaves, and to serve as a means of connection between roots and leaves. Therefore, we may expect their structure to be fitted for these two chief functions.

There are two main ways in which stems furnish support—by water pressure, and by mechanical tissue. Woody plants, trees, and shrubs are plants in which the main bulk of the stem is woody tissue. Such stems grow yearly in thickness, adding a ring of wood every year.

Contrasted with woody plants are the herbs, usually soft-stemmed plants, consisting mostly of fundamental

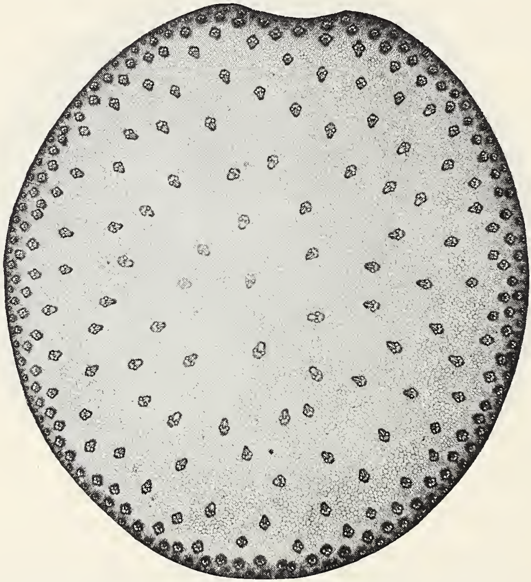


A cross section of young woody maple stem shows clearly pith, wood rings, and "bark." The bark really consists of part of the vascular tissue (phloem), a layer of cortex, and in very young stems remnants of epidermis cells. Can you tell how many years old this twig was?

tissue. Sometimes this tissue is made up entirely of soft, thin-walled cells, and the stems maintain their stiffness because of the water pressure of the cells. When they lose water, such stems become soft and limp. In other herbs, for example in the grasses, part of the fundamental tissue is modified in the form of thick-walled, mechanical cells.

Such stems may remain rigid, even when dry. Thus, corn stems have a hard rind, made up of thick-walled cells, strengthened with silica.

Conduction, or transportation of food materials, in stems is carried on through the vascular tissue, which may

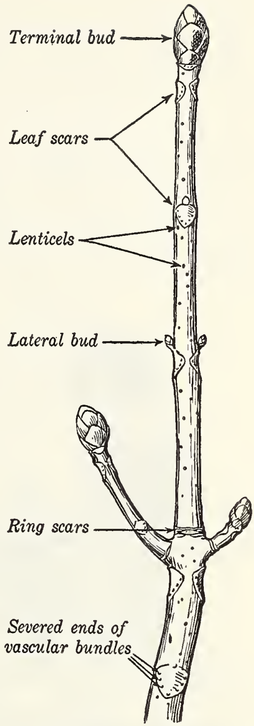


This corn stem cross section, magnified about 20 times, shows the large amount of fundamental tissue cells, the numerous small scattered vascular bundles, and the outer rind, partly epidermis.

be divided into two kinds, xylem and phloem, as was described for the leaf. There are many differences in the way in which the vascular tissue is distributed in the stem, which are very significant in plant classification but, as far as conduction is concerned, the tissues and cells are very much the same in all stems.

A study of the external appearance of a young, woody stem shows a number of interesting features. The epidermis dies during the first year and is replaced by a bark which forms in annual layers. The outer layers are always dead. In some trees, like canoe birch and sycamore, these outer layers scale and drop off naturally. In many trees they remain firmly attached to the younger, inner bark, often becoming inches and sometimes even a foot thick. Common bottle cork is the thick bark of a species of oak growing in southern Europe.

In a young twig the surface shows a number of markings called *lenticels.* They are scattered irregularly and appear as small raised spots or chimneylike openings which allow air distribution to the inner layers of the bark. Other markings found on twigs in the winter condition are the *leaf scars.* A twig amputates its leaves at the end of a growing season and forms a neat scar over the place where the leaf was attached. Each vein which passed to the leaf is represented by its own mark on the leaf scar. Another kind of mark-



The external structures of a woody twig are shown here in the horse chestnut. In cold climates, woody plants prepare for the winter by dropping their leaves, leaving healed surfaces or leaf scars. They protect the undifferentiated cells of the stem tip, or resting bud, against the cold with thick tough scales.

ing, in ring form, represents the scars of the bud scales of the previous season. The appearance of the resting buds is also an interesting external feature in twigs, since they possess protective scales instead of leaves.

Water Relations of Higher Plants

Every part of a plant contains some water; in young leaves, root tips, and fruits as high as 95 per cent of their weight may be water. Woody stems are about 50 per

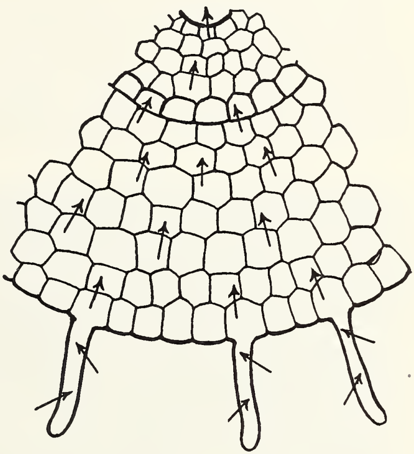
Plants may wilt if watered only on their leaves. How would this experiment work if you start with plants already wilted?

cent water. Even the driest seeds rarely contain less than 10 per cent water.

Roots and soil water. That roots are the only organs for water intake in most common plants can easily be demonstrated by a simple experiment. If two similar plants are removed from the soil, allowed to wilt slightly, and then given water, one through the roots and the other on the leaves, it will soon be apparent that only roots take in water.

There is really nothing new in the process whereby root hairs take in soil water. Each root hair is like a Spirogyra cell in providing the conditions necessary for osmosis. The soil water and the cell sap are the two liquids, and the plasma membrane of the root hair is the osmotic membrane. Under ordinary conditions, molecules of water, together with dissolved minerals, are constantly pressing inward.

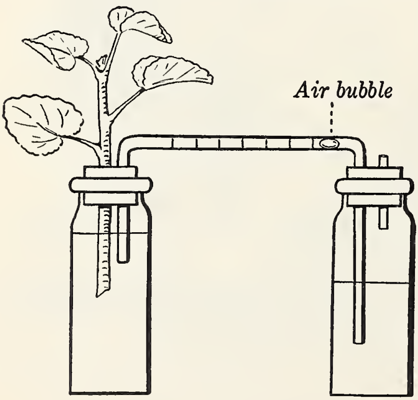
The further passage of water through the inner cells and through the main root is partly explained by the fact that the water concentration of the cell sap becomes less as it proceeds from cell to cell. This results in a continuous inward current from the root hairs, directed through the fundamental cells of the cortex and the vascular cells toward the stem. The considerable pressure caused in this process is shown by the "bleeding" of the cut stems of some plants.



Note the course followed by soil water into and through the cortex of an absorbing root. The last arrow, at the top, points to the vascular tissue.

Another factor in the rise of water through the root system may be illustrated by another experiment. A piece of glass tubing if heated to softness in a flame may then be drawn out into a fine hairlike tube, called a *capillary tube.* If several such tubes are prepared and placed in some colored solution, the liquid will rise into the tubes by *capillarity;* the finer the tube, the greater the height. In a like manner, since the vessels of the xylem are microscopically fine capillary tubes, water is bound to rise in them when it gets into the base of the tube.

Although osmosis and capillarity are probably the main factors involved in the rise of water through the root, they are not the only factors. There is undoubtedly much yet to be learned about the processes by which soil water rises in plants and those by which other liquids move downward.

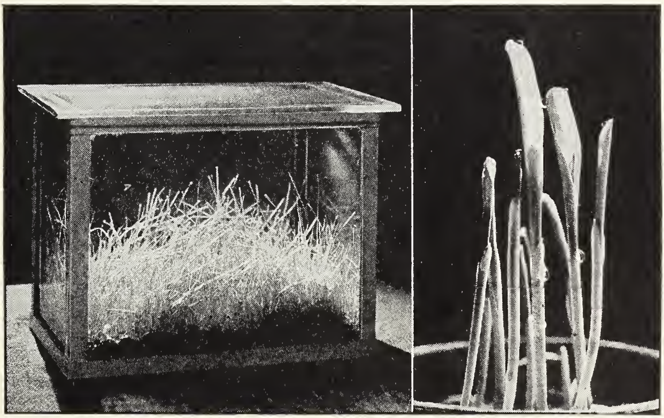


This experiment shows transpiration. In what direction does the bubble move? Why does it do so?

Transpiration and guttation. Let us now jump from the roots to the top of the plant and investigate the processes affecting the water content of the leaves. There are two processes by which water may be given off from leaves: *transpiration,* the loss of water by evaporation, and *guttation,* the loss of water in liquid form.

The rate of transpiration under any given conditions can easily be determined by weighing a potted plant at intervals. In performing such an experiment care should be taken to prevent evaporation both from the soil and from the pot. Another interesting experiment is to cut off the stem of a plant and to insert it in one of the openings of a two-hole stopper, using the apparatus shown on page 228. The transpiration rate can then be calculated by noting the progress of the air bubble along the horizontal part of the tube.

Transpiration goes on all the time except when the air is so saturated with water vapor that it cannot take up any more. The epidermal cells of a leaf are generally waterproof, but the stomata allow water vapor evaporating from the mesophyll to pass off into the air. The action



Photos by Hugh Spencer

Plants may give off water in liquid form.

of the guard cells is practically automatic; when the air is dry, the guard cells lose water and lengthen, thus decreasing the size of the opening; when the air is moist, the guard cells become *turgid*, that is, distended by osmotic pressure, and shorten, opening the pore.

Transpiration is responsible for the elimination of immense amounts of water. A single tree may transpire more than a hundred gallons per day. This process serves a

Photo from Publisher's Photo Service

Where rainfall is scarce plants store water within their tissues. Thick epidermis on the leaves prevents evaporation.

useful purpose in reducing the temperature of the leaves on a hot day. The effect of transpiration partly accounts for the coolness of forests.

Guttation is a much less familiar process than transpiration, but it is a most important one for the plant. It may easily be observed in grasses and in almost any common garden plant. A radish seedling shows the process especially well. If such a plant is covered with a bell jar so that the air becomes saturated with moisture from transpiration, little beads of water will form around the edges of the leaves. If the structure of the leaf is studied, a special kind of water-excreting structures will be found at the edges of leaves. These structures differ from stomata in that they always remain wide open and act as safety valves which allow excess water to escape in liquid form at times when transpiration cannot take place with sufficient rapidity. Much of the so-called dew on grass on summer mornings results from the escape of water at the tips of grass blades.

The rise of liquids through the whole plant. Think what a huge task it would be to carry or pump water to the top of a building as tall as some trees. From the lowest root to the highest twig, redwoods often reach well over three hundred feet. Some eucalyptus trees have a total height of four hundred and fifty feet, including the roots. That is as high as a building between thirty and forty stories tall. Here is a problem in the water relations of plants about which much remains still to be discovered. Probably the most important of the known factors that aid in the rise of soil water through the tissues of the plant are the following:

(1) Root pressure has already been described (see page 227). The osmotic pressure exerted by the roots, as can be shown by experiments, may be sufficient to raise water at least twenty-five or thirty feet. It plays an important part in the rise of water through the plant, especially in the spring before the leaves have been developed. Experiments indicate that root pressures alone may be great enough to send water even to the tops of the highest trees. In large trees with extensive root systems, the root pressure amounts to many tons.

(2) Capillarity helps in the rise of water in trees to some extent, although it is probably not responsible for very much of it.

(3) Transpiration in the leaves seems to play an important part. This loss of water through evaporation from the leaves causes osmotic pressure from the cells below. The osmotic pressure caused by the transpiration from all the leaf cells of a full-leaved tree sets up a strong pull at the top of the plant.

(4) Water in a column tends to hold together, as would a long wire of the same length. When transpiration exerts a strong pull at the top of the plant, the many fine, more or less continuous threads of water running through the whole vascular system of the plant tend to hang together and thus to be drawn toward the top.

(5) The phloem, particularly the sieve cells, plays an important part in the movement of liquid food materials through the veins to the stems and up to the growing buds, as well as down to the roots. Many food substances can be constructed only in green tissue, chiefly in the leaves, but rapidly growing stems and root tips must have these nutrients in order to build new cell walls and new protoplasm. Some scientists think that the little pores in the sieve plates allow such liquids to pass from one phloem cell to another.

Review and Thought Questions

1. Give the functions of three principal plant organs.
2. Distinguish at least three different kinds of buds.
3. What general types of tissue are found in a seedling?
4. Give the three different types of leaf arrangement and give an example of each.
5. Describe the general structure of some common leaf.

6. What part of a root is primarily concerned with absorption?

7. What is the difference in the general structure and function of the xylem and phloem vascular tissues?

8. What is the difference between an organ and a tissue in a plant?

9. In what way is a cross section of a tree trunk a record of climatic conditions?

10. Trace the course of water from root hairs through the leaves of a tree into the atmosphere.

11. Give two reasons for the coolness of a forest.

12. What factors seem to account for the rise of water in tall trees?

13. In what different ways are leaves fitted to get rid of excess water?

Activities

1. Use a razor blade, section razor, or a microtome to make thin cross sections of roots, stems, and leaves for microscopic examination.

2. Identify and compare the external parts of the roots, stems, and leaves of the plants you have in the laboratory or classroom.

3. Observe the root hairs of germinating seedlings. Place a drop of strong salt solution at the edge of the slide and watch what takes place.

4. Examine whatever prepared slides of the cell structure of plants there are in the school collection.

5. Make capillary tubes by heating and drawing out pieces of glass tubing. How high can you make the water rise?

6. Remove a branch from a geranium plant and fit a cardboard washer closely over the stem. Insert the stem into a graduate containing water so that the water level reaches the top of the scale marked on the graduate. How fast is water lost (*a*) in a warm, dry, light room? (*b*) In a cool, dark place?

References for Unit Four

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Unit 5

NUTRITION

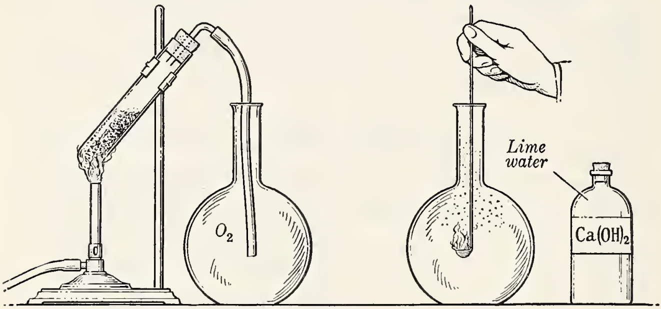
Most of the activities and processes of the simpler living things are related to the securing and use of food. The same is true of higher plants and animals. Just as the tiny green plants within a drop of pond water manufacture food for the tiny animals, so the larger green plants provide food for the larger animals. Moreover, many kinds of living things have developed highly specialized ways of securing and using food. The food relationships of all kinds of plants and animals are important to human welfare, as you will discover in Unit Five.

13. Nutrition in Green Plants

A chemist in his laboratory can do many remarkable things with matter and energy. He can combine some substances to form new substances and break down complex materials into simpler ones. He can cause chemical reactions to occur by supplying energy and can obtain energy from other chemical reactions. Some of the chemical changes carried on in the bodies of plants and animals can be duplicated in the laboratory. But living organisms, particularly green plants, can do many things that no chemist has yet learned how to do. The most important of these processes is the combination of carbon dioxide and water by means of the energy of sunlight.

It is usually easier to take things apart than it is to put them together. It is very difficult to combine carbon dioxide and water to produce starch or sugar, as the green plant does, but the reverse of this process may be illustrated by a simple experiment. Collect a bottle of oxygen by the downward displacement of air. Place a small amount of wood or other plant tissue in a deflagrating spoon, ignite it, and lower it into the bottle of oxygen. You will observe a rapid chemical change. You will also observe the condensation of water on the sides of the bottle and the residue of minerals left in the spoon. If a little limewater is poured into the bottle and shaken, you will conclude that carbon dioxide has been formed. Besides these three material substances, some energy will have been liberated as heat and light. You will have obtained the same materials and the same energy that were used in the formation of the original plant tissue.

Carbon dioxide Water Minerals Energy	→ Plant tissue + oxygen →	Carbon dioxide Water Minerals Energy



Left: collecting oxygen by downward displacement of air. Right: burning plant tissue in dry oxygen. What conclusions may be drawn from this experiment?

Foods and Nutrients

When we analyze the tissues of green plants, we find thousands of different kinds of substances. Among these are starches, sugars, resins, cellulose, dextrin, proteins, fats, and oils. These substances are products of chemical changes and are built of the basic raw materials: soil, water, and carbon dioxide. Most of the finished products that are built up by the chemical activity of green plants are suitable foods for other organisms. These food materials may be divided into three types of chemical compounds: *proteins*, *carbohydrates*, and *fats*. Together with *mineral salts* and *water*, they make up the group of substances which we call *nutrients.* Nutrients are the useful materials in the foods of plants and animals. Most common food substances are mixtures of these nutrients.

Carbohydrates. This name suggests two words, carbon and water. It is of these two substances that carbohydrates are composed. In the tissues of green plants,

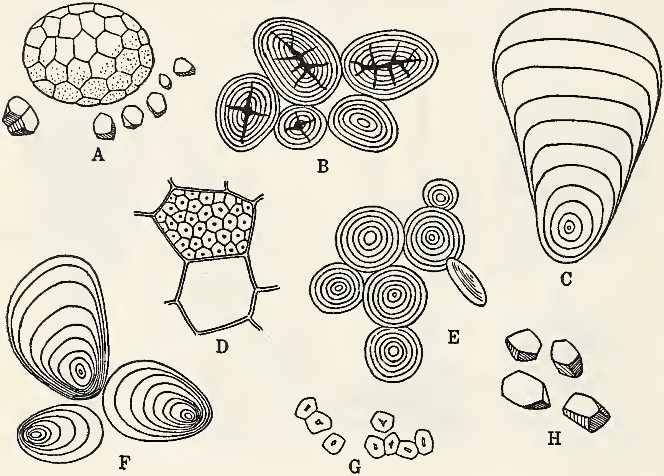
Potato *Cassava* *Wheat* *Sugar beet*

These plants are carbohydrate factories.

carbohydrates exist in greater quantity than any other class of compounds except water. Pour some concentrated sulphuric acid on a carbohydrate, such as a piece of wood, a lump of sugar, or a bit of starch. The acid will remove the water and leave a black residue which is carbon. Carbohydrates, then, are composed of carbon, hydrogen, and oxygen, the latter two elements being present in the same proportions as in water, that is, two atoms of hydrogen to each atom of oxygen.

Carbohydrates include sugars, starches, and celluloses. Of these, starches and sugars are most widely useful to animals, although cellulose is food material for some.

The presence of the different nutrients contained in foods can be determined by simple tests. In the previous unit we have had occasion to determine whether or not



Probably no two species of plants turn out exactly the same kind of compounds. Here are starch grains of (A) oats, (B) beans, (C) canna, (D) rice, (E) wheat, (F) potato, (G) corn, (H) millet.

starch was present in plant tissues, by noting their reaction to iodine. This same test may be used to determine the presence or absence of starch in foods. If we obtain a blue color by putting a drop of iodine on a substance, we know that it contains starch.

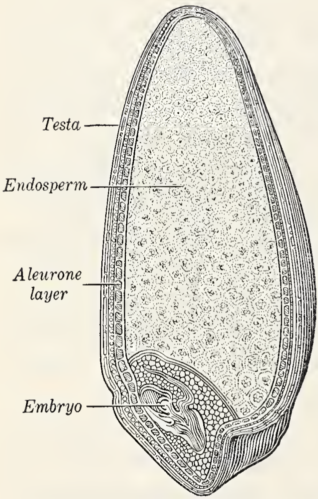
Another carbohydrate, *glucose*, or grape sugar, may be detected by the use of Fehling's test. This test is made by the use of two solutions, one colorless and the other blue. The blue solution contains a copper salt. When equal quantities of these solutions are mixed with a sugar solution and heated, a yellow-brown or red precipitate is formed. This colored substance is an oxide of copper and its formation indicates the presence of glucose or some related sugar. Cane sugar does not respond to this test, but in plants and animals the sugars present usually contain enough glucose or a relative to give the reaction just described. The presence of glucose may also be detected by the use of Benedict's solution. Physicians use this test because of its sensitiveness and high reliability.

Fats. Everyone knows that peanuts are oily, and that oils are obtained from castor beans, cotton seeds, and other materials. Lard, cod-liver oil, castor oil, and butter are common examples. Plant and animal fats are usually tested for by crushing the material to be tested and mixing it with ether. The mixture is then filtered and the filtrate allowed to evaporate until all the ether is gone. The "ether extract," a fatty material, remains. Another common test is to crush the material and warm it on a piece of glazed paper. If fats are present, a translucent spot will appear on the paper. This is not a very delicate test, since many oils will evaporate and not leave a permanent grease spot. For example, some of the oils found in coffee beans are volatile and their evaporation is largely responsible for the odor of freshly ground coffee.

Proteins. If nitric acid is added to a small amount of protein-containing material, a yellow-colored substance is formed. When washed with water to remove the excess nitric acid and then treated with ammonium hydroxide, it will change from a yellow color to a deep orange. Proteins are found in large amounts in bean seeds, lean meat, white of egg, cheese, and many other organic materials.

There are various kinds of proteins. The chemical formulas of these compounds are usually very complex, and chemists have so far been unable to produce them synthetically. The average elemental composition of proteins is approximately as follows:

Carbon	51 per cent
Oxygen	25 per cent
Nitrogen	16 per cent
Hydrogen	7 per cent
Sulphur	.4 per cent
Phosphorus	.4 per cent



Wheat and other cereals are important as sources of proteins. In the wheat grain the proteins are found in the aleurone layer.

The percentages given above vary considerably with different proteins. Phosphorus is not always present, and other elements such as iron enter into the composition of some proteins.

Water. Water makes up a large proportion of most food substances. Even plant or animal tissue which appears to be dry usually contains a considerable amount of water.

The amount of water that is present in any substance may be determined very easily. The apparatus needed is an oven and scales. If the specimen is weighed carefully before heating, together with the vessel in which it is contained, and then heated in the oven to drive out the water until repeated weighings show a constant weight, the difference in weights before and after heating represents the amount of water present in the original specimen.

Minerals. If you take the dried specimen left from the previous experiment and burn it, you will discover that some ashes are left which will not burn. Chemical analysis of such ashes will reveal the presence of several elements. Calcium, iron, sulphur, sodium, potassium, and phosphorus will usually be found, and possibly traces of copper, manganese, zinc, and boron. These elements will not, of course,

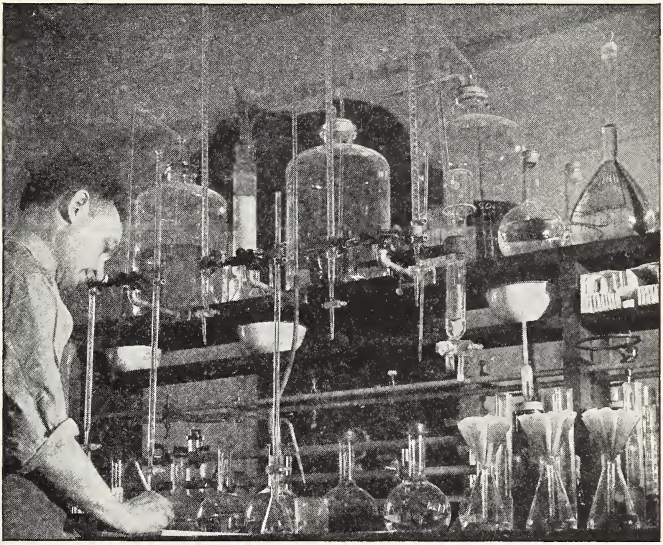


Photo from Ewing Galloway

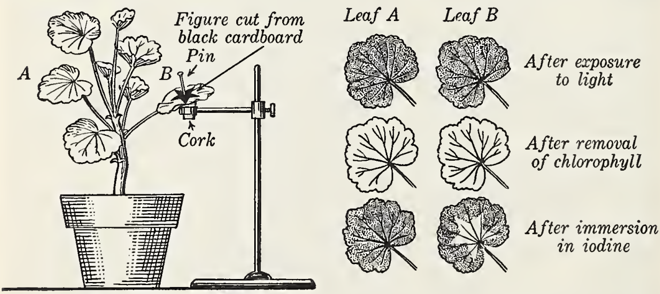
A chemical laboratory or factory of today can make an immense number of different compounds, but the green plant can do many things no chemical laboratory has ever accomplished.

be found in their free state. They are always found in the form of compounds. Such compounds are usually referred to as "minerals" in discussing plant and animal nutrition.

The Synthesis of Carbohydrates

Of all the nutrient materials used by plants and animals, carbohydrates are the most abundant sources of energy. They are also the first of the three great groups of energy-containing nutrients to be formed in the tissues of green plants by the *synthesis* (combining) of raw materials taken in from the environment. Without carbohydrates the existence of the kinds of living things we know would be impossible. Although we cannot watch the process of carbohydrate making, we do know a great deal about it, and our knowledge of it is constantly being extended by hundreds of research workers.

Remove a green leaf from a plant that has been exposed to the sunlight for several hours. Place the leaf in warm alcohol to remove the coloring matter and test it with

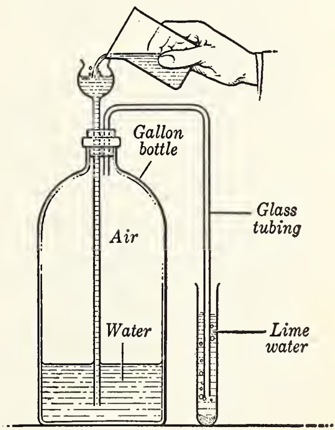


In the iodine test for starch to see under what conditions a green leaf manufactures starch, why does one part of leaf B remain light?

iodine. The blue color indicates that starch is present. We know that starch is composed of carbon, hydrogen, and oxygen. We also know that since starch is insoluble in water it could not have come from the soil. How can we account for the presence of starch in the leaf?

Sunlight. If portions of a leaf that has been kept in the dark are covered with tinfoil or other opaque material and the leaf is exposed to sunlight, the iodine test will reveal the presence of starch only in those portions that have received energy from the sun. The covered portions show negative results. Evidently sunlight is necessary for starch synthesis. It furnishes the energy for the plant factory.

Water. In the preceding chapter we learned that water in plants is obtained chiefly from the soil through the roots and that it moves up the stems to the leaves. Water and starch both contain hydrogen and oxygen in the proportion of two parts of hydrogen to one part of oxygen. Since there is no hydrogen in the air and the plant has no other means of obtaining hydrogen, we are led to the necessary conclusion that water is the source of hydrogen and oxygen in starch.



You can test air to see whether it contains the carbon dioxide which aids plants in manufacturing starch.

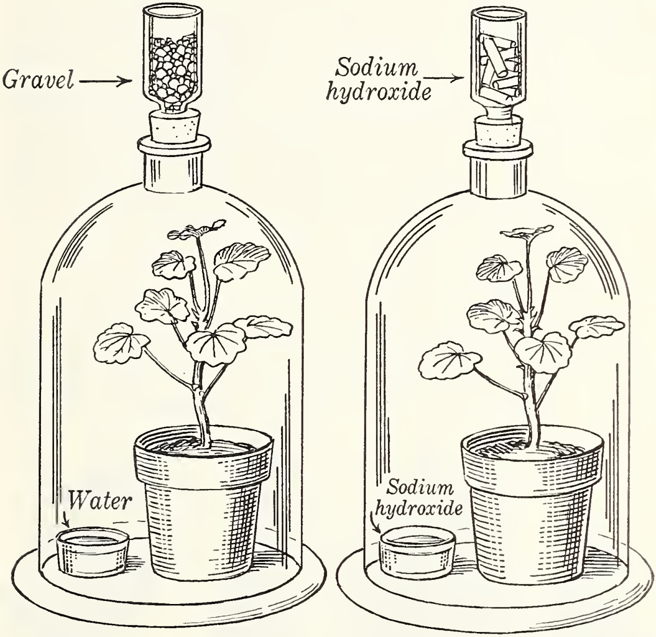
Carbon. Air is the source of the carbon which goes into starch manufacture. The element carbon is present in the air in the form of carbon dioxide. That air contains carbon dioxide can easily be shown by forcing air through limewater. The carbon dioxide reacts with the limewater and forms a white precipitate. Although air contains less than four parts carbon dioxide to ten thousand parts of air, this amount is extremely important, since plants cannot manufacture starch without it.

Now if we expose a leaf to sunlight in the presence of air from which all the carbon dioxide has been extracted, no starch is formed as indicated by the iodine test. Since carbon dioxide is the only constituent in the air from which carbon could possibly be obtained, the need of carbon dioxide for starch synthesis is evident. A further test may be made by coating part of the underside of a leaf with petrolatum and exposing it to sunlight. The covering closes the stomata, shutting off the supply of carbon dioxide, and the test for starch is negative in the covered part.

Chlorophyll. The leaves of some plants are not solid green in color. Certain varieties of grasses and geraniums, for example, have leaves with borders or streaks of white running through them. If such a leaf is exposed to light and then tested with iodine, starch is found only in those portions of the leaf that were green. We may then conclude that, in the leaf, chlorophyll plays an important part in starch synthesis.

In fact, it can be shown by experiments that starch may be formed not only in leaves but wherever chlorophyll is found in a plant. The stems of many plants and, in some species, the roots of plants contain chlorophyll. Cactus plants, such as the prickly pear, have no true active leaves. The so-called "leaves" of the prickly pear are stems, and it is in these stems that starch production is accomplished. The carbohydrates of these prickly pear sections are a valuable food for cattle. People in the Southwest often cook them and use them as food.

The action of chlorophyll in starch synthesis may be compared to the action of manganese dioxide in the laboratory preparation of oxygen. When potassium chlorate and manganese dioxide are heated together in a test tube, oxygen is given off. The oxygen really comes from



In this test to see if carbon dioxide is necessary for starch manufacture, the sodium hydroxide removes the carbon dioxide from the air. Should the experiment be set up first in the dark? If plants are used which have been standing for some time in the dark, a definite result is obtained much more quickly. Why?

the potassium chlorate but the presence of manganese dioxide helps to promote the reaction. Substances that act in this way to promote change in other substances without being changed themselves are called *catalysts.* Chlorophyll acts as a catalyst when water and carbon dioxide combine to form starch in green plant cells.

Scientists have already succeeded in combining carbon dioxide and water in the laboratory to form small amounts of carbohydrates. The process is not yet commercially profitable, but perhaps some day we shall be making sugar, starch, and other foods out of water and air on a large scale. For the present, however, we must depend upon green plants for our food. As long as the sun supplies them with energy, the clouds supply them with water, and the air supplies them with carbon dioxide, green plants will keep on making carbohydrates anyway.

The Production of Fats

Although plants have no specialized fat-producing apparatus, fats are formed in plants and are probably present in every living plant cell. In many plants of the lily family,

These plants are noted fat manufacturers.

tiny droplets of oil occur in the cells of the leaves as storage products instead of starch. In such leaves the iodine test fails to reveal the presence of starch at any time. Large quantities of fat may be stored in seeds and in some underground stems. The fat content of some plant tissues is very high. Castor beans and peanuts usually contain about 50 per cent fat, while the meat of the coconut may contain as much as 60 per cent. Like starch, fats are inactive storage substances and must be made soluble before being used by the plant.

Formation of fat from carbohydrates. There is abundant evidence that fats are built up from carbohydrates. In ripening seeds there is often a decrease in the starch content and an increase in the fat content. It has been shown that when sugars are transported to certain plant tissues, they disappear as the fat content of the tissue increases. The energy used in transforming sugars into fat is derived from the oxidation of a part of the sugar content and is not obtained directly from sunlight.

In the formation of fats, two series of chemical changes occur. In the first of these, carbohydrates are changed into fatty acids, the commonest of which are palmitic, stearic, and oleic. Fats result from the action of fatty acids on glycerin.

$$\text{Carbohydrates} \longrightarrow \left\{ \begin{matrix} \text{Fatty acids} \\ \text{Glycerin} \end{matrix} \right\} \text{Fats and oils}$$

Protein Synthesis

Protein molecules are larger and more complex than those of either carbohydrates or fats. Proteins are essential constituents of all plant and animal cells and of the protoplasm itself. They occur as fine granules in the sap of the cell vacuoles and as larger granules in the cytoplasm.

Protein synthesis may occur in almost any part of a plant but is carried on principally in leaves, where the carbohydrates are made. It has been shown experimentally that light is not an essential factor in the process, since plants are able to synthesize proteins in the dark.

Physical characteristics of proteins. The physical properties of proteins differ considerably from those of fats and carbohydrates.

The protein known as *gliadin* may easily be separated from wheat flour for examination. Make a stiff dough by adding water to white flour. Knead it and let it stand for twenty minutes. Then tie the dough in a piece of thin cloth, place it in water, and knead it a few more minutes. Test the water in which the dough has been kneaded with iodine. Hold the contents of the cloth under a faucet and keep kneading it until no more milky material runs out. Open the cloth and examine the contents. Apply the chemical test for proteins.

The protein *casein* may be separated from milk by adding about 2 cc. of vinegar to 10 cc. of milk, and warming gently until the solid portion separates from the liquid or whey. If the whey is filtered off, the material remaining on the filter paper will consist principally of casein. Casein is one of the main ingredients of cheese.

Chemical structure of proteins. When proteins are decomposed, compounds known as *amino acids* are formed. This indicates that proteins are compounds that result from the chemical union of simpler compounds. The amino acids which enter into the composition of proteins all contain nitrogen secured almost entirely from nitrates dissolved in soil water. The nitrogen occurs combined with hydrogen in the group of atoms NH_2. This NH_2 group of atoms is the fundamental chemical unit which distinguishes proteins from other food compounds. In protein synthesis, these NH_2 groups combine with other

Large quantities of proteins are produced by these plants: (a) pea, (b) alfalfa, (c) clover, and (d) bean. Animals can make their own proteins out of amino acids, but only plants can supply the animals with their needed amino acids.

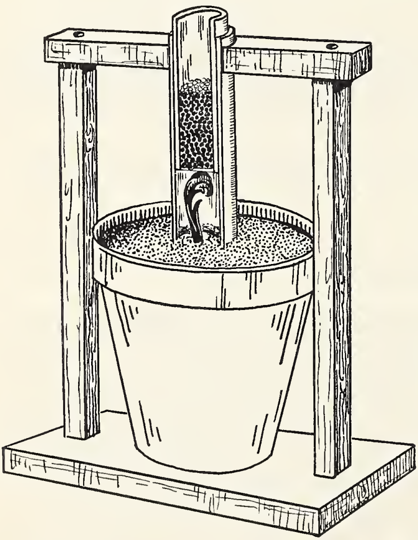
groups of atoms which were previously united by carbohydrate synthesis.

Digestion and Respiration

Proteins, starches and fats all have comparatively large molecules. Such molecules will not dissolve in water and are too large to pass through membranes in osmosis. In order to move these nutrients from the place where they are stored to the place where they are used in a plant, it is necessary to break down their large molecules and split them into smaller molecules.

Digestion in green plants. When the sun is shining and roots are taking in water, the materials necessary for the growth and activity of a green plant are readily available. But when a seed is germinating or a young plant is beginning its seasonal growth, it is necessary for the plant to draw on its supply of stored food. Since nutrients are stored in insoluble form, the making of these nutrients available for growth and energy requires digestion. In the process of digestion, water is chemically added to the original substances. This brings about a splitting of the large, complex molecules into simpler, smaller ones.

Digestive changes are brought about through the activity of chemical substances called *enzymes*. Enzymes are catalysts which, like chlorophyll and manganese dioxide, help to promote chemical changes without being changed themselves. The enzyme which enables plants to carry on digestion of starch is called *diastase*.



Could you lift as much lead shot in proportion to your size as this seedling does? What is the source of energy by which the seedling accomplishes this feat?

Respiration in green plants. If a thermometer is inserted into a bottle of germinating bean seeds, a rise in temperature will be noted. The release of energy by plants is also shown by the ability of seedlings to exert considerable force as they push their way out of the ground. The roots of trees often break rocks apart or push them out of the way.

Plants obtain heat or energy in the same way that animals do. The source of the energy is food. Combining food materials with oxygen breaks them down into water and carbon dioxide, and energy is released.

In plants, as in animals, the process of respiration goes on all the time. At night, when plants cannot manufacture food, oxygen is taken in through the stomata and carbon dioxide is given off. In the daytime, oxygen is constantly being released as a result of photosynthesis. Some of this oxygen is used in respiration, and the rest is given off into the air. Since respiration and photosynthesis are so often confused, the following comparison of the two processes is made in tabular form:

Photosynthesis	*Respiration*
H_2O and CO_2 are raw materials	H_2O and CO_2 are waste
Organic materials constructed	Organic materials destroyed
Storage of energy	Release of energy
Liberation of oxygen	Absorption of oxygen
Occurs in green tissues only	Occurs in all plant and animal tissues

Review and Thought Questions

1. Name three kinds or types of nutrients.
2. Of what chemical elements are carbohydrates composed?
3. How can you test for the presence of starch?
4. Why do physicians test urine with Benedict's solution?
5. How are the following plant and animal fatty products obtained: butter, peanut butter, lard, cod-liver oil, castor oil?
6. Why are beans or eggs often substituted for meat in a meal?
7. What elements enter into the composition of proteins?
8. The carbon in coal was once part of the air. Explain.
9. What is meant by a catalyst?
10. Contrast photosynthesis and respiration.

Activities

1. Select two leaves from a geranium plant and, without removing them, coat the upper surface of one and the under surface of the other with vaseline. Allow the plant to remain in the sunlight for several hours. Then test the leaves for starch. Explain the results.

2. Fasten a piece of platinum foil to one end of a wire. Run the wire through a piece of cardboard. Heat the platinum foil and place it over the surface of some wood alcohol in a beaker. The change of wood alcohol into formaldehyde is a good example of catalytic action.

3. Test various parts of plants and plant materials for sugar, starch, protein, fats, water, and minerals.

4. Water a plant with weak salt solution and observe.

5. Test seeds for sugar before and after germination.

6. Make a list of the experiments suggested in this chapter. Check the experiments you performed and write a summary of your conclusions.

7. For each of the following, starch, sugar, cellulose, fat or oil, and protein, make a list of five or more plant products which produce the largest amounts of these substances.

8. Soilless culture of garden plants is an important modern development. Look up magazine articles describing it. Send for materials to some seed company or other plant supply house and try an experiment in this method of raising plants.

14. Nutrition in Animals

Because of their activity, animals require large amounts of food. Most of this food is used to supply energy for heat and motion. Strangely enough, the greatest animal activity is in search for food, and most food is used to provide energy to search for more food.

The typical plant absorbs its food materials by diffusion through its external membranes and later builds them into organic materials. The typical animal takes in organic materials and then changes them into substances that may be absorbed through its internal membranes. The nutritive problems of plants are therefore much different from those of animals. Plants are said to be constructive in that they build up and store large quantities of energy in the form of organic substances. Animals are destructive in that they break down organic substances and thus release energy stored up by plants. The general term which includes all the building up and breaking down processes carried on by plants and animals is *metabolism.*

Animal Tissues and Organs

In our study of animal nutrition we shall consider the activities of tissues and organs rather than those of single cells. Beginning with Planaria, all higher animals are based on a three-tissue plan. All show, in their early stages of development, an ectoderm, an endoderm, and a mesoderm. In later development, these tissues undergo great specialization, as we shall find in some of the more complicated structures in the higher animal forms.

In the higher animal forms, it is a common practice to classify the tissues into five main divisions: *connective tissues,* which include bone, cartilage, and fat; *epithelial*

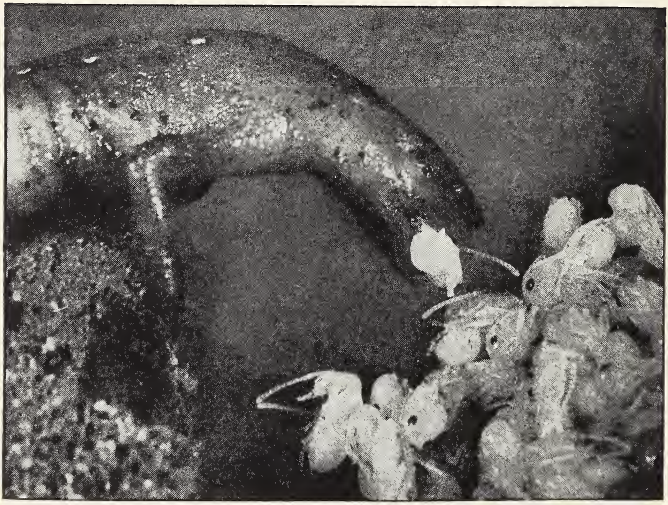
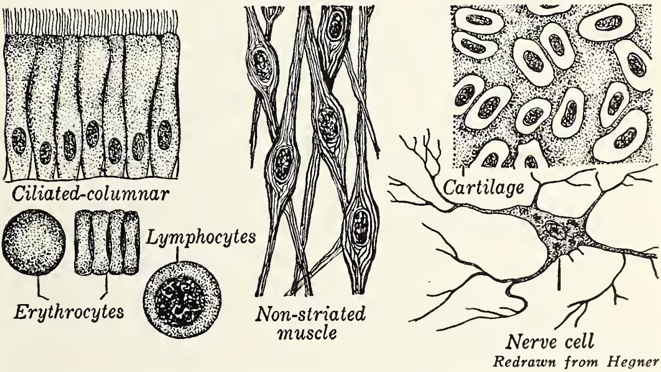


Photo by Lynwood M. Chace

An animal eats to live and lives to eat. This salamander is finding the mass of plant lice a wonderful meal.

tissues, which constitute all external and internal surfaces, including glands; *muscular tissues,* those fitted for accomplishing movement; *nervous tissues,* and finally, the *blood.* By examining prepared microscopic slides you should become familiar with the structure of these tissues and of the cells that compose them. For the purpose of understanding the general structure of higher animals, make a rather complete study of one form, drawing comparisons between the various tissues and organs of this specimen and those of higher animals, including man. The earthworm lends itself exceedingly well to detailed study in the laboratory.



The food the salamander eats, or the food that we eat, finally serves one of two purposes, energy, or the formation of tissues. Bread, butter, meat, and vegetables may eventually be transformed into body tissues, examples of which are shown.

The earthworm. Earthworms live all over the land areas of the earth except where the ground is too cold or too dry. There are a good many different species and genera. One kind, native to Australia, reaches a length of six feet. Living as they do in dark burrows, they have some of the peculiarities of dwellers in the dark, but they also show features of structure, of tissues and of organs, that make them generally important in biological study.

Habits and habitat. Anyone who has dug earthworms for fishing bait knows that the best way to get the largest "night crawlers" is to look for them after dark, using a flashlight. They may also be found outside their burrows after a rain. Earthworms may be raised in the laboratory in tubs filled with soil, and with the surface sprinkled with coffee grounds. In many regions where fishing is popular, earthworm farms have been established.

At night, earthworms regularly come out of their burrows to seek food, which consists mostly of dead plant material. Their holes are often stuffed with mown grass, which they pulled in during the night. They cannot stand bright sun or dry air because, in order to breathe, they must keep their body surface moist. In dry weather, they may retreat two or three feet deep in the ground. They dig burrows by taking the soil into their mouths and passing it through their bodies. Their burrows are marked by little piles of soil deposited about the entrances.

External structure. A live earthworm is a reddish, soft animal, with its body divided into rings, or *segments,* and with no definite head. The most conspicuous external structure is the *girdle,* a band about a third of the way from the darker and thicker end. In the other two thirds, back of the girdle, the body is somewhat flattened above and below. There are two openings, one at each end of the body.

The large earthworm, or night crawler, swings around a circle, picking up bits of grass and other organic matter. He eats his way through the soil, and deposits the indigestible part of what he has eaten at the mouth of his burrow.

By watching a live worm crawl it can be seen that the darker, rounded part is the forward part. If watched coming out of its hole in the evening, this is the end which is extended and moved about the ground, with the burrow as the center of a circle of action. Crawling is a matter of extending the forward end, which becomes smaller and longer. This part then is fixed and the hind part is pulled up toward it.

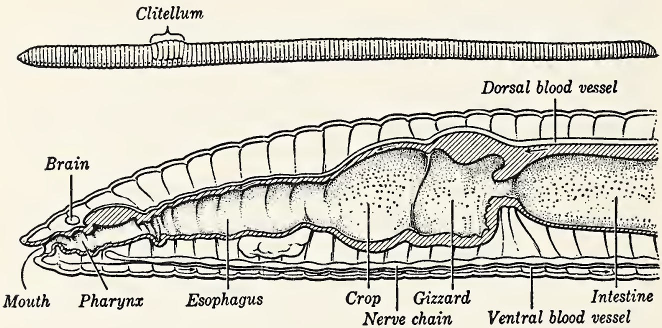
If a finger is passed along its under surface, several rows of bristles can be felt. These bristles are called *setae*. Sometimes they are extended toward the back, sometimes the other way. When you try to pull a worm out of its hole, it responds by extending the setae and by increasing the diameter of the hind portion, thus making it very difficult to dislodge.

Look at the back of the animal and notice a thin red line. If you will press down against this toward the back end, you will find that the part in front becomes paler. The red line is a blood vessel, and blood flows through it toward the front.

Internal structure. A good-sized earthworm is an interesting animal to dissect. The large preserved specimens supplied by dealers are excellent. If live ones are used, they should be killed by immersion in alcohol or formalin. A regular dissecting pan, with a layer of paraffin in the bottom, is most convenient for the process.

Fasten a worm by pinning it to the paraffin with its darker side up. Be careful to put the pins to the side, otherwise you may run the forward pin through some important structure. Using a pair of small, sharp-pointed scissors, start to slit the back of the worm, beginning back of the girdle. Be careful not to cut too deeply, only through the muscular body wall. As you extend the slit forward, pull the sides of the cut open, and pin to the side, exposing the internal parts. Run the cut clear to the pointed front end, but be exceptionally careful near the tip, because the most important nerve center lies just there. When you have completed the slit and pinned out the cut walls, you will be in a position to observe the internal organs, with the help of a magnifying glass. If a dissecting microscope is available, the structures can be seen much more clearly.

The most noticeable structure will be the long digestive tube or *enteron,* extending completely through the length of the worm. Next, you will notice that the space around this enteron is divided by cross partitions, or *septa* (singular *septum*). In front of the girdle, you will notice several rather large whitish bodies; these are reproductive struc-



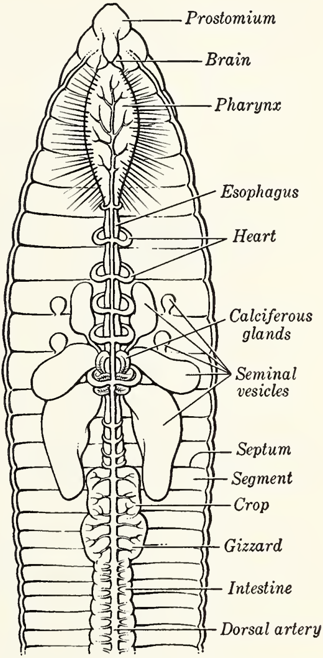
The earthworm body plan is that of most higher animals reduced to its simplest form. A food tube runs straight from mouth to anus, surrounded by a body wall.

tures. Along the back of the enteron runs the *dorsal blood vessel,* the main blood tube of the worm's body.

Digestive system. Notice that the enteron is divided into several sections, or digestive organs. At the front end, the mouth opens into a muscular *pharynx,* or throat, connected with the body wall by many slender muscles. Back of the pharynx is a narrower portion, the *esophagus.* Back of this esophagus is a much larger, thin-walled *crop,* a sort of storage place for food. Then comes the thick-walled *gizzard,* where food materials are ground up with the help of bits of sand. After the gizzard comes the long stretch of *intestine,* which extends all the way back to the posterior opening, the *anus.*

Other organs. Along the top of the intestine you may find the *dorsal blood vessel,* the main blood vessel of the body. From this, small branches extend around the intestine to join a smaller trunk vessel, the *ventral blood vessel,* under the intestine. In the neighborhood of the gizzard and crop, there are five pairs of larger branch blood vessels, known as the *aortic arches,* and sometimes called "hearts."

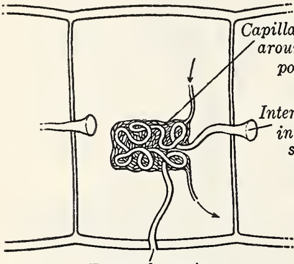
Cut away a small part of the intestine and look for a slender white cord underneath, next to the body wall. This is the *ventral nerve cord,* which extends throughout the body but branches near the very front into a pair of nerves which pass around the pharynx to join in a large double *ganglion,* or "brain," on top of the pharynx. If you will cut away the pharynx muscles very carefully, you can expose this ganglion as a small, white body.



Along the top of the intestine runs the main artery or dorsal blood vessel. Find the five aortic arches or hearts.

With a strong hand lens, or under the lower power of the microscope, examine a piece of body wall between two septa. You should find a coiled tube, the *nephridium* (plural *nephridia*), or kidney.

Here we have located and named a series of organs almost identical with those found in the human body. Each of these organs or organ systems carries on the function indicated by its name: ingestion, digestion, circulation, excretion, and nervous control. What organs present in your body are not found in the worm? You will realize that you have not found any air passages or sacs, like the lungs, but aside from this, the lowly earthworm shows the same general types of structures that man possesses.



The earthworm kidney, or nephridium takes useful substances out of the body fluid and discharges the wastes of metabolism outside the body.

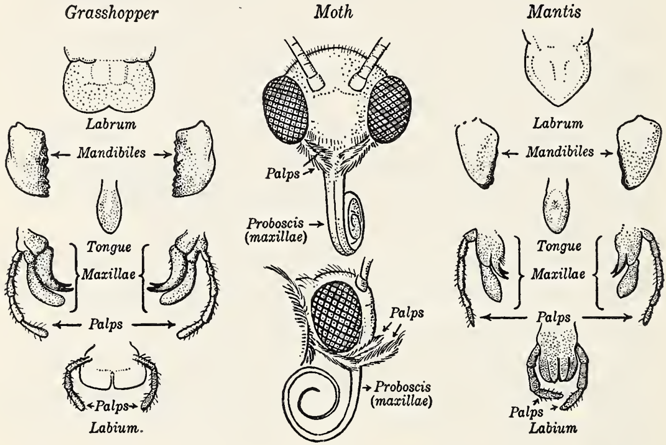
Ingestion, digestion, and egestion. With a mouth and slender upper "lip," the earthworm picks up food materials. It *ingests,* or draws these foods into its food tube, by suction created in the pharynx. There, a series of wavelike contractions push the food backward, through the esophagus, and into the crop. The food passes from the crop into the gizzard for grinding, and then on further into the intestine where *digestion* is completed.

While boring its holes, the earthworm may also take in quantities of soil with little organic matter in it. This and the other indigestible portions of its food are *egested,* or passed out, through the anus. The wavelike contractions of the alimentary canal are known as *peristalsis.* The same name is applied to similar contractions in our own alimentary canal.

Insects. Insects feed upon a great variety of foods. The female mosquito prefers blood, while the male is satisfied with the sap from plants. The elm-leaf beetle bites and chews the foliage of our shade trees. The honeybee and butterfly drink the nectar of flowers, while the carrion beetle devours decaying animal flesh. The housefly eats almost all kinds of organic matter, but prefers liquids, which are ingested with the aid of its spongelike tongue. Grain weevils gnaw the dry starchy food in grains, and the timber beetles are quite content with a meal of the dry wood of tree trunks. Others, such as bird lice, are satisfied with bits of feathers, and the clothes moths feast on the woolen fibers of our rugs or clothing.

Food-taking structures. With this range of food, it is obvious that the food-taking parts must show many differences. The grasshopper needs strong biting jaws; the mosquito and cicada have sharp, piercing beaks; the honeybee, the moth, and the butterfly each possesses a long, flexible sucking tube or proboscis; while the housefly has a broad, lapping tongue.

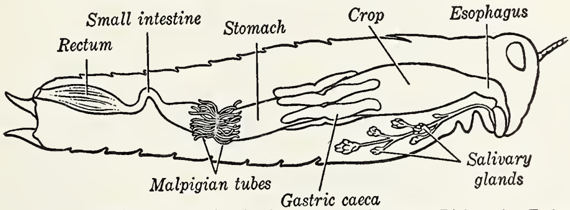
The mouth opening in insects is vertical instead of horizontal as in other animal groups. There are two sets of jaws: *mandibles* (upper jaws) and *maxillae* (lower jaws). In addition there are an upper and a lower lip (*labium* and *labrum*), the *labial palps,* and the *tongue.* These mouth parts are modified according to the type of food taken. In the great majority of flies, as also in moths and butterflies, the mandibles have become small through lack of use, while in the chewing type of insect they are large, strong jaws with toothed and grinding edges. The mandibles of the bee are trowel-like, for molding wax. They are long, slender, and sharp pointed in the piercing insects, so that they act as piercing needles to make punctures in the flesh of animals or tissues of plants. In moths and butterflies the long sucking proboscis is formed by two maxillae, which are greatly elongated and fastened together side by side. The two maxillae are grooved and so fastened together that the grooves form a tube through



The grasshopper eats leaves, and the mantis eats insects, but both bite and chew their food, and have very similar mouth parts. The mouth parts of a moth or butterfly suck in liquid food and are differently shaped, although built of the same basic parts.

which the liquid can be sucked. The labial palps in the housefly are expanded into broad plates which are fitted for rasping, while the labrum or underlip is modified into a proboscis. The tongue in the mosquito is used for sucking up liquid after the mandibles and maxillae have punctured some plant or animal victim.

Digestive system. Since most insects are highly fitted for getting food, digestion, as would be expected, takes place rapidly. In many sucking insects very little or no digestion is needed. It is in the chewing insects that the alimentary canal is most highly developed. As in the other higher animals, there is a central tube that extends the length of the body. In larvae, this tube is nearly straight, but in adults it is usually much longer than the body, and is consequently more or less folded. The following parts can be distinguished: a pharynx, an esophagus, sometimes a crop or sometimes a gizzard, a stomach, a small intestine, and a large intestine ending in an anal opening. Two



The animal digestive system almost always follows the same plan: a tube to hold the food, and glands to make the enzymes which dissolve the food.

salivary glands empty by a common duct into the floor of the mouth. It is in the crop that the "molasses" thrown out by the grasshopper originates. Here are found large irregular teeth armed with spines and hairs. From the anterior end of the stomach arise six large *gastric caeca* which secrete a digestive fluid that acts on food in the crop. The blood of insects is not enclosed in tubes, so that the digested food is quickly brought into contact with all parts of the body ready for assimilation and oxidation.

Vertebrates. Fishes, amphibians, reptiles, birds, and mammals are built on the same general plan. Characteristically they consist of a head region, a trunk region, and two pairs of limbs. The head is specialized for ingestion and sensation, the trunk for nutrition, and the limbs for locomotion. There is also a very close resemblance in internal structure. As in the earthworm and in the insect, the trunk region consists of two cylinders, one within the other. The inner cylinder, which is the alimentary canal, is usually very much longer than the outer cylinder. Along

Photo by Lynwood M. Chace

All vertebrates are alike in body plan. The medium-sized leopard frog here had better watch out or it will turn into a giant bullfrog! Note the ear drum, especially prominent in the bullfrog.

the alimentary canal there are numerous glands which represent outgrowths and enlargements of the canal.

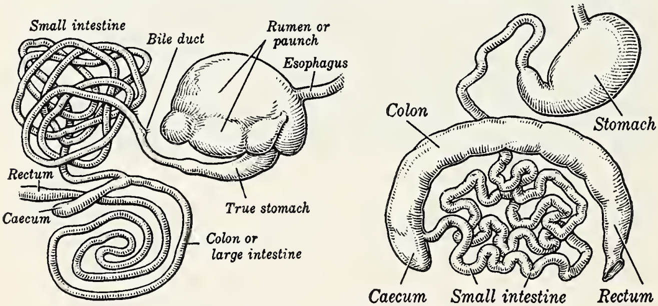
Perhaps the best way to obtain an understanding of the nutritional apparatus of vertebrates is to dissect some animal which is typical of the group, so that the various structures involved in nutrition may actually be seen. The most satisfactory and convenient subject for such observation is the frog. The internal organs of the frog are very similar in position, relative size, color, and shape to those of man and the other members of his phylum. In internal structure the chordates resemble each other even more closely than they do in external structure.

Dissection of the frog. Use a preserved specimen or a dead frog. The internal organs of the frog can, then, best be studied by cutting lengthwise through the muscular wall on the ventral side, being careful to keep to one side of the middle line so as to avoid cutting the central blood tube. Care should be taken in lifting the edge of the cut with forceps so that none of the abdominal organs are injured. Cut through the breastbone a little to one side so as to see the heart. Fasten back the flaps of the abdominal wall and keep the specimen flooded with fresh water.

The large dark organ covering most of the internal organs is the liver, which consists of two lobes. Under the lower free ends of the liver is the *bile sac*, which is connected with the liver and empties into the small intestine by a *bile duct*. The heart, a pear-shaped organ, lies just anterior to the liver and extends between its two lobes. The *pericardium*, a very thin sac, encloses the heart. Usually the short ventral *aorta* or blood vessel can be traced from the ventricle or lower part of the heart until it divides into branches leading to the head, body, and lungs. On each side of the anterior end of the heart and usually concealed by the liver are the two lungs. These are nearly plain, hollow sacs, and not spongy all the way through like the lungs of mammals. The *glottis* through which the air passes from the mouth to the lungs is just in front of the *esophagus* or food tube.

The short esophagus leads directly into a long tubular stomach, which can be seen by pushing the free ends of the liver to one side. A narrowing in the diameter of the tube divides the stomach from the small intestine. From that point the coils of the small intestine can be traced until the diameter suddenly increases, forming the large intestine or rectum, which passes without change of diameter into the *cloaca,* from which wastes are discharged. The *pancreas* is found in a loop formed by the stomach and small intestine and empties into the bile duct near its entrance into the small intestine. The *spleen* is a small, dark red organ lying near the beginning of the large intestine.

Under the organs of the alimentary canal on either side of the median line in the dorsal region is found a pair of reddish glandular bodies, the kidneys, and from each kidney a tube (*ureter*) can be traced toward the cloaca. Along the side of each kidney may be seen a yellowish threadlike structure, the *adrenal gland.* A many-branched yellow structure with a glistening appearance near the



Compare the digestive tract of a flesh-eating animal with that of a plant eater. Which is which?

large intestine is called the *fat-body* and is thought to be a storehouse of nutritive material to be used in the formation of the large numbers of reproductive cells.

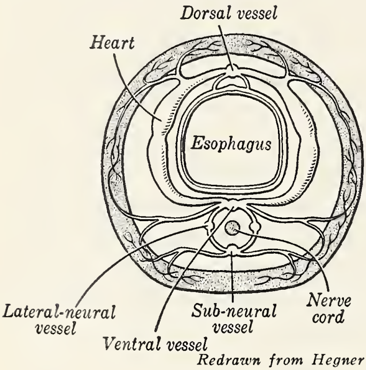
Food habits and the digestive system. Higher animals are often classified according to the kinds of food they eat.

Animals, such as horses, sheep, deer, and rabbits, that feed entirely or almost entirely upon plant materials are called *herbivorous* animals. In these plant-eating animals the alimentary canal is usually long in relation to the size of the animal, with portions of it adapted for storage of large quantities of food. Animals, such as frogs, that feed largely on the flesh of other animals are called *carnivorous* animals. Their alimentary canals are much shorter and smaller in capacity than those of the herbivores, since animal foods are generally more concentrated and require less time for digestion than plant foods. *Omnivorous* animals are those that eat both plant and animal foods. Their digestive systems are generalized, with some of the features of both the carnivorous and herbivorous types. Man is a good example of such an animal.

Circulation and Respiration

Since the function of the blood is the distribution of food and oxygen and the collection of wastes, there is no need for such a fluid in animals which are composed of only a single cell or a few cells. In the ameba or even in the Hydra, the digested food and the oxygen are readily brought into direct contact with all the cells. But as animals increase in complexity, some of their cells are placed so that they are not exposed to the food or oxygen supply. For this reason, higher animals need some system of distribution, and we find in most animals higher than the Hydra some kind of body fluid that answers the purpose of blood in our bodies.

Circulation in the earthworm. There is a true, closed system of tubes in the earthworm, conveying a red blood. Three main tubes are parallel to one another, one dorsal and two ventral. The dorsal blood vessel can easily be seen through the thin skin of the living earthworm, and the red liquid which it contains can be seen moving in somewhat regular pulses toward the head. The aortic arches receive most of the blood that flows forward in the dorsal tube and send it backward through the upper ventral tube. Circulation in the lower ventral tube is not so easily traced, but it is thought that it also flows backward. Branches from the main vessels subdivide into capillaries by means of which the blood is brought into contact with the various tissues of the body, and thus food is distributed and wastes are collected.



This cross section of a segment of an earthworm shows its hearts and blood tubes.

The red color of the blood is due to the iron compound, *hemoglobin,* dissolved in the blood fluid, the only corpuscles present being a few white ones. Besides the blood in the closed tube, we find the body cavity filled with a colorless liquid or *lymph,* and some of the food osmoses directly into this body fluid and is distributed by it, so that we actually have two methods of circulation in this single animal.

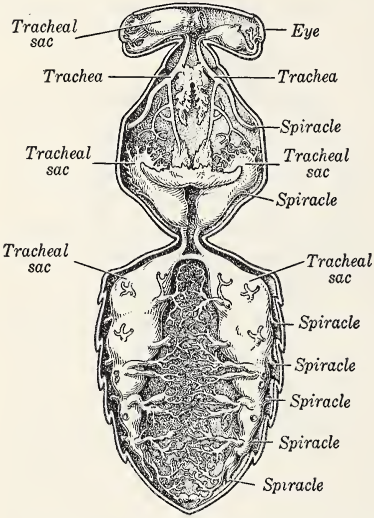
Oxygen enters the blood by osmosis through the thin, moist skin. Some of the oxygen is taken up directly by the lymph and some is taken in by fine capillaries just under the skin and distributed to the innermost tissues.

For the elimination of certain wastes, a pair of kidney tubes, the nephridia, is found in each segment except the first four. The inner end of each funnel-shaped tube is lined with cilia and opens freely into the body cavity. These organs act as simple kidneys. They excrete uric acid and water through external openings on the ventral side of the body near the bristles or setae.

Circulation in insects. The body fluid in insects varies in color from colorless to yellowish or greenish or even sometimes reddish. This fluid or *lymph blood,* as it is sometimes called, is not enclosed in closed tubes but freely bathes all the body tissues. There are no red corpuscles, or hemoglobin, as the air supply is distributed throughout the body by a system of closed tubes. Digested food osmoses into the body fluid from the food tube, and oxygen also is readily taken into the body cavity. The body fluid is kept in circulation by a flattened tube near the dorsal surface of the body. This tube with swellings along its sides is a sort of muscular pump or heart, closed at the rear end and open in front. Rhythmic pulsations of the muscular swellings cause the fluid of the body cavity to be drawn in through openings along the sides. These openings are protected by valves opening inward so that the liquid is forced forward and out the open end of the tube toward the head.

This very simple heart keeps the body fluid in motion, thereby bathing all the tissues with food and oxygen and receiving their wastes. There are numerous hairlike kidney tubes which extend into the body cavity from the intestines, and the absorbed fluid is excreted with the undigested food from the intestines.

The respiratory system and the circulatory system in insects are entirely separate. Air is brought into direct contact with the cells through a series of branching tubes called *tracheae.* Oxygen enters and carbon dioxide escapes into these tubes through the tube walls. The external openings of the tracheae are the *spiracles,* a row of which extends along each side of the abdomen. Circulation of air in the tracheae is obtained by expansion and contraction of the abdomen.



The respiratory system of a bee shows how insects ventilate their tissues by means of air tubes or tracheae. In insects alone of all the animals, the blood carries only food, not oxygen.

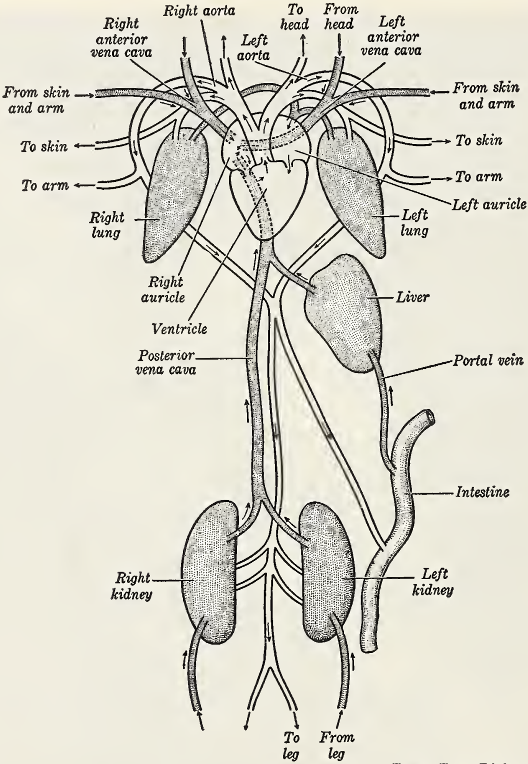
Distribution of food and oxygen in the frog. During the course of its life history the frog exhibits several types of respiratory apparatus that are characteristic of other animal groups. Very young tadpoles have external gills like the crayfish. Older tadpoles have enclosed gills similar to those of fish. Adult frogs use the skin as well as the lungs as an osmotic membrane and so are able to absorb oxygen and give off carbon dioxide when under water. They resemble the earthworm in this type of respiratory interchange. It is also interesting to note the differences in the digestive systems of the tadpole and of the adult frog. Tadpoles are almost entirely herbivorous and have the long food tube characteristic of animals that eat plants. Adult frogs subsist entirely upon animal foods and have the short food tube of carnivorous animals.

When out of water the adult frog breathes air by means of lungs. Air is forced into the lungs by a process resembling swallowing, since the frog does not possess a diaphragm to aid it in the breathing process.

Photo by Hugh Spencer

Frogs absorb oxygen through their lungs in air and through their skins in water. Here you see how a "peeper" peeps. Among frogs, the males make most of the noise.

The mechanism for circulation is similar to that found in man and other mammals. Oxygen enters the blood in the lungs. The pear-shaped heart has two auricles but differs



From Fox, *Biology*

Circulation in frogs is, in general, like that in man, except that the frog heart has only one ventricle. In this drawing the veins are shaded and the arteries are unshaded.

from the human organ in having only one ventricle. These parts are connected with a closed system of arteries, veins, and capillaries for distribution and osmosis.

When the blood returns from the lungs, it goes to the left auricle, and the blood from the rest of the body returns to the right auricle. The auricles force their blood, both pure and impure, into the muscular ventricle. By a complicated system of valves the two kinds of blood mix but little and the purest blood is sent to the head, the next best to other parts of the body, and the most impure to the lungs. Capillary circulation of blood may be observed in the web of a frog's foot under a microscope. The frog should first be put to sleep by means of a suitable anesthetic.

Besides the red blood in the closed-tube system, there is a well developed lymphatic or body-fluid circulation. The lymph, like blood without red corpuscles, occurs in many *lymph spaces* in various parts of the body and in special lymphatic vessels which pass fatty materials, absorbed from the intestine, into the veins. The lymph is assisted in its circulation by two pairs of *lymph* hearts, one near the shoulders and the other at the hind end of the body. The pulsations of the latter can be observed externally in the living frog. Wastes are taken from the blood as it flows through the kidneys. From each kidney a tube, the *ureter*, opens into the cloaca, from which the wastes are discharged.

From the foregoing studies of the earthworm, the insects, and the frog and from the comparisons that were made in circulation and other functions, certain generalizations can be made concerning the structure of all higher animals.

1. They have a food tube with two openings: one, the mouth, for taking in food and the other, the anus, for eliminating undigested substances.

2. In the walls of this digestive food tube and outside of it, there are various kinds of glands that pour their chemicals on the food as it passes through the tube.

3. This food tube is modified in its different parts for carrying on the various necessary steps in the digestive process.

4. Every higher animal has some form of circulatory system whereby absorbed food materials are distributed to the tissues and cells of the body, and wastes are removed from these same cells which have formed them.

5. Between the food tube and the body wall of the higher animal, there is a cavity containing the respiratory organs, certain excretory organs, nerve cords, reproductive organs, and other essential structures.

Review and Thought Questions

1. Why do most animals require a large amount of food?
2. What is metabolism?
3. Why are earthworms such suitable animals for laboratory study?
4. Compare the digestive system of an earthworm with that of man.
5. Why do chewing insects need a more highly developed digestive system than sucking insects?
6. Name at least ten internal structures in man that may be compared in function with similar structures in the frog.
7. Why is blood unnecessary in the one-celled ameba?
8. Why is it unnecessary for earthworms to have lungs?
9. Account for the fact that tadpoles have long food tubes while frogs have short food tubes.
10. How is respiration carried on by insects?
11. Why is it possible for some species of frogs to stay under water for some length of time?
12. What is the essential difference between blood and lymph?
13. Why is it advantageous for man to be an omnivorous animal?

Activities

1. Follow the suggestions given in this chapter for the dissection of the earthworm and frog. Words and pictures can never give you as complete an understanding of animal nutrition as can direct observation.

2. Observe circulation in the web of a frog's foot.

3. Keep some animals in the laboratory and observe their feeding habits.

4. Place small animals such as flies in a bottle of carbon dioxide. In a minute or two pour out the carbon dioxide and observe what has happened.

5. Secure a piece of stomach wall and a short section of the intestine of some animal. Examine with hand lens and microscope.

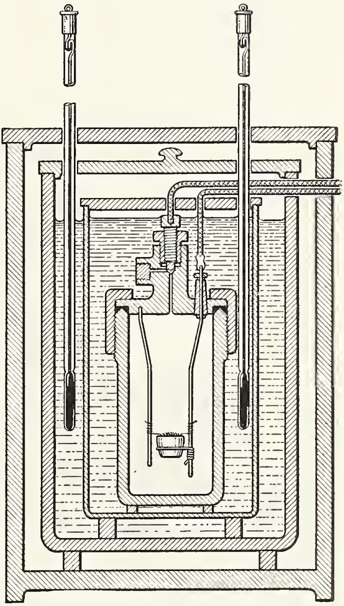
6. Examine prepared microscope slides of animal tissues.

15. Foods and Diet

Hunger is the incentive for many of man's activities. In common with the other animals, man requires a large and constant supply of food. Most of the energy he obtains from this food is used to secure more food. Man is omnivorous in his food habits, and almost every conceivable kind of edible substance, both plant and animal, is used for human food in some quarter of the earth. We have already considered the variety of plants and animals that contribute to man's food supply. It is interesting to note, however, that man depends upon the grass family for the major portion of his plant foods and upon the hoofed mammals for most of his animal foods.

Many different factors influence man's diet. Among the most important of these are food prejudices. In our own country such items as horseflesh, snails, rats, grasshoppers, and caterpillars are not popular items on the bill of fare, although they are consumed with relish in certain other countries. Food prejudices are often racial. Some races abstain from all meat, others from certain kinds of meat or fish. National habits and customs also influence diet: the English are known as beefeaters, the Norwegians as fisheaters, and the Chinese as rice eaters. Economic factors are often involved, as well as traditions that have survived from other days, some of which do not contribute toward the selection of a well-balanced diet.

Human beings use food to build protoplasm and to release energy as do other organisms. The amount of food required therefore depends upon the amount of energy expended plus the amount needed to furnish materials for the repair and growth of body tissues. Thus a man working at hard manual labor expends more energy than a man sitting at a desk. An Eskimo requires more energy to keep his body warm than a Negro in the tropics. A growing boy or girl needs more materials to make protoplasm than a person who is fully mature.



The bomb calorimeter accurately measures the heat value, or calorie content, of foods.

Nutritive and Energy Values of Foods

Since foods may be used for the production of either protoplasm or energy, their nutritive value can be measured in terms of energy content. The energy content of foods can be measured very accurately by means of a device called a *bomb calorimeter*. A carefully weighed sample of food is placed in the capsule in the inner compartment, and oxygen is forced into the compartment under pressure. The sample of food is then ignited by means of an electric fuse. Because of the excess of oxygen plus the enormous pressure, the sample of food is completely oxidized. The energy contained in it is transformed into heat, the amount of which is determined by measuring the rise in the temperature of the water in the surrounding chambers.

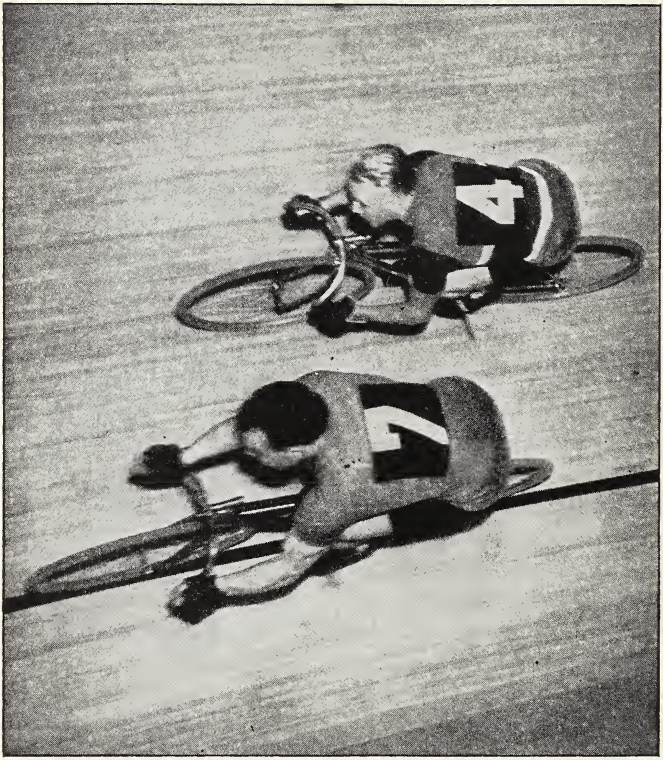


Photo from Acme Photos

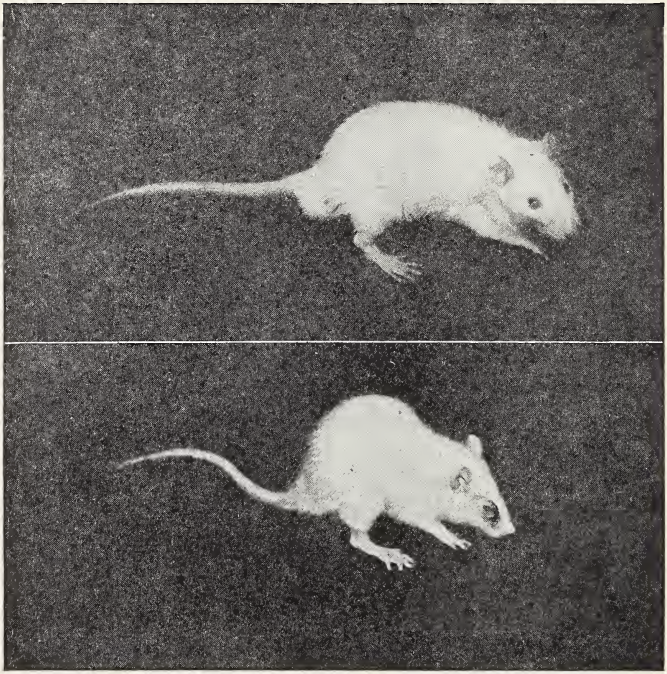
Food needs vary according to activity. A contestant in a six-day bicycle race may use as many as 10,000 calories.

Calories. It is customary to express the energy content of foodstuffs in terms of heat units called *calories.* A calorie is the amount of heat required to raise 1 kilogram of water 1 degree centigrade. The caloric content and approximate chemical composition of some common food compounds are given in the following table:

Substance	Calories per Gram	Per Cent of Carbon	Per Cent of Hydrogen	Per Cent of Oxygen	Per Cent of Nitrogen	Per Cent of Sulphur
Glucose . . .	3.75	40.0	6.7	53.3	—	—
Glycogen . . .	4.22	44.4	6.2	49.4	—	—
Body fat . . .	9.60	76.5	12.0	11.5	—	—
Butterfat . . .	9.30	75.0	11.7	13.3	—	—
Gliadin . . .	5.74	52.7	6.9	21.7	17.7	1.0
Albumin . . .	5.80	52.5	7.0	23.0	16.0	1.5

The daily energy requirement of the body varies with the energy output, climate, and age. The commonly accepted standard for white-collar workers is 2,500 calories per day. Farmers, the evidence shows, consume an average of about 3,500 calories daily. Maine lumbermen who work long hours in the cold may use up to 7,000 calories, and a contestant in a six-day bicycle race may use as many as 10,000 calories. For growing boys and girls, the average caloric requirement is about 20 calories per pound of body weight.

The well-balanced diet. One and one-half pounds of granulated sugar per day would furnish the average person with enough calories to take ample care of his energy requirements. Such a diet would be extremely unsatisfactory, since it would contain only one of the nutrients used by the body. Experience and experiments both reveal that we need a variety of food materials containing fats and proteins as well as carbohydrates. The *nutritive ratio,* that is, the proportions of the three organic nutrients, usually recommended to make up a well-balanced diet is one part protein, three parts fat, and six parts carbohydrate. However, the proportions vary with the occupation, the habitat, and the individual differences in men. Stefansson, the explorer, once went on an all-protein diet and proved that he could subsist on it for a time. Eskimos live on a high fat and protein diet. In the tropics people eat mostly fruits—a high carbohydrate diet. In temperate regions it



Courtesy of Mary Swartz Rose

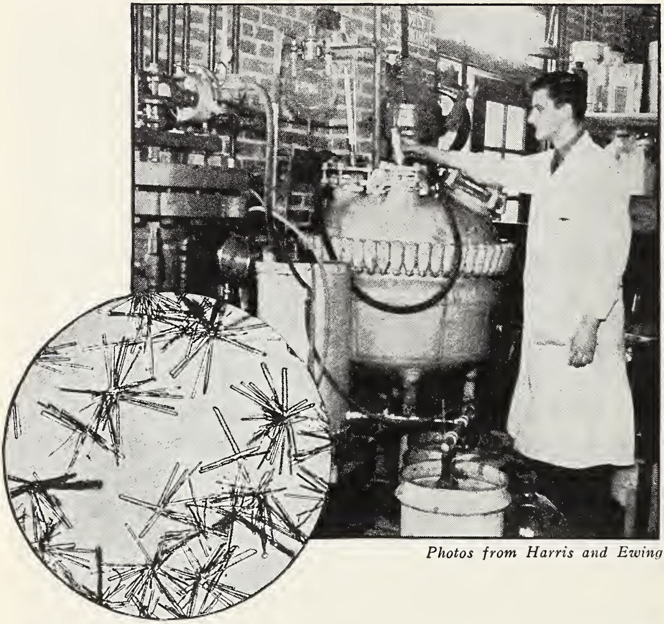
Since the food requirements of rats closely parallel those of men, hundreds of thousands of rats have been used in nutrition experiments. Results of a vitamin-A test are shown in this picture. The lower rat, fed without vitamin A, is much smaller and has a bad condition of the eyes.

has been found that a varied diet with the three organic nutrients approximately in the proportion of 1 : 3 : 6 is most satisfactory from the standpoint of the health and body efficiency of most people.

Most of what we know about foods and diet has been learned through experiments upon animals. For such experiments the rat has been found to be the most satisfactory animal. The dietary habits of rats are much like ours, and, taking their size into consideration, their life span is comparable to ours. At the present moment many thousands of them are being used in laboratories all over the world in food experiments. Other animals are also used—dogs, pigeons, guinea pigs, and monkeys. But white rats have revealed by far the greatest part of our knowledge of the nutritive values of foods.

The usual procedure followed in conducting nutrition experiments is to separate the young rats from the mother as soon as they are capable of self-feeding. They are then divided into an experimental group and a control group. A diet is selected upon which the control group will thrive, and the same diet is fed to the experimental group, except that one factor in the diet is omitted. Results are measured by comparing the two groups during the time that the experiment is in progress. By means of hundreds of thousands of such experiments, many discoveries have been made regarding the effects and functions of different substances in nutrition.

Vitamins. Perhaps the most significant discovery made in the field of nutrition within recent years is the discovery of *vitamins.* At the beginning of the century it was believed that all that was necessary to insure proper nutrition was to include the correct proportion of nutrients in the diet. Then, about 1906 Professor Frederick G. Hopkins in England published the results of some experiments which indicated that there were additional factors in foods besides proteins, fats, and carbohydrates. In 1911 Casimir Funk had obtained from rice polishings a substance which he called "vitamine," that would cure an abnormal condition in chickens that had been fed on polished rice. Extensive investigation since that time has shown that there



Photos from Harris and Ewing

Chemists have analyzed half a dozen vitamins, while nutrition tests have discovered another couple of dozen. Crystals of vitamin B, such as you see here, can be manufactured in the chemist's laboratory.

are many of these "accessory food materials" or vitamins and that all of them have important functions in human nutrition.

Vitamin A. This vitamin was first found in butterfat, then in egg yolk and cod-liver oil. It is very closely associated with *carotin*, the pigment which is responsible for the yellow color of carrots, some other root vegetables, and fruits such as oranges and yellow corn. Green vegetables such as lettuce, water cress, and spinach are also good sources of vitamin A.

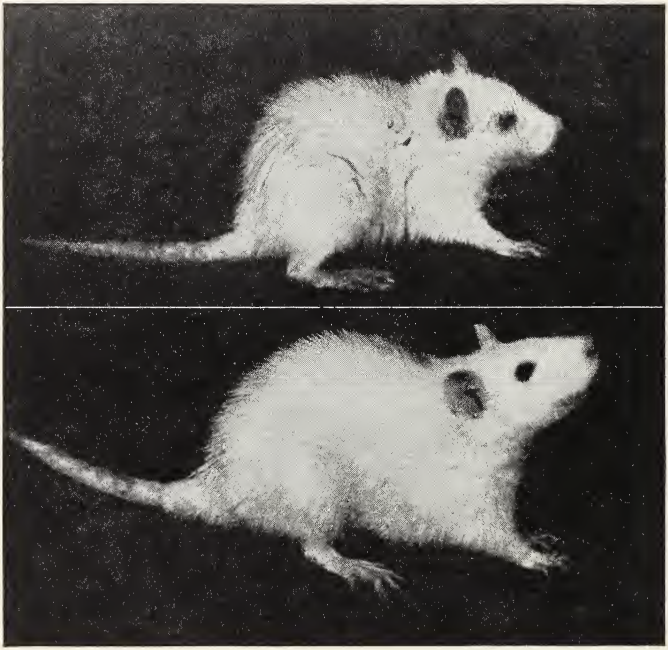
The vitamin is found in high concentration in the oils obtained from the livers of cod, halibut, and other fishes similar in habitat. These fishes feed on smaller animals that in turn obtain their food from green water plants. Although cod and halibut do not produce vitamin A, they are able to concentrate it in this indirect way. The vitamin is also abundant in the livers, kidneys, and sweetbreads of land animals. Long cooking in air will destroy it, but ordinary cooking does not do much damage. The principal effects on the body are the prevention of certain eye diseases, the promotion of growth, and the raising of resistance to infection.

Vitamin B. This vitamin is associated with the health and vitality of the nervous system. It is very complex and contains substances designated as B_1, B_2, B_3, B_4, and probably others. If heated to high temperature, the B_1, B_3, and B_4 are destroyed. The B_2 which remains is identical with vitamin G.

Vitamin B is abundant in many of our common foods, such as leafy vegetables, cereals, peas, beans, and fruits. It is especially abundant in spinach, water cress, lettuce, beet tops, and turnip tops. Yeast is an abundant source. White flour, polished rice, starch, and sugar are lacking in it. There is not likely to be a deficiency of this substance unless the diet is markedly restricted. Vitamin B prevents beriberi, a disease which causes paralysis of the nervous system.

Vitamin C. Scurvy was a prevalent and dreaded disease among sailors for a long time. Finally it was discovered that the juice of fresh limes would prevent the disease.

Limes were accordingly included in the provisions of English ships setting out for long journeys. Therefore, English sailors became familiarly known as "Lime-juicers" or

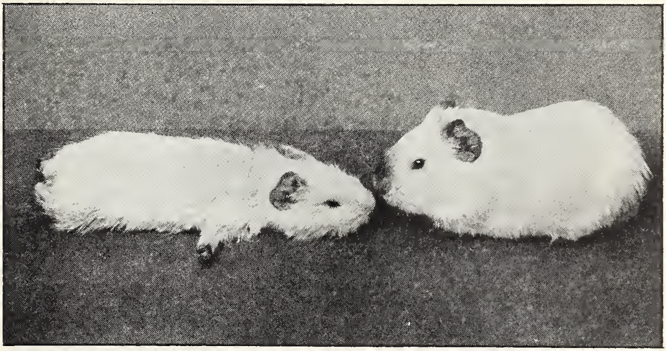


Courtesy of Mary Swartz Rose

A vitamin-B experiment started with two groups of young rats, about a month old, and weighing about 60 grams. One group, represented by the lower animal, had a complete diet. The other group had a diet complete except for vitamin B.

"Limeys." Scurvy was also formerly common among prisoners and in armies where the diet did not include fresh foods. The most striking symptoms of this disease are the ruptures of the smaller blood vessels which allow the blood to escape into the tissues. Vitamin C is easily destroyed, as, for instance, when milk is pasteurized. It is found abundantly in fresh fruits, especially citrus fruits. The chemical identity of vitamin C is now known. It is called *ascorbic acid.*

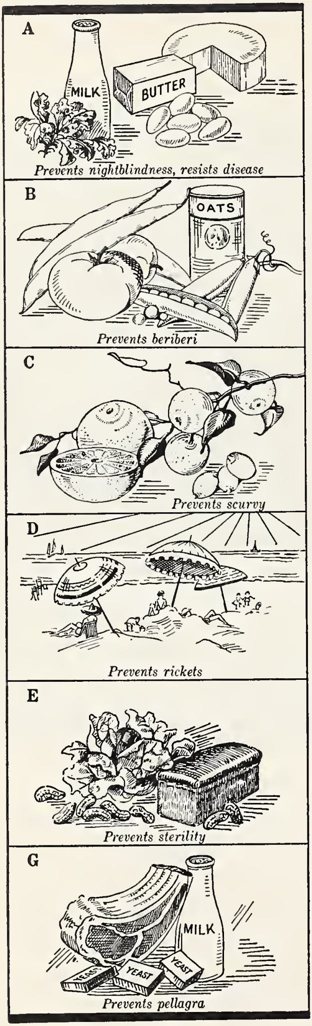
Vitamin D. This is the sunshine vitamin. It differs from the other vitamins in that the common foods are ordinarily



Courtesy of Mary Swartz Rose

Both guinea pigs had the same diet except for a tiny bit of vitamin C. Can you tell which? On long trips sailors and explorers without vegetables or fruits used to suffer severely from scurvy until it was found possible to carry some kinds of fruits.

deficient in it. When *ergosterol,* one of the higher alcohols found associated with many fats, is exposed to ultraviolet light, it is changed to *viosterol,* which is identical with the vitamin. This change also normally occurs in the body under the influence of sunlight. In winter when there is little exposure of the body to the sun's rays, there may be a deficiency of vitamin D. This deficiency may be made up by taking cod-liver oil or halibut-liver oil, which are the best sources of the vitamin so far discovered. Many foods are now irradiated with ultraviolet light to increase their vitamin-D content, but the results of this treatment are



Sources of vitamins A to G.

not uniformly effective. The lack of vitamin D produces *rickets,* a serious disease which causes bone deformities in children.

Vitamin E. Experiments upon rats have shown that vitamin E is associated with the reproductive process. Even when rats are fed a healthful diet, and all other vitamins are provided, without vitamin E they produce no offspring. In humans, vitamin E is necessary for the normal development of reproductive cells. Cottonseed oil, palm oil, peanut oil, lettuce, meat, and the germs of wheat are good sources of this vitamin.

Vitamin G. The absence of vitamin G produces a disease called *pellagra,* which has been common in the South. The symptoms are skin eruptions, intestinal disturbances, and a raw, swollen tongue. Yeast, milk, fresh vegetables, and lean meat supply the vitamin and cure the disease.

Vitamin K. This vitamin has recently been extracted from alfalfa, hemp seed, liver, spinach, and tomatoes. It aids in the clotting of the blood. Deficiency of the vitamin may cause hemorrhages into the joints, intestines, and muscles.

Common Foods as Sources of Vitamins

Food	A	B	C	D	G
Beef	+	++	− to +	− to +	++
Bacon	− to +	+ to ++	?		++
Pork	− to +	++	−		++
Ham	− to +	++	−		++
Lamb	+	++	−		++
Veal	− to +	+?			++
Liver	++ to +++	++	+	+	+++
Heart	+	++	+?		++
Kidney	++	++	+?		+++
Brains	+	++			
Fish, lean	− to +	+		− to +	
Oysters	++	++	+	++	++
Cod-liver oil	+++	−	−	++++	−
Eggs	+++	+ to ++	−?	++	+++
Milk, whole	+++	++	+ variable	− to +	+++
Milk, skimmed	+	++	+ variable	−	+++
Butter	+++	−	−	+	−
Bread, white, milk	+	+	− to +	− to +	+
Bread, whole wheat, milk	++	++	− to +	− to +	++
Peanuts	+	++			
Walnuts	+	++			
Beans, navy	+	++		−	
Beans, string	++	++	++	− to +	
Peas, green	++	++	+++	− to +	+
Peas, dry	+	++	?		+
Potatoes	+	++	++	−	++
Carrots	+++	++	++	− to +	++
Celery	− to +	++		−	
Lettuce	+ to ++	++	+++	−	++
Spinach	+++	++	+(cooked)	− to +	++
Tomatoes (raw or canned)	++	++	+++	−	++
Cabbage, raw, green	++	++	+++	−	++
Apples, raw	+	+ to ++	++	−	++
Oranges	++	++	+++	−	++

\+ contains vitamin   +++ excellent source of vitamin   − no appreciable amount
++ good source of vitamin   ++++ extraordinary source of vitamin   ? doubtful

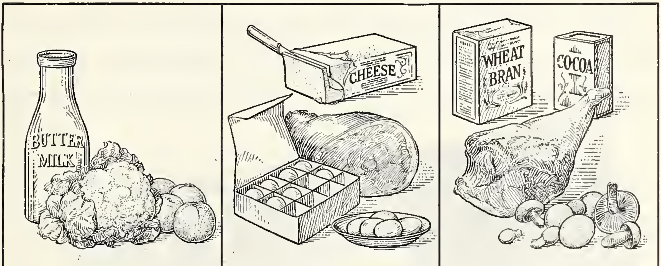
Courtesy of the National Live Stock and Meat Board, Chicago, Ill.

Hypervitaminosis. Progress in food studies is well illustrated by the rapid increase in our knowledge of vitamins. However, there has unfortunately been a tendency on the part of some commercial interests to capitalize on the wholesome respect that most people have for scientific discovery. Many useless and some positively dangerous preparations for which extravagant claims are made are on the market. Then, too, there is the danger of getting too much of a good thing. The medical profession recognizes a disease known as *hypervitaminosis* which results from too ample a vitamin intake. Cost is also a factor that sometimes needs to be considered in relation to the vitamin supply. Special foods such as yeast are good sources of vitamins, but a lettuce leaf is usually as good as a yeast cake. In general, a good selection of ordinary foods will provide all the vitamins necessary.

Minerals. A man weighing 150 pounds contains about six pounds of mineral substances. The greater proportion of them are found in the skeleton, but all tissues contain some minerals. In fact, the absence of any one of the elements sulphur, calcium, potassium, phosphorus, sodium, magnesium, chlorine, iron, or iodine would make life impossible.

Calcium is found in the largest amount. It is extremely important in metabolism, and the average requirement of the body is about one gram per day. Sodium, calcium, and phosphorus must be present in the blood at all times, since the proper functioning of the muscles depends upon them. About 2.5 grams of iron circulate in the blood constantly. It is an essential constituent of hemoglobin, the blood protein that is used in oxygen distribution. Sodium is a necessary constituent of the plasma of the blood and helps to maintain the osmotic pressure at a constant level.

Sulphur enters into the composition of all the body proteins and helps to render harmless some of the products of bacterial decay in the intestine. Iodine is needed by the thyroid



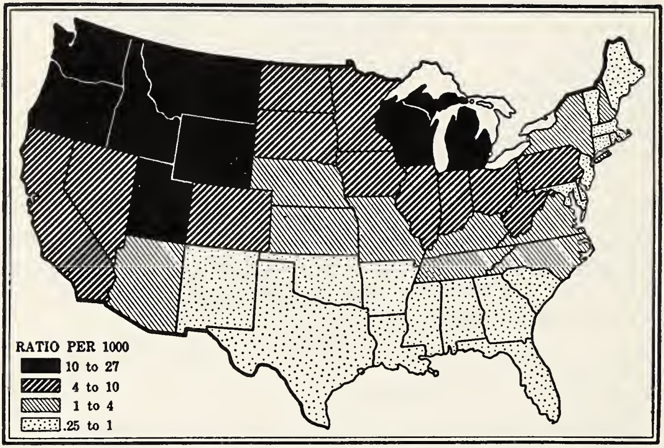
Calcium *Phosphorus* *Copper and iron*

Minerals are essential in foods purely as building material. A lack of enough calcium is one cause of poor teeth. The picture shows some of the foods which supply calcium as well as other essential minerals which should be included in your diet.

gland to produce thyroxin, and there are hundreds of other uses for minerals in nutrition.

The only one of the elements mentioned that is apt to be lacking in ordinary foods is iodine. Although the total quantity of iodine present in the body at any one time is equivalent to only about one tenth of a drop of the tincture of iodine, its presence is absolutely essential to normal metabolism. In the St. Lawrence River Valley and certain other inland regions there is very little iodine in the soil and consequently very little in the foods produced from such soil. To compensate for this iodine deficiency, the thyroid gland often enlarges, and the result is the disease known as *goiter*. The danger of contracting the disease in goiter belts may be materially reduced by adding ocean fish and other sea foods rich in iodine to the diet. While it is sometimes necessary to supply iodine in some form to whole populations, there are certain dangers in the indiscriminate use of such preparations as iodized salt. Too much iodine as well as too little may result in a disturbance of the functioning of the thyroid gland.

With the exceptions just mentioned, ordinary foods, particularly raw foods, green vegetables, and meat, contain



This map shows where goiter has been most common in the United States. In states having soils with little iodine, the element used by the body in making the thyroid secretion *thyroxin*, more people have been affected by a kind of goiter caused by insufficient intake of iodine.

sufficient quantities of minerals to supply the body requirements. However, a diet of very highly refined foods may result in a deficiency of some of the other minerals.

Selecting a Proper Diet

McCollum, one of the leaders in food research, points out that the diets of primitive peoples are satisfactory so far as their vitamin and mineral content is concerned. The food of our ancestors was probably crude but wholesome and well balanced, although they never heard of calories, vitamins, and minerals. Civilization with its increasing city life has brought many ills, a large proportion of which may be traced directly or indirectly to the diet. We are now just beginning to find out how to live in cities and still provide ourselves with a reasonably satisfactory and healthful diet.

Chief factors in a well-balanced diet. In making up well-balanced and nutritious menus, dietitians make use of the discoveries and data that have resulted from the thousands of research studies in nutrition carried on within recent years. In the scientific selection of a diet, four main factors should be considered. The total number of calories supplied should correspond with the individual requirement; the proteins, fats, and carbohydrates should be in the proper proportions; each of the vitamins should be present in adequate quantities; and foods that are good sources of minerals should be included. Other factors that need consideration are palatability, cost, digestibility, bulk, attractiveness, and variety. Keeping all these factors in mind, it will be interesting to make up an ideal menu for a single day by referring to the table of food values, on the next page, and to the information already given concerning the vitamins and minerals.

It might also be interesting to see how well balanced your diet actually is. Keep a record of everything you eat during one day. Use the table of caloric values to determine the number of calories of proteins, fats, and carbohydrates that were present in your diet, and check your list of foods for the presence of each of the vitamins. More complete tables of food values may be found in the references given on pages 337 and 338.

Caloric Values of Some Common Foods

Food	Average Serving	Calories			Total Calories
		Protein	Fat	Carbo-hydrate	
Apple	½ large	2	3	45	50
Asparagus	4 stalks	3	1	6	10
Bacon	4–5 small slices	13	87	—	100
Banana	1 medium	4	4	67	75
Beans, lima, fresh	½ cup	23	5	72	100
Beans, string, fresh	⅓ cup	3	1	11	15
Beef, lean, round	2 slices	96	104	—	200
Boston brown bread	½ in. slice	7	6	54	67
Bran, wheat	¼ cup	8	3	43	54
Bread, graham	1 slice	5	2	26	33
Bread, white	1 slice	7	3	40	50
Butter	1 pat	1	99	—	100
Cabbage, chopped	½ cup	2	1	7	10
Cake, sponge	1 piece	11	10	129	150
Carrots, cooked	2 medium	4	2	34	40
Cauliflower	⅕ small head	5	3	12	20
Cheese, American	cube, 1 in.	23	63	3	89
Corn, canned	⅓ cup	11	11	78	100
Egg, whole	1 egg	25	45	—	70
Fish, lean, broiled	1 slice	81	52	—	133
Grapefruit	½ large	7	4	89	100
Ham, boiled	1 slice	44	106	—	150
Ice cream	⅔ cup	13	202	105	320
Lamb chop, broiled	1 chop	40	60	—	100
Lettuce	¼ head	3	2	7	12
Liver, calf's, broiled	medium-sized serving	62	38	—	100
Macaroni, cooked	½ cup	7	1	42	50
Milk, whole	½ pt.	34	88	48	170
Oatmeal, cooked	⅔ cup	11	11	45	67
Onions	3–4 medium	13	6	81	100
Orange	1 medium	5	2	68	75
Oysters, raw	½ cup	37	18	20	75
Peanuts	20–24 single nuts	19	63	18	100
Peas	⅜ cup	14	2	34	50
Peas, dried	⅜ cup	70	6	177	253
Pork chop, lean	1 chop	64	136	—	200
Potato, sweet	1 medium	12	10	178	200
Potato, white	1 medium	11	1	88	100
Prunes	4 medium	3	—	97	100
Rhubarb	1 cup	2	7	16	25
Spinach, cooked	⅝ cup	3	2	20	25
Strawberries	⅔ cup	5	7	38	50
Sugar	1 T.	—	—	50	50
Tomato, fresh	1 small	4	4	17	25
Veal leg, lean, broiled	1 serving	105	45	—	150

Our changing food habits. There has been a great change in food habits in recent times. The change is due partly to the new conditions under which people live, partly to the development of better transportation facilities, and partly to the spread of knowledge revealed by scientific research. In some respects our dietary has been improved. We eat more fresh vegetables than formerly because they are now available at all seasons of the year. The knowledge that certain foods are valuable for their vitamin and mineral content has increased their popularity. Modern advertising and merchandising methods have also caused an enormous increase in the variety of foods we consume.

Sweets. In some respects the change in our food habits has not been beneficial. For instance, the consumption of sugar in the United States is now approximately one hundred and fifteen pounds per person per year. A hundred years ago it was eleven pounds. Thus the average American takes about one sixth of his daily energy supply in the form of sugar. But this food contains no building material, no minerals, and no protective substances. Furthermore, it crowds out of the diet an equivalent amount of other foods which besides supplying materials for energy would supply other necessary substances as well.

Bread. Another unfortunate change has been the substitution of white for whole-wheat flour. The former keeps better, an important consideration when flour is produced in one part of the country and used in another a long time after it is milled. Formerly flour was ground as and when needed. Advertising has educated the consumer to demand white bread, whereas there are many physiological reasons for preferring whole-wheat bread. In the milling process we remove important protective substances, as well as the part that promotes chewing,

Photo from R. I. Nesmith and Associates

Sugar cane furnishes an important energy food much used by the average American. In a well-balanced diet you eat a limited amount of sugar, however, because sugar gives you no building materials, no minerals, and no protective substances.

and bulky material which improves digestion and elimination. Recently a way has been found to produce white flour without destroying the vitamins. Vitamins are also added to some kinds of bread.

Alcohol. Experiments have shown that when alcohol is taken into the body, about 98 per cent of it is oxidized and only 2 per cent of it leaves the body unchanged in the breath and urine. It has also been shown experimentally that alcohol may be used to supply as much as one fifth of the daily energy requirement. It might be said, therefore, that alcohol fulfills the specifications set up in our definition of a food. However, alcohol has some properties that make it extremely unsatisfactory as food. It irritates the linings of the stomach and intestine and is a frequent cause of gastric ulcers. It stimulates the flow of digestive juices but greatly alters their composition, reducing very materially the amount of enzymes secreted. When taken before or during meals, alcoholic beverages do not help the digestive processes but retard them by causing a marked dilution of the digestive fluids.

Food fads and notions. The physiological effects of various foods and combinations of foods are the subject of widespread interest. It is a very fruitful field for research, but relatively little scientific information regarding it is yet available. Speculation about the effects of foods has given rise to many curious notions and fads. One belief is that "we become what we eat." Another is the fantastic idea that it is harmful to eat proteins and carbohydrates at the same meal. Vegetarians believe that it is wrong to kill living beings for food, obviously overlooking the fact that all our organic foods come from living beings.

Some of us go on raw-food diets, cooked-food diets, fruit diets, meat diets, and milk diets. Others of us who desire to become very slender adopt the starvation diet which consists of eating considerably less than the minimum requirement of food necessary for maintaining good health. Reducing diets of this kind are very dangerous and often lead to digestive troubles, tuberculosis, and permanent ill health. No special diet of any kind should ever be undertaken except under the direction of a competent physician.

Too many calories. Most of us now eat too much food instead of too little. In some high-school classes where the caloric content of the diet has been calculated, pupils have been found who were consuming several thousand calories daily in addition to their actual requirements. Eating too much is usually nothing more than a bad habit. Besides overworking the heart and digestive organs, it causes the deposition of unnecessary fat and is apt to lead to a great deal of misery later in life.

Photo from H. Armstrong Roberts

Some raw fruits and vegetables should be included in every day's menu. You need the vitamins and minerals they supply.

The wisely varied diet. All of us should have at least as much information about foods as has been given in this chapter. We all have to choose foods, whether to cook for ourselves, to prepare and serve to others, or to order at the restaurant. The appetite is usually a fairly reliable guide in the selection of foods, but many people have unconsciously developed undesirable food habits that impair their health and efficiency. Among the most important facts to remember in choosing our foods is that our diet should include a wide variety of foods and that some raw fruits or vegetables should never be omitted from the daily menu. The proportions of proteins, fats, and carbohydrates should be reasonably close to the ratio 1 : 3 : 6. Green vegetables are important sources of minerals, and dairy products, eggs, meat, vegetables, and the outside layer of cereals are especially good sources of vitamins.

Review and Thought Questions

1. What is the purpose of most animal activities?
2. Why does an Eskimo require more food energy than an African Negro?
3. Why does the average boy of 17 require more food than the average man of 70?
4. What is the average caloric requirement of a boy weighing 150 pounds?
5. How would the "nutritive ratio" be expected to vary with the climate?
6. Why are white rats satisfactory for nutrition experiments?
7. Why are some foods irradiated with ultraviolet light?
8. Describe the effects of five vitamins.
9. What is the source of the vitamins found in the livers of cod and halibut?
10. What disease is associated with a lack of iodine?

11. What are the four main factors that should be considered in the scientific selection of a diet?

12. Why are rapid transportation facilities important in relation to the diet?

13. Why should sugar not be used to excess?

14. Why is alcohol extremely unsatisfactory as food?

15. Why is it dangerous to eat either too little or too much?

Activities

1. Keep a record of your diet for one day. Refer to tables and calculate the amounts of the various nutrients consumed. Compare with estimates of your caloric requirements.

2. Use tables of food values to make up an ideal diet for a high-school boy or girl. Such a diet should take into consideration not only caloric values but minerals and vitamins as well. A useful reference is M. S. Rose's *Feeding the Family,* which devotes a special chapter to the high-school student's diet.

3. Plan a safe diet for a young man or woman who is overweight. M. S. Rose's *Feeding the Family* contains valuable material on this topic.

4. Plan a day's diet supplying the calorie needs of a person who does active physical work and another diet for a person whose work involves little physical activity. Consult M. S. Rose's *Feeding the Family* or some other helpful reference.

5. Report on the food habits of the people of other countries.

6. Clip misleading and dishonest advertisements of foods and vitamins from magazines.

7. Analyze samples of foods for the various nutrients.

8. Carry on nutrition experiments with rats or guinea pigs to test the effect of the lack of certain food essentials in the diet.

9. Benzoate of soda is used as a preservative in some food products but not in all. Why use it in some and not in others?

10. Collect labels and containers of ten package or canned foods. Can you tell which are entirely pure and which have some adulterants?

16. Human Nutrition

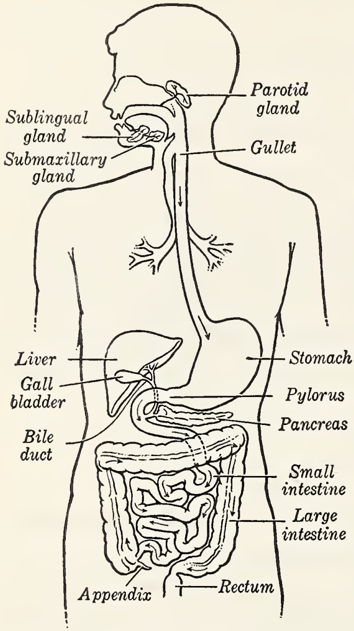
There are more than twenty-five trillion cells in the human body. As in all other animals, each of these cells requires a constant supply of food materials—oxygen, water, minerals, and organic compounds. A complete stoppage of the supply of these materials for even one minute would result in death. The process of nutrition includes the supplying of nutrient materials to the cells, the use of these materials by the cells, and the removal of waste products.

Digestion

As is well known, food materials are obtained through the mouth. Some nutrient materials, such as water, minerals, and glucose, can pass directly into the body proper through the inner membranes of the alimentary canal, but the other substances taken in require digestion.

The alimentary canal of man consists of the same parts as that of the frog: mouth, esophagus, stomach, small intestine, and large intestine. In some ways these organs are more highly specialized than those of the frog. But the digestive process is essentially the same in all higher animals and involves both mechanical and chemical changes.

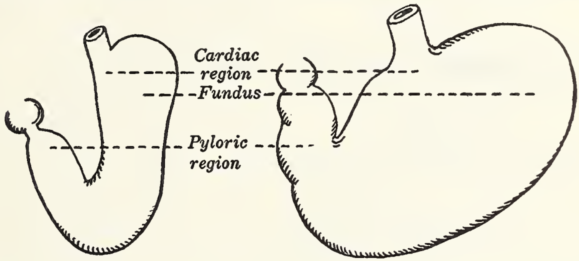
The mechanics of digestion. Since man is an omnivorous animal, some of his food requires *mastication,* or chewing and mixing with saliva. In the mouth, the food is ground into fine particles by the teeth with the aid of movements by the tongue and cheeks. The dental equipment of the human adult consists of from twenty-eight to thirty-two teeth, including eight chisel-like *incisors* at the front, four sharp-pointed *canines* next, eight *premolars,* and from eight to twelve *molars.* In the mastication of foods, the back teeth may exert pressure as great as three hundred pounds.



The human alimentary canal subjects food to various mechanical and chemical treatments along the thirty-foot trip through the mouth, the esophagus (gullet), the stomach, the small intestines, and the large intestine.

The process of chewing stimulates the flow of saliva. The saliva serves as a lubricant. It dilutes the food and helps to set off the swallowing reflex by means of which the mixture of food and saliva is pushed through the *pharynx* and into the *esophagus* by a series of automatic muscular contractions. The food enters the stomach by the relaxing of a ring of muscle which guards the entrance.

The stomach is a J-shaped organ, which may vary considerably in size, shape, and position according to the posture and amount of food ingested. The upper part near the entrance of the esophagus is called the *cardiac portion,* and the blind, rounded part to the left of this is called the *fundus.* These parts of the stomach serve the primary purpose of food storage. Although the walls of all parts of the stomach contain both longitudinal and transverse muscles, it is in the lower, up-turned *pyloric* part that most of the mixing and churning of the food occurs. When the food has been reduced to the consistency of thick pea soup and has become sufficiently acid, the *pyloric* valve, which sepa-

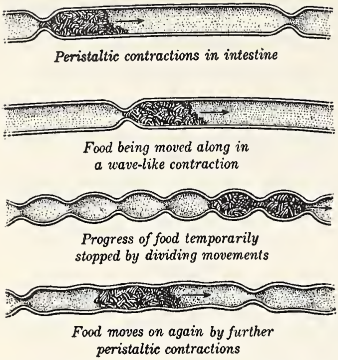


Compare the stomach before and after a Thanksgiving dinner.

rates the stomach from the small intestine, opens at intervals, and the fluid contents of the stomach, called *chyme,* are spurted into the small intestine.

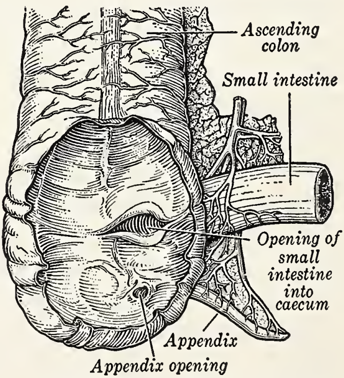
The small intestine in man is a tube about twenty feet long and an inch in diameter. Internally the lining of this tube is much folded, and under the microscope millions of minute fingerlike projections, the *villi,* are seen along the walls. Surrounding the intestine are longitudinal and transverse muscular tissues. Dividing movements alternating with wavelike movements bring the food in contact with the intestinal walls, mix it thoroughly with the digestive juices, and move it along the tube until it enters the large intestine.

The large intestine is only about five feet long, but it is much thicker than the small intestine and contains no villi. The progress of the food along it is so slow that



Movements of the muscles in the intestinal walls aid digestion.

about eighteen hours is normally required to complete the journey. At the beginning of the large intestine, there is a blind pouch called the *caecum.* Attached to it, is the *appendix*—a narrow, finger-like projection. In lower animals, these parts are often very important, but in man the appendix is not only useless but often a point of dangerous infection. As the contents of the intestine move along, most of the water is absorbed. This tends to conserve the water supply of the body, so that less water needs to be taken in than would otherwise be the case. Bacterial fermentation and decay also occur. Ordinarily these processes are perfectly harmless and produce no serious consequences unless they are allowed to continue for too long a time. The *feces,* which are eventually ejected from the body, contain indigestible materials taken in with the food, some undigested foods, residues from digestive juices, certain waste



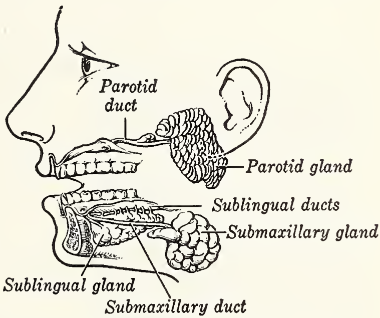
Redrawn from Cockefair and Cockefair, Health and Achievement

In this drawing, part of the wall of the caecum is cut away to show how the small intestine joins the large intestine.

products of metabolism, and countless numbers of bacteria, both living and dead. Indeed, the bacteria which grow normally in the large intestine usually constitute at least 50 per cent of the feces.

The chemistry of digestion. The basic chemical process upon which digestion depends is *hydrolysis.* In this type of chemical reaction, water combines with certain compounds to form new compounds. These new compounds then split into simpler compounds. By a series of such hydrolyses, complex molecules are broken down into simpler molecules.

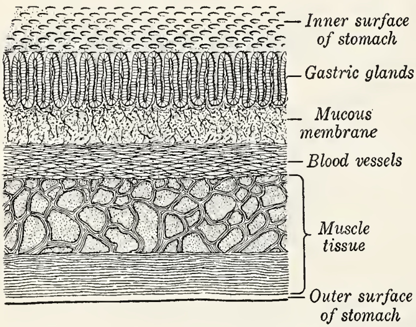
The hydrolyses that occur in digestion are brought about by the enzymes in the digestive fluids in the mouth, stomach, and intestine. These enzymes are specific in their action; that is, each enzyme will digest only one particular kind of nutrient. Each works only under conditions that are particularly favorable to the special kind of enzyme. Some will work only when an acid is present, while others require an alkaline environment.



Along the food canal are a series of glands which produce the enzymes needed to change the food into soluble form. The salivary glands are the first of these.

Enzymes are secreted by the digestive glands. Some of these glands are located in the walls of the alimentary canal itself, while others, such as the liver and pancreas, extend outward from the canal and are connected with it by ducts. A digestive gland is essentially a sac lined with epithelial tissue and having the special function of secretion. Each cell of a gland is surrounded by a network of blood vessels. While some glands may appear to be simple in structure, we must regard them as highly complex chemical factories that produce many substances which chemists are unable to duplicate.

As food is masticated in the mouth, it is mixed with *saliva,* which is a secretion from three pairs of glands. The saliva is usually slightly alkaline and contains an active enzyme, *ptyalin,* which converts starch into sugar. The process of starch digestion may continue in the stomach until the food reaches the part where acid secretions begin to be poured upon it.



After Peabody and Hunt

This cross-section of the stomach wall shows the gastric glands.

In the stomach, *gastric juice* is secreted by thousands of gastric glands which are located chiefly in the pyloric region. This secretion contains dilute hydrochloric acid and three enzymes: *pepsin, rennin,* and *lipase.* The most important of these, pepsin, attacks the proteins and splits them into *proteoses* and *peptones.* Rennin acts upon the chief protein in milk, forming an insoluble casein and a liquid whey. Lipase, the fat-splitting enzyme, has some effect upon fats in the stomach, although most fat digestion takes place in the intestine. The hydrochloric acid in the gastric juice helps to prevent fermentation and kills microorganisms that may have been taken in with the food.

Try the effect of gastric juice on the protein of egg. Take some hard-boiled egg white and divide it into three portions. Put each portion in a separate test tube. To test tube *A,* add some water and a pinch of pepsin. To test tube *B,* add water and a drop of hydrochloric acid. To test tube *C,* add water, a pinch of pepsin, and a drop of hydrochloric acid. Keep the test tubes in a moderately warm place and note the results the next day. Has any visible change occurred? Now add to each tube a small amount of sodium hydroxide; then, drop by drop, some very dilute copper-sulphate solution. A violet color indicates the presence of digested protein.

In the intestines, the further digestion of foods is accomplished by the secretions of the pancreas, the liver, and various glands located in the intestinal walls. In contrast to the acid condition existing in the stomach, the contents of the intestine are slightly alkaline.

The pancreatic juice contains three enzymes, *trypsin, amylase,* and *lipase.* Trypsin splits the protein products of gastric digestion into still simpler compounds. Amylase continues the starch-splitting process, resulting in the formation of sugars. Lipase is the fat-splitting enzyme. The fats are emulsified, that is, are divided into tiny particles suspended in the liquid medium, and when split, form fatty acids and glycerol.

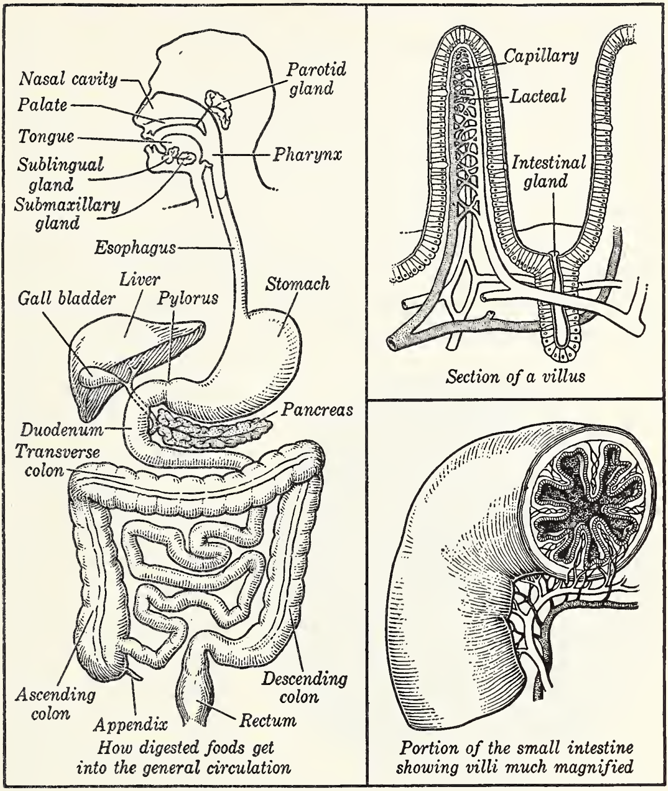
The liver produces *bile*, which results largely from the breaking down of red corpuscles of the blood. Bile does not contain any important enzymes. Its function in digestion can be well illustrated as follows: Put a drop of olive oil on a slide and examine it under the microscope. Then mix some olive oil with some sodium hydroxide. Put a drop on a slide and examine it again. The large drop has divided into many small drops. This change is called *emulsification*, and bile salts are powerful emulsifiers.

The intestinal juice contains five important enzymes. These enzymes act on the carbohydrates and proteins which were incompletely digested by the other enzymes. The final products that are formed by the action of the intestinal juice are simple sugars and amino acids.

Absorption and Circulation

Although water, alcohol, and some other substances may be absorbed by the body in considerable quantities through the inner surfaces of the stomach, nearly all the digested food materials enter the body through the villi. The small intestine is lined with villi throughout its entire length. Each villus is approximately one fiftieth of an inch long and is in constant motion, lengthening, shortening, and waving back and forth. Within each villus there is a *lacteal*, which takes in the digested fat and carries it away, and a network of blood capillaries. Water, minerals, sugars, and amino acids osmose into the blood capillaries of the villi and enter the vein which leads to the liver. In the liver, a part of the sugar is changed to *glycogen*, a kind of animal starch. Some of the sugar is stored as glycogen in the liver. The rest passes through the liver capillaries into the vein leading to the heart. Most of the amino acids also pass on into the general circulation, but under certain conditions they, too, may be changed to glycogen and stored in the liver.

The fats enter the blood by an entirely different route. They are absorbed by the cells of the villi in the form of fatty acids and glycerin. Before being passed on into the lacteals, these substances are recombined into fats. The



How digested foods get into the general circulation

Section of a villus

Portion of the small intestine showing villi much magnified

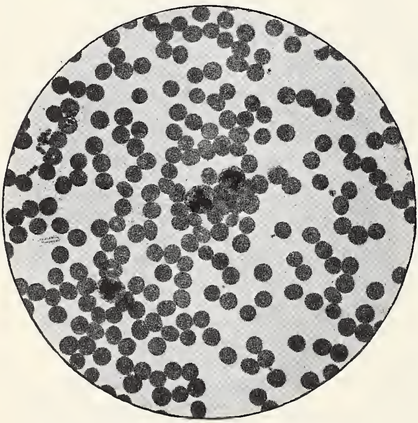
Redrawn from Cockefair and Cockefair, Health and Achievement

Digested foods pass through the walls of the intestine into the circulatory system (capillaries and lacteals). This process, absorption, is partly osmosis and partly an active process of the cells.

lacteals lead into larger vessels which combine to form the *thoracic duct.* Most of the fats used by the body pass into this system of vessels which empties them into the jugular vein in the neck to be carried away by the blood.

Composition of the blood. Besides serving as the medium for the transportation of food materials to the cells, the blood also carries away waste products from the cells. In addition it performs many other functions such as the regulation of body temperature, protection of the tissues against invasion by bacteria, and the distribution of hormones and other substances.

There are approximately six quarts of blood in an adult man. More than one third of this consists of corpuscles and the rest of a liquid called *plasma*. Plasma contains about 90 per cent water and 10 per cent solids. The inorganic salts in the plasma are very similar in kind and concentration to those in sea water. They help to maintain a proper osmotic pressure, so that the transfer of materials into and out of cells can proceed at a suitable rate. Other solids in the plasma include a little sugar, some fatty compounds, and a number of blood proteins. Cell and tissue wastes on their way to the organs of excretion are also found.



The red and white corpuscles of human blood look like this under the microscope. Note the larger size and smaller number of the white corpuscles. They have been stained to make them show more clearly.

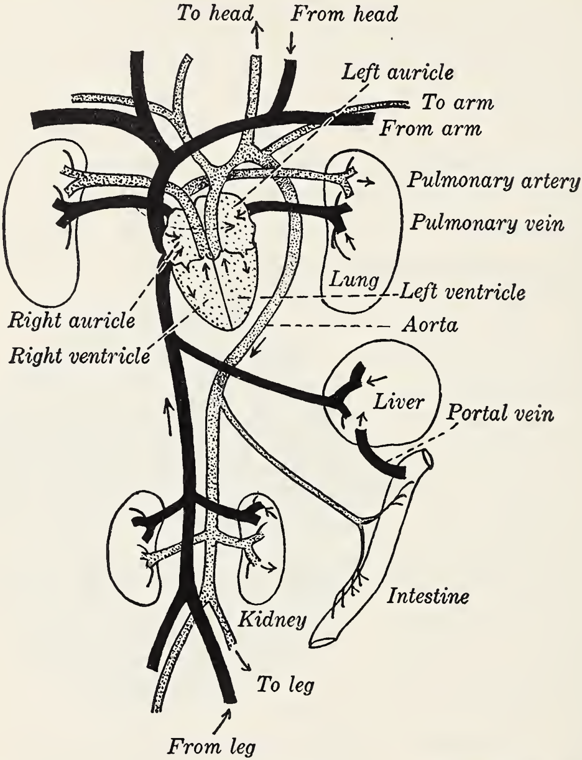
Under the microscope, two types of corpuscles, red and white, can be observed in the blood. Sterilize a needle in a flame and obtain a drop of blood by pricking the tip of your finger with the needle. Transfer the drop to a slide and spread it with a cover slip. Study the shape and arrangement of the corpuscles. On the average, a drop of blood (1 cubic millimeter) contains about 5,000,000 red corpuscles.

There are about five hundred red blood corpuscles to every white corpuscle. Each white corpuscle has a nucleus, while red corpuscles have none. Though larger than red corpuscles, white corpuscles can move about like amebas and can squeeze out of the capillaries. They are thus able to concentrate anywhere that bacteria may invade the body. Their chief function is to destroy foreign bodies that get into the blood. They also help in absorbing fats from the small intestine.

The *platelets,* a third type of solid particle present in the blood, cannot easily be seen under the microscope. They are very minute and break up quickly when blood is exposed to the air. They are thought to have some relation to blood clotting.

Circulation of the blood. The human mechanism for circulation differs from that of the frog chiefly in the structure of the heart. Like all mammals, man has separate ventricles for the distribution of pure and impure blood. This results in the separation of the circulation into the lung, or *pulmonary,* and the body circulation.

The heart acts as a double pump; both auricles contract at the same time, followed by a similar contraction of the two ventricles. In adult life, the average rate of heart beat is seventy-two times per minute. Blood from the body as a whole is sent out from the right ventricle through the pulmonary artery to the capillaries of the lungs and returned through the pulmonary vein first to the left auricle and then to the left ventricle. Leaving the left ventricle through the aorta, the blood is sent out to the

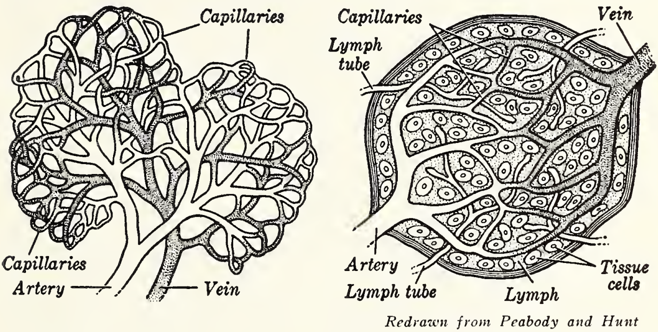


Redrawn from Fox

Man's circulatory system has separate channels for pure and impure blood. The heart pumps the blood out through the arteries (gray). The capillaries distribute it among the cells, and then return it to the veins (black) to be carried back again to the heart.

different parts of the body where oxygen and other nutrient materials are delivered to the cells. Waste products from the cells are taken into the blood and carried through the veins to the right auricle and thence to the right ventricle. The average time required for the blood to make the complete circuit of the body from the heart to the various organs and back again is between twenty and thirty seconds.

Capillaries are fine networks of blood vessels connecting the arteries with the veins. Although individual capillaries are rarely more than one fiftieth of an inch long, about



Capillaries connect the veins and the arteries. Their thousands of miles of tiny tubes extend to all the cells of the body.

two seconds is required for the blood to pass through them. It is in the capillaries that all of the chief functions of the blood are accomplished. Every body cell is either in contact with or very close to a capillary tube, so that it receives a constant supply of nutrient materials and is also afforded the opportunity to dispose of its wastes. Since the walls of the capillaries are only one cell thick, much of the blood plasma diffuses through them and fills up the spaces between the body cells. It is an interesting fact that the cells of land animals require conditions similar to those under which one-celled animals live. The relations that exist between the body cells and the lymph are very similar to those that exist between one-celled animals and the water in which they live.

The *lymph vessels* are tubes that take up the *tissue fluid* or overflow of plasma from the blood capillaries. They serve as means by which blood fluid which has escaped from the regular circulation can again enter the blood stream. Thus the lymph flow is always from the tissues to the blood. The great majority of the *lymphatics* enter the blood stream through the thoracic duct at the left side of the neck. At a corresponding point on the right side, a much smaller lymphatic trunk enters the main blood stream.

Assimilation and Oxidation

After food materials and oxygen have been transported to the cells by the blood, two important processes in metabolism occur. These are *assimilation*, by which some of the food materials are built into protoplasm, and *oxidation*, by which some are used to release heat and energy.

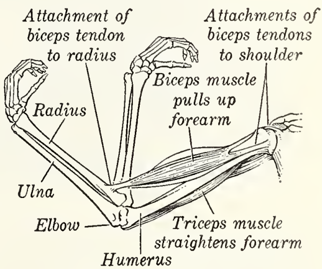
Growth and repair of tissues. Most cell division takes place before birth. In the early stages of growth, assimilation must take place in order to supply the materials needed to build new cells. Even after birth, the skin and some other parts of the body continue to add new cells and to build up protoplasm by the process of assimilation.

During childhood, the body grows principally by the enlargement of cells. For cells to enlarge, assimilation must supply additional protoplasm. Even after the body has attained its full growth, assimilation must still continue, because cell materials are constantly being used up in the carrying on of body activities. New protoplasm must be built up to replace the tiny parts of cells that become worn out and to repair cells that have been injured.

Since the replacement and repair of cell parts take place on such a small scale within each cell, it is not surprising that scientists have not yet learned much about how assimilation takes place. It is known, however, that amino acids are essential to the building of new protoplasm and that enzymes aid in the complicated building-up and breaking-down processes that are constantly going on in cells.

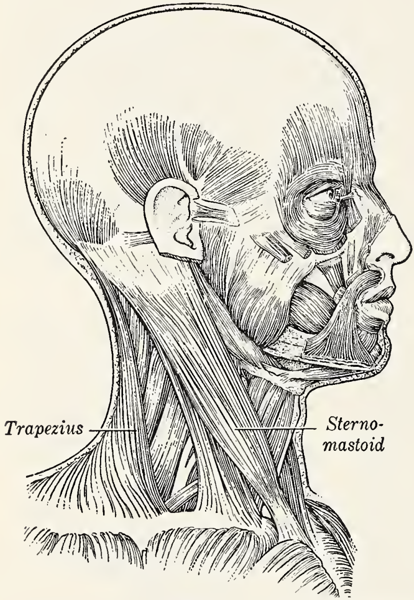
Respiration. Only a small part of the nutrient materials which reach the cell is used to build protoplasm. Most nutrients are used for the release of energy. Some are used to keep the body warm.

In order to liberate the energy contained in them, nutrients must be oxidized, that is, combined with oxygen to produce heat and energy. The process of oxidation which goes on in the body is often compared to the burning of fuel in an engine. Fortunately this process does not happen as rapidly in our bodies, otherwise we should be most uncomfortable. Our energy does not come from materials oxidized in a single firebox; each cell of the body carries on its own oxidation. This helps to preserve a more uniform temperature throughout the body than is the case in an engine.



Muscular work is the product of respiration.

The movement of any part of the body involves the changing of the energy contained in digested foods into mechanical energy. This requires a long series of chemical changes in the muscles. The immediate source of muscular energy is a complex compound containing phosphorus. When a muscle contracts, this compound breaks down into simpler compounds releasing energy for muscular work. Oxygen and glycogen must constantly be supplied to the muscle cells in order to provide the materials needed to maintain these chemical changes.

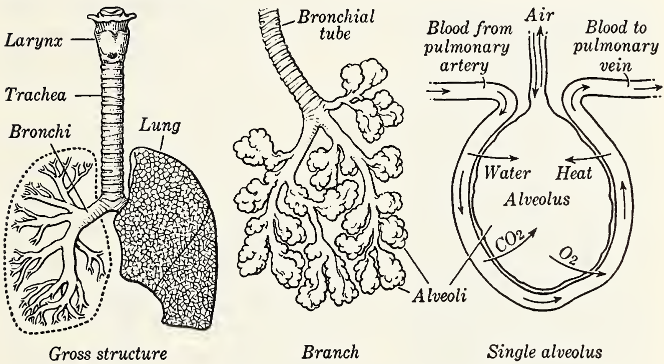


Redrawn from Peabody and Hunt

All movement in animal bodies is due to contractions of muscles. The complex motions of head, eyes, jaws, lips, etc., are produced by combinations of muscular contractions.

The oxygen required for oxidation enters the lungs through the trachea and passes into the blood through the thin walls of the *alveoli,* or air sacs. It has been estimated that the total surface in the lungs, which is available for oxygen absorption, if spread out flat, would cover a quarter of an acre. As oxygen molecules pass through the lung membranes, they unite chemically with hemoglobin in the red blood cells, forming a compound called *oxyhemoglobin.* When the blood reaches the capillaries, oxyhemoglobin breaks down into oxygen and hemoglobin. The oxygen molecules that are released then enter the body cells by diffusion. Here they combine chemically with digested foods to produce heat and energy. Carbon dioxide returns from the cells to the lungs dissolved in the plasma.

When the building up of protoplasm goes on faster than the oxidation of cell materials, the body grows

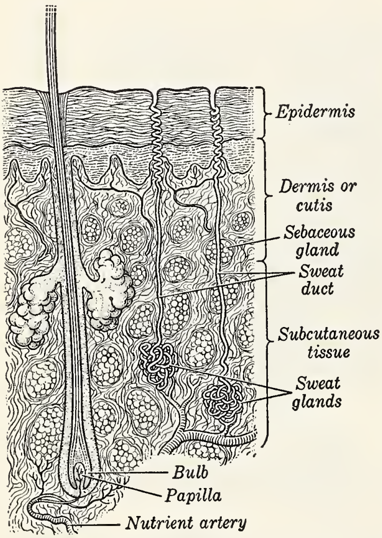


The branching of the air tubes in the lungs exposes about a quarter of an acre of tissue to the air.

larger. When cell materials are oxidized faster than they are built up, the body becomes thinner. Physicians often measure the rate at which metabolism goes on in the body by what is called the *basal metabolism* test. An apparatus is used which fits over the nose and mouth so that the amount of oxygen which enters the body and the amount of carbon dioxide given off can both be measured. There are tanks to supply the oxygen and tanks to catch the carbon dioxide. The results of such a test indicate whether the metabolism rate is above or below normal.

Excretion

The complex processes that take place in the human body result in the formation of certain waste materials that must be excreted. The principal substances excreted are water, carbon dioxide, mineral salts, and urea, all of which are relatively simple compounds. The four principal organs that are concerned with excretion are the lungs, skin, intestines, and kidneys.

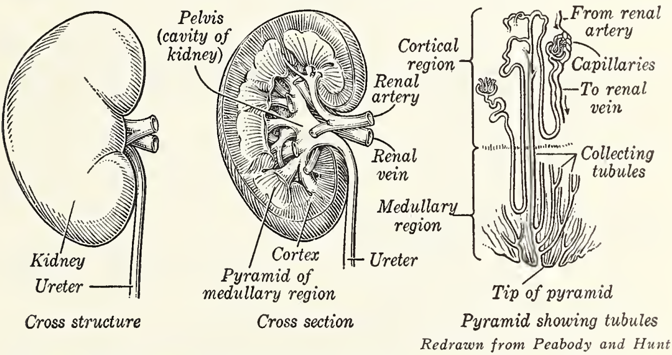


This vertical section of the skin shows the sweat glands which give some liquid excretion. The skin serves two other more important functions. It gives protection to the body and through its many capillaries it has much to do with regulating the temperature of the body.

The lungs excrete principally water and carbon dioxide. About the same amount of water is removed from the body during a day by the lungs as is removed by the kidneys. Carbon dioxide escapes into the air spaces within the lungs by diffusion.

The skin aids in excretion only incidentally. Its main functions are protection and the regulation of body temperature. The *epidermis*, or outer layer, consists mostly of flat, scalelike cells, while the inner layer, or *dermis*, contains numerous blood tubes, nerve endings, and glands. The normal body temperature of adults, which varies between 98.2° F. and 99.4° F., is maintained by a variation of the amount of blood which flows through the skin capillaries. When the temperature of the air is such that heat is not carried off rapidly enough in this way, *sweat* glands begin to pour out perspiration. There are about two million of these located in the skin, and the cooling effect produced by the evaporation of perspiration prevents any rapid rise in body temperature. In addition to water, the perspiration contains inorganic salts, principally sodium chloride, and small quantities of *urea* and carbon dioxide.

The intestine is not usually considered as an organ of excretion, and its excretory activities are largely confined



The human kidney removes nitrogenous waste, urea, from the blood, and passes this to the bladder for excretion from the body.

to the elimination of remnants of the digestive fluids which are of no further use.

The kidneys are two bean-shaped organs about four inches long, located near the spine, just above the waist. They excrete *urine*, which consists of about 96 per cent water and 4 per cent urea and various other soluble compounds. Amino acids are the source of the nitrogen contained in the urine. The body cells are unable to oxidize the nitrogen portions of amino acid molecules, but the cells of the liver have the ability to do this and to synthesize the remainder into carbohydrates and fats. The nitrogen is then excreted in the form of the relatively harmless compound, urea, which is removed from the blood by the kidneys. The carbohydrate and fats are kept and used by the body.

Review and Thought Questions

1. How do man's teeth indicate that he is an omnivorous animal?
2. What special functions are performed by the stomach?
3. Describe the mechanics of digestion as food passes through man's digestive system.
4. Why may digestion be described as a breaking-down process?
5. What are enzymes? Compare their action in the human body with that of chlorophyll in plants.
6. Name the enzymes that are important in the digestion of starch, fats, and proteins.
7. Why is alcohol so rapidly absorbed?
8. How do the villi of the small intestine function?
9. In what respect does the absorption of simple sugars differ from that of fats?
10. Trace the circulation of blood through the human body.
11. What becomes of the products of carbohydrate, fat, and protein digestion during the process of assimilation?
12. Sometimes people are overthin or overfat because their metabolism rate is not normal. Explain how a physician discovers this fact.

13. Name four of the waste products that must be eliminated from our bodies.

14. Describe two processes that help to maintain a uniform body temperature.

Activities

1. Test the action of saliva on foods that give a negative test for sugar.

2. Make up some artificial gastric and pancreatic juice. Test their action on various food materials at body temperature.

3. Make an emulsion of soap and water and examine it with a microscope. Define emulsification.

4. Observe the action of hydrochloric acid on bones and other substances containing minerals.

5. Study charts and models of the human body.

6. Make a stethoscope.

7. Weigh yourself just before going to bed, and immediately after rising. How much weight did you lose merely through breathing?

8. Weigh before and after a large meal. How much food did you take?

9. Obtain an accurate measurement of your height just before retiring and immediately after rising. Account for any difference observed.

10. Place your fingers so that you can count your pulse at your wrist. Then have someone tightly squeeze the upper arm. What happens to the pulse beat? Why?

11. Test the temperature of water with your hand, and compare what you judge from feeling with what the temperature shows. How hot can you stand water? What is the temperature of a hot bath?

17. The Balance of Nature

At the beginning of the school year, a group of pupils once placed a few goldfish, several snails, some water plants, and some clear pond water in an aquarium. A glass cover was sealed on top with some sealing wax. When the aquarium was inverted, it did not leak. It was airtight and watertight. It was then placed near a window.

Throughout the year, the pupils watched the aquarium closely. A few of the plants died. The remaining plants grew larger. The number of snails increased. At the end of the year, the fish, snails, and plants were apparently as healthy as at the beginning. Many of the pupils were surprised.

But what happened in the aquarium is no more surprising than what happens in the world outside. The fish, the snails, and the plants lived in a balanced world. They used the same materials over and over again. We also live in a balanced world. We use the same materials over and over again. We drink the same water that the Indians drank and we eat foods containing materials that have helped to make up the bodies of countless plants and animals that lived throughout past centuries.

Saprophytic Nutrition

Plants that secure their food directly from dead organic matter are called *saprophytes*. The dead bodies of plants and animals provide a large and important source of available food. Most of this food is utilized by saprophytic plants, but some animals also depend upon dead matter for food and are known as *saprozoons.* When living things grow, materials are removed from the inorganic world. When they die or are eaten, the materials they contain are returned to the inorganic world. Saprophytes and saprozoons aid in the process.

Photo from Wild Flower Preservation Society

Indian pipes, spring flowering plants which are white in color are saprophytic in their nutrition.

Decay and fermentation. When a plant or animal dies, decay sets in almost immediately. This is caused by the action of many kinds of organisms, most of which are bacteria and fungi.

Decay occurs when the bacteria and fungi use the dead bodies for food. Enzymes secreted by these organisms attack the dead bodies and change the organic compounds into simpler substances. These resulting substances are principally water, carbon dioxide, methane, ammonia, hydrogen sulphide, nitrogen, and hydrogen. The unpleasant odors associated with decay are due principally to gaseous compounds containing sulphur.

Some saprophytes, including the yeasts and many bacteria, are able to carry on respiration without free oxygen. They obtain the energy to carry on their life processes by changing sugar into alcohol. This process which is brought about by the aid of enzymes is called *fermentation.* In the change of sugar into alcohol, only a part of the energy is released. Alcohol can therefore be used as a source of energy by other organisms. Ordinarily, in nature, the next step in the simplification process is brought about by the action of *acetic acid bacteria* which change alcohol into acetic acid (vinegar).

Much of the energy that is released during fermentation and decay is transformed into heat. The amount of heat so released is often very noticeable where large quantities of organic matter are undergoing decay.

Nutrition in the larger fungi. Although not all fungi are saprophytic, there is little difference in the type of nutrition carried on in saprophytic and nonsaprophytic kinds. The bodies of the higher fungi are composed of branching threads called *hyphae.* The whole mass of these hyphae taken together is called a *mycelium.* In the case of the common mushroom, the mycelium may cover a considerable area at the surface or just underneath the surface of the ground. The mushrooms themselves are really fruiting bodies consisting of masses of interlacing hyphae that have grown upward.

Whether the fungus lives on bread, on decaying vegetable matter, or in the soil, its food consists of soluble organic materials such as sugars and amino acids. The hyphae also give off enzymes which enable the fungus to carry on a kind of external digestion. The large sur-

Photo by G. B. Wilmot

Decaying timber provides food for these fungi.

face area exposed by the mass of branching hyphae aids in the absorption of food materials.

Special Relationships between Living Things

Living things are sometimes classified as *dependent* or *independent,* as determined by whether or not they are able to synthesize organic nutrients. From this point of view, green plants are the chief independent organisms. But the distinction is not a very accurate or useful one because even green plants depend upon other organisms to change organic substances back into simple inorganic compounds. Probably no living thing is entirely independent of all other living things, but there are widely varying degrees of dependence. Curious partnerships and associations have been established among many kinds of plants and animals.

Symbiosis. When two or more different organisms live together in an intimate relationship, the association is called *symbiosis*, and the individual organisms are termed *symbionts*. Symbiosis may be regarded as a division of labor among organisms corresponding roughly to the division of labor in the tissues and organs of an individual. For example, there is a common kind of paramecium which is usually green in color. The green color is due to the presence of unicellular algae which live in the protoplasm of the paramecium. Under ordinary conditions both organisms thrive and gain from the relationship. However, if the culture is placed in the dark, the algae gradually disappear, being used up faster than they can reproduce.

The term symbiosis is restricted to very close associations between organisms. When two organisms live in a mutually beneficial relationship but not in actual contact with each other, the relationship is known as *mutualism*. One of the most interesting cases of mutualism is illustrated in the well-known relations existing between flowers and insects.

There are numerous organisms that are so closely associated that a separation would make life impossible for one or both. The lichens that grow on rocks and on bark, and make up much of the vegetation of the Arctic tundra furnish a good example of a very close symbiotic relationship. A lichen is composed of two types of plants—an alga which has chlorophyll and a fungus which has no chlorophyll. The alga carries on photosynthesis and produces carbohydrates for the use of both. The fungus supports and shelters the alga and secures water which is used by both. Another good example is found in the association of termites and certain wood-digesting protozoa. The termites cannot digest wood, but the proto-

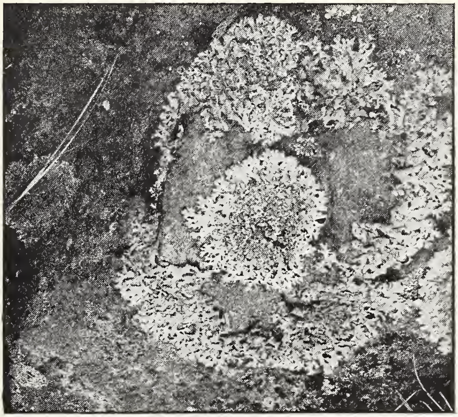


Photo from American Museum of Natural History

Lichens are distinctive examples of symbiosis. The main structure is a fungus mycelium, among the threads of which green algal cells are spread. The combination enables the lichen often to grow on bare rock.

zoans which live in their intestines carry on the digestion for both.

Parasitism. Unfortunately, all relations among organisms are not so happy or mutually helpful as the foregoing. When one form obtains its food from the other without giving any benefit in return, the relation is known as *parasitism.*

In parasitism one organism, known as the *parasite,* lives in, on, or with another organism, the second organism being known as the *host.* This relationship requires the closest contact between the cells of the parasite and the host. Plant parasites often penetrate the host by means of short branches through which the food enters the parasite. Parasites may be restricted to single hosts or may require different hosts for a complete life cycle. The tapeworm requires man and some other animal; malarial protozoa infest man and mosquito; wheat rust infests wheat and the barberry.

Photo by Lynwood M. Chace

The large green caterpillar here is covered by the cocoons of a parasitic insect. The parent parasite lays its eggs in a young caterpillar and the larvae feed on the tissues.

It is not surprising to find varying degrees of parasitism. Among plants, certain green parasites live by getting only their water and dissolved mineral supply from hosts; they obtain through their own leaves the carbon dioxide for photosynthesis. Mistletoe is a well-known parasite in the southern states. Its leaves are green, thus the plant can synthesize some starch, but it draws its water and minerals from the tree on which it grows, hence is known as a *water parasite.*

Some plant parasites and all animal parasites derive proteins as well as carbohydrates from their hosts. Not all plants without chlorophyll are parasites. The fungi and bacteria are either parasites or saprophytes, and there are some species that can derive their food from either living or dead matter. A parasite may kill its host and

Courtesy of U. S. Dept. of Agriculture

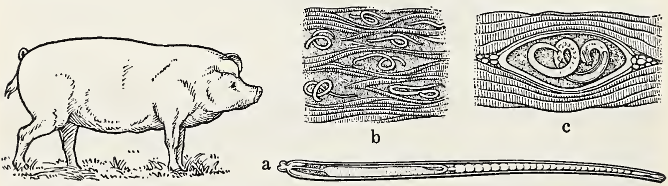
This isolated hackberry tree, near Belton, Texas, is loaded with parasitic mistletoe plants. The hackberry has lost its leaves for winter, but mistletoe is evergreen.

continue to live upon the decomposing body. Hence the distinction between saprophytes and parasites is not always clear.

In large plants death is seldom produced by a parasite unless it interferes with the water supply or invades the entire organism. In the wilt disease the fungus parasite blocks the vessels, interfering with the supply of water to the leaves, and death follows with surprising suddenness, often over night in some of our garden plants.

The drain on the food resources of the host may be so weakening that it succumbs to adverse conditions which would otherwise be overcome. In some cases the parasite may act merely as a stimulus to local growth, in others it may produce substances which kill the host. The location of a parasite is often marked by deformities; leaves are crinkled or thickened, as in peach curl; swellings (galls) may be found on leaves or stems, as in the black knot of cherry and plum trees. In oysters, pearls are formed by secretions around worm parasites.

Like other animals, man is subject to attacks by parasites, both external and internal. Tapeworms occasionally extend the entire length of the intestine, and other worm



Trichina or porkworm, sometimes parasitic in pigs, may become parasitic in human beings who eat insufficiently cooked pork.

parasites are responsible for such dreaded diseases as trichinosis and elephantiasis. Malaria, yaws, amebic dysentery, and sleeping sickness are caused by parasitic protozoa. Most of the other infectious and contagious diseases are caused by parasitic bacteria. The poisons and toxins produced by these bacteria are spread so quickly through the body by the blood that important tissues may be destroyed, causing death. Diphtheria bacteria, for instance, flourish chiefly in the throat, where they may produce no serious change in the tissues, but the poisons they produce reach the heart and kidneys and sometimes fatally injure these organs.

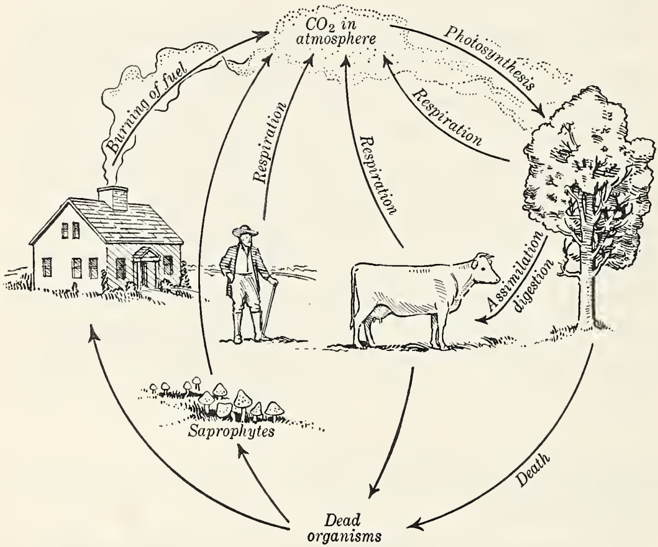
Insectivorous or carnivorous plants. A few plants possess the power of digesting and absorbing animal food. These plants are found in bogs and have highly specialized leaves adapted for catching insects. The sundew is a good example of an insectivorous plant. The leaves are fringed and covered on the upper surface with stalked glands that secrete a sticky fluid in which the insect may become entangled. After the insect is caught, the secretion, which becomes more watery, contains an enzyme to digest protein. The capture of insects probably supplements a scanty supply of nitrogen or soil nitrates in the plant's habitat.

Relationships between Living Things and the Environment

An aquarium, in which plants and animals are living, must contain hydrogen and oxygen. These elements are always present because their principal compound, water, is absolutely necessary to the life of living things in any habitat. In addition to water, the elements carbon, nitrogen, sulphur, and perhaps a dozen others must also be present.

Perhaps we can arrive at a clearer understanding of the relationships that living things bear to the environment if we take a few of these elements one by one and follow their molecules along some of the fascinating journeys they take through the organic and inorganic worlds.

The carbon cycle. The coal that we burn came out of the air. All of the coal that has ever been mined and all that still lies deep in the earth was once in the form of carbon dioxide. Molecules of carbon dioxide at some



Trace the carbon cycle. There is probably no store of carbon on earth which has not been used in the nutrition of living things. However, a large amount of carbon has been locked up, out of circulation. in the form of coal and limestone.

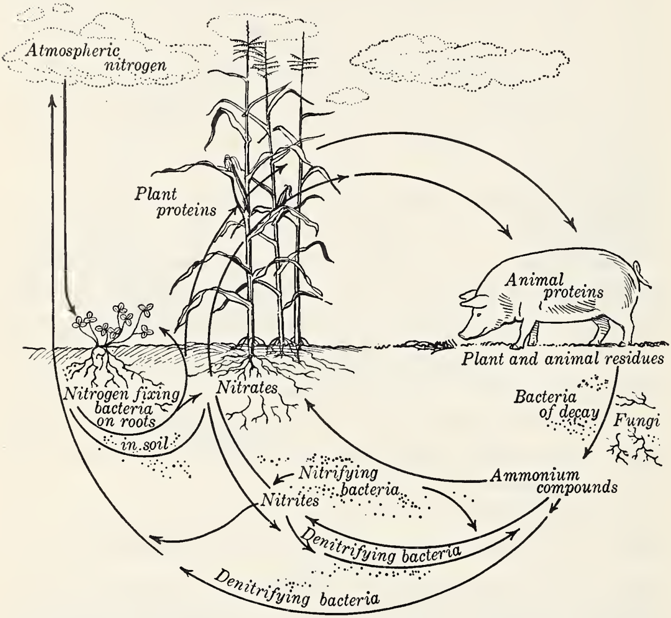
time in the past found their way into the stomata of green plants and were synthesized into carbohydrates in the same way that green plants are doing it today. Coal is the fossilized remains of these green plants, and when we burn it, carbon dioxide is returned to the air again. It can be used by plants now living to produce carbohydrates and perhaps sometime more coal.

When carbon molecules become locked up in coal, they are of course taken out of circulation until the coal is burned. Probably less coal is being formed today than in earlier ages. Instead, the organic compounds built up by green plants are broken down by animals and saprophytes. The carbon they contain is oxidized and returned to the air as carbon dioxide ready for use again by green plants. This circulation of carbon and its use over and over again to carry on the same processes is referred to as the *carbon cycle.*

The nitrogen cycle. Proteins which are essential for tissue building contain the element nitrogen. Plants take in this element as a mineral salt or nitrate. They make protein for themselves, and animals obtain some of this protein for their food. The plant proteins are then assimilated and converted into animal proteins. Later, through the death of animal tissue, or in the process of excretion, nitrogenous waste products are given off. Dead plant tissues also contain nitrogen. What becomes of all this nitrogenous material?

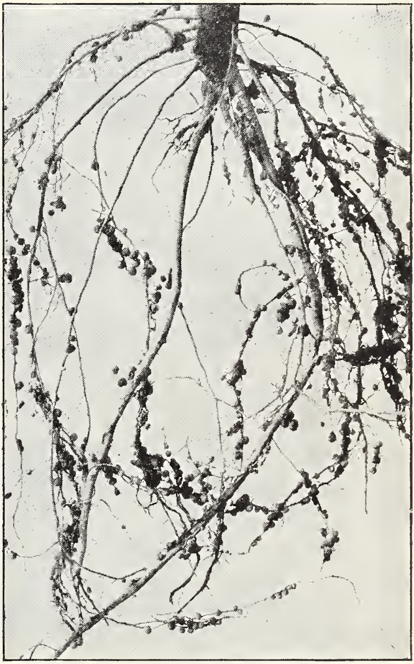
In materials that are undergoing decay, we find a variety of bacteria. Some of these, the *ammonifying bacteria,* convert proteins into ammonia or ammonia compounds. Others, *nitrite bacteria,* use ammonia in their metabolism and convert it into chemical compounds called *nitrites.* These are not fit for plant use, but still other bacteria convert nitrites into *nitrates.* Nitrates may then be used by green plants in building proteins.

Some nitrates are decomposed by still other bacteria to form free nitrogen. Some escapes into the air and is then no longer available as food for plants. Fortunately there are bacteria in the soil that convert free nitrogen into nitrates. These are called *nitrogen-fixing* bacteria because they form nitrogen compounds from free nitrogen. Some of them live free in the soil, others grow among the roots of leguminous plants upon which they live in a symbiotic relationship.



Nitrogen may pass through many different cycles among living things, and between the vast store of nitrogen in the air and living organisms. A complete cycle may involve a succession of a dozen different plants and animals.

Other cycles in nature. All of the elements which are necessary to the life processes of living things pass through cycles comparable to those that have been described for carbon and nitrogen. The cycle for oxygen is one that you might find interesting to work out for yourself. Those of sulphur, iron, iodine, and magnesium are also very interesting and exhibit some unique variations of their own. In the case of sulphur, a kind of organism is involved which we have not yet mentioned. These are the *autotrophic bacteria,* which have the power to derive energy from inorganic substances without the aid of light or chlorophyll. The *sulphur bacteria* oxidize hydrogen sulphide and store up free sulphur within their protoplasm. They change this sulphur into sulphuric acid and excrete it as sulphates, which may then be used by other plants.



Courtesy of U. S. Dept. of Agriculture

Peas, beans, and clovers, always have numerous small tubercles on their roots. These swellings contain nitrogen-fixing bacteria which live symbiotically with the legumes.

Throughout this unit we have emphasized the importance of energy to living things. The storing up of the sun's energy by photosynthesis and its release in respiration are often referred to as the *energy cycle.* This cycle differs, however, in one important respect from the other cycles we have been considering. Nitrogen, carbon, and the other elements may be used over and over again in the vital processes, but energy that is obtained from the sun is gradually released in the form of heat and does not return to its source.

Review and Thought Questions

1. Explain or define the following terms: parasitic, saprophytic, symbiotic, mutualism.
2. Name at least four important products of decay.
3. What part do nitrifying bacteria play in nature?
4. How may digestion be carried on by bacteria or fungi?
5. How are green plants independent in their nutrition?
6. Why do lichens furnish a good example of a close symbiotic relationship?
7. Explain the difference between a parasite and a saprophyte.

Activities

1. Make a special study of the balanced aquarium in your classroom or laboratory. If you have one that is perfectly balanced, try sealing it up.
2. Set up a balanced salt-water aquarium. Consult references for information regarding marine aquaria.
3. Examine the roots of legumes for nodules of nitrogen-fixing bacteria.
4. Collect pictures of symbiosis, parasitism, and saprophytism.
5. Open the cloaca of a freshly killed frog and draw out a drop of the contents with a medicine dropper. Mount a drop on a slide. Look for parasitic Gregarines that inhabit frog intestines.
6. Grow molds, bacteria, and fungi. Observe under the microscope.
7. Fill a gallon bottle with sugar solution and add a yeast cake. Observe under the microscope from time to time.
8. Secure some cider vinegar and look for "vinegar worms."

9. Make an original chart illustrating the oxygen cycle.

10. Report to the class on some molds, bacteria, or fungi about which one of the following should be well informed: a cook, a farmer, a nurse, a florist, a barber, a life guard, a butcher, a housewife, or some other everyday worker whose vocation interests you. Make use of any useful books among those listed as references for the unit on this and the following page and of any other helpful books or magazines you may find in your school or public library.

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Unit 6

RESPONSE

Why do amebas behave as they do? Why do monkeys behave as they do? Why do some people behave differently from others? Even one-celled plants and animals have definite patterns of behavior. Bacteria, mushrooms, and other of the lower plants respond to heat, light, gravity, and other stimuli. In higher plants and animals, behavior becomes more complex. You will find in this unit that study of other living things helps you to understand why we behave like human beings.

18. The Behavior of Animals

Even the simplest animal, such as an ameba, can do many things which the same amount of lifeless material cannot do. It can move. It can take in substances from outside and build them into more of its own substance. In other words, the protoplasm of this single-celled animal shows the powers of movement, metabolism, and growth. But an ameba can do something else that sets it off from nonliving matter, even more than the three properties just mentioned. It has the power we call *response,* also sometimes referred to as *irritability,* or in a broader sense as *adaptation.* Everyone understands what is meant when a living thing is said to adapt itself to its surroundings. Adaptation to the surroundings is usually brought about by a continuous series of separate response activities.

Studies of the response activities of living things are often called studies of *behavior.* This is especially true so far as studies of animals are concerned. The animal is watched to see what it does under various circumstances. It is experimentally subjected to contact, to changes in temperature, to light, or to various chemical substances. Responses may be classified as *positive* and *negative.* If an animal such as an ameba comes into contact with a bit of food, it may respond by engulfing it. This would be a positive response. If it moves away from some unfavorable situation, it exhibits a negative response. The object or situation to which a given response is made is called the *stimulus.*

Practically all of the visible activities of plants and animals are in the nature of responses. The responses of higher plants and animals are usually very complex, and their study is complicated because of the fact that many different kinds of stimuli often operate at the same time. For this reason the simpler living things are the best subjects with which to begin the study of behavior.

Response in Amebas

Direct observation of a living ameba furnishes an excellent opportunity to study its response activities. Moving about in its liquid environment, it encounters many stimuli: solid obstacles that impede its progress, changes in light intensity and in temperature, food materials, and hostile organisms. An hour spent in watching an ameba in its native habitat will teach you many things about its private life and reveal better than any description how it responds to various stimuli.

Many thousands of hours of such study have been given by biologists since Leeuwenhoek announced his discovery of microscopic animals. Some of the men best known in the history of biology have been close students of protozoa, men like Von Mohl, Schultze, and Schwann. Using all that these earlier observers have discovered, and adding many new facts from their own studies, a number of modern biologists have brought to light many new facts about the life of one-celled animals. Probably the most thoroughgoing study of their behavior has been made by an American biologist, Herbert Spencer Jennings.

Response to food. Jennings' accounts are so clearly given that we can let his own words report his observations of the response of an ameba to food.

In the water in which Ameba lives are found many other minute animals and plants. Upon these Ameba preys, taking indifferently an animal or a vegetable diet. Its behavior while engaged in obtaining food is very remarkable for so simple an animal.

Herbert Spencer Jennings, of Johns Hopkins University, whose studies of the behavior of protozoa, made over thirty years ago, established many facts about the reactions of these animals.

Spherical cysts of Euglena are a common food with Ameba proteus. These cysts are smooth and spherical, easily rolling when touched, so that they present considerable difficulties to an Ameba attempting to ingest them. One or two concrete cases will illustrate the behavior of Ameba when presented with the problem of obtaining such an object as food.

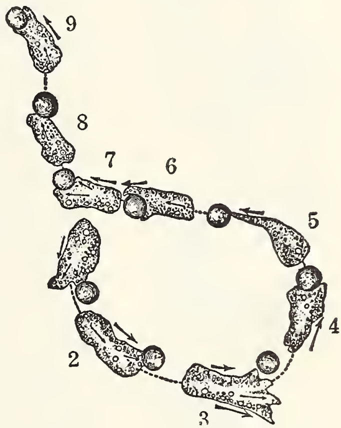
A spherical Euglena cyst lay in the path of an advancing Ameba proteus. The latter came against the cyst and pushed it ahead a short distance. The cyst did not cling to the protoplasm, but rolled away as soon as it was touched, and this rolling continued as long as the animal moved forward. Now that part of the Ameba that was immediately behind the cyst stopped moving, so that the cyst was no longer pushed forward (Figure 1). At the same time a pseudopodium was sent out on each side of the cyst (Figure 2), so that the latter was enclosed in a little bay. Meanwhile, a thin sheet of protoplasm passed from the upper surface of the Ameba over the cyst (Figure 3). The two lateral pseudopodia became bent together at their free ends; the cyst was thus held so that it could not roll away (Figure 4). The pseudopodia and the overlying sheet of protoplasm fused at their free ends, so that the cyst was completely enclosed, together with a quantity of water. It was then carried away by the animal.

From Jennings

An ameba gets its meal, a rounded Euglena cyst.

Ameba does not always succeed in obtaining its food so easily as in the case described. Often the cyst rolls away so lightly that the animal fails to grasp and enclose it. In such a case Ameba may continue its efforts for a long time.

Thus, in a case observed by the author (Jennings), an Ameba proteus was moving toward a Euglena cyst. (See figure, page 345.) When the anterior edge of the Ameba came in contact with it, the cyst rolled forward a little and slipped to the left. The Ameba followed. When it reached the cyst again, the latter was again pushed forward and to the left. The ameba continued to follow. This process was continued till the two had traversed about one fourth the circumference of a circle. Then (Figure 3) the cyst when pushed forward rolled to the left, quite out of contact with the animal. The latter then continued straight forward, with broad anterior edge, in a direction which would have taken it away from the food. But a small pseudopodium on the left side came in contact with the cyst, whereupon the ameba turned and again followed the rolling ball. At times the animal sent out two pseudopodia, one on each side of the cyst (as in Figure 4), as if trying to enclose the latter, but the spherical cyst rolled so easily that this did not succeed. At other times a single, long, slender pseudopodium was sent out, only its tip remaining in contact with the cyst (Figure 5); then the body was brought up from the rear, and the food pushed farther. Thus the chase continued until the rolling cyst and the following ameba had described almost a complete circle, returning nearly to the point where the ameba had first come in contact with the cyst. At this point the cyst rolled to the right as it was pushed forward (7). The ameba followed (8, 9). This new path was continued for some time. The direction in which the ball was rolling would soon have brought it against an obstacle, so that it seemed probable that the ameba would finally secure it. But at this point, after the chase had lasted ten or fifteen minutes, a ciliate infusorian whisked the ball away in its ciliary vortex.



From Jennings

Ameba does not always succeed in obtaining its food easily, as this drawing shows.

Such behavior makes a striking impression on the observer who sees it for the first time. The ameba conducts itself in its efforts to obtain food in much the same way as animals far higher in the scale.[1]

This meal got away. After the ameba had ingested part of another ameba, the latter, only a piece, managed to crawl out again and escape.

The paragraphs just quoted are taken from a chapter of twenty-five pages devoted entirely to the behavior of this one animal. One of the most interesting accounts given in the chapter describes the pursuit by one ameba of another ameba which had been cut partly in two. After a long chase, the pursuing animal succeeded in enclosing the cut portion of its prey and moved off. Later, when the piece of ameba that had been engulfed was surrounded by only a thin layer of protoplasm, the cut-off piece began to move. Finally it broke out of its captor and moved off entirely free.

What does an ameba do when it starts to engulf a filament of alga many times longer than its body? In one case, as Jennings describes it, the ameba takes in a portion of the filament, then bends double, bending the filament with it, whereupon it can flow over another length. This process continues until the whole filament is twisted into a tangle

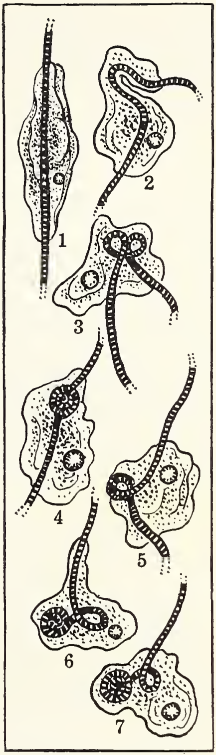
[1] From Jennings' *Behavior of Lower Organisms,* by permission of Columbia University Press.

small enough to lie within the body of the ameba. In another case, the ameba behaves differently toward a filament. After a portion of the alga has been engulfed, the protoplasm contracts so strongly that a piece of the filament is cut off and enclosed. An ameba may sometimes "bite" in two a paramecium.

An ameba does not always behave the same way toward the same kind of food substance. On some occasions, it may persistently follow the food material; on others, it may touch the same thing and turn away.

Response to other stimuli. What is true regarding responses to food materials is true for responses to other kinds of outside influences. An ameba responds to contact differently according to the nature of the touching object. When it meets some obstacle as it flows along, it usually changes its direction so as to avoid the obstruction. If it is more violently touched, or "poked," as with a fine glass point, it will withdraw the portion touched and start a pseudopodium in a new direction. By repeated pokings it can be directed in any desired direction.

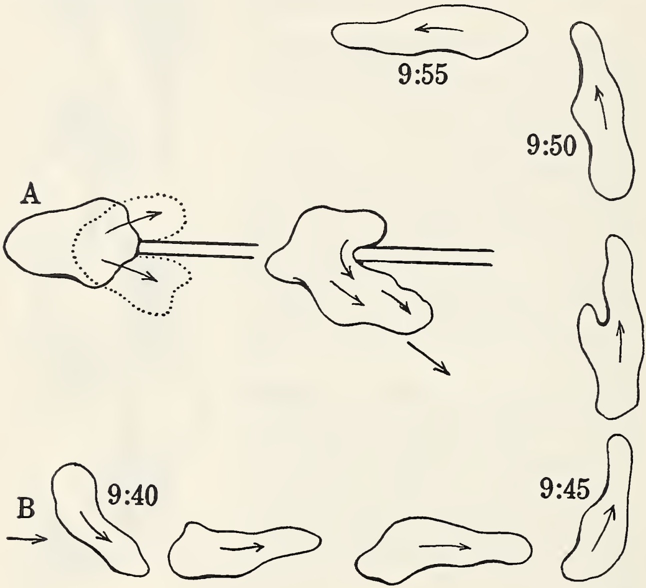
With respect to various chemical



After Newman, from Rhumbler

Some people eat spaghetti in the way this ameba is eating an alga. The algal filament is gradually brought inside and rolled up. But the ameba may sometimes "bite" off part of an object which is too large.

stimuli, Jennings reports: "Such experiments show that ameba is very sensitive to changes in the chemical composition of the water surrounding, and is inclined to move away whenever it comes to a region in which the



From Jennings

A. The response of a particular ameba to a particular poke.
B. Successive positions and shapes taken by an ameba and the time required.

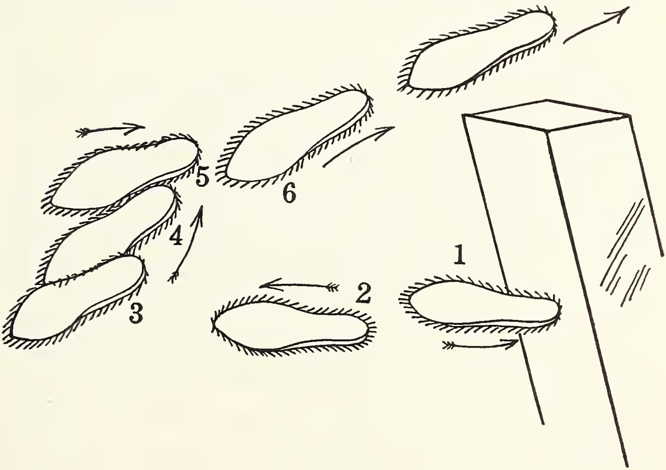
water differs even slightly from that to which it is accustomed." Similarly, it responds to heat in a negative manner.

Amebas react to light according to the strength of the illumination. Strong white light seems to be undesirable. "Blue light acts in the same way. Other colors have intermediate effects." In an experiment that was conducted recently, amebas were exposed to ultraviolet rays. The response was negative. A thirty-second exposure killed the animals.

Response Movements of Paramecia

A paramecium is a much more complex animal than an ameba in its structure and its means of response. In Jennings' book one chapter was enough to report on the ameba, while several chapters were required to deal with the paramecium.

Food and contact. A paramecium recognizes food materials largely by contact. As it swims along and strikes against an obstacle, it may react in either of two ways. (1) It may back up, turn a little to one side, and start



From Jennings

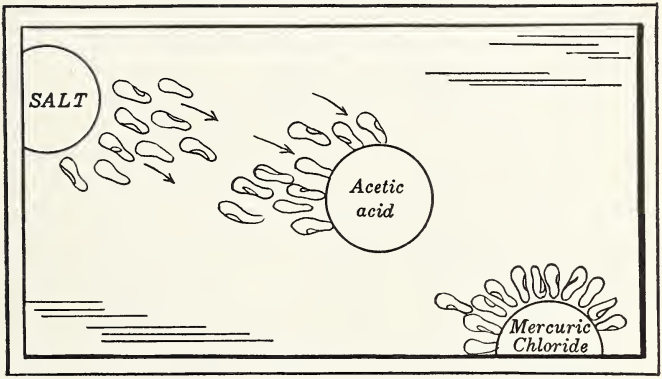
When a paramecium runs into a solid object, it reverses, turns a little to one side, and goes forward again. To get past a large object it may have to repeat this "avoiding reaction" several times.

ahead again. This is called an "avoiding reaction," and it is the means by which a paramecium tries to find a clear course. (2) Sometimes, when it bumps into an obstacle, it stops moving, and settles down in contact with the obstruction. In other words, it responds positively. The difference in response seems to depend chiefly on the kind of obstacle against which it bumps. If it is relatively large, smooth, and hard, the animal will back off, turn, and try to get past the obstruction. If it is composed of small granules, or has a soft, yielding surface, the paramecium tends to stop.

Masses of bacteria on which a paramecium feeds lead to the positive reaction. The animal settles down in contact, and keeps only its oral groove cilia moving. These cause currents of water which bring bacteria to its mouth. It will, however, react positively to any granular material, as we have seen in the case of carmine, which is not of food value. Apparently a paramecium does not have any quick means of "tasting" and refusing small granules.

Gravity response. The reaction of paramecia to gravity has been studied in a very interesting experiment. It has been noted that these animals tend to accumulate toward the top of a culture. This is advantageous because masses of bacteria are often found at the surface. In the experiment referred to, the paramecia were first fed with powdered iron, in granules small enough to be taken into the food vacuoles. Then a magnet was brought over the culture so that the iron particles were attracted against the upper surfaces of the food vacuoles. Thereupon these paramecia swam downward, contrary to their usual response. From this it was concluded that the perception of gravity was located in the food vacuole surfaces and that the gravity response was negative.

Chemical responses. While paramecia do not seem to discriminate between useful and nonuseful particles with which they come into contact, they do show one chemical response which is beneficial in helping them find food.



From Hegner

Paramecia respond positively to some chemical stimuli, negatively to others. Mercuric chloride kills them, so stopping all reaction.

They respond positively to weak acid, swimming toward regions which are slightly more acid. Since masses of bacteria often produce a mild acid condition in the water surrounding them, this acid reaction of paramecia tends to bring them into contact with food.

Responses of Other Protozoa

Response always involves some kind of movement, and movement requires energy. The energy which produces movement is derived from the changes that take place within an organism. Withdrawing reactions, the ciliary motion of a paramecium, or the extension of a pseudopod from an ameba thus really result from changes in protoplasm. Stimuli from the environment merely start these changes.

Response in Euglena. Like a paramecium, the Euglena shows a variety of reactions to different influences in the environment. But because of its chlorophyll and the ability to carry on photosynthesis, it has a special need of being able to respond to light.

Euglena responds to light by swimming toward the source. It moves by pulling itself along by means of the long whip-like flagellum. Other nongreen protozoa may respond positively or negatively to light, but Euglena has a special light-sensitive structure, the *eye-spot,* by which light rays are detected. This eye-spot is a reddish point which is always kept forward as the organism moves toward the light. (See illustration, page 179.)

Euglena is able to make a very different kind of response when placed under unusual conditions. If a culture is kept in the dark, the cells under ordinary conditions are unable to form starch. If a small amount of sugar is then placed in the water, the Euglena cells can use this as food. Under these circumstances they do not need light or chlorophyll. Their green color gradually disappears, and they live a saprophytic life.

Can a protozoan learn anything? A paramecium keeps on bumping into obstacles, and attempting by the "trial and error" method to avoid them. The ameba is also a relatively stupid animal. Some recent investigations, however, indicate that even an ameba can learn a few things and remember them for a time. It has been noted that an ameba responds negatively to white light. In one experiment a strong beam of light was passed through an ameba culture. At first, avoidance of the beam proceeded on the basis of trial and error. But, as the observations

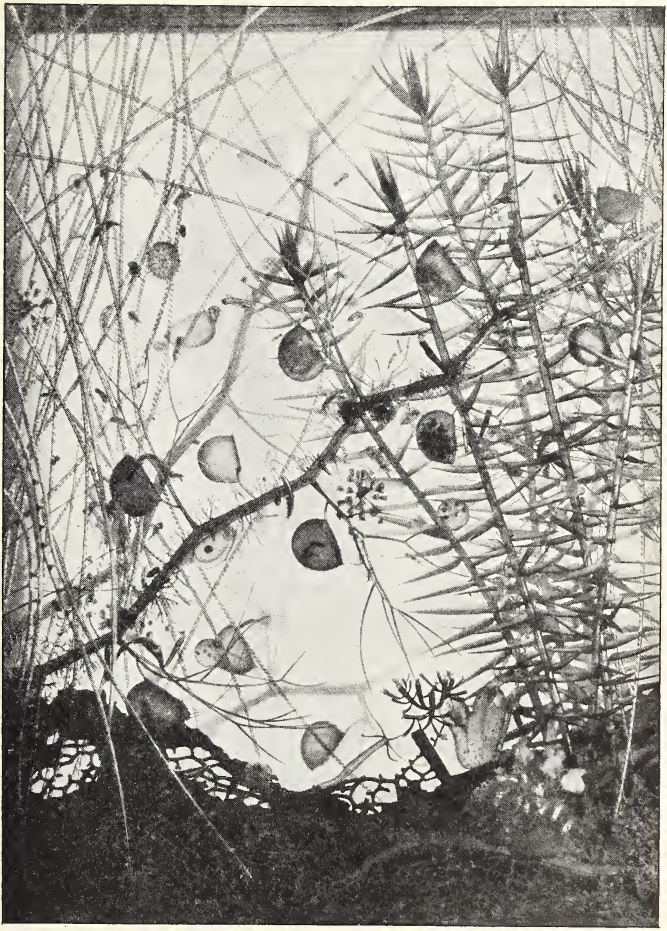


Photo from American Museum of Natural History

What responses are taking place in this fresh-water community? The green plants are most conspicuous, Elodea at the right, Spirogyra filaments at left, and bladderwort in the middle. The bladders are traps in which small water animals are caught and used as food by the bladderwort. Some colonial protozoa may be seen near center and at the left.

were continued, it was found that the amebas made considerably fewer errors than at the beginning of their experience with the beam. Paramecia likewise show some capacity to learn to avoid unfavorable stimuli.

Jennings reports a behavior in another kind of protozoan that seems to show a higher type of learning process. *Stentor* is a large, trumpet-shaped relative of the paramecium. It is able to swim rapidly through the water, but often remains quiet, with its narrow end attached to some object, while the cilia around its broad end cause currents of water to flow toward the mouth opening.

When stimulated by something unfavorable, it may respond in several different ways. If the water brings it something of no food value, it may draw in its cilia, and contract, closing its mouth. Or, it may reverse the motion of the cilia, creating a current away from it. After a time, however, it will show a third kind of reaction. Since it has not been able to avoid the unfavorable stimulus by the other two methods while attached, it breaks its hold, and swims away to a different place, where it again becomes attached. Apparently its protoplasm has been changed in some way so that instead of repeating many times the avoiding motions in the same place, it adopts the third kind of reaction and swims away from the unfavorable region.

Behavior of One-Celled Animals

While much is yet unknown regarding the responses of the smallest animals there are a few general conclusions which are worth setting down.

1. The protoplasm of one-celled animals is sensitive to a great variety of outside stimuli: to contact or touch, to

chemical stimuli, to gravity, to electrical influence, to light.

2. The outside influences may be detected by undifferentiated protoplasm, as in ameba, or there may be some special receiving structure, such as the eye-spot of Euglena.

3. In response, the usual method is by "trial and error"; that is, the animal keeps trying over and over again the same kind of response until it happens to strike a response which takes it away from an unfavorable stimulus, or toward a favorable one. It may, however, as in Stentor, develop a changed behavior.

Review and Thought Questions

1. What American biologist has made a thoroughgoing study of the behavior of one-celled animals?
2. Are amebas carnivorous or herbivorous in their diet?
3. Describe the actions of the ameba in its efforts to obtain food.
4. What is a pseudopodium?
5. Why are the response reactions of paramecia considered more complex than those of amebas?
6. How may paramecia respond to a magnet held over the culture?
7. Why does the response of Euglena to light have special significance?
8. Name five types of stimuli to which the protoplasm of one-celled animals is sensitive.
9. Give five examples of the specialization of protoplasm for response in a one-celled organism.
10. What evidence is there that even a one-celled animal may learn from experience?

Activities

1. Observe the trial and error responses of paramecia by placing them in a medium containing many solid particles. If a binocular microscope is available, these responses may be observed most easily.

2. Find vorticella in your protozoan cultures and observe the responses that they exhibit.

3. To observe trichocysts in paramecia add a small amount of blue fountain-pen ink to the culture.

4. Touch an ameba with a needle and observe the response.

5. Determine the responses of paramecia to different dissolved substances by placing them on a slide and putting drops of different solutions at the edge of the cover glass. Try nitric acid, ammonia, sodium chloride, etc.

6. Repeat the same experiment with other protozoans.

7. Report on the work of one of the scientists mentioned in this chapter.

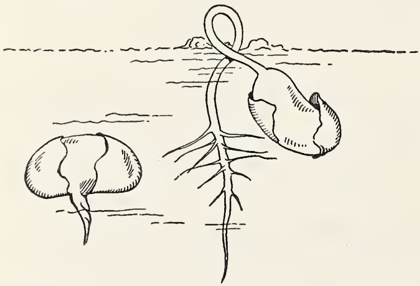
19. The Behavior of Plants

The responses of plants are carried on by cells and tissues which have other tasks to do as well. Plants do not seem to need special sense organs or sense cells, nor any special tissues for the conduction of impulses from one part to another. As a plant grows, its leaves, stems, and roots extend themselves in various directions so as to place its organs in the positions in which they can work best. The young roots and leaves grow bigger and, at the same time, point in the right directions. Later, with fully grown organs, if these are disturbed in position, they may move so as to regain their preferred position, but without any increase in size.

Besides the more familiar response movements, plants also show some less familiar kinds. Growing stems and leaves wave about to a considerable extent, but so slowly that it ordinarily is not noticed. Such movement is seen in the young stems of vines which may rotate in wide circles until they touch some support. The leaves of not a few plants regularly show sleep movements. The sunflower turns its face to the sun throughout the day, changing from east to west. A few plants have sensitive leaves. Insectivorous plants show extraordinary movements.

Tropisms

Plant organs can react to a number of different kinds of stimuli, and as a result accomplish growth or movement. These movements of plant organs have been called *tropisms*, or "turnings." The term tropism means a change in position of a plant organ which is related to the direction from which the stimulus comes. They are named and classified according to the kind of stimulus causing them.



The embryo plant in any seed usually has to accomplish tasks which would be impossible for the average animal. It must break a seed coat, determine directions for root and stem, and push through soil.

Gravity and geotropism. No matter in which position a bean is placed in the ground, its first root will turn down as soon as it emerges from the seed, and its stem and leaves will turn upward, pushing first through the soil, and then upward into the air. We say that the root is *positively geotropic*, and the stem *negatively geotropic*. The pull of gravity is in some way connected with this response.

A mushroom responds to the pull of gravity even when removed from the soil.

In general, only the main root is entirely positively geotropic. Branch roots tend to spread out at right angles or diagonally. With the stem system of a tree, a similar distribution of branches is accomplished. A main stem responds by growing straight upward, but the branches grow out away from each other and do not interfere with each other.

Light and phototropism. After a seedling stem has emerged from the ground, gravity may cease to be the

Photo by Hugh Spencer

Many plant responses result from growth. Leaves are held with surfaces toward the light. Roots grow downward into the ground. Branches spread so that they do not interfere with each other, as in this white oak.

most important influence in determining the direction of growth. Light then comes into play, and the usual position of stems and leaves is the result of the combined effect of both gravity and light. In the dark, leaves and stems respond to gravity alone, but in light, *phototropism* is mainly to be observed.

Roots ordinarily show negative phototropism. Naturally, such a response is advantageous, since it tends to direct their growth downward where moisture and soluble food are to be found.

Hydrotropism and other turnings. Roots often turn in response to the presence of water. Poplar trees have been found to be unpleasant dooryard neighbors because of the strong tendency to push their roots in search of water. In sewer pipes and drains they sometimes form ropes of branch roots which stop up the pipes. Roots will even grow upward against the force of gravity when the greater supply of water is above them. Water response is called *hydrotropism.*

Roots will also turn in the soil toward regions with greater supplies of soluble food material. This is a response to a chemical influence, a turning which is called *chemotropism.* Plant organs may also exhibit a negative response to chemicals. If some poisonous substance, such as a crystal of potassium permanganate, is placed directly in the path of a growing root tip, the root will change its course so as to avoid the poison.

Plant organs are often sensitive to touch or contact. This has the awkward name of *thigmotropism.* It is seen especially in climbing plants which respond to touch by coiling their tendrils around a support, as in grape vines. In climbing bean plants and morning glories, the growing stem coils around the pole. Some roots, for instance those of ivy plants, respond to contact by growing against the wall which serves as support.

Plants respond to several other kinds of stimuli and for each stimulus a different kind of tropism has been named, such as *galvanotropism,* the reaction to electricity; and *thermotropism,* the reaction to heat.

The results of some recent investigations seem to indicate that all tropisms are really negative. Thus the turning of a root in the direction of water may be actually a

Photo from American Museum of Natural History

This shelf fungus grew on a standing dead tree. When the tree fell, the edges again began growing parallel with the ground.

turning away from a condition of dryness, and the positive response of leaves to light really may be a turning away from darkness.

Other Responses of Plants

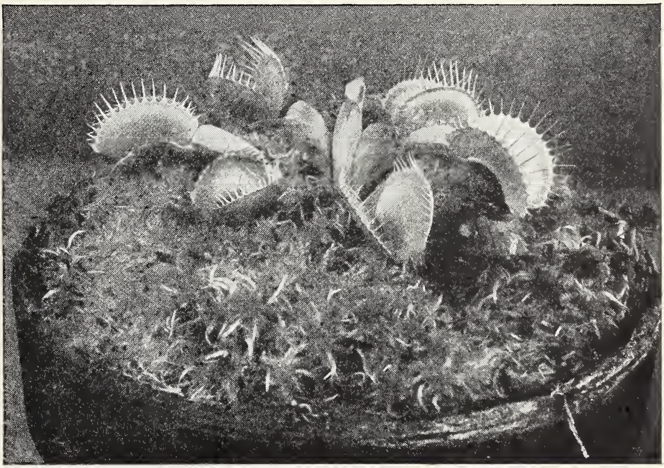
Not all of the responses of plants are related to the direction of the stimulus. Many plant movements are of a purely mechanical nature and hardly deserve to be classified as responses at all. Others, such as the unusual responses of sensitive plants and the still more rapid movements of insectivorous plants, may involve the whole plant or extend throughout a considerable portion of the plant but are in no sense discriminative movements. Still others are of such a nature that they suggest a high degree of discrimination. If a growing root tip is photographed at ten- or fifteen-minute intervals and the resulting photographs are projected as a moving picture, the root will resemble a highly intelligent, white worm pushing its way carefully through the soil and exhibiting judgment in the selection of the route. Actually, however, the whole procedure can be explained on the basis of mechanical factors affecting the root's growth. If, for instance, the extending tip comes in contact with a rock, growth will be impeded at the point of contact. Cell division will then take place with greatest rapidity on the side where the external pressure is least, and the root will grow around the rock.

Sleep movements. The common white clover illustrates sleep movements very well. Every evening its three leaflets droop down, folding with their backs together, but when daylight comes they resume their extended position. Peas, beans, and some other legumes exhibit similar sleep movements, while many flowers, such as tulips and four-o'clocks, close up at night and open in the morning. Such movements of leaves and floral parts are not related in any way to the sleep of animals.

Rapid responses. In sensitive plants, there is a regular sleep movement, but the parts of the leaf and the whole leaf may also change their position quickly, when touched. A single leaf has many separate leaflets on a branching leaf framework. Each little leaflet may drop separately.

Groups of leaflets may drop together, and finally the whole leaf may suddenly drop downward. After a short time, the parts of the leaf will gradually resume their usual positions.

In some plants which have trap leaves, the response movements are rapid. The most notable is the Venus's-flytrap, a plant found in a limited region of North and South Carolina. It has leaves hinged in the middle, with



Courtesy of Brooklyn Botanic Garden

The Venus's-flytrap is in many ways the most unusual of all plants. The blades are about one inch long. The halves are hinged along the midrib and can close instantly if the right place is touched. They grow wild in North Carolina.

a row of bristles around the margin. When properly stimulated, the halves close quickly, and the bristles interlock to form a closed trap. Then another interesting response takes place. The surface cells of the leaf pour out digestive enzymes which act on proteins, and the body of the insect is digested and afterwards absorbed. Then the halves of the leaf open again and are in a position to catch another insect victim.

Response by means of variation in growth. Young organs which have not reached full size change the direction of growth. If a potted plant with a half-formed young leaf is turned around so that the leaf points away from the light, it will bend around until it is pointed right again. The light falling on one side of the leaf stalk causes the cells on that side to grow more slowly than those on the shaded side. Consequently the leaf stalk tends to bend over until the leaf stalk is equally illuminated on all sides.

Changes in cell water pressure. When a mature leaf is turned so that it does not face the light with its broad surface, it is usually capable of bending around until it is again favorably situated for photosynthesis. The mechanism in such a case is probably chiefly a change in the water pressure of the cells on different sides of the leaf stalk. Those on the brighter side lose some of their water; those on the shaded side gain in water pressure, and therefore elongate, pushing the leaf back into its ordinary position.

In the turnings of flowers to follow the sun, the same mechanism seems to operate. In the sleep movements of leaves and in the rapid movements of sensitive plants and of insectivorous plants, changes in cell pressure are also involved, but in these cases, the leaf has a special structure by which the speed may be increased. The base of each leaflet of the sensitive plant and of the whole leaf has a swollen place, called a *pulvinus.* The cells of this structure are capable of discharging water into intercellular spaces quickly when stimulated, causing a sudden loss of water pressure, and the resultant drop of the leaf

Photo from American Museum of Natural History

Fern leaves take these successive stages of uncoiling in light or dark. Do you think the unrolling movement is determined from without or from within?

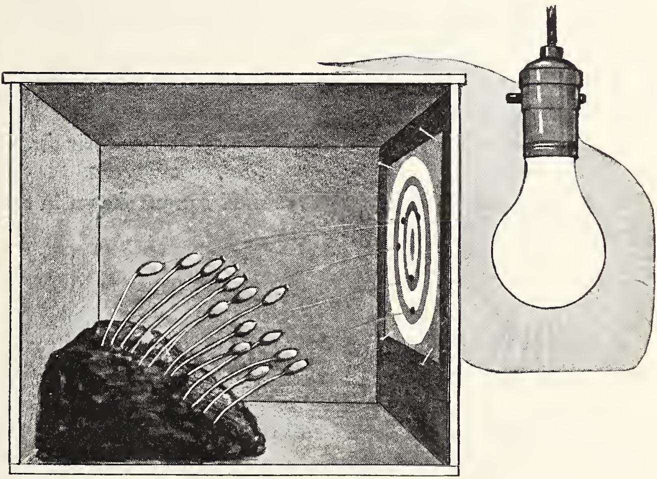
part. Gradually the cells take the water back in again, and the leaf or leaf part rises.

Plant hormones. Many plants, particularly sensitive plants, show a slow, continued transmission of stimulus through many inches of leaf tissue. In the sensitive plant, it is necessary to touch only a single leaflet to induce a complete reaction of the whole leaf. Gradually, one after another, the leaflets drop, and within a short time the impulse is seen to spread to all parts of the leaf.

Courtesy of Boyce Thompson Institute for Plant Research

Until recently it was impossible to reproduce many kinds of woody plants from cuttings. They could only be grown with difficulty from seeds. Discoveries at the Boyce Thompson Institute in Yonkers by Dr. Zimmerman and others have shown that holly, yew, and other plants will respond to the plant hormone, auxin, by sending out roots.

It has been suggested that the transmission of such an impulse may be brought about by means of certain chemical substances called *hormones*. Studies based on many kinds of plants indicate that plant hormones are of considerable importance and are widely distributed. The so-called "wound-hormones" apparently stimulate cell division and therefore aid in the healing of wounds. Another hormone, *auxin*, which is found in both plant and animal tissues, is related to growth. It is found in abundance in the tips of many young seedlings and seems to be responsible for the extreme sensitivity that seedlings



The fruiting stalks of the fungus Pilobolus shoot their spores toward light. What tropism is this?

exhibit in relation to light. By causing enlargement of cells in the darker portion of the tip, it causes the bending of the whole organ in the direction of the source of light. Such hormones furnish a possible explanation of other tropisms and may prove to be the underlying factors involved in other plant responses.

Review and Thought Questions

1. Is the protoplasm of plant cells specialized for response?
2. By what two methods may a plant secure the best possible position for the performance of its various functions?
3. Describe at least five common types of tropisms.
4. What is meant by the "purely mechanical" nature of some plant movements?
5. Describe one example of rapid response in a plant.
6. Account for the movement of a leaf in response to light.
7. What evidence is there that hormones are important to plant growth?
8. What possible benefit may insectivorous plants derive from the insects they capture?
9. Explain how the stems of a plant may change their direction of growth.
10. Explain what happened to the shelf fungus shown in the illustration on page 361.

Activities

1. Invent original experiments to test the responses of roots, stems, and leaves to light.
2. Place a soaked sponge in a wire soap shaker with soaked seeds placed between the sponge and the wire on both the upper and the lower surfaces. Fasten to a support so that the seeds will remain in the same position. Keep the sponge moist.
3. Grow sensitive plants from seeds. When the seedlings are about three inches high, you can begin studying their responses to touch.
4. Grow sweet-pea seedlings. Bring the first tendrils into contact with (*a*) a wire, (*b*) a pencil, and (*c*) a flat surface. Notice the responses that the tendrils exhibit.

5. Study sleep movements in oxalis or white clover by placing opaque objects over the plants.

6. Treat cuttings of various plants with commercial preparations containing auxin. Compare with controls, that is, with other cuttings not so treated.

7. Collect and post on your bulletin board interesting clippings and pictures on plant behavior.

8. Report on some practical application of our growing knowledge of plant behavior with which you have become acquainted through everyday experience or through newspaper and magazine articles.

9. Set long paper or cardboard tubes over growing seedlings. Use similar seedlings grown without such tubes as controls.

10. Place the root ends of several onion bulbs in water until the roots begin to grow. Then place the roots of some of the bulbs in a weak solution of colchicine for a few days and compare their growth with that of bulbs not treated with colchicine.

11. Make a list of stimuli to which plants respond.

12. Make a complete list of tropisms.

20. Animal Response Systems

Upon several occasions in previous chapters, one-celled animals have been compared with many-celled animals. In digestive systems, there is an increasing degree of complexity from the simple cell of the protozoon to the highest development of the vertebrate nutritive system. Similar stages occur in the development of the oxygen-using apparatus, and in the mechanisms for circulation, absorption, and excretion. Another such series connects the automatic responses of an ameba with the more complex responses of higher animals.

Types of Animal Response Systems

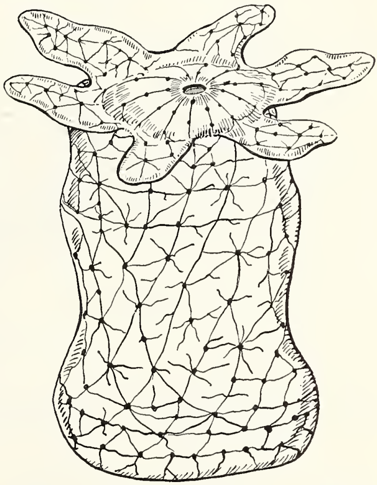
Considering types of animals in a series according to the increasing complexity of their general body plans provides a satisfactory basis for comparing the various kinds of animal response systems.

The protozoan type. Ameba and paramecium are typical examples of this type (see Chapter 18).

The cell-colony type. Each of the cells of a Pandorina or a Volvox is as independent as an ameba in its relation to the environment so far as its ordinary activities are concerned. In movement, however, there is a distinct advance over the one-celled stage. These little green balls of cells move by rolling along on the bottom, or through the water. The motions of the flagella are co-ordinated so that they do not interfere with each other, but each contributes toward the forward movement of the colony.

So far as is known, there are no special structures for response in colonial animals. Each cell is connected with the adjoining cells by strands of protoplasm. Stimuli travel from cell to cell through these strands just as they travel through the single-cell mass of an ameba.

The simple multicellular animals. In Hydra there is a net of special response cells. Stimuli may travel in any direction over these cells. There is no central mass anywhere, but the simple net serves its purpose of connecting the tentacles, the mouth, and the rest of the body so that the whole animal can move as a unit.

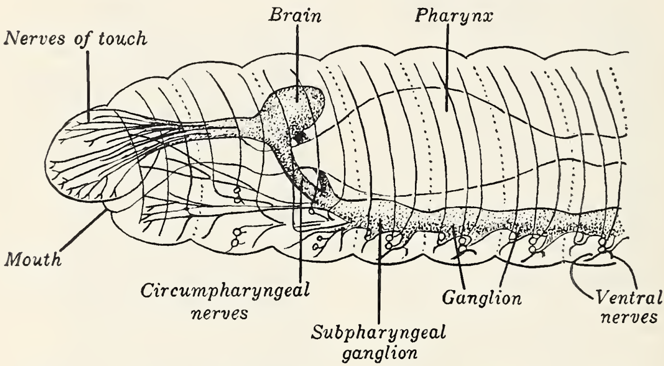


The nerve net of hydra is a connecting system of cells by which the motions may be controlled and made to work together.

The advantage of such a *nerve net* over the protoplasmic strands of the colonial organism is that it affords a better performance of the conduction process. The nerve cells of hydra can conduct impulses much more rapidly and efficiently than undifferentiated protoplasm can do it. Without this more rapid conduction of impulses, the hydra cell mass would be too large to act efficiently as a unit.

Flatworms represent a still higher development of nerve system and tissues. Two main strands of nerves run along each side of the body, with two masses of nerve cells called *ganglia*, near the head end, connected with each other.

The annelid type. Segmented worms present several points of advance over the simplest multicellular forms. These animals have a concentration of nerve tissue at the front and a row of ganglia extending along their entire

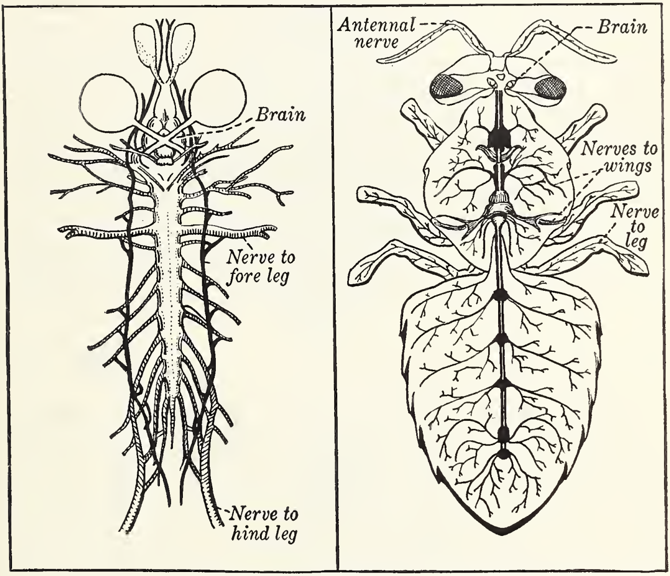


What an advance over hydra an earthworm represents! It has a central nervous system, with an enlarged mass of nerve tissue at the front end and with many sensory and motor branches.

length, just below the food tube. A main nerve cord connects the ganglia with each other and with the large ganglion or brain at the front.

Although earthworms have no special sense organs, such as eyes, both the anterior and posterior ends are dotted with numerous nerve endings which are sensitive to light and chemical stimuli. That earthworms respond to light may be easily demonstrated by flashing a light on them in a dark room. The sensory cells or receptors connect with the central nervous system, enabling the organism to coordinate its responses. It may be noted here that the coelenterates are the only phylum in which the nerve cells carry impulses in either direction. In all higher animals, a nerve cell is a one-way track.

The arthropod type. The arthropod response system is basically like that of the annelid in its general plan of a



By Woodruff, from Eikenberry and Waldron, Educational Biology

As the nervous systems of the frog and the bee show, the vertebrate and arthropod nervous systems have similar plans of arrangement. But the dorsal position of the nerve cord and its protection in a bony case are two very important differences.

main nerve cord, with special enlargements at the head end. But arthropods are in a class by themselves in some aspects of their nervous systems, particularly in the complexity of their types of response behavior involving instincts and communal life. Their well-developed jointed appendages require well-developed mechanisms for co-ordination.

Their sense organs are also in general more highly developed than those of annelids.

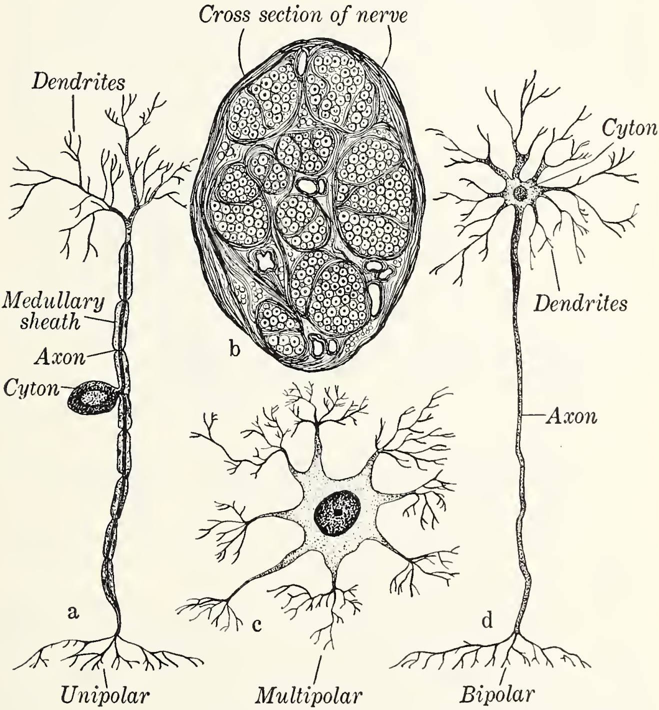
The vertebrate type. Vertebrates have a single main nerve cord along the dorsal side as contrasted with invertebrates, which have theirs along the ventral side. In vertebrates this nerve cord is typically enclosed in a protective bony structure consisting of the *cranium* at the anterior end, which encloses the *brain,* and the *vertebral column,* which extends along the dorsal side and encloses the *spinal cord.* Numerous branch nerves extend outward from both the brain and spinal cord. Their general body structure allows vertebrates to grow to a much larger size than invertebrates and also to develop a much greater mass and concentration of nerve tissue.

Response in Vertebrates

The communicating systems of vertebrates might be compared to a central telephone exchange, including the trunk lines that run into it and the branch wires that connect the central exchange with the individual subscribers. The brain corresponds to the central exchange and the nerves to the wires leading out from it. At the ends of the wires and of the nerves are instruments for sending and receiving. Messages travel from one part of the system to another in a never-ending stream, and the central station is kept busy switching calls here and there and making the proper connections.

Neurons. In all higher animals messages are carried from one part to another by means of nerve cells or *neurons.* Neurons exist in enormous numbers and are found in all parts of the organism. It is estimated that there are more than ten billions of them in the human brain alone.

Neurons are usually longer than other animal cells, some of them being several feet in length. Most of the length consists of the nerve fiber, or *axon*. Around many axons

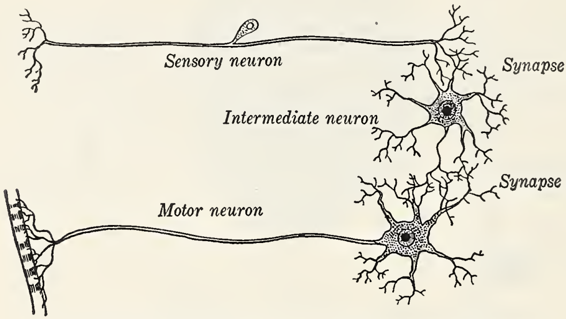


Redrawn from Cockefair and Cockefair, Health and Achievement

Three kinds of neurons (a, c, d) and a cross section of a nerve, showing bundles of axons (b) are pictured. The cyton is the main cell body with its nucleus.

there is a *sheath* of tubelike cells that nourish the axon and insulate it from adjacent axons. There is also a nucleus and cytoplasm mass in a central body called the *cyton* from which the axon is an extension. A bundle of axons is called a *nerve.* Axons end in branching fibers, the *dendrites;* and there may be similar branching fibers from the cell body.

Neurons may be divided into three groups according to their position and function. A first group starts from the exterior or from the internal cells of the animal and stretches toward the central parts of the nerve system. These are called the *sensory* or *afferent* neurons. From the



In a three nerve-cell circuit, the axons of sensory and of motor nerve cells are sometimes a foot or more long.

central system, another set of neurons extends outward, ending in muscles, in glands, and elsewhere. Their task is to carry outward-bound impulses, hence they are called *efferent* neurons. Because they carry impulses which cause the muscles to move, efferent neurons are also called *motor* neurons. The third type of neurons are the *intermediate* neurons, which lie between the afferent and efferent neurons. There may be many intermediate neurons in a chain, and they may extend in all directions, connecting many sensory and motor neurons.

The primary function of neurons is of course the conduction of impulses between different parts of a multicellular body. Since the neurons of higher animals are able to conduct impulses in only one direction, every response involves at least two neurons, one afferent and one efferent. Usually, however, one or more intermediate neurons are also brought into play to connect the sensory neurons with the motor neurons so as to result in the appropriate pattern of response. If an animal is traveling through a narrow opening, the sides of the opening touch its body at several points, and sensory neurons located in the skin send impulses inward. In order to make the appropriate response, many different muscles need to be moved, and their movements need to be co-ordinated. Large numbers of intermediate neurons are required to do this.

The synapse. The point of nearness between two nerve endings is known as a *synapse*. Momentarily the dendrites of two neurons are able to close the circuit and make some kind of contact. This contact is probably made through a chemical substance secreted by the ends of the nerve and discharged across the gap. The ease with which the connections between adjacent neurons is made may vary greatly. Habitual actions result from the most frequently used paths.

Speed and Efficiency of Animal Response

The speed with which impulses travel along the nerves of animals has been measured for a number of animals. In his book *Science of Life*, H. G. Wells makes some interesting observations concerning the relative speed at which impulses travel along the nerves of a fresh-water mussel, a slug, a king crab, a frog, and a human being. The speed of these impulses varies from two or three seconds to an inch in the fresh-water mussel to 400 feet per second in a human being.

The significance of speed. Wells continues by pointing out the significance of this difference in speed. He suggests that we imagine a man with the nerves of a fresh-water mussel, carelessly letting his cigarette slip between his fingers until it commenced to burn him. Not until two

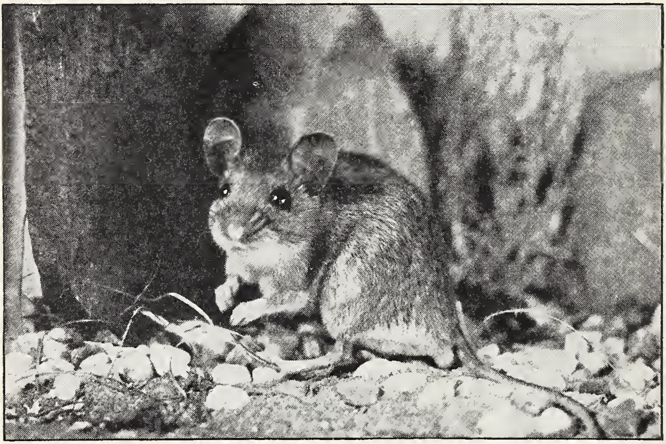


Photo by Walter J. Schoonmaker

How is the ability to make rapid responses important to this white-footed mouse?

minutes later would he feel the pain. Then, if his brain reacted at once, the impulse saying "drop your cigarette" would stimulate his fingers about two minutes later.

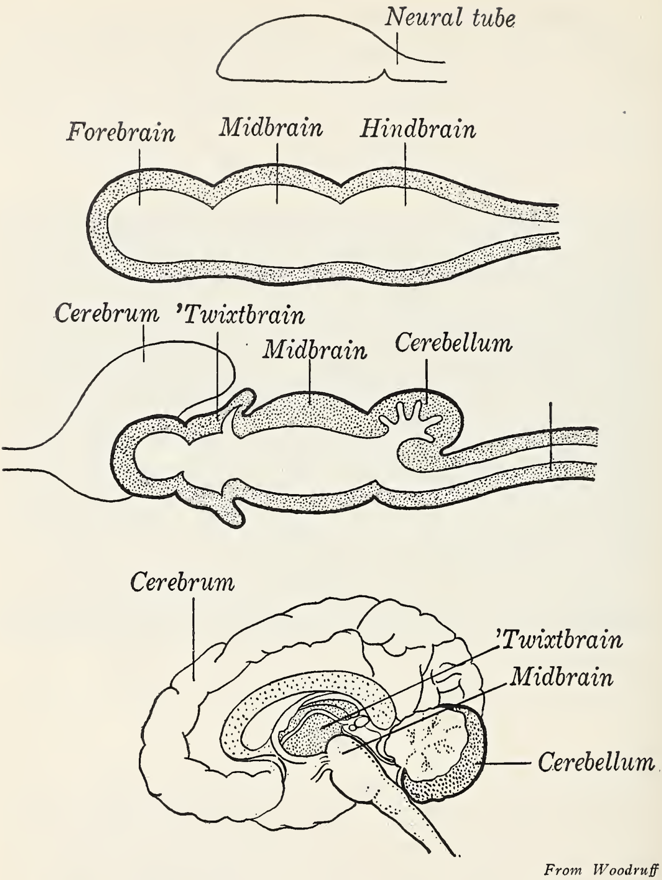
A large multicellular animal such as man could not exist if it depended on the slow protoplasmic transmission of impulses. Even with the complex nervous system of a fresh-water mussel, it could not cope with many of the problems of its environment. Adjustment to the surroundings requires not only the proper kind of response but also a high speed of response.

Efficiency of response. Not only does each organ of a complex animal body require regulation, but all the organs need to work together so that the various processes are co-ordinated and carried on at the proper speed. Every adjustment that an animal makes to the environment involves some kind of internal change. A sudden movement necessitates the release of energy in the muscles. The heartbeat and respiration rate must be increased, and numerous other adjustments must be made. To accomplish these adjustments, many neurons are necessary. These neurons are intermingled with the other kinds of cells in every organ of the animal body, and they enable each organ and tissue to respond at the proper time and at the proper speed so that the organism is able to maintain itself in the most favorable relation to the environment.

The Nervous System

In the simplest multicellular animal, the hydra, the ectoderm is concerned with protection and other general reactions to the environment while the endoderm is concerned with nutrition. This is true also of all other multicellular animals from the lowest to the highest, including man.

The origin of the brain and spinal cord. Every vertebrate animal begins as a single cell, which divides and redivides until the organism becomes mature. In the very early stages of this cell division, a groove forms along the back surface of the *embryo,* as the animal is called in the early stages of its development. The edges of this groove fold over and finally grow together, leaving a tube composed of ectodermal tissue buried in the mesoderm. This *neural tube* develops into the nervous system with all its



The diagram shows four of the steps in the development of the brain of a mammal.

millions of afferent, efferent, and intermediate neurons. While the embryo is developing, the neural tube enlarges, and its walls thicken. Finally it becomes the *spinal cord.*

At the anterior end of the spinal cord, the enlargement is not uniform but is much greater at some points than at others. Some portions push outward and fold over other portions. Eventually it becomes a brain.

In the simplest vertebrates the mass of nerve tissue at the head end of the animal is so insignificant that it hardly deserves the dignity of being called a brain. But in fishes, amphibians, reptiles, birds, and mammals, five definite brain regions can be distinguished. In the development of these forms, three brain regions, the *forebrain,* the *midbrain,* and the *hindbrain,* become differentiated rather early. As development proceeds, the forebrain divides, the front portion becoming the *cerebrum* and the hind portion the *'twixtbrain.* No division occurs in the midbrain, but the hindbrain becomes separated into the *cerebellum* and the *medulla oblongata.* In the lower vertebrates, the largest portions are the optic lobes of the midbrain and the medulla, but in mammals the biggest part is the cerebrum. The intelligence of an animal is almost in direct proportion to the size of its cerebrum.

The three nervous systems. The brain and spinal cord make up the *central nervous system.* From the central nervous system, many pairs of branch nerves lead outward through openings in the skull and vertebral column. These nerves go to the organs and the tissues and make up the *peripheral nervous system.* Nerves leading directly from the brain are called *cranial nerves.* Nerves extending from the spinal cord are called *spinal nerves.*

The peripheral nervous system gives rise to a third group of nerves known as the *autonomic nervous system.* This consists of a series of ganglia situated in the body cavity on the ventral side of the vertebral column. These ganglia are connected to the central nervous system and to nearby organs by means of branch nerves. In general, the autonomic nervous system is concerned with the regulation of

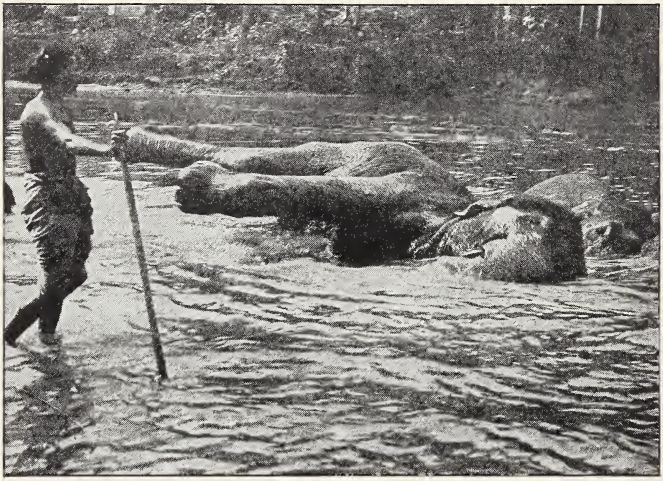


Photo from Publishers' Photo Service

An elephant enjoys a bath. Only in higher animals do we see activities which seem to be performed for the pleasure they give.

involuntary activities, while the peripheral and central nervous systems are concerned with the regulation of voluntary activities.

Review and Thought Questions

1. What evidence may be found among colonial animals that co-operation exists between the individual cells?
2. Describe the response system of Hydra.
3. Why is the response system of flatworms considered more advanced than that of Hydra?
4. In what animals do nerve cells seem to be able to carry impulses in either direction?

5. Compare insects and earthworms with reference to special sense organs.

6. In what respect is a telephone system unsatisfactory as an analogy to the communicating system of a vertebrate?

7. Describe the general structure of a neuron, using scientific terms for important parts.

8. How does an impulse pass from one neuron to another?

9. What relation has speed of response to man's safety in modern civilization?

10. Name and locate five brain regions in higher vertebrates.

Activities

1. With a dissecting needle, touch one of the tentacles of a Hydra, and observe the response. After the Hydra has returned to its normal position touch other parts and determine the areas of greatest irritability.

2. Place a drosophila in a long, glass tube of large diameter. Wrap black paper around the tube loosely enough so that it will slide back and forth. Expose the tube to the light with a few inches at one end uncovered by the black paper. Then slide the paper the other way and expose the opposite end to light.

3. Invent a way to test the responses of earthworms to light.

4. Cut a half-inch hole in the bottom of a shallow pan and set the pan on a box of earth. Place earthworms in the pan and cover with a piece of glass. Observe what happens.

5. Train goldfish to come for food by tapping on the aquarium near the place where food is dropped. After a week try tapping without providing food.

6. Make a maze and watch a rat solve it.

7. Automobile drivers are often tested to find their "reaction time," that is, their speed of response. Test to find your own reaction time in applying the brake after a given signal.

21. Human Behavior

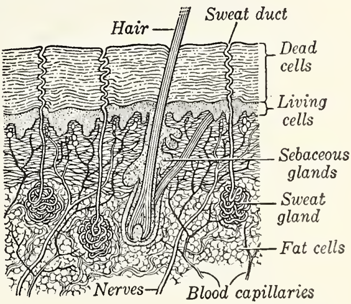
The response behavior of all higher animals may be reduced to four steps: (1) Stimuli of various sorts are received from the outside or from the inside. (2) Impulses run from the sense organs along nerves toward the spinal cord or the brain. (3) Something happens in the central nervous system by which the final reaction is determined; that is, co-ordination takes place. (4) A definite reaction occurs. This may be a visible movement, or it may be an invisible thought train, or it may be a chemical change. Since man is a higher animal, these same four steps are also characteristic of human behavior.

The Twenty-five Senses

We actually receive sensations in many more ways and from many more sources than is ordinarily realized. Let us consider first the different ways in which we may become affected from outside the body.

The senses of feeling. Some parts of our body are much more sensitive in feeling than others. The finger tips and the upper surface of the tongue are most sensitive. The sense of feeling depends upon a number of different kinds of sense impressions which can be rather simply demonstrated, and for which there are separate and different kinds of nerve endings.

Draw a warm nail point lightly along the skin, and you will find that its warmth is felt at definite areas and not felt at others. The same will be found if a cold nail is used, and the sensation of cold will be felt at different points from the sensation of heat. Hold two nails with the points a centimeter apart, and touch someone who cannot see just what you are doing. Along the finger tips he will recognize two separate points. On the back of the hand or on the upper arm, the points will have to be more than a centimeter apart if they are to be recognized as two separate pressure points. Pressure is felt by special types of nerve endings, and these are differently spaced in different parts of the skin. Also there are two kinds of pressure endings.

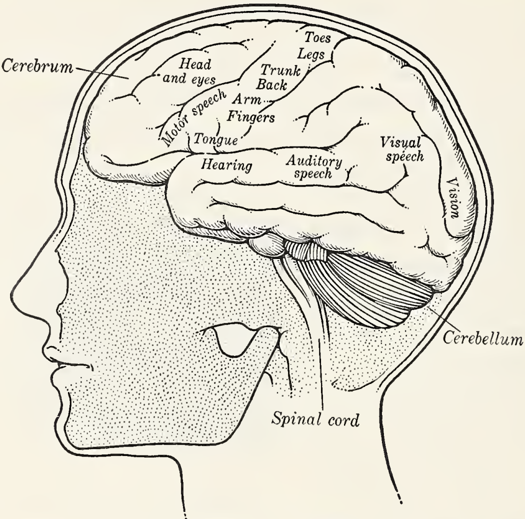


Find the nerve endings in the skin.

Pain is recognized by means of a different kind of nerve ending. These are very widely distributed through the skin, although closer together at certain places, as in the finger tips, than at others. Some internal parts of the body, the intestines, for instance, do not feel pain from the surgeon's cuts but do report pain when the intestine is distended with gas.

One of the most sensitive means for recognizing the touch of some outside object is found in the hairs of the body. Each hair has wrapped around it near the base the branching ends of a nerve, different from any of those so far mentioned.

When we pick up an object, we are able to estimate its weight. The sense of weight depends upon pressure, and also upon the strain put upon the muscles, and upon certain joint reactions. Many other impressions which we usually think of together under the heading of "feeling" depend upon combinations of two or more of the different



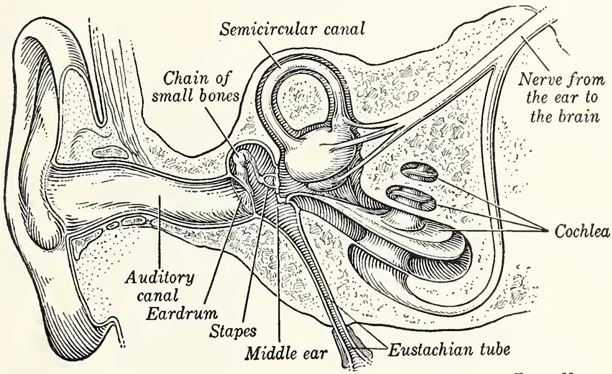
After Eikenberry and Waldron, Educational Biology

You cannot see with your eyes or hear with your ears any more than a camera can see or a telephone can hear. Eyes and ears are merely devices for receiving stimuli. The actual centers where these and other senses are really perceived lie in the brain. Different areas of brain activity have been located so that we have a fair map of brain activity.

senses already mentioned. For example, a hot object calls forth both a recognition of its heat and of pain at the same time.

The sense of hearing. When we hear a sound, the outer ear collects air waves which set the drum membrane to vibrating back and forth, slowly or rapidly. From the drum, these motions are carried over a little chain of three bones to the liquid of the inner ear, which is contained in a coiled tube shaped like a snail shell.

Lining this coiled tube are the sensory cells connected with branches of the nerve of hearing. Each cell has, also, a number of hairs. When the liquid is vibrated, the hairs are brought into contact with a surface, and the effect of



From Hegner

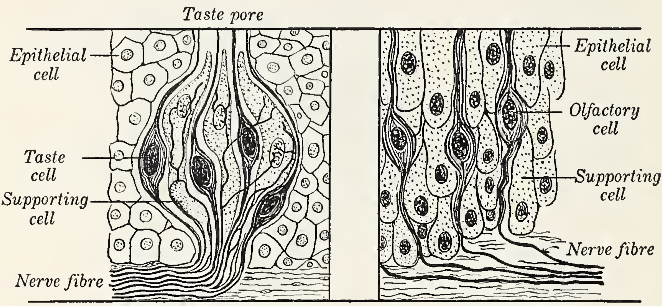
The ear takes care of the reception of sounds, and also of the sense of balance. In the coiled tube, vibratory hairs of various lengths serve to take note of sounds of different pitch.

this contact is transmitted by the auditory nerve and is recognized as sound. In other words, hearing depends finally on contacts made by special cells in the inner ear.

The sense of balance. Another part of the ear is partly responsible for our being able to tell when we stand upright, and when we move away from any given position. The three *semicircular canals* act somewhat as do the carpenter's level. Each is full of liquid. When the head is suddenly moved the liquid presses harder against one side of the canal than against another. This change in pressure is recognized, and is interpreted as a change of position.

From other parts of the body come messages regarding the way in which the body is held. Nerve endings in the muscles, joints, and elsewhere report changes in position. The eyes contribute in an important way. Many other different kinds of sense stimuli are also involved in what we may think of rather simply as a sense of balance.

The senses of taste and smell. A protozoon recognizes difference in the chemical nature of substances by



Redrawn from Hunter, Walter, and Hunter, Biology

An ameba takes note of all kinds of stimuli with the same protoplasm. Our bodies divide up the task and form specialized cells for the different kinds of stimuli. For the detection of chemical stimuli, we have the special sense organs of taste and smell.

means of the capacity of the protoplasm of its single cell. In man a number of different kinds of special cells are necessary for any recognition of chemical differences. As far as we know, only these special cells are able to react to such differences.

For taste, there are apparently four different kinds of "taste buds" and four different varieties of the sense of taste. Also, to be tasted, in a strict sense, the substance must be dissolved in water. This can be shown by a simple experiment. If you dry the surface of your tongue, you can place on it a little sugar and something as bitter as quinine and you cannot distinguish between these until they become moistened.

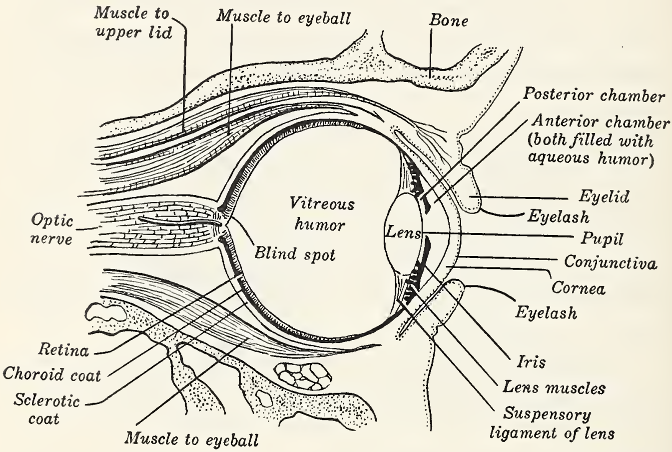
The four different kinds of taste sensation are sweet, sour, bitter, and salty. Usually the food we eat presents two or more of these separate kinds of stimuli in combination. But taste is further complicated by the fact that most foods also affect our sense of smell, and we get a combination effect in eating things in which we do not ordinarily distinguish between sensations received in the mouth and those received at the same time through the nose. You can prove this easily by testing different substances in your mouth while holding your nose. Closing your nostrils tends to keep the food material from producing any effect on the sense organs of smell. A cold in the head has something of the same effect.

For the sense of smell, there are special areas in the upper nose passages where the nerve cells are located which are affected by substances in the air. Probably the sense of smell is also sometimes partly confused with the sensation of pain resulting from more active chemical agents, such as ammonia.

The sense of sight. There is good reason for believing that in the human eye mankind has one of the finest devices for receiving and reporting differences in light rays that exist in the animal kingdom. Other animals, such as dogs and donkeys, with their movable ears, are far ahead in hearing, but in man the sense of sight is more highly developed than in almost all other animals.

The eye is a device much like a camera. It has a shutter, the *iris,* for controlling the amount of light admitted, a *lens* for focusing the light rays accurately, and a sensitive surface, the *retina,* on which a small image is actually projected in an inverted position. Whatever you look at is momentarily focused on the retina of each eye.

In the retina there are two types of light-sensitive cells, the *rods,* which are sensitive to intensity of light and the *cones,* which are sensitive to color. These are bathed in a

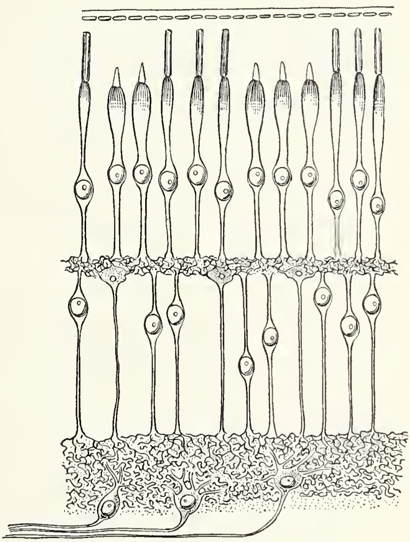


From Woodruff

All vertebrate eyes are built on the same general plan, as are the eyes of two mollusks, the squid and the octopus. For all-round capacity the human eye is probably the best of all. How does the focusing of the human eye differ from the focusing of a camera?

liquid which contains a light-sensitive substance. The effect of light in different degrees of brightness is to cause different amounts of chemical change in this substance. These chemical changes affect the rods and cones in differing degrees, and the optic nerve transmits the result of the stimulus and we say we "see."

More than twenty-five senses. It is clear that each of the sense organs contains several kinds of receptors. If we count all of these, we may be sure that there are many more than twenty-five different senses. Almost every cell of the body is connected in some way with nerve endings through which stimuli may be started toward the central nervous system. In the human skin there is estimated to be about 16,000 receptors for heat, 150,000 for cold, 500,000 for pressure, and between 3,000,000 and 4,000,000 for pain. We are definitely conscious of those stimuli which start from some of the surface structures of the body, but the internal parts also have their nerve connections and are constantly sending messages reporting their condition and any changes that happen to them. It appears that one may have as many different kinds of sensations as there are different kinds of nerve endings in the body.



Some of the layers in the retina of the eye are shown in cross section. The rods are sensitive to light and the cones to color.

Co-ordination and Response

The receiving stations for nerve impulses consist of two main great divisions, the *central nervous system*, including the brain and spinal cord, and the *autonomic system*, consisting of several plexuses, or nerve knots, in the body cavity. In the central system there are several grades or levels of activity. Many incoming messages are taken care of by the spinal cord. Others have to be sent to the *cerebellum* for co-ordination, while still others are sent to the highest level in the whole system, the *cerebrum.*

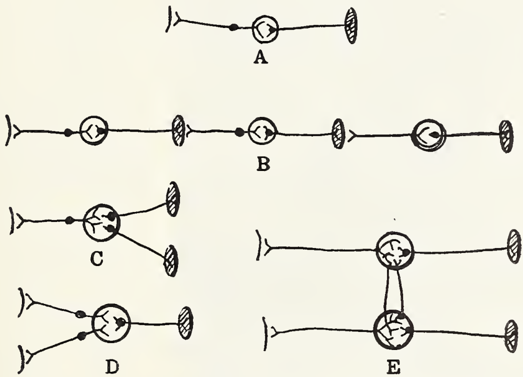
The cerebrum consists of two halves, or hemispheres. It is the seat of all conscious actions, of all feelings which we recognize, and of all processes of thought. The lower parts of the brain, the spinal cord, and the autonomic system are the centers of all co-ordination which is unconscious and automatic.

Reflexes. Many incoming sensory messages, upon reaching the spinal cord, lead to an immediate outgoing impulse called a *reflex.* In the simplest reflex the sensory and motor neurons may be connected through a single synapse, but usually one or more intermediate neurons are also involved. The word reflex suggests that the incoming message is "reflected" or sent back to the place where it started. Of course the same message is not sent back, but something determined at the nervous center goes out in the form of an impulse for muscles to contract, for gland cells to secrete, or for some other kind of cell action.

Sometimes the action takes place in the part which was stimulated, as when a bee sting leads to a prompt movement of the hand. However, the action may take place in an entirely different organ. If a frog which has had its brain removed is irritated on the body with a little acid, the leg will automatically be brought up to brush off the offending material.

Reflexes may be connected in chains or series. An *instinct* is usually such a series of reflex actions, each response acting as a stimulus for a new response so that the result is a quite complex behavior pattern. In general, the greater the amount of voluntary nervous action and the more the cerebrum comes into play, the fewer the instincts. In man there are few actions which may be classified as instinctive.

Reflexes we have in immense numbers. The digestive system, for instance, with its millions of muscular and glandular cells, is entirely under reflex control. Imagine how busy we would be if we had to think about all the countless muscles and glands which are incessantly working in our bodies.



From Herrick's Introduction to Neurology

Diagram representing several types of arrangement of neurons in reflex arcs. A, simple reflex; B, chain reflex; C, one receptor with paths leading to two effectors; D, two receptors affecting same effector; E, complex arrangements.

Conditioned reflexes. Pavlov, the eminent Russian physiologist, showed the importance of *conditioned reflexes* in learning and training. Conditioned reflexes are acts that are initiated by stimuli other than those usually associated with a given response.

In Pavlov's experiments, a dog was fed every day by the same man. He learned to associate the appearance of this man with feeding. When food was brought, the dog's saliva began to flow. This was continued for some time, so that the dog's brain formed a memory association between the food and the man who brought it. Later, when the man appeared without food, the saliva flowed just the same. The man served as a substitute stimulus for provoking the reflex act of secreting saliva.

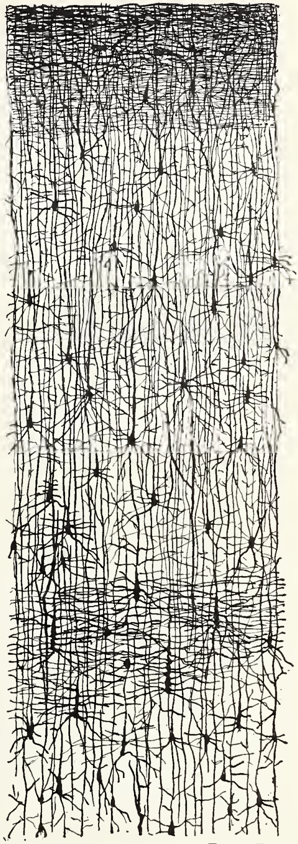
Photo from Ewing Galloway

Conditioning desired actions by satisfying approval or rewards of food helps pets and children to establish new habit patterns.

The principle of the conditioned reflex has been found to be very useful when applied to human beings. For example, a child can be conditioned against certain fears. Some children are fearful about getting off a chair. If the child is rewarded in some way, it may be induced to climb down. Later the child will readily climb down without fear even though no reward is offered.

Memory, thinking, and reasoning. In certain regions of the *cortex,* or outer surface of the brain, the neurons are sensory. They receive stimuli from afferent nerves originating in the sense organs. If these neurons are stimulated, a sensation is the result. In other regions the neurons are motor. Stimulation of these regions produces activity in some part of the body. Other regions are neither sensory nor motor. These we call the *association areas.* The neurons in these areas are connected with one another and with the *sensory areas* and *motor areas.*

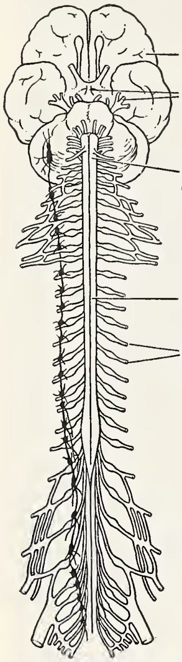
The association areas in the cerebrum constitute a large portion of the cortex. In man this area is larger than in other vertebrates. These areas are the parts of the brain that are needed for what we call intelligence. The neurons in these parts develop later than do those of other parts of the nervous system. It is believed that these great areas are blanks at birth, and upon them is somehow recorded the story of a lifetime.



From Fox

In the cortex of the human brain, the association area is larger than in the brains of other animals.

The association areas, therefore, are the regions on which habits and conditioned reflexes are impressed. They develop and change so as to record the effects of experience. The capacity to record such experiences we call *memory.* The comparison of new experiences with those previously recorded which takes place in these areas, we call *thinking* or *reasoning.*



Redrawn from Cockefair and Cockefair, Health and Achievement

Compare the underside of the central nervous system of man with that of a frog on page 373.

Forming habits. A girl is enrolled in the typing class in school. She is placed before a typewriter, the keys of which are unlettered. She moves her fingers according to instructions and a chart at the front of the room. She writes a word slowly, laboriously, deliberately, consciously. The word is repeated again and again and again. Gradually the speed is increased and the word is written automatically with little effort. The more often it is written, the more perfect the performance. "Practice makes perfect."

Physiologically, it is believed that a habit consists in forming a reflex path. This involves closing more readily the synapses between the neurons in the path. The more often the path is traversed, the more readily does the nerve impulse travel across these synapses. This is the reason why a skilled worker is less fatigued by the performance of a given amount of work of a certain kind than an unskilled worker doing the same job. He does not have to think about each step.

Practice, then, is the first principle in forming a habit.

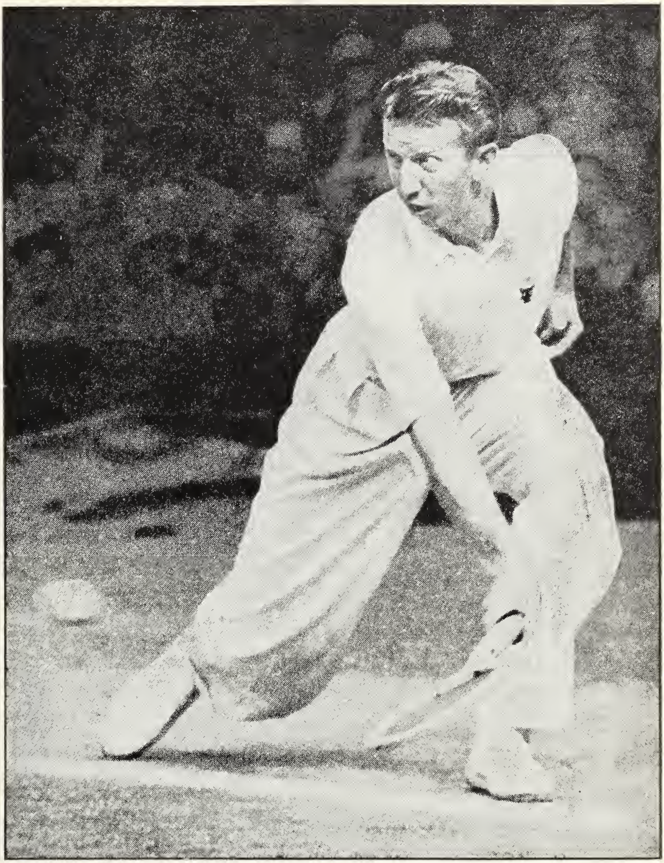
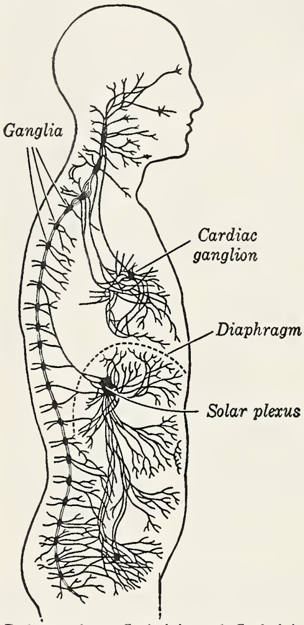


Photo from Acme Photo

Skill in any game, such as Donald Budge's mastery of tennis, is the result of a sound nervous system plus practice.

However, the learning is made less disagreeable and the habit is formed more quickly if the desire to form the habit is strong and satisfaction is experienced in doing it. A boy who likes to play a violin will learn to play more quickly than one who practices under compulsion.

Changing habits. It is unfortunately true that we can learn to do well acts that may not be socially desirable or advantageous even to ourselves. We call these "bad" habits. The child who has formed the habit of biting his fingernails may be cured by having some disagreeable-tasting substance painted on the finger tips. This makes him aware or conscious of the act, and the habit is soon abandoned.



Redrawn from Cockefair and Cockefair, Health and Achievement

If we did not have this sympathetic nervous system to control the activities of our digestive systems, think what a lot of time we would have to spend learning how to do and look after things!

Another way of changing habits is illustrated by a boy who had developed the habit of whittling his initials in every tree, post, or wall that he could find. He was taken in hand and taught how to whittle objects. He subsequently developed an interest in wood carving. Thus a bad habit may be changed into a good one by substitution.

Importance of habits. This capacity that we have of forming habits is tremendously useful to us. Imagine how little we could accomplish or learn if our minds had to be concerned constantly with activities necessary for mere existence! How much could you write if you had to attend to the manner of forming your letters? When would you get to school if you had to stop to think each morning what you had to do, and how to do it, to get ready for school? Habits release time and energy and thought for acquiring new knowledge and skills. They are more than time savers. Habits improve the efficiency and accuracy of our activities. They release time for thoughtful activities, and enable us to solve new problems intelligently. They make work easier by decreasing fatigue.

Mental disorders. Stimuli that reach the cortex usually result in activity somewhere in the body. Certain circumstances arise, however, that lead us to withhold or *inhibit* the activity. Some individuals are more inclined to action, others to inaction. In the cortex the afferent impulses produce either excitation or *inhibition.* Sometimes there is a conflict and an inability to do one thing or another. Some individuals may lose the power to control the response so that there is a constant state of excitement or, on the other hand, of inaction. These states we call *neuroses.* They are disorders of the nervous system that are not caused by any injury to it. More serious disorders have been called *psychoses,* and in extreme forms they are known as the different types of *insanity.*

Mental disorders must be regarded as diseases, as truly as are cases of mumps, indigestion, or severe infections. We are coming to appreciate this point of view slowly. Not many years ago people who were mentally ill were treated like wild animals. Instead of curing the conditions, such treatment merely aggravated them. Today we are beginning to adopt a more reasonable attitude toward those who are mentally ill and are developing successful methods for the treatment of neuroses and psychoses.

Alcohol and behavior. It is easy to observe that alcohol affects behavior. The chief and most significant effect is upon the higher centers of nervous control which involve the expression of intelligence, will, emotion, thought, memory, and judgment. The degree of effect is dependent upon the amount which is taken up by the tissues of the brain and the spinal cord from the blood which supplies them.

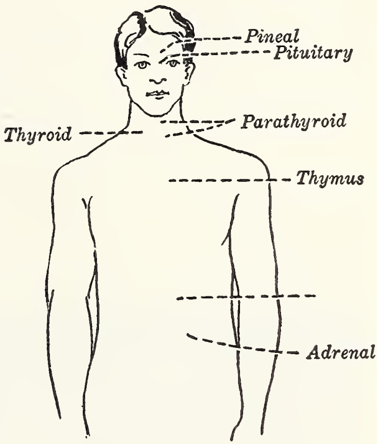
One of the most immediate effects of the intake of alcohol is the dilation of the blood vessels of the skin. This is caused by the partial paralysis of the tips of the afferent neurons. The neurons relax their control over the blood vessels, more blood flows through the skin capillaries, and there is a sensation of warmth.

Although alcohol when first taken seems to produce a stimulating effect, it has been shown by delicate instruments that even small doses slow down the time required for responses from 5 to 15 per cent. The knee-jerk reflex is reduced 10 per cent in speed and 50 per cent in amount for as long as an hour and a half after the taking of a very moderate dose of alcohol. The reactions of other organs, such as the hand, eyelid, head, and finger, have similarly been shown to be from 50 to 60 per cent less accurate and rapid when an individual is under the influence of ordinary doses of alcohol.

The significance of this slowing-up in reaction time caused by alcohol can readily be appreciated in relation to motor traffic. It accounts for a large proportion of accidents that would never have happened if the responses of operators of motor vehicles had taken place at their normal speed and accuracy. At a speed of sixty-miles per hour, an automobile travels eighty-eight feet every second. A delay of even a fraction of a second in applying the brake pedal may result in a fatal accident.

Endocrines and Behavior

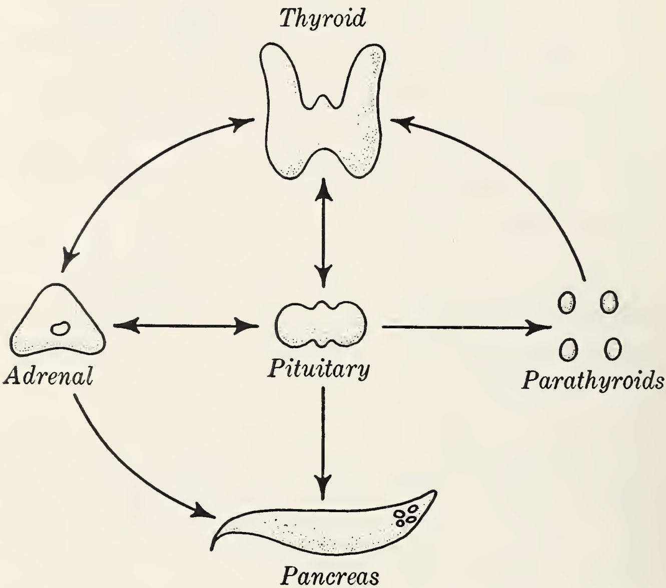
In the human body there are many structures which function as chemical laboratories. They remove certain substances from the blood and build them into new substances. The secretions of most of these glands are carried away by tubes or ducts. Tears produced by glands near our eyes and the digestive juices are examples of secretions which have special functions to perform at particular places in the body.



Not many years ago the functions of the endocrine glands were unknown. Now new facts are being discovered about them so fast that it is impossible for even a specialist to keep up-to-date on all points.

Another group of glands called the *endocrines* produce secretions which are discharged directly into the blood. Their function is to regulate the speed at which various body processes take place. These secretions which excite or stimulate certain life functions are called *hormones.* Those that slow down or retard certain functions are called *antihormones.* Because of their capacity to retard and stimulate body activities, the endocrines may be considered a part of the human response system. There is no doubt that endocrines produce effects which influence behavior. Personality is also to a large extent determined by the relative amounts of various hormones and antihormones produced by the endocrines. The term hormones is commonly applied to both of these secretions.

The pituitary gland. This gland may be considered as the general headquarters of the endocrine system. Not



Endocrine glands influence each other. The arrows indicate the direction of the influence of each gland. What is the relationship of the pituitary to the other glands?

only does it possess important regulative functions of its own, but it exercises a control over every other ductless gland. The *pituitary* gland is located near the center of the base of the skull and is thus extremely well protected. Although it weighs less than one grain, it consists of three distinct lobes; the anterior, the intermediate, and the posterior. Together, these lobes secrete at least fifteen different hormones and antihormones.

The secretions of the anterior lobe of the pituitary gland regulate the growth of the skeleton and of most of the other organs. In addition, they stimulate the development of those bodily characteristics which distinguish males and females. The intermediate and posterior lobes regulate the amount of pigment or coloring which goes into the skin and hair. They also affect blood pressure, water metabolism, respiratory rate, and many other functions.

Most giants and midgets are the result of the production of too much or too little of the growth hormone of the pituitary gland. The improper functioning of the gland is

Courtesy of Jackson Clinic

The whole physical and mental make-up of this child deficient in thyroid has been changed by giving thyroid extract.

also responsible for a disease in which there is an abnormal enlargement of jaws, hands, and feet. Pituitary tumors may cause other body abnormalities.

The thyroid gland. This gland is shaped like the letter *H* and is located on the anterior surface of the larynx. It secretes *thyroxin*. Thyroxin regulates the rate of metabolism and makes the tissues sensitive to the influence of the hormone *adrenalin,* which is secreted by the adrenal glands.

Iodine in the food or water is necessary for the production of thyroxin. In regions where there is a lack of sufficient iodine, the thyroid gland often becomes enlarged, causing the disease known as *goiter.* This and other diseases of the gland may often be prevented by eating foods rich in iodine or by the use of iodized salt.

An improperly functioning thyroid gland may have very important effects on behavior and personality. Where there is a lack of sufficient secretion, the individual is usually sluggish, both physically and mentally. Too great an

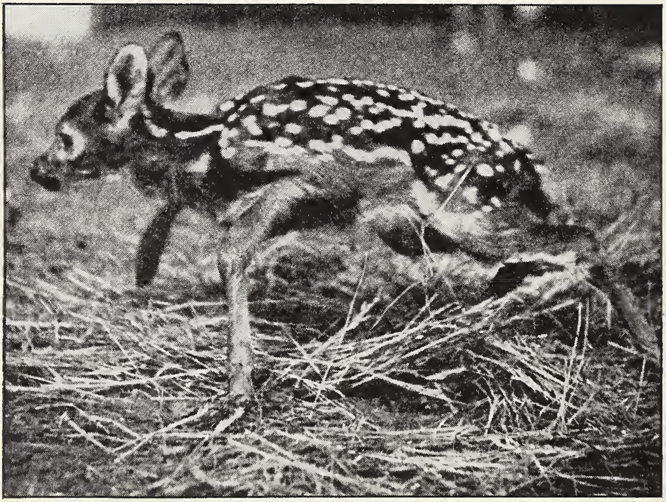


Photo by Lynwood M. Chace

What hormone is probably being released here?

amount of secretion increases the rate of metabolism, causing an excess of wear and tear on the tissues and a nervous, jittery temperament. Physicians employ the basal metabolism test when there is reason to suspect that the thyroid gland is functioning improperly.

The adrenal gland. On the top of each kidney is a gland which resembles a little cocked hat. Together these two glands are called the *adrenals.* Each gland has a central part or medulla which secretes adrenalin, and an outer part, or cortex, which secretes *cortin.*

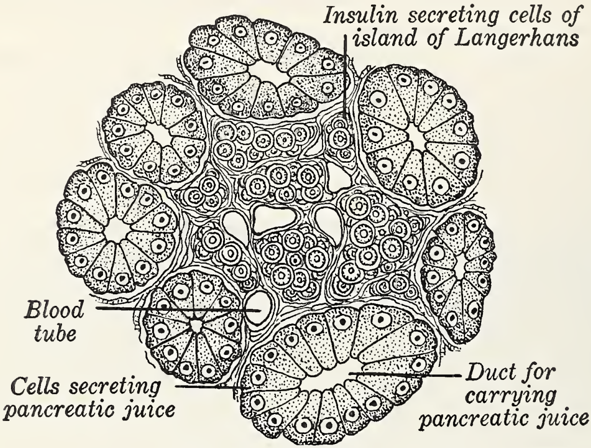
Adrenalin is a general stimulant which acts on all parts of the body and is especially important in emergencies. Fear and fright cause adrenalin to be poured into the blood, and the resulting stimulation aids the body in meeting whatever emergency may be present. Cortin regulates salt and water metabolism and is soothing and restful to the body in contrast to the stormy effects of adrenalin.

Parathyroids. In man these consist of four pea-sized glands on the windpipe near or embedded in the thyroid gland. The effect of their secretion is the release of calcium into the blood where it is essential to muscular activity. By withdrawing their activity, the parathyroids cause calcium salts to be deposited in the bones.

The pancreatic islands. Embedded in the tail end of the pancreas are a number of little groups of cells called the *Islands of Langerhans.* Their principal function is the secretion of *insulin,* the hormone that regulates the amount of sugar in the blood.

Normally, the regulation of the amount of sugar released into the blood is automatic. When a large amount of sugar is taken into the stomach, water is taken up to dilute it. The sugar is then slowly absorbed into the blood. The excess is changed into glycogen in the liver and muscles. When the amount of sugar present in the blood falls to a certain level, some of the glycogen is changed back into sugar once more.

The special function of insulin is to change sugar into glycogen. In the disease *diabetes,* the Islands of Langerhans lose their capacity to secrete insulin, and the body has no means of regulating the sugar content of the blood. In diabetic patients, the amount of blood sugar can now be



This portion of pancreas shows one of the insulin-secreting areas, surrounded by cells that secrete pancreatic juice.

regulated artificially by careful diet and by periodic injections of insulin.

Other endocrine glands. In addition to the glands mentioned, many other regions of the body undoubtedly also produce hormones. Several kinds of hormones are known to be secreted in tissues located in the reproductive organs. These have important effects upon body development and personality. The *pineal* gland, located in the head and the *thymus,* located at the front of the body cavity just above the lungs produce still other hormones, but the functions of these are not fully known. The same is true for the liver and the spleen. Nerve cells produce the hormone *acetylcholine* which is discharged across the gaps between neurons and makes possible the transmission of nervous impulses.

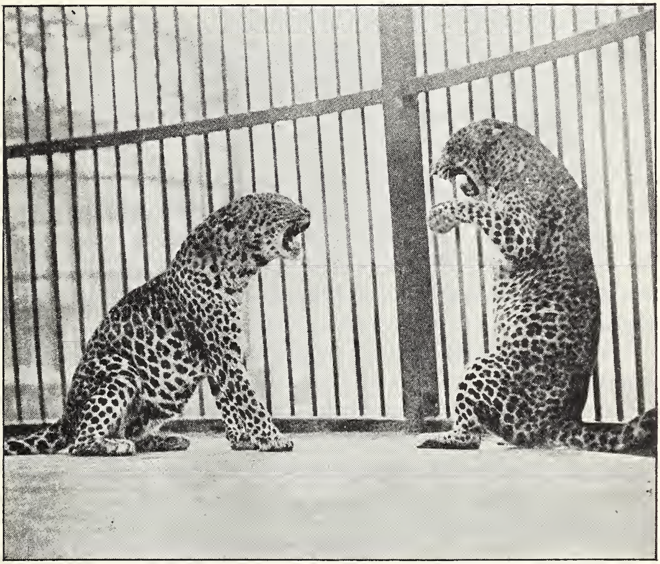


Photo from Wide World Photos

What endocrine glands are functioning here?

Endocrines are of such great importance that a new branch of science called endocrinology has grown up during the last few years. Hundreds of investigators are constantly making discoveries and adding to our knowledge of hormones. Thousands of pages reporting new findings in this field appear every year in scientific journals.

Chemists are now able to make several of the hormones in the laboratory. Others are extracted from the substances produced by animals. Physicians use these hormones in the treatment of patients whose endocrine glands do not function properly.

Review and Thought Questions

1. Describe four steps in a human response.
2. What evidence is there to support the belief that nerves are specialized for different kinds of feeling?
3. Compare the make-up of the human ear with a telephone transmitter.
4. What factors contribute to a sense of balance in a human being?
5. If there are only four different taste sensations, how is it possible for a blindfolded person to identify many different liquids?
6. Compare the structure of the human eye with that of a camera.
7. What is the position of the image formed on the retina of the human eye?
8. Is a system of rewards justified in encouraging the development of desirable habits in the case of a child? Why or why not?
9. What defense can be made for a system of penalties for correcting human behavior?
10. What is the biological explanation for the development of a habit?
11. Give the biological explanation for the accidents caused by drinking drivers.
12. Describe three abnormal conditions produced by an excess or insufficiency of endocrine secretions.
13. Why are we likely to be able to run faster when we are afraid than at other times?
14. Why do diabetics take insulin?
15. Why do physicians give basal metabolism tests?

Activities

1. Place ten objects in a covered box. Cut a hole in one side large enough to admit a hand. Have each of your friends feel the objects without seeing them. At the end of a minute each should write a list of the objects he recognized and remembers.

2. Place twenty objects in a covered box. Open the box for one minute. At the end of a minute, close the box and let each person make a list of the objects he can remember seeing.

3. Prepare a number of common objects which have a distinctive odor by placing liquids in bottles covered with black paper, and placing solids in dishes covered with gauze so they cannot be seen. Number each so you will know what they are. Allow your friends two minutes to smell and name the ten substances.

4. Determine the location of the various taste areas of the tongue by means of solutions of salt, quinine, sugar, and vinegar. Draw a map of the tongue showing the areas of greatest sensitivity to these substances.

5. Most of our fears are conditioned reflexes—habits that we can unlearn. Read and report on this topic. Albert Edward Wiggam's *Exploring Your Mind,* Chapters VII–IX, will give you excellent material.

6. Select ten words that you are likely to misspell. Fix them so firmly in mind that you will never misspell them again.

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Unit 7

REPRODUCTION

If a species is not to vanish from the earth, it must replace with new offspring the individuals that perish each year. Reproduction in living things may be considered as a kind of growth—a growth in which one part of the parent is detached to become a new individual. This happens in a variety of ways. Some individuals have one parent; some have two parents; and some are merely parts of the parent, growing in a new place. In the study of this unit, again, we will find it a good plan to begin with the study of reproduction in the simpler living things and to progress to that of the more complex.

22. Race Preservation

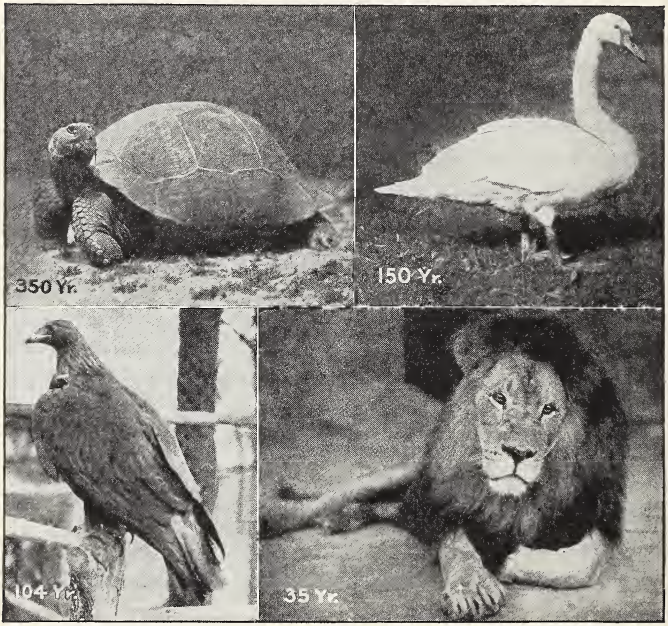
Reproduction is the way by which races and species are continued through the ages. It is the means by which the stream of living matter is maintained from generation to generation. In this process, the individual is important not for itself, but only as the source of new individuals of the same kind. *Reproduction* may be defined as the function by which an organism produces new individuals which have the characteristics of the species.

For any species to continue on earth, two things must be accomplished: (1) Its individual members must compete successfully for nutrition and protection with members of other species to reach vigorous maturity. (2) Some, at least, of the members of the species must contribute to race preservation through the process of reproduction. They must give rise to new individuals that continue to exist and in turn perpetuate their species.

In self-preservation the individual works for itself, competing with its own kind and with others for the largest amount of space, food, light, and air. In race preservation, the individual works for its offspring. For them it gives up food and energy, often its very tissues and life.

The Life Span of Plants and Animals

Among animals, man is certainly one of the longer lived, whether we take into account the exceptionally old people or the average age of large populations. The life span of domestic animals is much shorter than that of man. Dogs and cats are old at eight or ten years, and few live beyond twelve or fifteen. Cows do not often live much longer, but for horses an age of fifty may occur.



Photos from New York Zoological Society

The Galapagos tortoise, the swan, the eagle, and the lion are examples of animals that live to be very old.

The longest-lived organisms. There is common belief that certain other animals may reach great ages: elephants, parrots, turtles, and eagles, for example. Elephants undoubtedly are very long lived. Their use as domestic animals in India affords some basis for accurate records; one was recently reported as being 150 years old.

Among plants, extremely long life is a common and well-recognized occurrence. In the case of trees, with their annual wood rings, we have an accurate means of determining the exact life span. The distinction of being the longest-lived organism probably belongs to the big trees of California, the *Sequoia gigantea.* John Muir, the great naturalist, estimated that one partly charred stump represented four thousand years of growth. The Forestry Service gives definite figures of 2,300 and 2,600 as the largest number of annual rings which they have checked for the big trees of the West. In the eastern states, no tree reaches even half these figures.

The shortest-lived organisms. A rat becomes mature at three or four months of age, and old and decrepit at five or six years. Houseflies complete a generation in three weeks. Cabbage aphids, or plant lice, have been observed to pass through thirty generations in a single year, each generation requiring little more than a week.

In unicellular plants and animals, generations may be measured in hours or even minutes, instead of days or longer. While a single paramecium may exist as an individual for over a month, under usual conditions it divides to form a new generation within a single day. The lowest limit of brevity is probably found among bacteria in which a generation may be as little as half an hour. The total possible population attainable, even within one day, is incredibly large.

Reproduction Among Unicellular Organisms

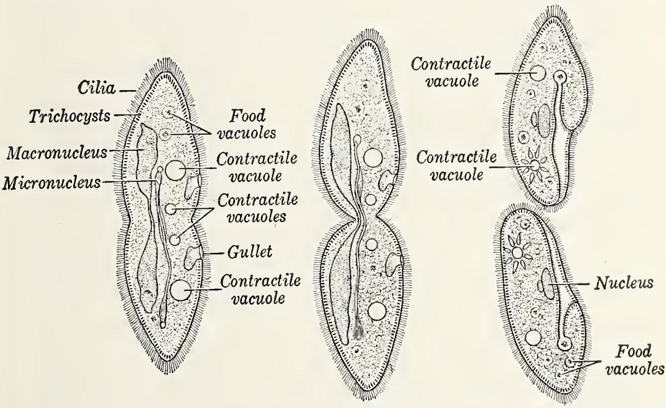
A study of single-celled organisms will illustrate for us the essential facts regarding reproduction. There are two general methods: cell divisions, known as *asexual* reproduction, and cell fusions, known as *sexual* reproduction.

Photo by W. W. Ashe, Courtesy U. S. Forest Service

Sequoia trees are probably the longest-lived organisms.

Four different varieties of asexual reproduction in lower forms of life may be recognized: (1) simple cell division, or *cell fission;* (2) *cell budding;* (3) *sporulation;* (4) *resting spores.*

Reproduction by cell fission. Whenever a one-celled plant or animal reaches its normal maximum size, it is likely to carry on the process of cell division. The result



Reproduction occurs by cell division in Paramecium.

will be two new cells, in place of the single parent cell. This is the commonest method of reproduction among all single-celled organisms, both plant and animal.

Different stages in the process of fission are easy to find in a culture of paramecia which has a plentiful supply of food. The first thing that happens is a division of the *micronucleus,* or reproductive nucleus. Next, a constriction appears near the middle of the cell. The constriction gradually increases and finally separates the paramecium into two approximately equal parts. The macronucleus, or nutritive nucleus, also divides in this process.

Reproduction by cell budding. Fission is the usual method of reproduction in bacteria, blue-green algae, and protozoa. However, in many unicellular forms, the parent cell does not divide into two equal daughter cells. Instead, it pushes out a smaller projection, or *cell bud*, which eventually breaks away as a separate cell. This method of sending out branch cells is known as *budding*, and is clearly shown in the ordinary reproduction of yeast cells.

Cell budding occurs in yeast. The new cells are smaller than older cells.

Reproduction by special cells, or spores. Sometimes in one-celled living things, the nucleus divides several times within the confines of a single cell wall, and forms four, eight, sixteen, or more small nuclei, each with a tiny mass of cytoplasm. Such minute cells may then break out through the old cellulose wall, and separate as new individuals which proceed to grow larger and become normal cells of the species. This method is known as *sporulation* and the specialized cells are called *spores*. Sporulation is common among both algae and fungi.

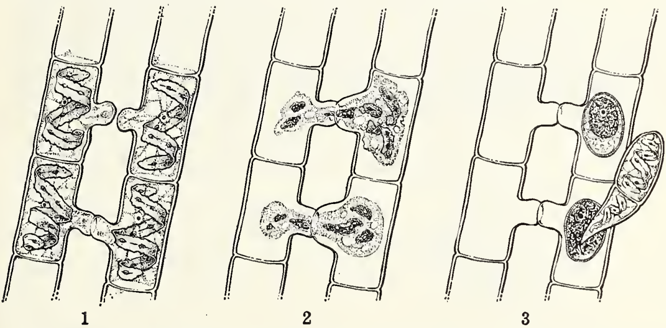
A spore may be defined as a single cell specialized for reproduction, capable of growing directly and independently into the parent type. The word *spore* is more commonly used in relation to plants than to animals.

In animals, spores are produced chiefly among the protozoa, of which one whole class, the *Sporozoa*, is named for this method of reproduction. The malarial parasite is a good illustration of sporulation among protozoa. Its cells, injected into human blood by the malarial mosquito, penetrate the red blood corpuscles. There, each single cell sporulates, and many small spores break out of the corpuscle to attack new blood cells.

Reproduction by resting spores. The name *spore* is also applied to a kind of cell which does not serve directly as a reproductive body. In some bacteria, cells of the ordinary vegetative type may change their form and develop a thick, protective wall. In this condition, as a *resting spore,* the cell may be able to resist very unfavorable conditions, such as dryness, cold (almost as low as absolute zero), and even boiling for a short time.

Sexual Reproduction in Unicellular Organisms

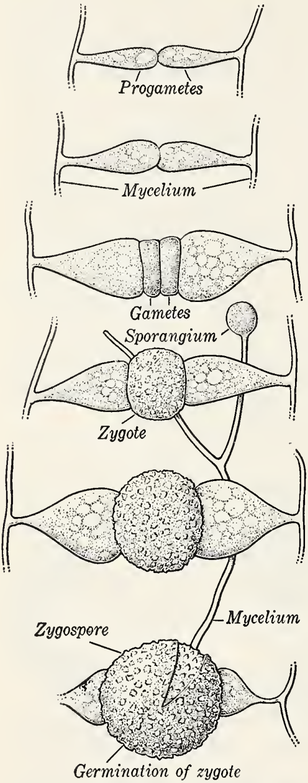
Many kinds of one-celled plants and animals reproduce sexually as well as asexually. In asexual reproduction, a single protozoon divides to form two protozoa.



Spirogyra reproduces by conjugation, the sexual union of similar gametes. What is happening to the zygote?

Sexual reproduction may be defined as the process in which *gametes* are formed and unite in pairs. Any cell which is capable of combining with another cell for the purpose of reproduction is called a gamete.

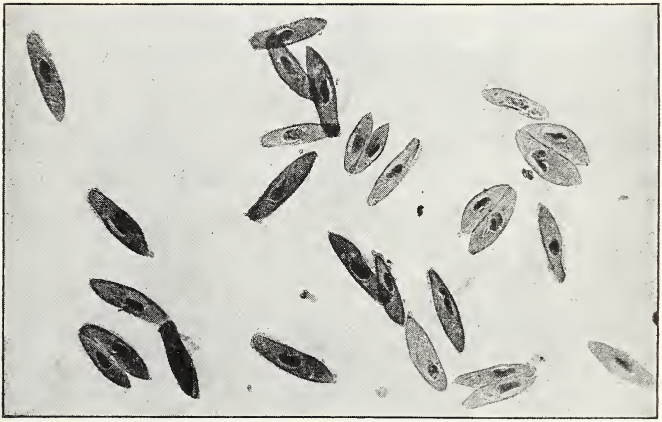
Conjugation. Spirogyra is an example of an organism which carries on reproduction by *conjugation,* or the union of similar gametes.



Bread mold reproduces by conjugation.

Throughout the summer months a Spirogyra filament keeps adding new cells by fission, but in the spring or fall sexual reproduction often takes place. In preparation for this process, the first step is a pairing of the filaments so that the cells lie side by side. Projections then grow from adjacent cells to form a continuous bridge or tube between two cells. The contents of both cells then discharge water and become gametes. One of the gametes then migrates through the connecting tube and fuses with the other. The resulting double cell or *zygote* next forms a protective wall about itself and becomes a resting spore. It may remain in this state for an indefinite period and perhaps be blown about as a particle of dust. When conditions become favorable it may grow.

When paramecia conjugate, they first become attached and swim about as a double cell. In each cell the micronucleus divides several times to form a number of small nuclei. Then from each cell, one of these small nuclei passes into the other parent cell and there fuses with one of the small nuclei which remained behind. In other words, there is an exchange of nuclei, and nuclear fusions then occur. The two parent cells separate and swim about independently. Each consists of the same cytoplasm as be-

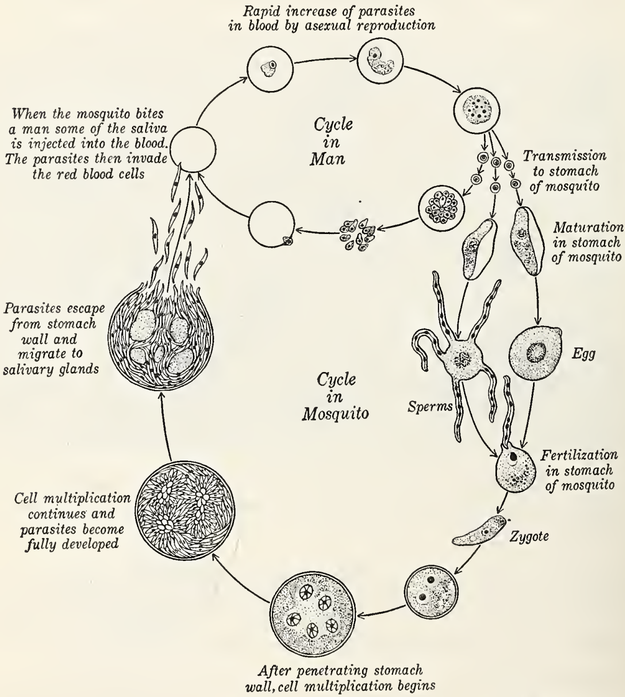


The sexual fusion of Paramecium cells is temporary while the two cells exchange nuclear material. Nuclear fusion takes place after the cells separate.

fore, but has a new micronucleus, consisting partly of its own material and partly of that from another cell. Reproduction then proceeds by cell fission, which is the more common process.

Fertilization. In higher plants and animals, reproduction involves the union of *sperms* and *eggs*. Sperms or male gametes are usually quite small, often consisting of little more than a nucleus and a tail-like flagellum. They occur in large numbers and are usually very active. Eggs or female gametes are larger, full of food material and usually motionless. The union of a sperm and an egg is called *fertilization.*

Even among one-celled forms, there are many organisms which produce unlike gametes and reproduce by fertilization. The protozoa which cause malaria are an example.



The life cycle of the parasitic protozoa which cause malaria shows both asexual and sexual reproduction.

During one stage of its life history, the malarial protozoon reproduces by sporulation. During another stage, it reproduces sexually. When a mosquito sucks in blood from a malarial patient, it takes in some of the spore stages of the malaria protozoon. These pass into the mosquito's stomach, become active, and crawl into the stomach walls. Here they undergo differentiation, some as eggs, some as sperms. After fertilization, the zygote divides, and its cell products migrate into the mosquito's salivary glands, whence they may be injected into a human being.

Asexual Reproduction in Multicellular Organisms

The reproduction of larger plants and animals is a topic which has a great deal of practical importance in agriculture and other pursuits.

Reproduction by branching. Branching, which is the simplest method of reproduction in multicellular organ-

Photo by L. W. Brownell

The leaf tips of the American walking fern bend into the soil, and produce new plants.

isms, takes place through the natural growth and increase in size of the living thing. We may find examples of this throughout the whole plant kingdom and in many kinds of animals. If your home has a flower garden, you know that nearly all perennial plants tend to develop clumps of plants from a single beginning. You know also that it is common practice to dig up such groups and separate them into several independent plants from time to time.

Courtesy of Brooklyn Botanic Garden

The three children of this Boston fern parent all grew from buds along the slender specialized branch or runner.

Among animals, reproduction by branching is common among the lower multicellular types, such as sponges and corals. While not common in higher forms, asexual reproduction occurs in every animal phylum, including the chordates.

Reproduction by specialized branches. The strawberry is an excellent example of reproduction by means of specialized branches. Here, slender, horizontal branches, or runners, grow out from the plant in all directions. These take root some inches away, and develop new erect stems and leaves. In the potato, similar runners grow out underground, but do not directly form leaves. Each runner swells into a tuber. The familiar potato is a much enlarged stem with buds, or "eyes," and scalelike leaves. The common house plant, the Boston fern, reproduces by means of runners, much like those of the strawberry. The tiger lily forms numerous small bulbs along its erect stems. These are really resting buds. When they fall to the ground, they may grow.

Among animals, specialized branches are less common than in plants, but there is a very interesting case in one group of the coelenterates, the hydroids. These resemble hydras, but occur in branching colonies, chiefly in salt water. From time to time, the colonies produce specialized branches which form a succession of little jellyfishlike structures that float away and then produce eggs and sperms.

Reproduction by regeneration. Starfish have always been a serious enemy of oyster beds. Formerly it had been the custom when catching starfish to cut them into pieces and throw them back into the water. It was realized later that practically all the pieces were able to regenerate any missing parts and grow into a complete new starfish. After that was discovered, the starfish were destroyed by exposing them on dry land or dipping them into hot water.

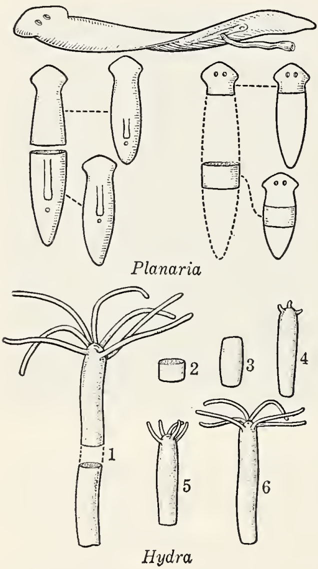
Reproduction by regeneration is a very important natural process, and it is doubly important to us because of the use we make of it in the propagation of many common crop plants.

By regeneration we mean the power of a living thing to repair injuries, such as wounds. In a unicellular form it has been shown experimentally that some protozoa can reproduce parts which have been cut off. In multicellular organisms, regeneration depends upon the ability of the living thing to form new cells to take the place of those which have been lost.

Regeneration in animals. The power of regeneration varies greatly with the different groups of plants and animals. It is much more highly developed among lower forms than among higher, but it seems to be generally found in all the main groups of the plant kingdom.

In man, it is limited to the repair of wounds, the growth of new bone tissue in broken bones, and similar tissue-repair processes. It is also limited in the other higher vertebrates, mammals, birds, and reptiles.

In some lower vertebrates, for example salamanders, a complete new leg may be regenerated. A lobster can reproduce a lost claw, a leg, or an eye. The lower we go in the animal kingdom, the greater the capacity for regeneration. Among the echinoderms, the flatworms, and the coelenterates, a complete new animal may be regenerated from a very small part.

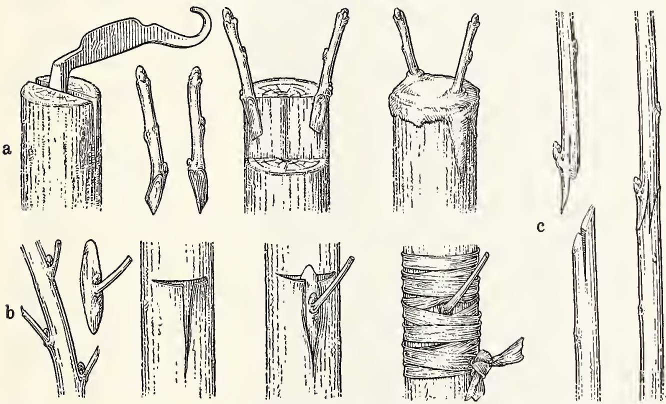


In Hydra and Planaria, a complete animal may be regenerated from a small part.

With Hydra and with Planaria, many very interesting experiments have been carried on to discover upon what the regeneration depends. It seems that these animals possess in almost all parts a considerable proportion of relatively unspecialized cells, and that these are the basis of the regenerative power.

Regeneration in plants. Most plants, even of the highest groups, contain generalized cells in root, stem, and leaf. This is a fact taken advantage of in the propagation of many sorts of garden plants. Even plants which are not known to reproduce naturally by regeneration are often induced to do so by gardeners. The propagation of new plants from "cuttings" takes advantage of this capacity. Such cuttings are usually portions of stems, as with geraniums, poplars, and willows. In other cases, leaves may be used as cuttings, as with the begonia, the African violet, and the snake plant.

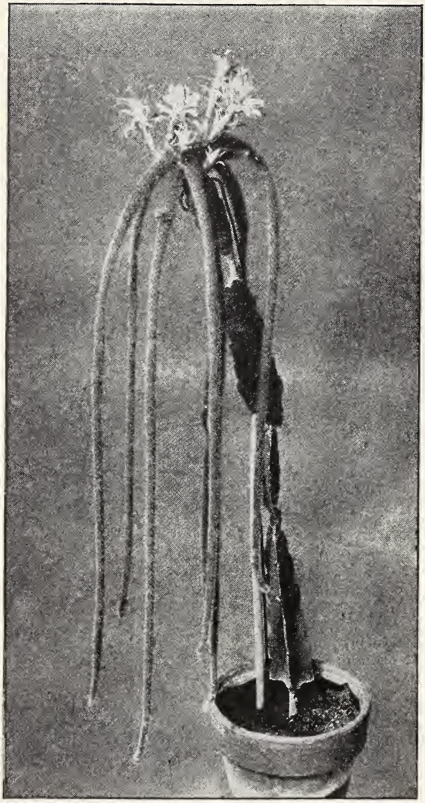
Grafting. This method of artificial reproduction is necessary with a great many kinds of plants, because they will not reproduce the variety true to seed. In grafting, the



Three methods of grafting: (a) cleft grafting; (b) budding and (c) whip grafting.

cutting is "planted" on the stem of a plant which is already rooted. If the cambium layers are brought together in the graft by such methods as are illustrated above, new cells will form from both sides of this tissue until the two stem sections have grown together.

Such artificial reproduction introduces a complication. The biologist is puzzled to know where to draw the line between individuals and parents. All seedless oranges have been propagated from a few branches brought from Brazil during the 1870's. Every seedless-orange tree consists of the root and stem base of a wild, sour type of orange, with the upper stem and branches developed from graft cuttings. In other words, all seedless orange trees are parts of one original Brazilian tree except for their stem bases and roots.



Courtesy of Brooklyn Botanic Garden

Branches of rattail cactus have been successfully grafted on another species.

What would you call such an individual tree as the following: a crab-apple-stem base and roots, with branches of several kinds of pears, such as Bartlett, Kiefer, and Seckel, and with other branches bearing different kinds of apples, such as McIntosh, Greening, Pound Sweet, Red Astrakhan, Baldwin, King, Delicious, Spitzenberg, and Russet? It would be entirely possible to produce such a tree. To a lesser degree, grafting is possible even with animals.

Review and Thought Questions

1. Can you tell why it is difficult to determine the age of most animals?
2. Name five domestic animals in order according to the highest age limits they may attain.
3. Why is it possible to estimate closely the age of very old trees?
4. Were any of our trees living at the time George Washington was President, Columbus discovered America, the Crusades were being carried on, or Caesar was in power?
5. Distinguish between annuals, biennials, and perennials.
6. In the lifetime of a big tree 3,000 years old, how many generations of human beings would there be?
7. What two things are necessary for any species to maintain its continued existence?
8. Describe four different varieties of asexual reproduction among lower organisms.
9. Why is it fortunate that most disease-causing bacteria do not produce resting spores?
10. How is sexual reproduction carried on by Spirogyra? By bread mold?
11. Which is the larger, a micronucleus or a macronucleus? (See picture on page 417.)
12. Contrast branching, as in Hydra, with regeneration, as in starfish.
13. Why can geraniums and other plants be grown from cuttings?
14. Fig and pecan trees are often but not necessarily produced by grafting. Why must seedless-orange trees be produced by grafting alone?

Activities

1. By inquiry find out the probable age of the oldest examples of plants and animals in your vicinity: cat, dog, horse, tree, perennial plant, house plant.

2. Capture several kinds of insects and keep them in a suitable container with food, air, and water. How long does each live?

3. Isolate a single paramecium or ameba and keep it in a hollow-ground slide to determine how long it lives.

4. Collect and examine spores of different kinds of plants such as mosses, ferns, mushrooms, bread mold, and bracket fungi.

5. List ten common plants that reproduce chiefly by branching.

6. Figuring three generations per century, calculate how many ancestors you must have had in the year 1800; in the year 1000; in 800 B.C.

7. List five kinds of plants grown in your neighborhood, for which grafting is used in their reproduction.

8. Find out how the spores of the following plants are spread: athlete's foot, bread mold, milk-souring bacteria. Find out how the spread of each may be restricted.

9. Consult books or periodicals on gardening and report on the care of perennials which tend to develop clumps of plants by branching from a single beginning.

10. Find out how to plant potatoes.

23. Gametic Reproduction

Reproduction by gametes is a very widespread process among living things. Most kinds of plants and animals are known to reproduce in this way, and gametic reproduction probably occurs in many cases in which it has never been seen. Though it may be doubted whether all the lower forms of life can reproduce sexually, it is certain that this process is practically universal among the higher multicellular forms.

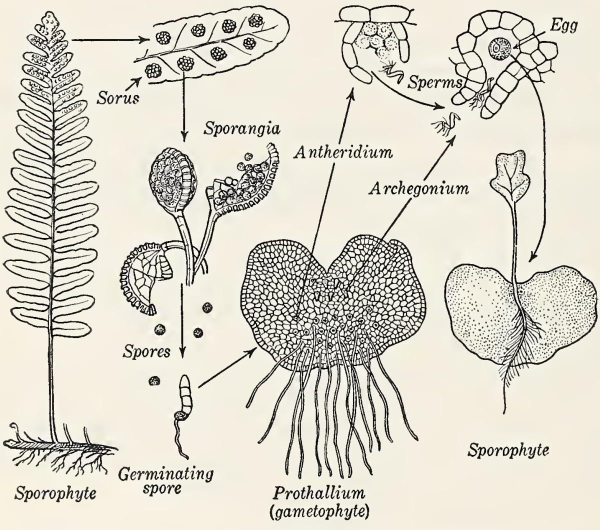
Sexual Reproduction in Multicellular Organisms

In both unicellular and multicellular organisms, we have found that sexual fusions may occur between ordinary cells. In higher forms, the process is more elaborate and usually involves several stages, as follows:

1. The formation of gametes.
2. The bringing together of gametes.
3. Fertilization or cell fusion.
4. Development of the fertilized cell into the adult organism.
5. Distribution of the offspring.

The methods of sexual reproduction are much more complex among the higher organisms than among the lower. They are usually much more elaborate among land forms than among those living in the water. However, if the basic steps are kept in mind, it is fairly easy to understand the processes which occur. This book can deal only with a few different organisms, but different methods of reproduction constitute one of the most interesting of topics for special reading and study.

Reproduction in ferns. The ordinary fern consists of a short stem bearing a circle of large compound leaves. On



The life cycle of a fern shows how sexual reproduction occurs in higher plants.

the backs of the leaf divisions are numerous small fruit dots, each of which consists of scores of *spore cases,* or *sporangia.* Each sporangium usually bears sixty-four thick-walled brown spores.

If a spore falls in a favorable spot, such as a crevice in moist soil, it germinates, sending out a short green algalike thread, which later widens by cell division to form a heart-shaped cell plate, about the size of a small fingernail. The cells of this *prothallium* get soil water by means of slender cell projections. The prothallium produces the sex organs on its under side. Eggs are produced in flask-shaped organs, the *archegonia,* one egg in each. Sperms are formed in tiny spherical *antheridia.* Fertilization results when sperms swim through a film of water to the neck of an archegonium and down this to an egg.

Courtesy of Brooklyn Botanic Garden

This young leafy fern plant is still attached to its parent prothallus.

The fertilized egg cell divides repeatedly, forming first a root, then a leaf and stem, receiving its nourishment from the prothallium. When the root has grown into the soil and the first leaf is unrolled, we have an independent fern plant. At maturity the plant will bear spores.

Distribution of offspring is accomplished by the sporangia which are provided with an elastic ring of cells that snaps open when ripe, flinging the spores into the air. The spores are light and can be carried by the wind for hundreds of miles. Furthermore, the spores are provided with a thick, protective wall which resists drying and cold. Fern spores have been subjected to a below-zero temperature as low as 452°F., and yet have lived and grown.

Reproduction in Hydra. In multicellular animals, eggs are produced in sex organs, or glands, called *ovaries.* Sperms are produced in corresponding organs called *testes,* or *spermaries.* In Hydra these are small swellings on the body. An ovary develops toward the lower part; a testis toward the upper. A single cell is finally formed in an ovary and held there for fertilization, which is accomplished when the sperms are discharged into the water and swim to an ovary.

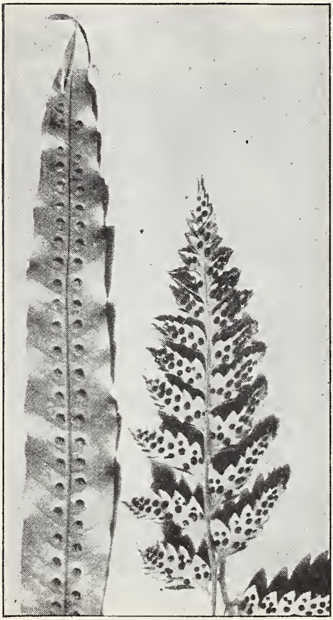
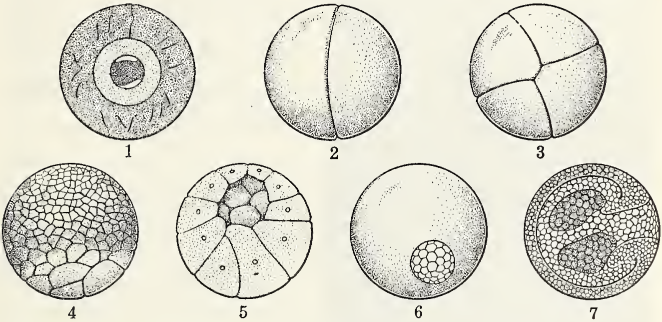


Photo by R. C. Benedict

The fruit dots on the back of fern leaves consist of scores of spore cases.

A fertilized egg enters upon a period of development which shows certain features generally characteristic of animal reproduction. The cells division of the zygote is called its *cleavage.* This proceeds until first a compact berry-like mass of cells is formed. This expands into a hollow ball-like form, the *blastula,* with a wall one cell thick. From the blastula a two-layered *gastrula* is formed, which may be compared to a hollow ball dented on one side. The outer cells are the ectoderm and the inner ones the endoderm. The ectoderm cells are provided with cilia, which enable the young embryo to swim about until it lengthens out to form the mature animal.

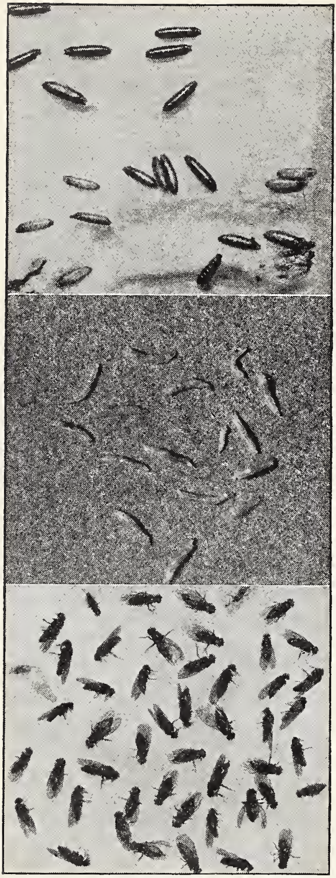
In the Hydra the process of animal reproduction and development is represented in its simplest form. Fertilization requires water so that the sperms may swim to the egg. Development passes through an early stage of cell division, and a later stage of cell and tissue differentiation. Essentially the same steps are followed by higher animals.



These stages in a frog's zygote illustrate cleavage in higher animals: 4-5 blastula (5 is a cross section); 6-7 gastrula (7 is a cross section).

Reproduction in the earthworm. In the earthworm, as in land animals in general, sexual reproduction is much more complicated than in water forms. Both the organs and the processes are more complicated.

Gamete production in ovaries and testes is followed by storage of the gametes in special containers, with associated *oviducts,* tubes to carry out the eggs, and *sperm ducts* to carry out the sperms. A single animal possesses both male and female sex organs and, as such, is called an *hermaphrodite.* Sperms are brought into contact with eggs by a *reciprocal insemination,* that is, two animals become attached to each other and each injects sperms and liquid into the body of the other. After the worms separate, each



Courtesy of Carnegie Institute of Washington, Cold Spring Harbor

Indirect metamorphosis occurs in fruit flies. Here you see the larva, pupa, and adult stages.

worm discharges eggs and sperms together into a container produced from the girdle, the smooth band around the body. This container is passed off over the head end of the animal, and then becomes a small, brownish *cocoon,* in which an egg and a sperm fuse in fertilization.

Reproduction in Higher Invertebrates

Generally speaking, the processes of gamete formation in higher invertebrates follow the pattern already described. Eggs are produced in ovaries, sperms in testes, and fertilization is brought about through insemination. Cleavage processes follow similar lines of development. However, some of the later changes such as *metamorphosis* in insects, parental care, and *parthenogenesis* need to be especially considered.

Metamorphosis. By this is meant the familiar series of different forms through which many insects pass in their development from egg to adult. Flies often hover about uncovered garbage cans, where they are attempting to lay their eggs. Later, the maggots, or *larvae,* change into quiet *pupae.* Finally, adult winged flies emerge from the pupae cases. The life histories of many other insects follow a similar pattern. Insects that pass through four distinct stages (egg, larva, pupa, adult) are said to have *indirect metamorphosis.*

In the spring you may have caught small, wingless grasshoppers. These are grasshopper *nymphs.* In grasshoppers, praying mantises, crickets, and some other insects there is no pupal, or resting stage. Such insects are said to undergo *direct metamorphosis.*

Parental care. The insect egg starts with a supply of food adequate for the development of the embryo. After hatching, the young larva must take care of itself, but the parent has usually made some provision by laying the eggs in a favorable situation. Various kinds of butterflies select particular plants on which to lay their eggs. The codling moth lays its egg on a leaf of an apple or pear tree. When the "worm," or larva appears, it crawls toward a young fruit and enters it. Parasitic insects often insert their eggs inside the bodies of the host on which the young then feed. The mud wasp stings spiders into a dormant condition, and places several in a cell with a single egg. The black widow spider, sometimes so deadily, is the favorite food of one kind of mud wasp.

In social insects we find the most elaborate provisions for feeding the young. The eggs of bees are laid in open cells, and fed by the workers. As the larvae change to pupae, the cells are sealed; and when metamorphosis is completed, the bees emerge as adults. Ants take extraordinary care of their young. If an ant nest is disturbed, it is a common

Photo from Publishers' Photo Service

Parental care is more highly developed in vertebrates than in invertebrates, as is shown by these koalas of Australia, the original "teddy bears."

sight to see the adult insects rushing from the nest to carry the pupa cases, as large as themselves, to a place of safety.

Parthenogenesis. The name comes from the myth about the goddess Athena Parthena, who was supposed to have been born fully grown from the head of Jove, king of the gods. Parthenogenesis is the production of

Photo by Lynwood M. Chace

Consider the ants if you want an example of the community care of the children. This picture shows an opened burrow of carpenter ants. They are trying to move the pupa cases of their young to safety.

new individuals from the unfertilized eggs of the female parent. With honeybees, all the males are parthenogenetically formed, that is, the fathers have mothers, but no fathers. With plant lice, or aphids, many successive generations of females may arise in this way. A single female insect may give rise to many young at one time, and the young may themselves reproduce the same way within less than two weeks. Toward the end of the season, both males and females will be produced parthenogenetically, and fertilization will take place. In these insects parthenogenesis has the advantage of doubling the number of producing parents.

Review and Thought Questions

1. List five stages in sexual reproduction.
2. What plant cells actually swim?
3. Why is water necessary in the reproduction of ferns?
4. In animal reproduction, the following terms are used to describe the development of a zygote: cleavage, blastula, and gastrula. Define each.
5. Of what advantage is the formation of many more sperm than egg cells?
6. Distinguish between metamorphosis and parthenogenesis.
7. What are the advantages of sperms that can move about?

Activities

1. In a fresh-water culture of common algae there are often to be found many small, green, swimming zoospores (asexual spores) and gametes. Examine cultures for such cells.
2. Plant some freshly collected fern spores on a piece of soft brick which is kept moist in saturated air. Examine the surface of the brick at intervals for prothallia. They have a threadlike appearance at first.
3. Grow cultures of common insects such as flies, mosquitoes, beetles, and cockroaches. Watch for egg laying and metamorphosis.
4. Old leaf piles often contain the small, brownish cocoons of earthworms, about the size of small peas. Try to find some of these and keep them until the worms emerge.
5. Make forms in modeling clay to represent various cleavage stages in the development of the fertilized egg of an earthworm.
6. Report on the stages at which some insect pests are most effectively destroyed. Herrick's *Insects Injurious to the Household* contains much useful information on this problem.

24. Seed Plants

Seeds are formed in *fruits,* and fruits develop from flowers. Through the activities carried on by each of these three structures, the seed plant accomplishes the five steps of reproduction outlined in the preceding chapter: gamete formation, bringing together of the gametes, fertilization, embryo development, and distribution of the offspring.

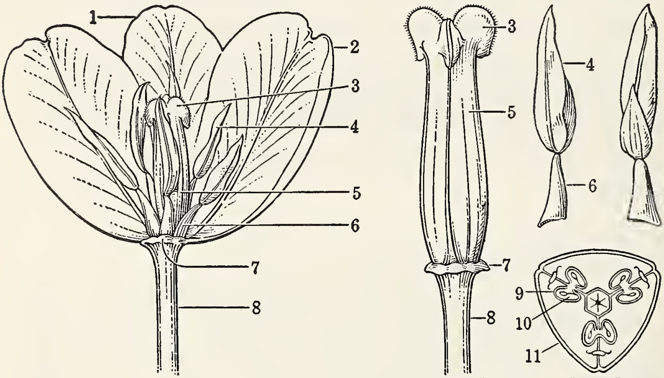
The Parts of a Flower

A flower arises usually as a small bud, which at first may be indistinguishable from a leaf bud. As it develops, however, differences begin to appear. Instead of forming the usual elongated stem and green leaves, a flower stem stops growing and terminates in a series of *floral organs,* often arranged in circles. In the most complete sort of flower, there are four different kinds of floral organs: *sepals, petals, stamens,* and *pistils,* listing them in order from the outside.

Sepals and petals. The outermost flower parts, the sepals, are usually green and rather leaflike in appearance, and serve as the protective cover for the inner parts. Petals are the showy, bright-colored flower parts. Sometimes both petals and sepals are bright in color, as in tulips and lilies. Sometimes one or both of these parts may be absent.

Stamens and pistils. Within the circle of petals are the stamens and pistils. From them are formed the male and female gametes. Stamens and pistils often occur together in the same flower but they may occur in separate flowers.

A *stamen* is a sort of sporangium, consisting of a stalk, the *filament,* and a spore case, the *anther,* at the top. The



Courtesy of C. A. Gramet

These are the parts of a tulip flower: (1) sepal, (2) petal, (3) stigma, (4) anther, (5) ovulary, (6) filament, (7) receptacle, (8) peduncle or flower stalk, (9) cavity of ovulary, (10) ovule, (11) ovulary wall.

anther usually consists of two *anther sacs,* in which are formed numerous *pollen grains.* Each pollen grain is a single cell with a thickened outer wall often roughened and sculptured, and containing first one, then two nuclei.

A *pistil* in its simplest form is like a single, folded leaf with the edges grown together. A pea pod is a good illustration of such a simple pistil. Many pistils are much more complex, as if made from a number of simple pistils fused into one. Thus in the apple flower, the pistil consists of five compartments.

Externally, a pistil consists of three parts: the hollow base, or *ovulary* (also called ovary); a projecting stalk, or *style,* on which is borne the *stigma.* The stigma ordinarily has an expanded surface, which is often sticky or roughened. The ovulary may contain a single cavity or a number of compartments. Within the ovulary are found the *ovules,* from which the seeds may later develop.

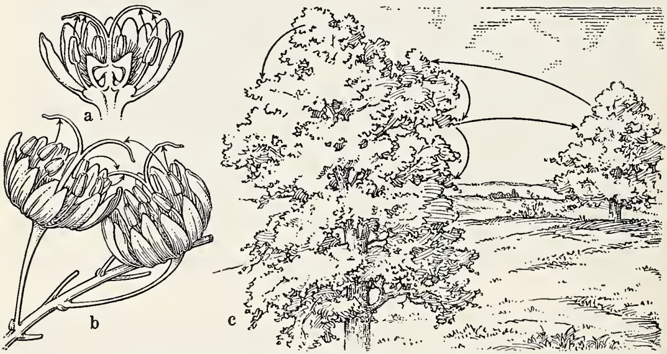
This cross section of a lily anther shows the pollen grains (spores) in their anther sacs.

In the flower stage, the pistil is usually too small to allow its structure to be readily observed, but by examining such enlarged and developed pistils as cucumbers, tomatoes, and peppers, a good idea of the pistil structure may be gained.

Gamete Formation and Fertilization

The accomplishment of these two steps, which take place together, is perhaps the most complicated of the whole reproductive process in seed plants. For a complete understanding, we shall need to make use of the microscope to observe all stages. We may note in general that the female gametes, or eggs, are formed in special structures in the ovules, and the male gametes, or sperms, are formed and transferred to the eggs through the agency of the pollen grains. In accomplishing their duties, pollen grains undergo separate processes, known as *pollination* and *pollen-grain development.*

Pollination. When a stamen is mature, its anther sacs open and expose the pollen grains. The pollen is then carried away by various interesting devices, and some pollen is likely to reach the stigma of the same kind of flower. This transfer of pollen from an anther to a stigma



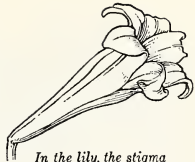
Self-pollination and cross-pollination occur in maple trees.

is called *pollination.* If the transfer is from an anther to a stigma in the same flower or on the same plant, it is called *self-pollination.* If the stigma is on a different plant of the same kind, the process is called *cross-pollination.*

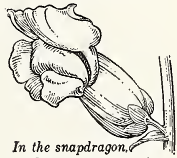
Self-pollination takes place in many kinds of plants. In most flowers anthers and stigmas are close to each other, and the pollen is bound to come in contact with the stigma. Some kinds of flowers never open, and self-pollination is the only process which can occur. However, for most seed plants the reverse is true. Cross-pollination seems to be the preferred method. Indeed, in many flowers, self-pollination is impossible, and is prevented in a great variety of ways. For example, stamens and pistils may ripen at different times, or may grow completely separated from each other. In some plants they are in separate flowers, or on separate plants.

The promotion of cross-pollination is not merely a matter of preventing self-pollination. There is also a positive side of the situation. There are many adaptations in flower structure, which are designed to help bring about the transfer of pollen from the flowers of one plant to those of another. Since plants are stationary, the transfer must be accomplished by outside agencies, chiefly wind and insects.

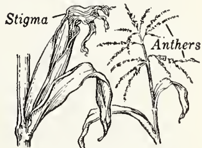
Wind-pollinated flowers are usually inconspicuous in color and in shape. Individual flowers are small, but they may occur in great clusters. Frequently they appear before the leaves develop. Great quantities of pollen are produced, and the pollen is light, sometimes winged. The stigmas of wind-pollinated flowers are often much di-



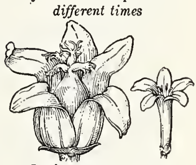
In the lily, the stigma is out of reach



In the snapdragon, anthers and stigma ripen at different times



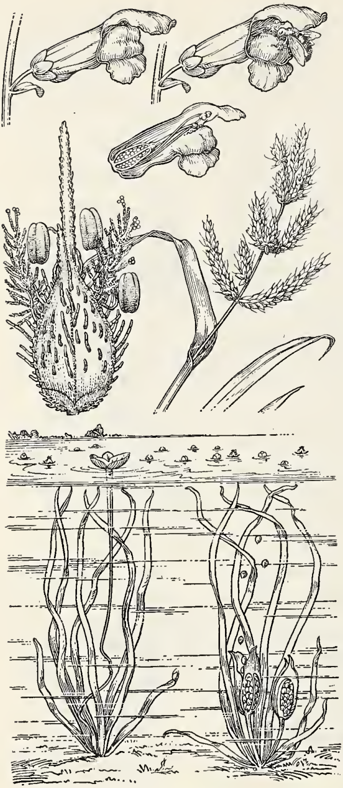
Corn has unisexual flowers that ripen at different times



In the papaya, stamens and pistils are borne on different trees

Trap flowers have stamens and anthers enclosed

Plants have devices for preventing self-pollination.



Plants have various devices to secure cross-pollination. The snapdragon (top) has a landing place, guide stripes, and nectaries; the grass (center) is adapted for wind-pollination; the valisneria sends up its pollen in little boats.

vided and feathery, and consequently fitted to intercept any floating pollen.

Insect-pollinated flowers are showy in size and color, and often fragrant. Ordinarily they produce a small quantity of sugar solution, known as *nectar.* Insects visit flowers to get pollen and nectar. In many flowers, the shape may serve as a protection for insects in bad weather, and flowers are usually several degrees warmer than the surrounding air. All of these factors aid plants in cross-pollination.

Some flowers have developed so that they may be pollinated only by a special kind of insect. If transplanted to regions where this insect does not occur, they fail to seed. Besides insects, birds, especially humming birds, are agencies for pollen transfer, as anyone who has watched a summer garden readily appreciates. A few kinds of flowers are designed to be pollinated by water-borne pollen. In one common kind, the pollen floats along in little boats.

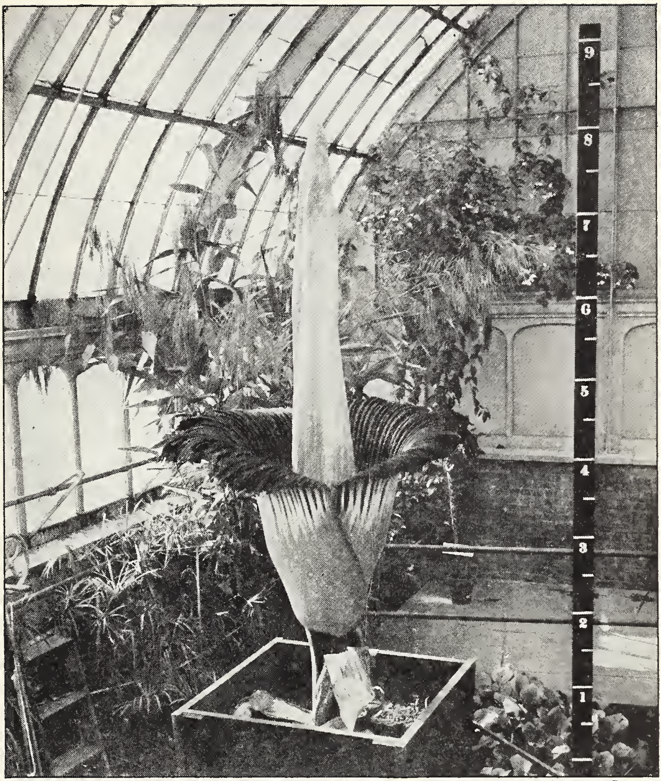
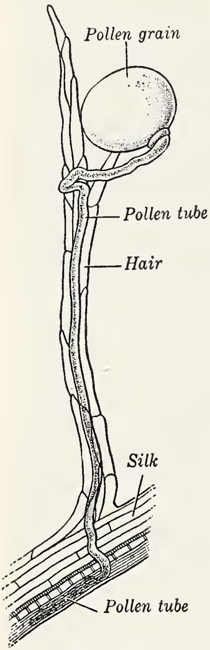


Photo from New York Botanic Garden

This giant flower of the East Indies, the *Amorphophallus titanum*, promotes cross-pollination by its vile smell. Its pollen carriers are flies. It is an oriental member of the lily family, related to the calla lily and the jack-in-the-pulpit.

Pollen-grain development. When the pollen grains fall on a receptive stigma of the same kind of flower, they are likely to germinate and form *pollen tubes.* This can be experimentally shown by placing the ripe pollen grains in a weak sugar solution. A slender colorless tube sprouts out and grows to a length many times that of the pollen grain. On the stigma, the pollen tube grows down through the cellular tissue, through the style, and into the cavity of the ovulary and to an ovule. Food for its growth is supplied by secretions of the stigma and by material stored in the pollen grains.



Courtesy of the Dept. of Agriculture. After Miller

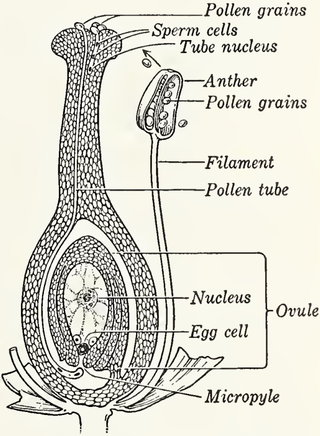
A pollen tube of corn begins its journey toward the ovary.

Male gamete formation takes place during the development of the pollen tube. One of the two nuclei serves as a "vegetative nucleus" and seems to control the growth activities of the tube. The other divides to form two sperm nuclei. These follow along the lengthening tube and so finally reach the ovule, where an egg cell has been formed.

Female gametes are formed in the ovules, usually only one to an ovule. The first part of this process consists in the formation of an *embryo sac.* This begins as a single large cell in the ovule of the developing flower. Then its single nucleus divides, and two more divisions occur until there are eight nuclei within one large cell wall. This compound cell is the embryo sac, and one of the nuclei is the egg cell.

Fertilization. Each ovule may be thought of as a small case, containing one embryo sac with its egg cell and accessory nuclei. On one side of the ovule there is a small pore extending inward toward the embryo sac. The pollen tube grows into this pore, the *micropyle,* penetrates to the embryo sac, and discharges the two sperm nuclei inside the sac.

One of the sperms fertilizes the egg nucleus, thus forming the zygote. The other sperm ordinarily fuses with two of the other embryo sac nuclei, thus forming a triple nucleus, which sometimes continues development to form a definite part of the seed structure.



Pollination and fertilization in a flower is shown here in cross section.

Embryo development and seed formation. Three processes go along together as the fertilized egg divides to form a many-celled embryo: embryo development, ovule development, and fruit development.

The form which the embryo finally takes may easily be seen by studying the structure of a few mature seeds, such as beans, castor beans, and corn grains. In these, the embryo has developed into a miniature plant, usually with recognizable seed leaves, or *cotyledons;* seed stem, or *hypocotyl;* and seed bud, or *plumule.* In the corn grain a seed root, or *primary root,* may also be found.

But a seed is not all embryo. The outer covering, or seed coat, is formed from the tissues of the ovulary. In seeds like the castor bean and the corn grain, there is also an *endosperm,* a mass of food material derived from the triple nucleus of the embryo sac. In grains like corn and wheat, the covering is derived from the ovulary.

The embryo sac begins as a single large cell in the ovule of the developing flower.

Then there is a fruit development, in which the ovulary and pistil are concerned. The seeds of ordinary flowering plants are always contained within closed fruit walls. In order to provide space for the enlarging seeds, it is obviously necessary for the ovulary to expand. Other changes besides mere increase in size also occur. These, with special developments in both the embryo and the ovule parts of the seed, represent the final stage of the reproductive processes, the provisions for the welfare of the offspring.

Distribution of Seeds and Development of Young Plants

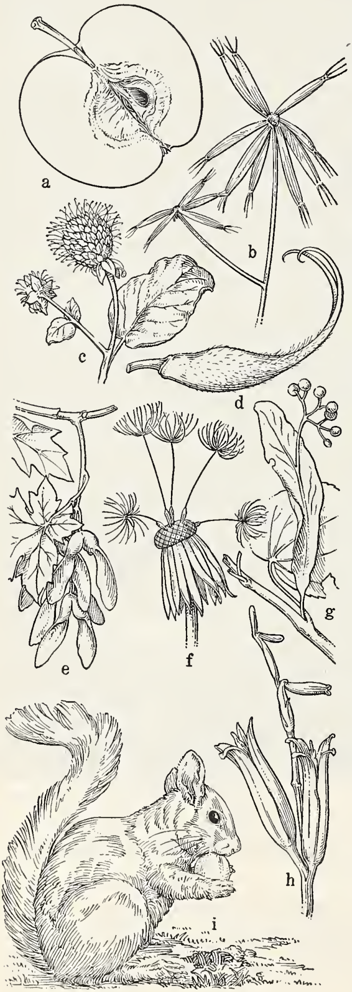
It may seem strange to think of the ordinary plant as capable of making any provision for another generation, but there can be no doubt that plant parents take care of their offspring. The seedlings are supplied with food, and a great variety of devices exist by which a wide distribution of seeds is accomplished. One kind of common plant, the peanut, goes so far as to plant its seeds each season.

Courtesy of Brooklyn Botanic Garden

In its second and final year, the cultivated carrot, a biennial, develops flowers, fruits, and seeds.

Distribution of seeds. As the flower may be called the organ by which fertilization is accomplished, so we may similarly assign to fruits the general function of promoting the welfare of the seed children.

Fruits function through two periods in the life of the seeds. First, they serve as the container in which the developing embryos are nourished and provided with protective coats. Second, they serve in various ways to disperse the seeds more or less widely, so that all do not fall to the ground in a mass, where they have to grow up in competition with each other and perhaps with the parent plant.

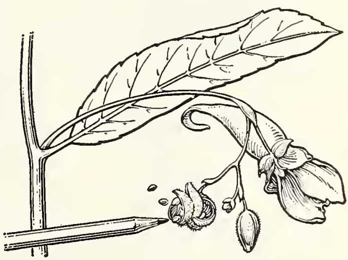


The main different fruit types, from the standpoint of seed dispersal, are: fleshy, nut, bur, winged, buoyant, explosive, shaker, and self-planting. It will be perceived that almost all the types mentioned above depend upon the aid of agencies outside the plant itself. Fleshy fruits, nuts, and burs are animal-carried; floating seeds are water-carried; winged and shaker types depend upon the winds. Only the fruits which open automatically with considerable force, and those which actually place their seeds in the ground, are independent of outside forces.

How do these plant parents promote distribution of their seed: (*a*) apple, (*b*) Spanish needle, (*c*) burdock, (*d*) Devil's horn, (*e*) maple, (*f*) dandelion, (*g*) linden, (*h*) evening primrose, (*i*) nut?

In the city parks, as well as in the country, the way in which squirrels and other food-hoarding animals help in spreading and planting nuts is commonly seen. Some of the planted nuts are never called for, and so are already in a good position to germinate and grow the following season. Hundreds of different kinds of seeds may be carried in currents of water. Streams which flood their banks in the spring leave behind not only a layer of soil but also quantities of seeds as well. Oceans carry fruits and seeds great distances and may cast them well up on shore in the waves of a storm.

Perhaps the shaker type may not be so familiar to everyone. By this is meant the kind of fruit which stands erect, even after the plant is dead, often sticking up through a blanket of snow in the winter. Such fruits often have openings at the tops and their seeds remain inside, except when the strongest winds shake the fruits back and forth violently.


The touch-me-not has pods which snap open when touched.

Not everyone has an acquaintance with fruits which open automatically or with some mechanical force. Many kinds have this capacity in some degree. Two common species in the eastern states are exceptional examples. The "touch-me-not," or jewelweed, a plant common in low, moist situations, forms small, greenish podlike fruits which snap open when ripe, or when touched lightly just before ripening. Witch hazel has seed capsules which snap open and send the seeds ten to twenty feet away.

Do you know any plant which plants its own seeds? Anyone living in the southern states will think at once of the peanut. Peanut plants can easily be grown in other parts of the country and the process watched. After pollination, the young seed pod bends downward, and its stalk lengthens until the pod is finally carried well under the surface of the ground, where ripening is completed.

How do fleshy fruits secure seed distribution? As an apple develops after pollination, the fruit remains hard, bitter, and actually indigestible until the seeds within are well developed. Its green color renders it relatively inconspicuous, but when fully ripe, it usually advertises its mass

The life cycle of a bean shows how seed plants reproduce.

of fragrant, well-flavored pulp by turning some conspicuous bright color. Eaten by man, or by some grazing animal, the tough fibrous core tends to protect the seeds within. If swallowed whole by some horse or cow, the seeds are still protected from the action of the digestive juices by their hard, brown coats, and are finally carried perhaps miles away from the parent tree. The seeds are still further protected by their somewhat bitter taste, like that of bitter almonds, actually due to a trace of a violent poison, prussic acid. The amount present does not harm a larger animal, but very likely serves as a deterrent to many smaller seed-eating animals.

Review and Thought Questions

1. Name four different kinds of floral organs.
2. What are the essential organs of a flower?
3. Describe the general structure of a "perfect" flower.
4. Contrast *self-pollination* with *cross-pollination.*
5. Describe two methods which insure cross-pollination.
6. What are the two most common agencies of pollination?
7. Both flowers and insects have structures that promote pollination. In what ways are flowers useful to insects?
8. In pollinated plants when and where are male gametes or sperms formed?
9. What purpose is served by a "vegetative nucleus" in a pollen grain?
10. Describe the development of a typical embryo sac.
11. Beginning with fertilization, outline the development of a seed.
12. Define a fruit. Name several fruit types from the standpoint of seed dispersal.

Activities

1. Collect different kinds of flowers and note differences in shape, arrangement, and number of the sepals, petals, pistils, and stamens.

2. Collect pollen from such plants as pines, willows, grass, apples, cherries, lilies, and potted plants. Examine under the microscope. (See picture of pollen grains on page 443.)

3. Try growing several kinds of pollen in a 3 per cent sugar solution and note the formation of pollen tubes.

4. Make a collection of seeds and seed pods.

5. Plant some uncooked peanuts in a pot or in the garden. Watch the growth of the plants and try to grow a crop of peanuts.

6. The cultivated carrot plant pictured on page 451 was grown from an ordinary carrot planted in soil and kept in good light. Try growing similar plants from carrots, beets, parsnips, sweet potatoes, turnips, and other root vegetables, and see if you can bring them to flower.

7. In the fall and winter it is easy to grow beautiful flowers from bulbs of hyacinths, crocuses, narcissus, and lily-of-the-valley. Some kinds of narcissus need only a dish containing coarse gravel and water. Look up the proper methods and start one or more kinds to growing.

25. Reproduction of Vertebrates

Among invertebrate animals, the more highly organized the animal, the less frequent the occurrence of asexual reproduction. Vertebrates are the most highly organized of all animals, and, as might be expected, asexual reproduction is practically unknown in the group.

In the invertebrates the land forms show a more complicated sexual reproductive process than the water forms. In the vertebrate group, which includes both land and water forms, there is a similar variation in complexity. In general, fish and amphibians carry on sexual reproduction in a simpler manner than do reptiles, birds, and mammals.

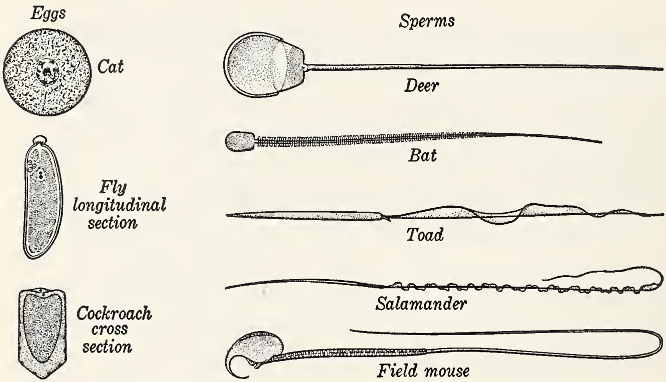
Similarities in Reproductive Processes

Let us note first those respects in which all vertebrates are alike in their reproductive processes. It should be realized, since man is a vertebrate, that what is said applies just as much to the human species.

1. The sex cells, or gametes, are produced in special organs, the *gonads,* and as with invertebrates these are respectively the ovaries for the female gametes, and the testes for the male gametes, or sperms.

2. A given individual vertebrate is ordinarily either a male or female and produces only one kind of gametes. There are no normal bisexual, or hermaphroditic, vertebrates. Only rarely and abnormally does an individual vertebrate possess both male and female gonads. Such her-

maphroditic vertebrates are not able to function as both female and male. However, there are cases among vertebrates where an individual may start out as one sex, producing functional gametes, and later change over to the other sex. This has been observed twice among birds and occurs



A vertebrate animal is ordinarily male or female, producing only one kind of gametes.

regularly in some fish. With frogs, it has been found possible to control the sex development. A given batch of frogs' eggs may be made to develop either as males or as females by modifying the food supplies.

3. Associated with the ovaries and testes are the appropriate ducts and other organs by which the gametes are discharged and brought into position for fertilization.

4. The production and discharge of gametes is a process which ordinarily takes place at regular intervals. While a male vetebrate usually possesses living sperm cells at all times, in the female the egg cells are matured and discharged from the ovaries only periodically, at times often determined by the season of the year.

Reproduction of Various Animals

Reproduction in fishes. The general method followed by many fish is no more complex than that carried on by many invertebrates. The female fish produces a large number of eggs and deposits these in some appropriate situation. The male then deposits a large quantity of sperm cells over the eggs in the water, and fertilization takes place unless interfered with by some outside influence. In a great many kinds of fish there is no parental care shown other than the effort made to place the eggs and sperm in a favorable situation. The egg cell when laid has a small supply of food material in a yolk sac. The simplicity of the process in many fish is taken advantage of by man in artificially propagating and rearing various food fish, such as trout.

However, many species, which give greater care to their eggs and young, cannot be artificially raised by such methods. Black-bass eggs are laid and fertilized in the water, but a special nest is prepared for them, and after fertilization the male fish stands guard over the eggs and over the young fish for a considerable time. The common sunfish follows a similar procedure, making cleared spots in shallow water and then standing guard. They will attack fiercely anything brought near the nest. The stickleback, a small fresh-water fish, builds a nest of twigs in which the eggs are laid, fertilized, and watched.

In the effort to deposit their eggs in favorable situations, many kinds of fish take long journeys, often losing their lives as a result. The story of the Pacific salmon, which return for spawning to small brooks often hundreds of miles from the ocean, is familiar. It is at this time that salmon are caught for canning, and the greed of men in taking practically all the fish ascending the streams has at times brought the whole industry to the verge of disaster.

The common eel of the Atlantic coast swims out into the ocean for hundreds of miles, practically to mid-ocean, to spawn. The young eels, or *elvers,* are very different from

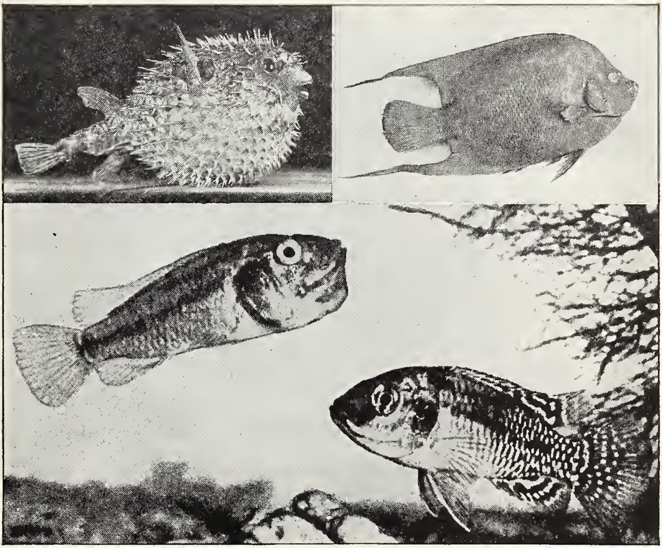
Photo from American Museum of Natural History

A little marine fish, the blinney, has in this instance used an oyster shell as a nest for its eggs.

adult eels in appearance, and it was a long time before it was recognized that they were not a distinct species. They make their journey back to the coast and ascend fresh-water streams to live until fully grown.

While eels of both Europe and America produce their eggs in the same general mid-ocean region, their young travel back to the continent from which their parents came. Migrations as remarkable as those of birds are thus carried on by fish, but how they chart their long courses is still unexplained.

Not a few kinds of fish carry on reproduction in a more complicated way. The eggs of many of the little tropical



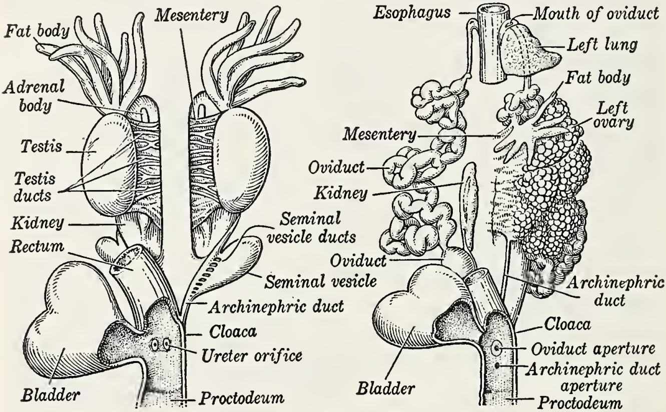
Photos from American Museum of Natural History

Some tropical fish have peculiar breeding habits: upper left, the puffer fish; upper right, the blue angel; below two African cichlids. The one at the lower left has eggs in her mouth.

fish, so popular with aquarists, are fertilized inside the body of the female and pass through the embryo stage within the mother. One kind carries its young inside its mouth for protection.

Reproduction among amphibia. With a few exceptions, the amphibia reproduce in the water. They may spend their lives as adults entirely on land, like the common garden toad, but when the mating season arrives, they make for stream or pool. Fertilization takes place in the water, and after hatching, the young animal spends a considerable period as a fishlike tadpole.

Although fertilization is external, frogs and toads nevertheless mate in pairs. The various noises of these



These are the reproductive organs of a male frog (left) and of a female frog (right).

animals are chiefly mating cries. The trilling serenade of the common toad is uttered by the male and enables the female to find him. As the female deposits her eggs, the male covers them with sperm. Toad eggs are laid in long strings; those of the common frogs are laid in large masses.

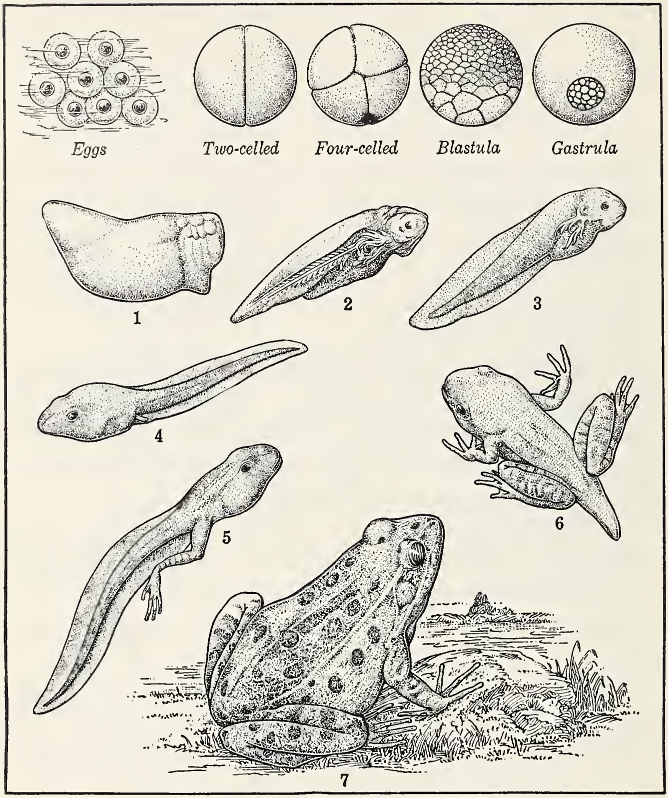
After a short time the eggs show a change in appearance. This can easily be watched in the springtime, if some of the eggs are collected and kept in a good-sized jar of water. The globular, blackish egg cell within its mass of jelly gradually takes form as a small tadpole, and finally squirms free of the jelly. At first it breathes by means of external branching gills. Later these are absorbed, and internal gills take their place.

The developing pollywog is a hungry feeder on dead organic matter, plant or animal. With constant eating, it grows larger. After a time a pair of hindlegs, then a pair of forelegs develop and push through the skin. The tail disappears, and the animal is ready to leave the water and live on land. With the common toad, this development takes only a few weeks. With the bullfrog, it extends over two years.

In addition to external change, a considerable internal change also occurs. The tadpole of the common frog has a long intestine, coiled like a watch spring, and suited to its plant-feeding habits. The adult frog has a short intestine, suited to its carnivorous habits.

Amphibia live in many different situations and occur in widely differing forms. As might be expected, they show considerable variation in their reproductive habits. One European salamander which lives in the mountains does not go to the water for its reproduction. The eggs are fertilized inside the female and there develop, passing through a gilled stage like the ordinary water forms. The young salamander tadpole actually uses its gills for breathing when within the body of the mother.

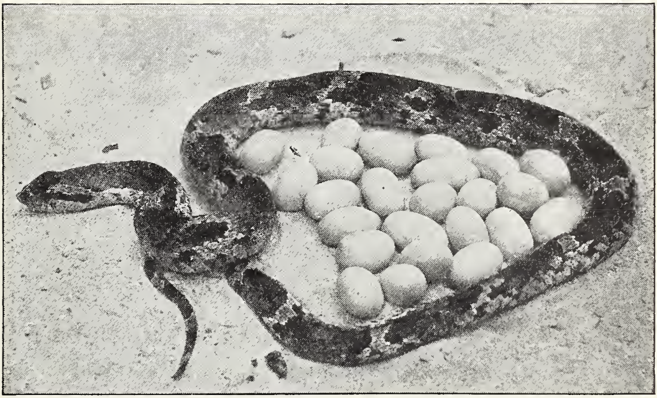
Frogs and other amphibia have been used extensively in the experimental study of reproductive processes. Normally, a given species produces and lays its eggs only at definite seasons of the year. For most of the common kinds of frogs in the eastern states, the season is the early spring. It has been found, however, that egg-laying can be induced at any time of the year by injecting a small amount of the extract of a frog's pituitary gland. These



The life history of a frog shows how amphibians reproduce. After the cleavage of the egg, the pollywog is at first provided with external gills. Later internal gills develop, and the tadpole is a vegetarian with a long, coiled intestine. Finally legs emerge, lungs develop, and the intestine shortens to the length appropriate to a meat eater.

eggs may then be fertilized by sperm taken from male frogs. In this way, growing frogs can be provided for study at any season of the year.

Reproduction among reptiles. Reptiles, like fish and amphibia, are cold-blooded animals and thus controlled by external temperature in their ordinary activities. Unlike other cold-blooded animals, the reproduction of reptiles occurs entirely on land. They do not require water either for fertilization or for the early development of the young.



From New York Zoological Society

Some snakes, such as garter snakes and rattlesnakes, hatch their eggs within their bodies. Others bury their eggs in the ground to hatch by themselves.

Fertilization always takes place in the body of the female. Then the eggs are provided with a supply of food, and also with a tough leathery outer membrane for protection. Most reptiles lay their eggs in the ground, where embryo development and hatching take place under natural conditions without further attention from either parent. Reptile eggs are usually much larger than those of amphibia and fish, with a larger supply of food. The young animal completes its development within the eggs and emerges in a form like that of its parents, though sometimes different in color.

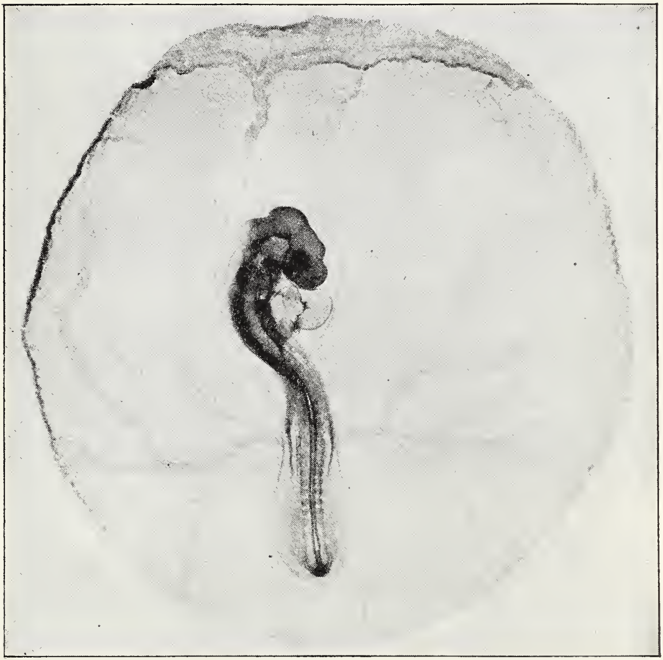
In some reptiles, such as a number of common snakes, the eggs are retained for hatching within the body of the female, and the young are born alive. This is the case with rattlesnakes and copperheads, and with the common garter snake. The story that the garter snake will take its young in its mouth for protection probably arises from the finding of snakes with unborn young.

Reproduction in birds. The process of reproduction in birds is like that of reptiles. Fertilization is always internal, the young are always born from eggs. None are hatched within the mother, and none are born alive. Birds' eggs have a tough, leathery covering and a hard limy shell, both added after fertilization. The eggs must be warmed in order to hatch. Nearly all birds "sit" on their eggs to keep them warm. While this is ordinarily the task of the mother bird, the male in some species takes a turn. The common gander fills in the times when the females leave their nests for food by sitting upon the eggs himself. At other times he is ready to attack fiercely any threatening visitor, be it cat, dog, or man.

Because of the large size of the hen's egg, and because of the possibility of controlling its development, these eggs have become important for the study of embryology. We know more about the embyro development of the common fowl than of any other higher vertebrate. Artificial incubation and careful observation of the development of hen's eggs were carried on more than two thousand years ago.

While in most bilaterally symmetrical animals, most body organs occur in pairs, as two kidneys, two lungs, and two of each kind of gonad, in birds there is only one ovary, the left. Most people have probably seen the ovary of the hen in connection with the cleaning or drawing of a chicken for the table. Such an ovary will show eggs in various sizes and stages of development, from the size of a pinhead to that of the full-sized yolk. The yolk of a bird's egg is a single egg cell.

When an egg cell has reached full size, it is discharged from the ovary into the body cavity. Here it is picked up



In this early stage of a chick embryo, note the developing head; the division of the body into parts, and the blood vessels which extend into the stored food of the egg.

by the open funnel-like end of the oviduct and passed gradually down this tube, where it meets and is fertilized by a sperm cell which has worked its way up the oviduct from below. After fertilization, the egg cell receives coatings of clear, thick "white" from glands lining the tube. When it is full-sized, the tough, leathery membrane is added, then the shell, and it is ready to be laid. In the common hen, egg production goes on regularly whether the hen mates or not. A flock of hens without any rooster will

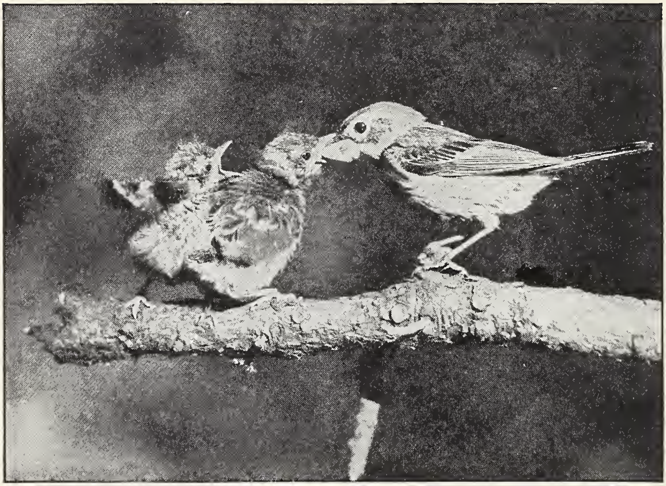


Photo from the National Association of Audubon Societies

Among birds parental care is furnished chiefly by the mothers. Here a magnolia warbler is feeding two young birds almost as big as herself.

lay regularly, but such eggs are sterile and, of course, cannot hatch. As a food product, such eggs command a higher price than fertilized eggs, because they have better keeping qualities.

Reproduction in mammals. In mammals, with the exception of two very interesting Australian egg-laying mammals, the duckbill and spiny anteater, the young are always born alive. Fertilization is always internal, as is also the development of the embryo. As a consequence, the study of mammalian embryo development is much more difficult than with the other vertebrates. Between the time when the sperm cells are injected into the body of the female and the actual cell fusion of the gametes, a varying length of time may ensue. Then, too, in order to obtain different stages of embryos it is necessary to study a large number of different mother animals. While this has been done for a number of common animals, such as the rabbit, rat, and mouse, as far as most mammals are concerned, relatively little is definitely known. For man we know much less than might be expected. However, we may be reasonably sure that the process in man, as well as that in most other mammals which have not been thoroughly studied, is essentially like that of the rabbit, about which most is known. A beginning has been made in the test-tube growth of young rabbit embryos.

The female rabbit possesses two ovaries, and the male two testes. In the female the ovaries mature the egg cells periodically, a few at a time, and discharge them to be picked up by the two oviducts where fertilization takes place. The fertilized eggs pass down the oviduct into one of the two *uteri,* or wombs. Here the egg or eggs become fastened to the wall of the uterus. The fertilized egg undergoes cell division and enlargement, being nourished by the parent. Eventually it develops to form a hollow sac full of liquid, with the little animal to be born suspended in the liquid and connected with the walls of the sac by a cord containing blood vessels. The wall of the sac grows in close association with the walls of the parental uterus. The uterus wall is supplied with blood vessels from which food materials escape by osmosis into the cells of the sac and so through another system of blood vessels through the cord, and into the new animal.

Photo by Walter J. Schoonmaker

The mother raccoon keeps her young in a safe place and defends them against any intruder. Like all other mammals, she feeds her young by nursing them.

When the term of development is complete, the whole structure of the cord and suspended embryo, together with part of the uterus wall, breaks away and is discharged to the exterior. The mother animals usually bite through the cord and thus sever the young animal from the no longer needed mass of membranes, collectively known as the *placenta.*

The mammal may be born in a condition to stand and walk almost immediately, as is the case among such animals as deer, cattle, and horses. Or it may come into the world blind, hairless, and absolutely helpless to do anything for itself. Rats, rabbits, and mice are examples of animals born in a helpless condition. With such animals, the mother has usually prepared some sort of nest and hiding place.

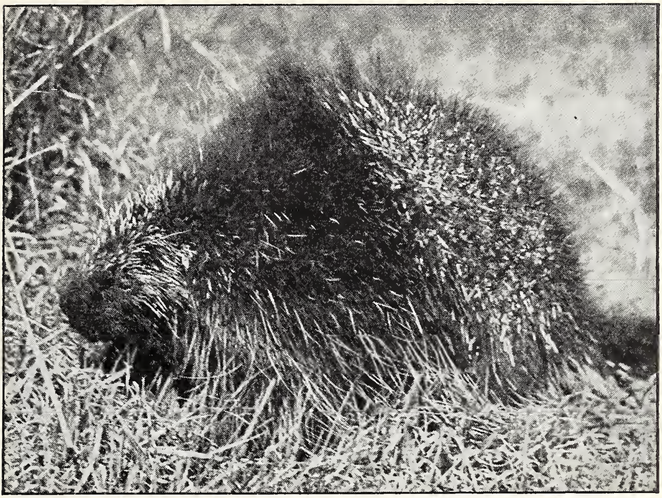


Photo by Walter J. Schoonmaker

Although porcupines carry their own means of protection, the parents teach their young to hunt and hide.

The mother rabbit pulls out large tufts of hair from her body to make a warm nest. Rats and mice may tear up paper, clothes, etc., for bedding.

Finally, all mammals, even the two that lay eggs, nurse their young. That is, they feed them with milk secretion from *mammary glands.* These are the structures from which the name *mammals* is derived. The nursing period may last for months or it may be measured only in days. It usually ceases when the young animal has developed teeth suitable for dealing with the regular diet of the animal.

The young mammal during and after nursing is under the watchful eye of its mother, with occasional help from the father. The mother guards, warms, and cleans her offspring. Among many kinds, various training exercises are practiced. The play of the kitten with its mother, the chases of the puppies and mother, all have their value in developing muscular agility. Animals of prey, like the cat

Photo from the American Museum of Natural History

This walrus family consists of an old bull, a younger bull, a female, and one small pup.

and wolf, catch and bring home living food for their young; then later take the young along to teach them how to stalk and pounce. With a great many mammals the parent-offspring relation is not finished until the bearing of a new litter is about to begin.

Review and Thought Questions

1. Account for the fact that the water plants and animals show a simpler reproductive process than the plants and animals that live on land.

2. Why are many kinds of fish very easily produced in fish hatcheries?

3. Why are egg cells in birds relatively few in number and large in size?

4. Describe the migrations made by salmon and eels for purposes of reproduction.

5. Describe the life history and reproduction of the common toad.

6. Why are hens' eggs very satisfactory for the study of embryology?

7. In what bilaterally symmetrical animals is there only one ovary?

8. Is fertilization necessary in the production of eggs?

9. Describe the development of the rabbit embryo from fertilization to birth.

10. Compare the nature of parental care in the case of fish, birds, and mammals.

Activities

1. Grow some guppies or other rapidly-breeding tropical fish. Do guppies lay eggs? How many young are produced at a time?

2. If convenient, visit a fish hatchery and see how fish are raised artificially. Write for government bulletins describing the work of hatcheries.

3. Obtain some fish for dissection and examine the ovaries and spermaries.

4. In the spring, collect a few frogs' eggs or toads' eggs and allow them to hatch in the laboratory or classroom.

5. Birds' nests can be studied at any season of the year. Care should be taken when the nests are in use, as some birds will desert their nests if disturbed. What birds take the most care and the least care in building their nests?

6. If the chicken for the family dinner is a female fowl, ask for permission to open it yourself. See whether you can find the single left ovary of the hen and the eggs in various stages of development.

7. Look up the ways in which two egg-laying mammals reproduce and care for their young.

8. Report on the ways in which pouched mammals, such as

opossums, kangaroos, and Australian koalas or "teddy bears," care for their young.

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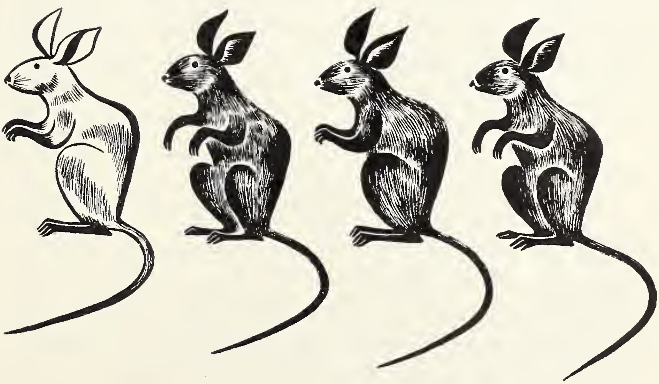
Unit 8

HEREDITY



Fifty years ago, almost nothing was generally known regarding heredity. From the earliest times, it had been observed that offspring resembled their parents, but why this happened or how traits were carried down from generation to generation was unknown. The discoveries upon which our present knowledge of heredity are based have nearly all been made since the beginning of the twentieth century and are among the most outstanding of the scientific achievements of recent times. Today thousands of research workers are busy pushing back the frontiers of our knowledge, and this knowledge is being applied more and more in the improvement of living things.

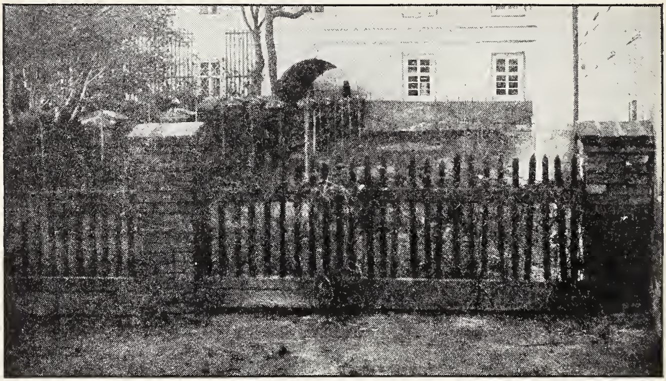
26. Inheritance

Before much was known about heredity, an experiment was performed in which a purebred black male mouse and a purebred white female mouse were mated. All of the offspring were black. The experimenter was surprised at this result and decided to try another experiment. This time a purebred white male mouse was mated with a purebred black female mouse. Again all the offspring were black in color. Both experiments were repeated with the same results.

Before drawing any conclusions from these experiments, the experimenter decided to mate several pairs of the offspring of the black and white mice. The results of these matings were just as surprising as were those of the original matings. Instead of being black like their parents, one fourth of this second generation of mice were pure white and three fourths were purebred black in color. Both of these experiments have been checked hundreds of times and the results are always the same. Today we have sufficient knowledge of heredity to explain these results.

Mendel's Laws of Inheritance

The first carefully planned experiments in heredity were begun about 1854 by Gregor Johann Mendel, an Augustinian monk, in a little monastery garden at Brünn. Instead of mice, Mendel selected garden peas as his subjects for the study of heredity. He worked with twenty-two different varieties of peas which differed from each other in such factors as height of the plant, whether tall or dwarf; form of seed, whether smooth or wrinkled; and color of ripened peas, whether yellow or green. He crossed varieties that differed from each other in one or more characteristics and noted the characteristics that appeared



Courtesy of Dr. George H. Shull and © Journal of Heredity

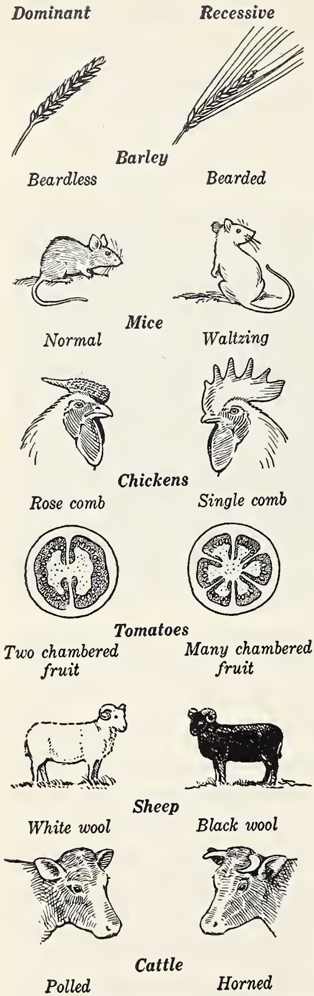
In this famous garden at Brünn, Mendel, a monk, with a liking for growing plants and a scientist's curiosity found a long-sought clue to the mystery of inheritance.

in the resulting *hybrids.* Then he crossed the hybrids and carefully counted the numbers of different types of offspring. In one experiment, 7,324 seeds were harvested from 253 round-wrinkled hybrids. Among them were 5,474 round seeds and 1,850 wrinkled ones. The ratio of round to wrinkled seeds was therefore 2.96 to 1. In another experiment 258 yellow-green hybrids yielded 6,022 yellow seeds and 2,001 green seeds, a ratio of 3.01 to 1.

In crossing his peas, Mendel first removed the anthers from the flowers that were to be cross-pollinated. He then secured pollen from plants whose ancestry he knew and dusted it carefully on the stigmas of the antherless flowers. To guard against the possibility of foreign pollen being carried into the flowers by insects and affecting his results, he placed a number of potted plants in a greenhouse to act as controls for each experiment.

After working eleven years and checking his results over and over again, Mendel summarized them in a paper entitled *Experiments in Plant Hybridization.* He read this in 1865 before the Natural History Society of Brünn, but his hearers were not impressed and forgot all about it. Mendel died in 1884, and his paper was not rediscovered until about 1900, when Correns, DeVries, and Tschermak, working independently on plant hybridization, obtained results similar to Mendel's. In reporting their results, they cited the previous investigation of Mendel, and today his findings, with some modifications, are regarded as the basic laws of heredity.

Mendel's first conclusion. One of the first observations that Mendel reported was that in all cases where tall plants were crossed with dwarf plants, the offspring were all tall. "Transitional forms were not observed in any experiment," he writes. He also crossed plants differing in the color of the seed coat, in the form of unripe pods, in the position of the flowers, and in other traits. When yellow peas were crossed with green peas, the offspring in the first, or F_1 (read F-one) generation, were all yellow. There were no mixed yellow, striped yellow, or speckled peas. However, when these peas were planted and the flowers of the resulting plants were self-pollinated, the green color reappeared in one fourth of the offspring of the second, or F_2 (read F-two) generation. Because the green color receded in the F_1 generation, Mendel referred to the green color as *recessive.* Because the yellow color was



Knowledge of the behavior of dominant and recessive traits aids in breeding better stock.

present in all the offspring of the F_1 generation and in three fourths of the F_2 generation, he called the yellow color *dominant.*

Mendel himself later discovered that what was true for peas was not always true for other living things. Many hereditary traits show dominance or recessiveness, but there are numerous exceptions. Sometimes a blending or mixing of traits occurs in the hybrid offspring of parents having unlike traits. Today dominance is not regarded as a law of heredity.

Mendel's second conclusion: the law of segregation. In the F_2 generation that resulted from the self-pollination of the yellow-green hybrids, Mendel found that the offspring were really of three different sorts. There were yellow peas which, when self-pollinated, produced only yellow offspring. There were green peas which never produced anything but green offspring. There were hybrid yellows which produced some

Plate III. How does this picture show Mendel's findings?

In order to get a complete understanding of the machinery of inheritance, it is necessary to trace the cell processes from their very beginning. One of the most significant developments of modern biology has been the discovery of the behavior of nuclei and chromosomes during reproduction.

The gene theory. Hereditary factors are now called *genes.* With microscopes that magnify several hundred diameters, it is possible to see chromosomes within the nuclei of cells. Along the chromosomes are little disclike structures which are believed to bear the genes.

Courtesy of Carnegie Institution of Washington, Cold Spring Harbor, L. I.

The large salivary chromosomes of fruit flies look like this under the microscope. The markings indicate gene positions.

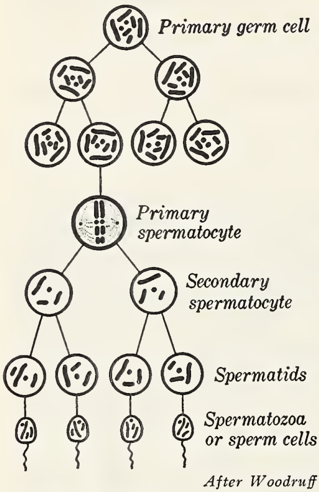
Our understanding of how hereditary traits are transmitted is based on the assumption that genes are pure for each hereditary trait. Characters are inherited equally through the male side or the female side. Since this is true, it is assumed that for most traits a *pair* of genes determines what the offspring will inherit. The gene theory thus provides a basis for understanding the inheritance of a trait such as color of seed coat in garden peas. Purebred yellow peas have two genes for the dominant character, yellowness; hybrid yellow peas have one gene for yellowness and one gene for greenness in the nuclei of their cells; green peas have two genes for the recessive character, greenness.

Chromosomes in inheritance. The center of the whole sexual reproductive process is the fusion of two gametes in fertilization. In each species of plant or animal the number of chromosomes contained in the gametes is usually the same. In man, sperms and eggs each have twenty-four chromosomes; in the corn plant, each gamete has ten chromosomes; in the fruit fly, Drosophila, the number in each gamete is four.

When gametes fuse in fertilization, the new zygote cell receives a double number of chromosomes, the sum of both egg and sperm sets. The new human zygote nucleus contains forty-eight chromosomes; the new corn zygote has twenty; the new Drosophila zygote, eight.

Gametogenesis in animals. In multicellular animals, gametes are produced by a series of cell divisions known as *maturation.* For the eggs this takes place in ovaries; for sperms, in testes.

The maturation of sperms includes first a series of division and growth processes by which a considerable number of cells known as *spermatocytes,* or sperm mother cells, are produced. The spermatocyte, or sperm mother cell, contains the double number of chromosomes, consisting of two sets, one derived from each parent. The chromosomes of one set are matched by the chromosomes of the other set, and the similarities of corresponding chromosomes can often be determined with the microscope. Each pair of chromosomes is similar in size and shape.

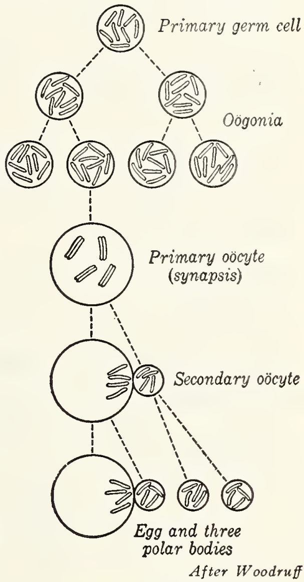


Spermatogenesis follows these steps (see also page 487).

Then, in each spermatocyte the chromosomes undergo first a process known as *synapsis*. In synapsis, pairs of chromosomes move together and line up in close position, often appearing finally as a single chromosome. Sometimes it can be seen that they twist around each other like the fibers of twisted strings.

Next, coming out of synapsis, the paired chromosomes split, thus forming a quadruple chromosome unit or *tetrad*. Then, by two successive nuclear divisions, the collection of tetrad chromosomes separates so that four nuclei are formed, *each with a single set of chromosomes.* At one of these divisions the reduction in numbers is actually accomplished. This is called *meiosis*, or *reduction division.* These four nuclei, with the half chromosome number, then proceed to form four sperm cells. This whole process of gametogenesis for sperms is known as *spermatogenesis.*

In egg formation, or *oögenesis,* the process is essentially the same as far as chromosome behavior is concerned. To begin with, the egg mother cell grows much larger, so as to provide the large supply of food which most egg cells contain. Synapsis occurs as with the spermatocytes, but the two divisions of the mother cell do not form four egg cells. Instead, there is a first division at which a single set of chromosomes, together with just enough cytoplasm to contain these chromosomes, is pushed out of the egg-cell mass. This is the *first polar body* which cannot function as a gamete and soon disappears. Then, at the second division, a second polar body is pushed out, leaving nearly the whole mass of cytoplasm with its food for the one functional egg.



In oögenesis, or egg formation, notice what happens following synapsis.

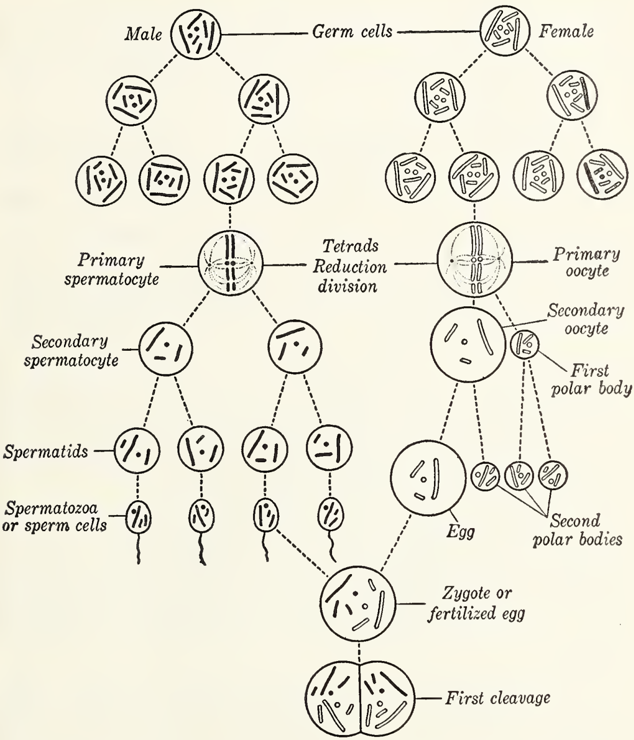
Gametogenesis in plants. The process during which the reduction division occurs is essentially the same for plants as for animals. It includes a synapsis, with two subsequent nuclear divisions by which a group of four spores is formed, each with the reduced, or half number, of chromosomes. Further divisions in these spores produce respectively the eggs and the sperms.

The result is the same for plants as for animals. The gametes which fuse at fertilization have the reduced number of chromosomes, but fertilization restores the double number.

Fertilization and the law of chance. A plant or animal that is purebred for a certain character can produce only one kind of gamete with respect to that character. A mouse purebred for black hair color has two genes for black hair color, one from the mother and one from the father. In spermatogenesis, these genes will be separated at the reduction division and a single gene must go into each sperm. Remember that the genes are *borne* upon the chromosomes. This is why separation occurs at reduction division. Every sperm will therefore carry one gene for black hair color. In oögenesis, the pair of genes will also be separated at the reduction division, one going into the egg and the other into the first polar body. No matter which one of this pair of genes goes into the functional gamete, every egg will carry a gene for black hair color.

If a plant or animal is hybrid for a certain character, a different situation arises. A hybrid black mouse, for example, has one gene for black hair color and one gene for white hair color. In spermatogenesis, equal numbers of each type of sperms will be produced. In oögenesis, the gene for black hair color may go either into the functional gamete or into the polar body. The chances are therefore fifty-fifty that any egg will receive a gene for black hair color and fifty-fifty that it will receive a gene for white hair color.

What happens when the gametes meet in fertilization is also dependent upon the laws of chance. Where different types of sperms or eggs are present, it is impossible to predict what combination will result in each fertilization. But the probability that a certain combination of genes will take place can be predicted. Suppose we wish to predict the percentage of pure dominants, hybrids, and recessives that will be found among a hundred mouse offspring where both parents are hybrid with respect to fur color. A convenient way to do this is to use two similar coins. Let each coin represent a parent which produces



This diagram shows the entire process of gametogenesis and fertilization.

equal numbers of each type of gene. Let "heads" represent the gene for black hair color and "tails" the gene for white hair color. Flip both coins together a hundred times. Tally your results under three headings: two heads will represent a mouse with two genes for black hair color; one head and one tail will represent a hybrid; and two tails will represent a pure recessive with two genes for white hair color. The ratio will be approximately 1:2:1, the same as Mendel obtained by crossing peas and the same as actually occurs in comparable cases in mice, men, and other organisms.

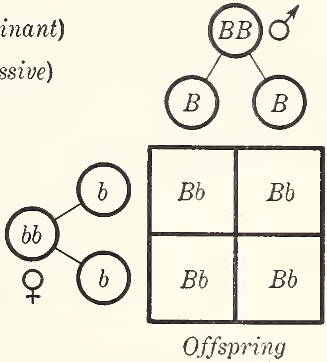
Segregation of genes. Whether a mouse is purebred black, hybrid, or purebred white is determined at the moment of fertilization. If two genes for blackness come together in the zygote cell, the mouse that develops from this cell will have two genes for blackness in every cell of its body. Such a mouse is said to be *homozygous,* or purebred, for black fur color. If a gene for whiteness and a gene for blackness come together, the offspring is said to be *heterozygous* with respect to fur color. If two genes for whiteness come together only genes for whiteness will be present in the succeeding cells. Such a mouse is said to be homozygous for white fur color.

The gene combinations that result when gametes come together can be shown most conveniently by means of diagrams. In the diagrams given, capital B stands for the gene for blackness and small b stands for the gene for whiteness.

Let us consider first the simplest case, that of a cross between a purebred black mouse and a purebred white mouse. Every cell in the black mouse will have a pair of genes which can be represented as BB. Every cell in the white mouse will have a pair of genes which can be represented as bb. When these genes become separated in gametogenesis, it is obvious that each gamete produced by the black mouse will contain a single B gene and that each gamete produced by the white mouse will contain a single b gene. Our diagram will then be as follows:

KEY

B = gene for black color (dominant)
b = gene for white color (recessive)
BB = purebred black mouse
Bb = hybrid black mouse
bb = purebred white mouse
♂ = *male*
♀ = *female*



Note how the genes combine in a cross between a purebred black mouse and a purebred white mouse. All offspring are hybrid black.

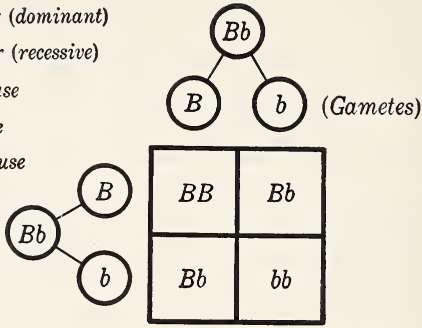
In this diagram the squares represent the combination of genes that come together in the zygotes. Although thousands of sperms and many eggs are usually present, it will be noted that no matter which sperm fertilizes which egg, each zygote will be heterozygous with respect to fur color. In other words, each zygote will be a hybrid with a set of Bb genes. When the zygotes develop into adult mice, however, all of them will have black fur because black fur color dominates over white fur color.

We may use a similar diagram to illustrate what happens when two hybrids are crossed. In this case each parent will have the formula Bb. Each will produce B gametes and b gametes in approximately equal numbers.

Since each square represents 25 per cent of the total number of offspring, it will be seen that the ratio is 1:2:1, or 25 per cent purebred for the dominant character, 50 per cent hybrids, and 25 per cent pure recessives.

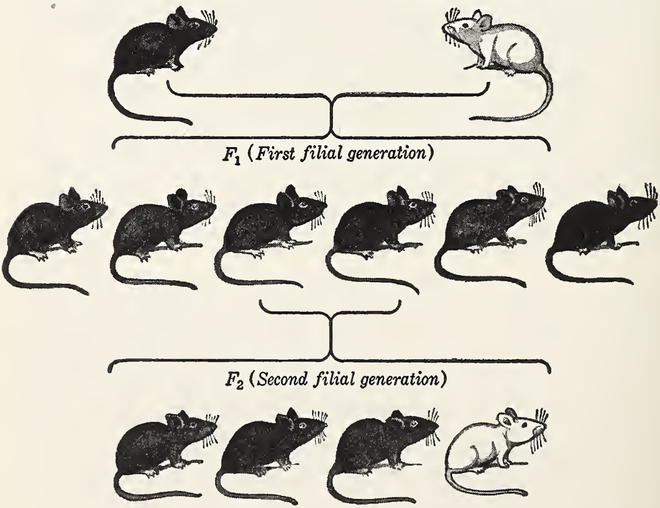
The mice which have the formula BB will, of course, be black. Those having the formula Bb will also be black, *KEY*

B = *gene for black color (dominant)*
b = *gene for white color (recessive)*
BB = *purebred black mouse*
Bb = *hybrid black mouse*
bb = *purebred white mouse*



25% purebred black; 50% hybrid black; 25% purebred white

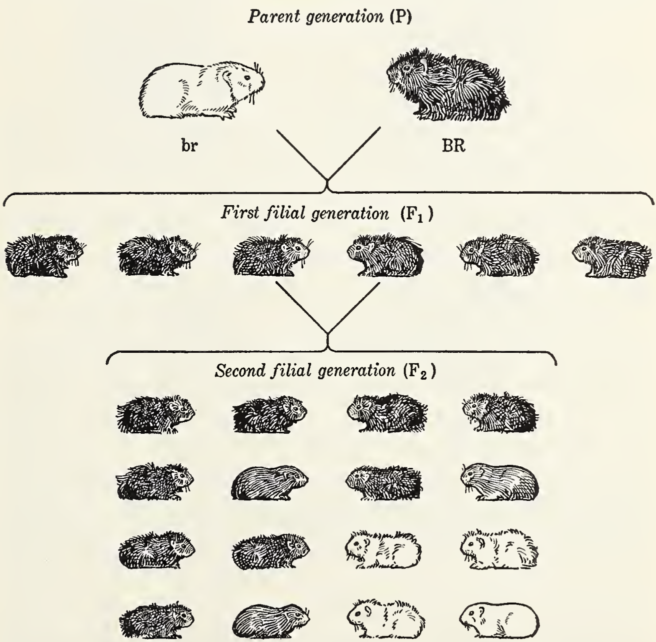
Note what happens when two mice which are hybrid for skin color are crossed.



In descendants of black and white mouse grandparents, white disappears in the children (F_1) but reappears in the grandchildren (F_2).

since black is dominant. Those having the formula bb will be white. The actual ratio of black mice to white mice will therefore be 3:1 but the genes for white fur color will still be hidden away in all of the Bb mice. This type of behavior illustrates Mendel's law of segregation.

Independent assortment of genes. In guinea pigs, rough coat is dominant over smooth coat and black fur color over white fur color. If a rough-coated, black guinea pig is mated with a smooth-coated, white guinea pig, the offspring in the F_1 generation will all be rough coated and



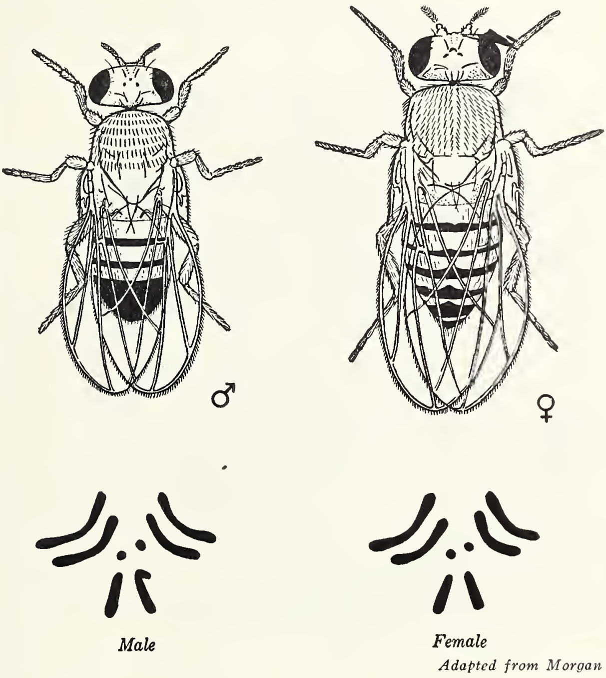
Independent assortment of two pairs of characters is illustrated in guinea pigs. The male parent is smooth and white; the female rough and black. How many of the F_2 generation will breed true?

black but will carry genes for smooth coats and whiteness. If two of these hybrids are mated, the F_2 generation will show four kinds of guinea pigs: rough-black, rough-white, smooth-black, and smooth-white. But the ratio of rough-coated to smooth-coated pigs will be 3:1 and the ratio of black pigs to white pigs will also be 3:1. This indicates that the genes for type of coat have no influence whatever upon the genes for color of coat. Each character is inherited independently of every other character. This type of behavior illustrates Mendel's law of independent assortment.

Other Varieties of Hereditary Behavior

As soon as Mendel's paper was rediscovered in 1900, biologists began to test his findings with a wide variety of plant and animal material. Some used peas, to check the work Mendel had reported. Others tried out different plant genera, and still others began to work with various kinds of animals. Many results completely confirmed Mendel's work with peas, but a number of cases of inheritance were found which did not follow the ratios expected from Mendel's laws. Outstanding in this period of reinvestigation and extension of Mendel's results has been the work of Professor Thomas H. Morgan. Working in the Department of Zoology at Columbia University with a succession of brilliant students and co-workers, he extended our knowledge of the chromosome basis of heredity and developed the theory of the gene as the basis of inheritance. His material has been a tiny fly, Drosophila, familiarly known as the fruit or vinegar fly. His success was honored in 1933 with the award of the Nobel prize in medicine.

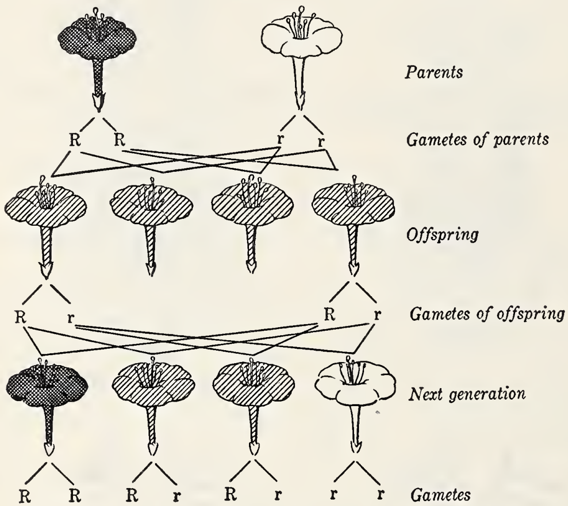
The hereditary behavior which conforms to that found by Mendel is ordinarily spoken of as "simple Mendelian heredity," and includes all cases in which the results are



The tiny fruit fly, bred in bottles by millions, has revealed many secrets of inheritance. A male and a female fruit fly (Drosophila melanogaster) are shown here with their chromosomes. Note that one of the male chromosomes differs in shape from the corresponding chromosome of the female.

of the standard numerical ratios which he discovered. Other ratios have distinctive names of their own.

Blended inheritance. Because in Mendel's crosses, in all his pairs of characters, one was always dominant over the other, he thought that dominance was a law of heredity. Later work has shown that this is not so. Sometimes the first generation of a cross is intermediate between the parents. Thus, when a red-flowered four-o'clock is crossed with a white-flowered four-o'clock, the flowers of the first



Why is it said that the simple Mendelian ratio is basically 1 : 2 : 1 instead of 3 : 1? How does the inheritance of four-o'clock demonstrate this?

generation are all pink, neither white nor red, but intermediate in color. When these are bred for the next generation, there results a proportion of one white-flowered plant, two pink-flowered, and one red-flowered. This type of inheritance is known as *blended inheritance.*

Lethal factors. The recognition of *lethal factors,* or "killing factors," came about through the finding of ratios in a one-factor cross which came out 2:1 instead of 3:1. It was found that when a yellow-coated mouse was bred, it was never possible to get a pure or homozygous yellow offspring. Yellows always bred in a way that in-

Courtesy of Dr. Blakeslee, Carnegie Inst. of Washington, Cold Spring Harbor, New York

Here a lethal factor shows in the Jimson weed (*Datura*). From time to time seedlings in this and other plants develop lacking chlorophyll. They can grow as long as the food supply of the seed holds out, but no longer.

dicated that they were heterozygous, but when two yellows were bred together, the result came out 2:1, not 3:1.

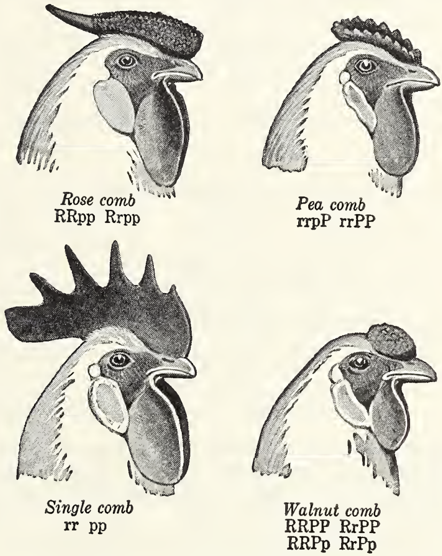
The suggestion was made that perhaps the gene for yellow in a double dose had a lethal or killing effect; that the young animal of this type could not grow. Proof of the truth of this suggestion came when an examination of a number of pregnant yellow females showed that regularly some of the young started to develop, but died before birth.

Not infrequently young corn seedlings are found which show complete absence of green color. They can grow only as long as the stored food in the corn grain lasts them. Here the killing effect of the hereditary factor is obvious, but in the yellow mouse, the reason why a homozygous yellow animal dies is unknown.

Multiple factors and interaction of factors. The lethal effect of the yellow fur color in a mouse shows that a single factor may produce more than one effect in inheritance. Not infrequently, a single inherited characteristic may require the action of more than one factor for its production. This is what is meant by *multiple factors.* Sometimes several factors seem all to produce the same kind of effect in heredity, but the more of these factors present, the stronger is the effect produced. Sometimes two or more factors may unite to produce an effect which is quite different from what any single one produces by itself. The latter case is referred to under the heading of *interaction of factors.*

In animals, the best example is probably found in the inheritance of comb shape in fowls. Four different comb shapes are involved, each due to a different line-up of two pairs of factors. A single-combed chicken is one which has both rose-comb and pea-comb factors in a double recessive condition. This is expressed rr-pp. A rose comb is due to the presence of one or two doses of the dominant factor for rose, R, and is produced by either one R or two;

thus, RR-pp or Rr-pp. A pea comb results when the rose is recessive and there is a dominant factor for pea; thus, pP-rr or PP-rr. When both of these two factors are present in homozygous or heterozygous dominant form, a fourth

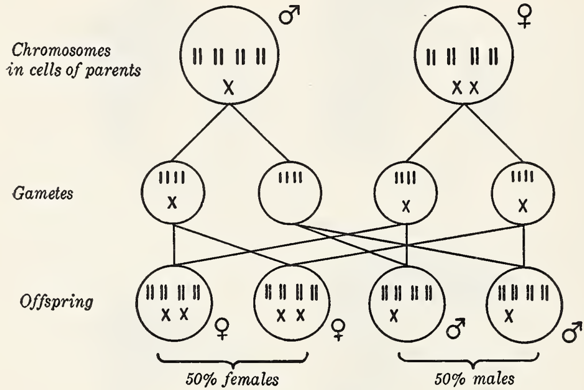


Interaction of factors produces added effects. In the inheritance of comb shape in chickens, two pairs of factors may lead to four different kinds of combs.

type of comb results, the walnut. A walnut-combed fowl may have four different formulas: RR-PP; Rr-Pp; Rr-PP; or RR-Pp.

Inheritance of sex. In some organisms males and females have a different number of chromosomes in all body cells. In birds, females have one less than males. In some insects, males have one less than females. In such cases, the sex of the organism is obviously determined at fertilization and depends on the number of chromosomes received.

When a male insect with nine chromosomes forms sperms, half will get four, and half five. But the female, with ten chromosomes, will form eggs all of which have



In many organisms sex inheritance depends on the different number of chromosomes in sperms and eggs. As the diagram shows, half the gametes have an X-chromosome, half do not. On fertilization, two kinds of zygotes are formed: one is female, the other male. All the body cells of one sex have one more chromosome than the cells of the other sex.

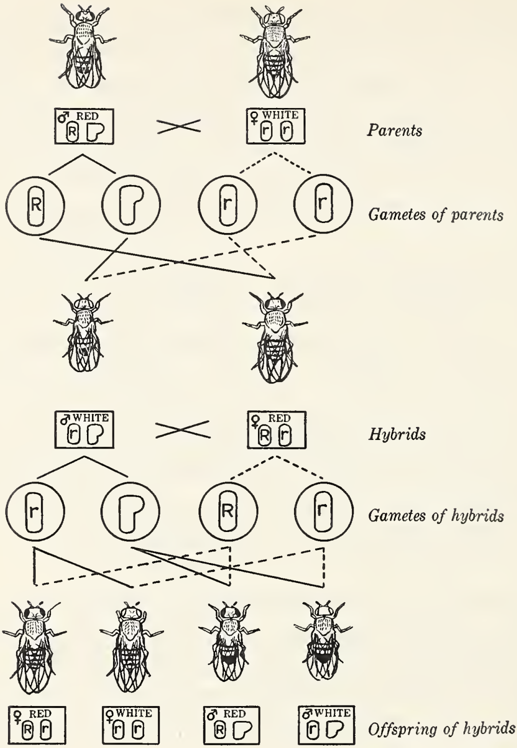
five. Eggs fusing with sperms having four chromosomes will result in males. Those fusing with sperms having five chromosomes will form females.

In man, Drosophila, and many other organisms, sex is determined in a different way. Both sexes of these animals have the same numbers of chromosomes, but only one pair has anything to do with the determination of sex. These two chromosomes are known as the sex chromosomes and are designated by the symbols X and Y. In man, males have twenty-three pairs of chromosomes plus an XY pair; females have twenty-three pairs of chromosomes plus an XX pair. Since the XY pair always splits in reduction division, X-type sperms and Y-type sperms are produced in equal numbers. Since females produce only gametes containing an X chromosome, approximately the same number of XY zygotes (males) and XX zygotes (females) are born.

Sex-linked inheritance. One positive result has come from the discovery of the fact that there may be differences in the chromosomes of males and females. Take the case of Drosophila, with its clearly distinguished X and Y chromosomes. A case of inheritance of eye color was discovered in Drosophila which was definitely linked with the X chromosome of the animal. A white-eyed female bred with a red-eyed male (red is the normal eye color) gives two classes of F_1 offspring; 50 per cent red-eyed females; 50 per cent white-eyed males.

Reverse the cross, using white-eyed males and red-eyed females, and all the progeny will be red eyed in the first, or F_1, generation. The reasons for this behavior are that red eyes are always dominant over white and that the Y chromosome of the male carries no factor for eye color at all.

When the white-eyed female was bred to a red-eyed male, the Y of the male could be joined only by an X chromosome with a factor for white eye. But red is dominant over white. Therefore, such females would have heterozygous red eyes. In the reciprocal cross of the red-eyed female to the white-eyed male, every egg which entered into fertilization brought a dominant factor for red eyes. Those eggs which fused with sperms containing Y chromosomes formed males with red eyes. Those eggs

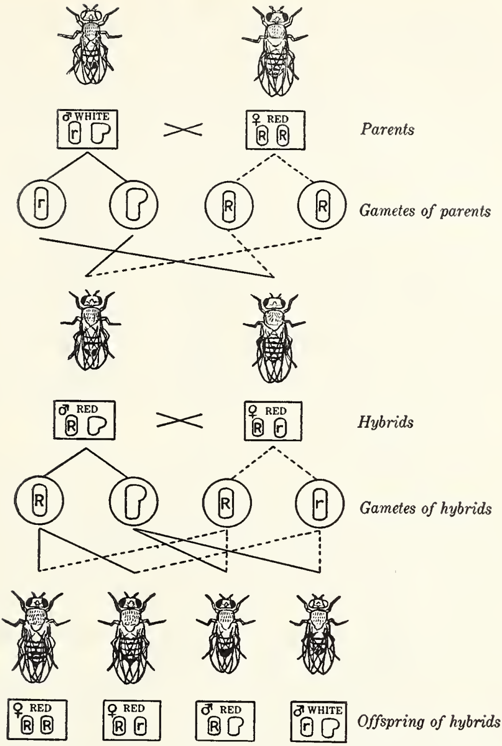


Adapted from Morgan

If the X-chromosome carries a factor not present in its mate, only the offspring receiving the X-chromosome will show this trait. This explains the crisscross inheritance of sex-linked traits. White eye color in Drosophila is sex-linked.

which fused with sperms containing the X with a factor for white eye became females heterozygous for eye color.

This kind of inheritance is sometimes called crisscross inheritance. It has been recognized in man for at least two characteristics: *color blindness* and *hemophilia,* the tend-



Adapted from Morgan

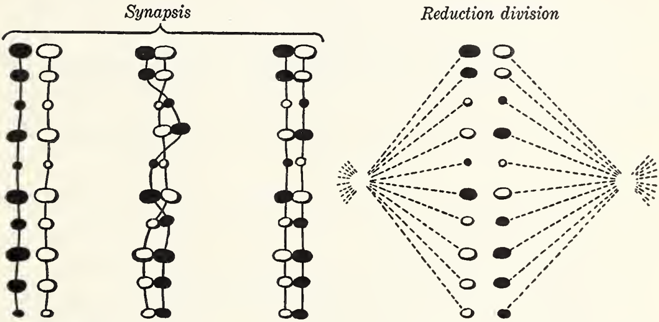
The behavior of sex-linked characters furnished the clue upon which the chromosome and gene theory of heredity was founded. This diagram shows the effect of a cross opposite to that in the preceding illustration.

ency to bleeding. Women may transmit the latter without being affected by it. With a father who has either of these handicaps and a mother who carries no factor for this trait, the children will all be normal, but the daughters will all be heterozygous for the factor. These daughters in turn mated to normal men may have sons, half of whom have the difficulty.

Linkage and crossing over. In the early days of the investigation of Mendel's results, cases were found which failed to show the expected ratios. Thus, when corn with starchy endosperm and a purple layer was crossed with corn with sweet endosperm and a white layer, most of the offspring were the same as the original parents. A few, however, showed the new combinations of characteristics, e.g., starch with white, and sweet with purple. It was found that it did not matter how the characters were first associated; the parent combinations tended to stay together. Purple and sweet would stay together just as firmly as purple and starchy.

The final explanation was an important step toward our present gene theory; that is, that such characters tended to stay together because they have their position in the same chromosomes. Only when factors are in separate chromosomes is it normal for them to become independently assorted. The name given to this association in one chromosome of two or more factors is *linkage.*

Linkage is a regular occurrence with many factors. In Drosophila, which has only four pairs of chromosomes, hundreds of different factors have been identified. Obviously each of the chromosomes must contain a large number of genes linked together. At synapsis, chromosomes have been observed at times to twist around each other. If, in the subsequent separation after synapsis, some parts of a pair of chromosomes were interchanged, this would provide an explanation of the occasional separation of linked factors. This separation has been called *crossing over.* The crossover ratios are not the same for all factors within one chromosome, but the ratios for any pair of characters are constant. Some cross over much more frequently than others. It has been suggested that the rate of crossover furnishes a basis for calculating the distance two factors may lie apart within one chromosome. With



This diagram shows how linkage may be caused. Chromosomes may be considered as groups of genes linked together. During synapsis the chromosomes are sometimes in such close contact that, when they separate in the reduction division, there is an interchange of genes. This is the probable cause of crossing over.

this basis, the Drosophila chromosomes have been mapped, and the relative position of hundreds of factors or genes is now known.

Linkage of factors in chromosomes is one of the major discoveries of T. H. Morgan and his associates. It has been widely confirmed by the study of other organisms, and forms one very important stone in the arch of the chromosome and the gene theory of inheritance.

Review and Thought Questions

1. What conclusions did Mendel draw from his experiments?
2. With hybrid black guinea pigs, why are two kinds of egg cells and two kinds of sperm cells produced?

3. Explain why segregation takes place in the offspring of two hybrid black mice.

4. Explain what is meant by Mendel's law of independent assortment.

5. In what structures are the genes which determine an individual's inheritance located?

6. Describe the process of meiosis.

7. Why do scientists repeat the same experiments again and again?

8. What organism did Morgan use for his experiments in heredity?

9. Distinguish between a homozygous yellow and a heterozygous yellow mouse.

10. How is sex inherited?

11. Give one example of sex-linked inheritance.

12. Explain how it is impossible to locate the relative positions of the factors or genes in the chromosomes of the fruit fly.

Activities

1. Refer to the color plate opposite page 478 and figure out (*a*) the 1-factor ratio between yellow and green peas and between smooth and wrinkled peas, (*b*) the 2-factor ratio between the two pairs of seed characters.

2. Draw a Punnett square for three pairs of characters in peas: height of plant, flower color, and seed color. A Punnett square is a checkerboard type of diagram, similar to that on page 489.

3. Breeding Drosophila requires less space than breeding small mammals. A few pint milk bottles, with cotton plugs for stoppers, are sufficient. More specific directions and cultures of special fly types may be obtained from supply houses.

4. In genetics reference texts, look up additional cases of lethal factors, interaction of factors, and sex linkage.

5. Report on a "chromosome map" for Drosophila.

6. Construct models of the nuclei of Drosophila showing the eight chromosomes of the ordinary body cells and the four chromosomes in the sex cells.

7. Examine or make charts illustrating spermatogenesis and oögenesis.

8. Make diagrams of gametogenesis for organisms having different numbers of chromosomes.

9. Make a table of the chromosome numbers of different organisms. Consult references to find out how to construct the table.

27. Variation

The word *variation* has so many different meanings that it is important to get a clear understanding of the way it is used in biology. In science, accuracy is a first essential, and accuracy in the use of words is just as important as accuracy of observation or of measurement.

In biology, variation means "change" or "difference." The differences among the children of one family are called variations, as are the differences between parents and their children. Similarly, the word is applied to the differences among the individuals which make up a species.

But the word variation is also used for changes which do not arise as a result of hereditary processes. The environment is responsible for many of the differences we see in related organisms. If some of the children of a family emigrate to a tropical country while the remainder of a family stay in a cold, northern land, the former would be almost sure to develop differences in the color of the skin. If part of a litter of young rats are fed a complete diet, while the others are given a diet lacking vitamin A, the second group will be much smaller and less vigorous than their more fortunate brothers and sisters.

Biologically, variations are classified into two main groups, according to the basis of their origin: (1) hereditary or genetic variations; and (2) environmental or acquired variations. Hereditary variations are those which have arisen through reproductive processes; they depend upon the chromosomes and genes. Environmental variations are the differences which have been caused by environmental influences. The only sure method of distinguishing these two kinds is by breeding experiments. Environmental differences are not inherited; genetic variations are.

Genetic Variations

Hugo De Vries, a famous Dutch botanist, was one of the first to make clear the importance of the distinction between variations that were inherited and those which

Courtesy of Dr. Blakeslee and The Journal of Heredity

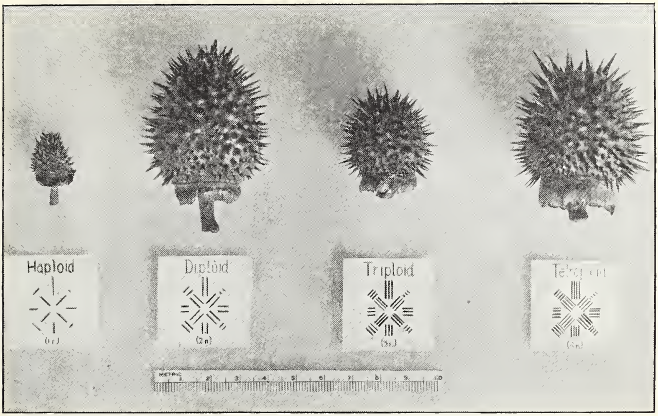
Variation in corn due to crowding is called *fluctuation*. Both groups are grown from the same kind of seeds.

were not. The conclusions of De Vries were based principally upon his study of the evening primrose. In his book on evolution, *The Mutation Theory*, published in

1901, he pointed out that only variations which are inherited can be of any significance in evolution. He is also credited with being the founder of the experimental method in the study of evolution. It was he who established the name *mutation* to apply to inherited variations, as distinguished from environmental differences, which he called *fluctuations*. Formerly variations were a complete mystery, but through many years of careful study and research many of the bases of genetic variation have become clear.

Recombinations. The differences which result from independent assortment and crossing over of genes are known as *recombinations*. Nothing unusual occurs in these processes, but through the interaction of factors, new characteristics may appear. This is well illustrated among the various types of combs on fowls.

Changes in the chromosome number. Drone honeybees, since they are produced by parthenogenesis, that is, the development of an unfertilized egg, have only half the usual number of chromosomes. Likewise, in some organisms it sometimes happens that individuals are produced which have more than the usual number of chromosomes for their species. Such variations do not as a rule show great differences from the normal type. However, this type of variation is of great interest as a possible cause of species change, because there are known among plants several series of species in which the chromosome number differs by definite multiples of the usual number. This is true for wheat, in which one species has fourteen, another twenty-eight, and another forty-two chromosomes. Similar series are known in roses, in strawberries, and in other plant genera. It seems probable that the species with the larger numbers have arisen by variation from species



Courtesy of Dr. Blakeslee and The Journal of Heredity

These differences in the fruits of Jimson weed were determined by different numbers of chromosomes. The normal diploid plant has 24; the triploid, 36, and the tetraploid, 48 chromosomes.

with the smaller numbers. Varieties with doubled chromosome number can be caused in tomatoes by repeated pruning.

Gene mutations. The variations so far described represent nothing new, merely the shuffling of the same genes over and over again. Most authorities now believe that some variations are the result of changes in single genes, presumably some sort of chemical changes. Such gene mutations, if completely proved, would be the most important kind of variation since they represent a change in the hereditary material itself.

The most extensive work on gene mutations has been done with Drosophila. The classic case was the occurrence of a white-eyed variety of fruit fly, a single different individual in a breeding bottle. This same variation has occurred at least twenty-five times among the thirty million Drosophila flies which have been raised in experimental work. It may be mentioned that gene mutations show two features: (1) They are very rare, only about five hun-

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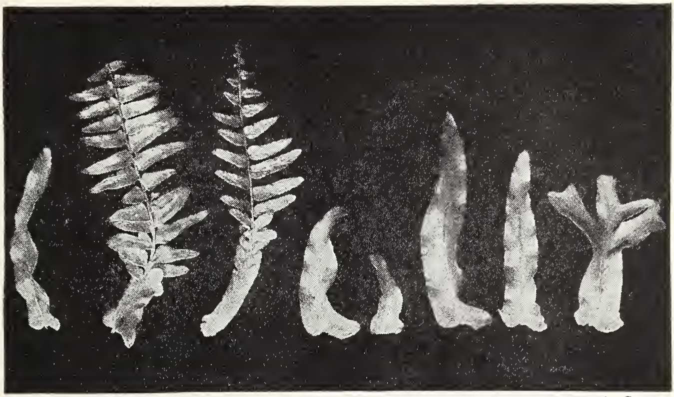
The dwarf mouse represents a genetic variation, or *mutation.*

dred have been noted among the thirty million flies. (2) The individuals showing these mutations are mostly, if not all, recessive and defective.

There are many different variations, the origin of which cannot be safely guessed. They probably are due to some of the various changes in chromosome arrangement, or in gene relation, or to gene mutations. Only genetic analysis, or a study of the chromosomes of such forms, will enable us to reach any definite conclusions.

Genetic changes may take place either in sexual or in asexual reproduction. Among plants, there are many cases of bud variations, the origin of new forms in the course of branching. Many kinds of new fruits have arisen in this way. Scores of kinds of new fern varieties in the Boston fern group have had this origin.

For only a few of these the chromosome changes which have been responsible are known, but not for most of them. In some cases the chromosomes are so small that even to count them is almost impossible.



Courtesy of Brooklyn Botanic Garden

Mutations often occur in cultivated fern species. The picture shows seven distinct leaflets enlarged to show their differences. The left-hand one represents the Boston fern, from which the others arose as *bud variation.* The cause of these variations is quite unknown.

Acquired Variations

Let us examine some evidence of the way environment may act upon protoplasm. If we could take two identical individuals and put them in different environments, we should get some valuable data regarding the effect of the environment on living things. Fortunately, it is possible to do this in the case of several organisms.

We may take our example of identical individuals from three groups of living things: from unicellular animals, from multicellular plants, and from man. Most protozoa reproduce frequently by simple binary fission, that is, cell division. The resulting individuals come from the same protoplasm. With this method of reproduction there is no opportunity for the introduction of new genes. In higher plants that are reproduced by budding and grafting many examples of individuals consisting of the same basic protoplasm may be found. A twig or bud from any variety of apple contains in its cells the same genes as are present in the cells of the tree on which it grew. In many animals, examples of organisms with identical genes are much less common. Multiple births in pigs, rabbits, dogs, and cats

Photo by Walter J. Schoonmaker

These young woodchucks are probably fraternal twins. Notice the flies on top of their heads.

are usually the result of the fertilization of several egg cells that ripen at the same time. These egg cells contain different combinations of genes, as do the sperm cells that fertilize them. The resulting offspring, although born at the same time, are really no more alike than offspring born at other times from the same parents.

In higher animals, multiple births are the exception rather than the rule. When twins occur in such animals as horses, cattle, or human beings, they may arise from a single egg, in which case they are called *identical* twins, or they may come from two separate fertilized eggs and be designated as *fraternal* twins. Fraternal twins may be either of the same sex or of the opposite sex, but each has a different assortment of genes. What is believed to happen with identical twins is that the single cell develops for a while, and then divides into two separate groups of cells, each portion continuing to develop as a complete embryo. Identical twins are always the same sex.

Modifying development in paramecia. A single paramecium, reproducing by cell division, gives rise to two new paramecium cells with the same chromosomes as the parent cell. Suppose we take two such cells and give them different treatment. If one paramecium is given the best possible conditions, it will respond by developing to its largest possible size and activity. It will reproduce often, and the culture will eventually come to contain a great many large and active cells. If the other of the two daughter cells is at the same time subjected to unfavorable conditions of food and temperature, we shall find that fewer cells will be formed and that these will be definitely smaller.

If we consider the changes in size of the cells due to a difference in the surrounding conditions, we may readily see why these modifications are spoken of as nonhereditary. By switching some paramecia, and reversing the conditions, we can easily cause the better nourished to become smaller, and the starved animals to grow larger and more active. If changes are found which persist under varying cultural conditions, such variations are hereditary.

Modifying development in plants. Many new varieties of apples have originated as bud variations: the spontaneous appearance of a branch on a tree with characteristics different from the tree as a whole. If the new variety has desirable characteristics of fruit, it can be propagated by grafting its twigs on young seedling trees of any other kind of apple. Such grafted trees produce fruit according to the branch which has been grafted above; not according to the kind which furnished roots and lower stem.

Courtesy of Boyce Thompson Institute for Plant Research

Most plants flower the better the more sun they get, but Salvia prefers short days.

Some differences can be produced by changes in soil and climate. A Spitzenberg apple grown in the eastern states has a somewhat different shape from one grown in the Far West; the apple grown in the Far West is usually longer. There may also be some difference in taste. If, however, western trees are planted in the East, they then develop some of the characteristics of eastern trees.

Other examples of modifications in plants are numerous. The effects of various types of fertilizer on crops are familiar to many. Experiments have shown that change in the length of day may cause outstanding changes. Some plants when given longer periods of light than usual are unable to produce flowers and fruit; some are induced to flower and fruit in a much shorter period than usual. The change from a mountain to a lowland environment and vice versa produces remarkable differences in the same kind of plant.

Similarities in the life history of twins. Two conclusions seem certain from studies of identical twins.

First, heredity ensures that such twins will develop very much alike, even when raised under different conditions. Their physical resemblances remain close, as a rule. They often go through similar types of illnesses at the same ages, even unknown to each other. They tend to grow up to have similar tastes, to show similar aptitudes in school and in other respects.

Secondly, however, different training, different amounts of education, produce some differences in manners and skills. If one twin takes lessons in the playing of some musical instrument and the other does not, there is bound to be a different development of skill.

A case of unmodified development. Several years ago Professor Castle of Harvard grafted into an albino guinea pig the ovary of a black guinea pig. The original ovary was completely removed. When the white female recovered from this operation, it was bred to a white male. The young of this mating were born black. Their later history showed that they were heterozygous for fur color, just as if they had been formed as a result of the mating of purebred black with white. The maternal tissues and blood did not produce any more modification of the genes in the egg than is produced by the stem and roots of a tree on the branch grafted on it.

This was not so much an experiment to change the development of an individual as it was an attempt to see whether the genetic constitution could be changed in this way. It is true that the whole embryo development of the young guinea pigs took place in an environment different from the ordinary, but the environment was complete since it furnished favorable conditions and an adequate food supply.

Can genetic variations be produced? Biologists have long been interested in this question and many times have thought that they had succeeded in changing the inheritance of different organisms. But when the experimental methods of breeding were introduced and rigidly applied, many cases of the supposed changes in heredity were found to be without adequate foundation. At present two examples of artificially altered inheritance seem to be established: (1) changes caused by radiation and (2) changes caused by the application of chemical stimuli.

X-rays and radium emanations when applied to various organisms have led to various abnormalities in chromosome distribution. These radiations are powerful agents, and their effect seems to be to break chromosomes into pieces, and otherwise to derange normal cellular processes. Experiments with chemicals have been tried over a period of thirty years, with moderate results. Very recently, it has been observed that a plant poison, *colchicine,* sometimes doubles the chromosome number by stopping mitosis before cell division is completed. The doubling of chromosomes has also been caused in tomato plants by repeated pruning.

The Modification of Species

For thousands of years mankind has taken advantage of the common occurrence of variations to improve domesticated plants and animals. Great changes have been brought about by the method of artificial selection. Every common cultivated species, with its numerous varieties, is an example of the modification of species accomplished through this method. From time to time men have theorized as to the possibilities of some similar modification of species by nature.

Lamarck's theory. About 1800, a French biologist, Lamarck, reached the conclusion that species of living things were changing. He proposed a theory to account for variation, called the "inheritance of acquired characters." He believed that modifications or changed characteristics acquired during lifetime were influential in producing heritable changes. For example, the children of a blacksmith should inherit brawny muscles. The children of a musician, or of one who practiced a great deal, should have increased musical capacity. The idea seems plausible. It is one of those notions which we like to believe. Accordingly, it has persisted and some people still believe in it.

Many experiments have been conducted to test the truth of this theory. One of the most famous was performed by the German scientist Weissmann. Weissmann cut off the tails of mice and mated them. He continued to do this for thirty generations of mice but the result was that the tails of the final generation of mice were just as long as were those of the original mice. Since Weissman's time no satisfactory evidence has been found to support the theory of the inheritance of acquired characters, and modern genetics finds no basis for the theory.

Natural selection. About one hundred years ago, the thought came to Charles Darwin that man's selection of superior types of domesticated plants and animals may be paralleled under natural conditions. He reasoned that if man, by artificial selection, has been able in some thousands of years to produce great changes in the characteristics of various species, there might be a corresponding *natural selection.* This would involve elimination of the less vigorous, or otherwise deficient, offspring, and the preser-

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What would probably happen to a hairless sheep under an environment leading to natural selection?

vation of those young organisms better fitted to cope with the struggle for existence. Let us see how this principle might apply in a few examples.

In a large litter of young wild animals, the weaker individuals would tend to lose out in the struggle with their stronger brothers and sisters. The more vigorous get more of their mother's milk, and gain in weight and strength at the expense of the smaller. In cases of danger from beasts of prey, the weaker tend to be the first to be caught and devoured. The more vigorous have a better chance of reaching maturity and producing more of their kind.

L. H. Bailey has said that the principle of natural selection might more appropriately be called the principle of "natural elimination." Untold billions of eggs, seeds, spores are produced every year with the chances probably a million to one against any individual organism's growing to maturity. Chance kills off a great proportion of the whole lot. Among young organisms, the fitter and the less fit have about the same chance of being eaten or destroyed in some other way. The lake waters catch and destroy the strongest seeds as well as the weakest. But of those which do happen to fall into favorable conditions, the ones which have the best natural factors for growth, disease resistance, and vigor have the best chance of being "naturally selected" for survival.

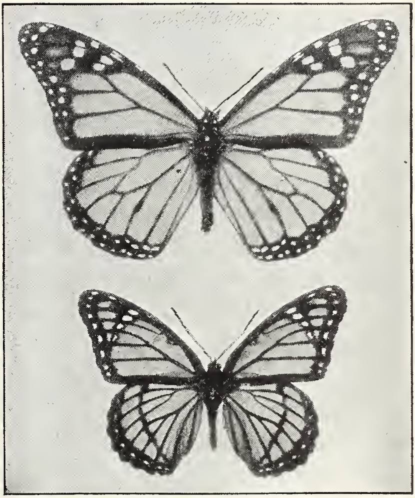


Photo from American Museum of Natural History

The Viceroy butterfly (bottom) has a protective resemblance to the Monarch butterfly (top).

Any difference which gives a young organism the advantage over its fellows tends to contribute to its chances to escape destruction. One of the factors noted by Darwin is known as *protective resemblance.* By this is meant any coloration or shape which makes an organism less conspicuous than it would otherwise be. There are many familiar examples of such resemblance. The katydid with its bright green color and leaflike wings is familiar. The walking stick with its resemblance to a twig, and the "leaf insect" of the tropics, are other examples. One kind of protective resemblance is given a special name, *mimicry.* By this is meant the resemblance of an animal to some other animal, a resemblance which is helpful because the thing mimicked is already well protected. Thus a common large fly which frequents flowers looks so much like a honeybee that most people think it is one. Other flies are striped like the yellow jacket. The Viceroy butterfly has the same general color and striping as the Monarch butterfly. The latter is bitter in taste and avoided by birds.

We still do not know how any natural species of plant or animal originated. Some biologists believe that evolutionary change and the production of new species are chiefly due to natural selection acting upon small mutations; others think that only large variations are important.

Review and Thought Questions

1. Describe a simple experiment that may be performed to illustrate the difference in the inheritance of genetic and acquired characteristics.
2. Contrast mutations with fluctuations.
3. Explain the statement, "Inheritance produces not only likeness but unlikeness."
4. Give an example of a gene mutation.
5. Mention two characteristics of gene mutations.
6. Why are variations not wholly due to heredity?

7. Distinguish between identical twins and fraternal twins. How may many differences in identical twins be accounted for?

8. Contrast artificial selection with natural selection.

9. Why is Darwin's theory of natural selection an incomplete explanation of variations?

10. What is meant by protective resemblance? Give examples.

11. How did De Vries amend the theory of evolution?

12. What is the status of the experimental evidence for Lamarck's theory?

13. Explain why Lamarck's theory has been so widely accepted.

Activities

1. From a study of the illustrations and the text of this chapter and the preceding one, make a list of variations due to recombinations.

2. Make a distribution curve, according to length, of one hundred or more seeds of some large-seeded plant, such as beans or castor beans.

3. Set up an experimental demonstration similar to that of the corn plants in the illustration on page 507. Use some quick-growing seeds. Plant some very thickly and others well separated. Keep the pot in a favorable environment for some weeks.

4. Make a collection of insects which show some kind of protective coloration, such as those mentioned in the text.

28. Plant and Animal Breeding

Man was a breeder of plants and animals long before the dawn of recorded history. The man who first saved the seed of some wild plant to grow the following year started the long process by which all our modern crop plants were developed. Soon after primitive man began to save seeds of plants, he must have noticed that some plants were better food producers than others. As he selected these better sorts and saved them for later crops, he was promoting the improvement of a crop plant. He was the first plant breeder. Similarly, with animals, the taming and development of useful types began long before any records were kept.

The Improvement of Plants

Nowadays, newspapers are quick to report the production of any new variety of plant or animal which may be useful. If anyone comes to be well known for breeding work, he is dubbed a "wizard," and his deeds are eagerly reported in the daily press. However, the principal species of food plants and animals have not been discovered or "created" by any modern worker. Their selection and improvement were the work of men of long ago.

The principal varieties of crop plants and domesticated animals were as well known to the people of ancient times as they are to us. Very few new species have been domesticated within modern times. Modern breeders have merely carried further the lines of improvement already started by their unscientific predecessors. Among the few useful species that have been brought into cultivation within recent times are the American grape and the American blueberry.

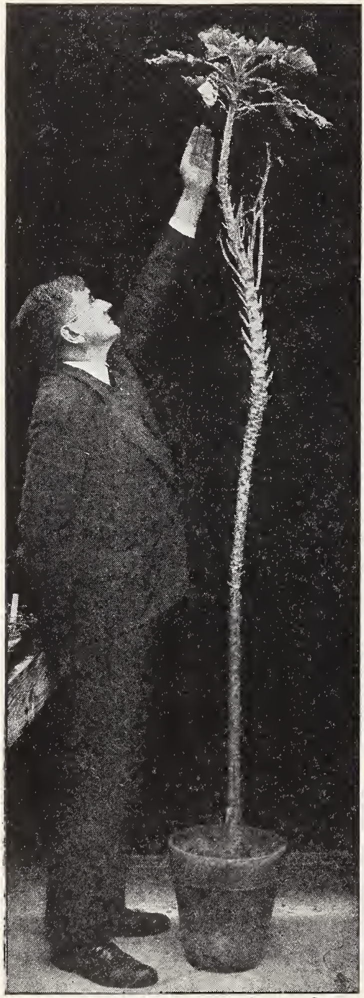
Breeding methods of the past. The improvement of plant and animal types before modern times seems to have been carried on in three or four ways, and these are the

Courtesy of Brooklyn Botanic Garden

Artificial selection produced these five varieties of the cabbage species, pictured in their second year: kale, Brussels sprouts, broccoli, kohlrabi, and cabbage.

methods we still use. *Selection* and *isolation* were principally used, but to these we may add the *introduction of new types* from other places, and to some uncertain extent, *hybridization*.

The men, or more likely the women, who cared for the few kinds of plants which were cultivated would note the



Courtesy of Brooklyn Botanic Garden

An eight-foot variety of cabbage; tree kale is interesting, but useless.

appearance of any new types that might be found. They would naturally save such better sorts, *select* them, and continue their culture in separate patches, that is, *isolate* them.

In early days, introductions must have been chiefly connected with human migrations. In good times men wandered because of crowding populations. In bad, they wandered in search of better territory. In such migrations, farmers took with them as prized possessions the animals they had tamed, and the seeds of the plants they had raised. In this way cultivation of local varieties became more widespread.

The fourth method of breeding, that of intentional crossing of species and varieties, is a very modern invention. It seems first to have been used experimentally in the eighteenth century. However, before that time accidental hybridizations had produced many new varieties from which selection could be made.

Modern plant-breeding methods. What do we do differently today in breeding work? Have we learned any new methods that our predecessors did not know? We can answer these questions best by considering in turn the various methods already referred to and by seeing whether we have had occasion to modify or improve these in any important respect.

Nowadays, instead of waiting until chance journeys lead to the finding of desirable new species, we explore for plants. The United States Department of Agriculture has a special Bureau of Plant Introduction which maintains a constant search for useful new kinds of plants. Thousands of introductions have been made and grown in testing grounds. State agricultural departments have made many thousands more. Private interests have sent expensive expeditions into far-off lands in search of new plants for drugs, horticulture, and industry.

The study of genetic heredity has contributed greatly to our understanding of what variations to look for, and the kind of variations which may most profitably be selected. It has also made clear the principles on which isolation may be practiced most successfully.

In any sample of seeds of a common crop plant, there is always likely to be great variation in size, weight, and other characteristics. If a quantity of such seeds are plotted for size, it will be found that they may be grouped in what is called a normal distribution curve. A few seeds will be large, a few very small, but most of them will be intermediate in size. If single seeds are selected and grown, the seeds of the next generation may also be placed to show distribution curves, but the average for each curve is likely to be different from the curve for the original lot. This discovery, made by a Danish botanist, Johannsen, working with beans, has proved very valuable for practical plant and animal breeding.

Johannsen's work showed that a population of apparently uniform stock might really consist of a number of distinct pure lines, or as De Vries called them, *elementary species*. This work was valuable for breeding, because it represented an improvement upon the method of selection.

Hybridization and selection. In breeding work, it is usually not practicable to wait for a new mutation to occur along any desired line. You might grow millions or even billions of bean plants and not get a variation which would increase the size of the bean. You would get variations of different sorts, but possibly none which would have any practical value. No commercial grower could afford the space and time which would be needed to work out such a method extensively.

What may be done is well illustrated in the improvement of the garden flowering plant, gladiolus. For a long time the colors ranged through various shades of red, pink, and white. There was no yellow. Finally a yellow species, with small flowers, was introduced from Africa and crossed with the older sorts, and selection was made for a combination of large size and yellow color. Now we have a wonderful series of large-flowered yellow varieties of gladiolus.

Hybridization and inbreeding. Here is a practice about which there was much misunderstanding until the work of experimental genetics cleared up the difficulties. Breeders knew that *inbreeding* of plants, that is, the fertilizing of an individual with its own pollen or with that of

Plate IV. Plant breeding produces new kinds of iris.

NEW KINDS OF PLANTS

In different parts of the country, a number of iris species grow wild. The two flowers at the top are from two species which grow in Louisiana and nearby states. Iris fulva is the orange-colored kind, Iris foliosa is the lavender-flowered species. In the same region, several other different forms have been described as new species, based on different flower color and different plant growth. The six other flowers in the plate were all raised by one man. The upper one was raised in Indiana, and named "Dorothy K. Williamson." The other five were raised as seedlings of the Williamson plant by Dr. George M. Reed at the Brooklyn Botanic Garden. These seedlings differ among themselves just about as much as do some of the forms which have been called new species.

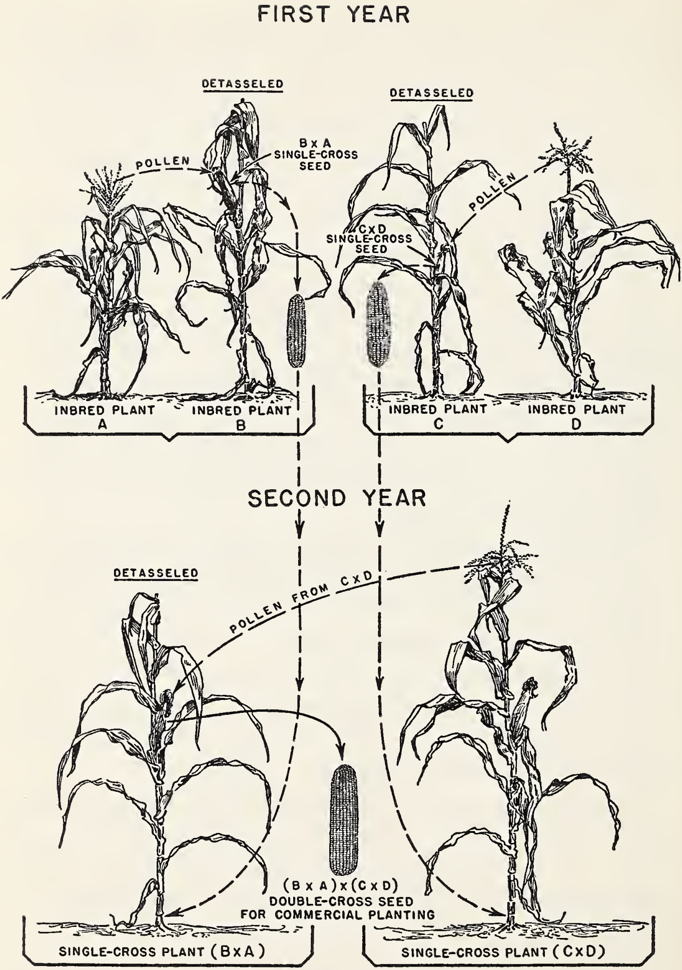
a close relative, often resulted in decreased vigor of the offspring, sometimes did no harm. Darwin had shown by his experiments that there were some plants which suffered from inbreeding, but that other kinds did not. It was also known that new types obtained by crossing must be inbred to *fix* the variety; that is, to make it uniform.

The solution of the problem was gained finally through the work of American plant breeders who bred corn. The corn plant normally is cross-pollinated. The flowers occur separately, the young ear being a cluster of many pistillate flowers, one for each grain, and the tassel at the top consisting of many staminate flowers. These two kinds mature separately, and a single plant usually cannot be naturally self-pollinated. A lone corn plant may grow vigorously, but set no seed, because the wind has not brought pollen from another plant.

However, if the pollen from a plant is collected and carefully placed on the stigmas of the same plant, self-pollination, or *selfing,* will occur, although not many seeds will ripen. If the matured grains are planted, they will grow into a series of plants of several types. None will be as tall and vigorous as the parent plant, and many will be weak and defective in a variety of ways. Some will be so feeble that it would be difficult to raise them.

Each strain is again self-pollinated. Some will set no seed at all. None will be as large as the original sort, although a few will be healthy plants of smaller size. These may be self-pollinated generation after generation, and continue to be uniform.

How can we explain the fact that selfing of corn leads to decreased size and vigor, and also to many hopelessly defective strains? The case of the yellow mouse furnishes the clue to the corn behavior. You will recall that a yellow-



U. S. Dept. of Agriculture Farmers' Bulletin No. 1744

One of the methods used by modern plant breeders for the improvement of crop plants is known as the *double-cross.* Study this illustration to find out how corn plants are double crossed.

colored mouse is always heterozygous for yellow and some other color; that a purebred, homozygous yellow mouse is impossible, because this factor is lethal. When plants of an ordinary corn variety are selfed, the result is to bring together pairs of hidden lethal factors, harmless when heterozygous, but harmful when homozygous. Some are completely lethal and prevent the ripening of the grain. Some are not immediately fatal. The grain develops and sprouts, but the young seedling is imperfect and may not flower.

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In broomcorn, dwarf parents may produce giant offspring through heterosis.

It will be interesting to follow a little further the experiments made by corn-breeders. After they had obtained various pure lines of corn, they tried the effect of crossing two of the healthy strains; these inbred lines were normal, although the plants were small. The result was a new generation of heterozygous plants, which were as tall and strong as the original type and more productive. Here we have an example of *hybrid vigor*, or *heterosis*.

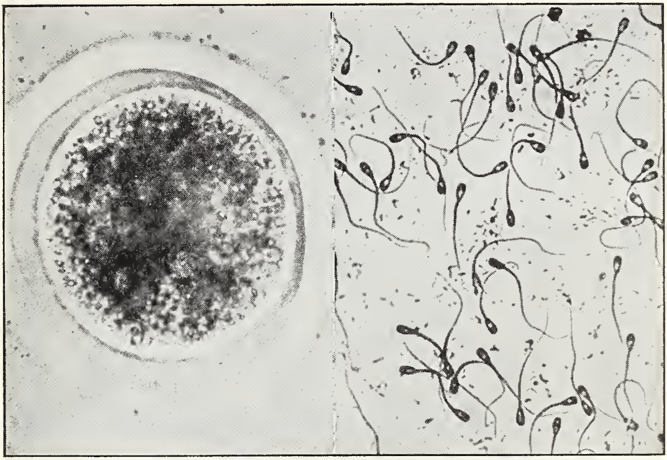
It is now possible to obtain selected strains of corn which have had all the hidden defects bred out of them by self-pollination and which can be crossed to get the benefits of hybrid vigor. Such strains when crossed are known as *hybrid corn* and are now replacing the older-named varieties in seedsmen's catalogues.

Genetics and Animal Breeding

The general history of animal breeding is similar to that of plants. It seems certain that animals were domesticated before plants, the dog first of all. The next stage was the improvement of the useful kinds.

Pedigree culture. Pedigree culture has been applied to animals, in the breeding of horses and cattle. Our modern race horse can be traced through many generations, and the names of the ancestors given for a hundred years in many cases, often better than in the case of human ancestry. The persistence of desirable qualities in inheritance from some particular horse is well known. From Hambletonian, a horse of about 1849–1876, is traced the blood of all the best trotting horses. In cattle, a particular bull is often known by the quality of his descendants. The capacity to produce large amounts of milk or beef is definitely handed down through the male as well as through the female.

Animal breeders keep careful records of matings, and from these it is possible to trace the ancestry of the animals back several generations. In order to insure accuracy and uniformity in such records, registry associations for each breed of animals have been established. Each purebred



When the egg of a cow (left) is fertilized by sperms (right), the chromosomes of the single cell represent all the hereditary traits of a new animal.

animal is given a name and a number, and no animal can be registered unless both parents have been similarly registered. By this means the ancestry of such animals is known with a high degree of accuracy. Animal breeders also tabulate pedigrees showing the parents, grandparents, great-grandparents, and great-great-grandparents of individual animals. The following is the pedigree of Stockwell's April Pogis of H. P. 694554, one of the highest-producing cows of the Jersey breed. Her official record is 1218.48 pounds of butter fat in 365 days.

	Grandsire
Sire	Wm. Rufus of Bleak House 106466
Col. House of Bleak House 118121	Granddam
	Bomba of Bleak House 216420
	Grandsire
Dam	Imp. Rozel's Noble 96627
Rozel's Stockwell Duchess 315286	Granddam
	Stockwell's Oxford Duchess 276931

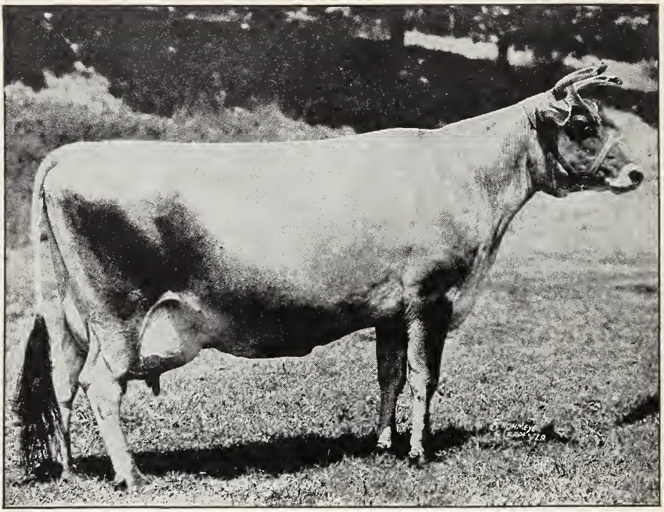
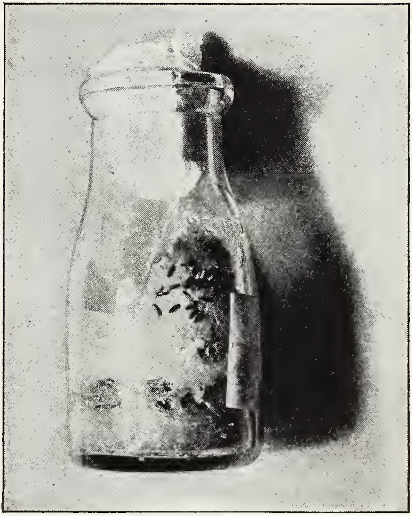


Photo from Strohmeyer and Carpenter

Stockwell's April Pogis of H. P. 694554 came of ancestors selected as exceptional milk producers.

Hybridization and inbreeding. Inbreeding in a plant species is very often a matter of *selfing* an individual which possesses both kinds of gametes: eggs and sperms. In the higher animals this is impossible, and in practically all the lower animals selfing is a rarity. Inbreeding with animals must be accomplished by the use of two individuals. When the process is carried out experimentally, the practice is to mate animals that are more or less closely related. When this practice is continued for several generations, it is known as *line breeding*. When a line-bred animal is mated with another unrelated animal of the same breed, the result is called an *outcross*.

One of the most successful methods of improving domestic animals is that of line breeding from a single outstanding individual of the breed. For instance certain race horses are said to be line bred from Hambletonian 10. This means that Hambletonian 10 appears many times in the pedigrees of such horses. In this way the genes carried by a specially valuable animal may be preserved in its descendants instead of becoming scattered and mixed up with other genes. Line-bred animals are therefore more likely to produce offspring very similar to themselves than are animals of mixed breeding.



Courtesy of Carnegie Institution of Washington, Cold Spring Harbor

The fruit flies, so much used in genetics, are usually grown in half-pint milk bottles, with a wad of cotton for a stopper. Food is supplied in the form of a piece of banana, or in specially prepared nutrient media made with agar. Yeast is added as part of the food.

In no significant respect are the results with animals different from those with plants. Drosophila has been inbred for hundreds of generations, and rats for fifty or more, without any decrease in vigor. It is hardly practical to use the method extensively with larger stock animals because of their size and slow breeding. However, if breeding experiments were continued for a sufficiently long time, healthy homozygous strains of large stock animals could be developed.

Review and Thought Questions

1. Who were the first plant and animal breeders?
2. Name five common varieties of cabbage.
3. Name three methods that were probably carried on before modern times in the improvement of plant and animal types.
4. How are these same methods employed today by modern breeders?
5. Explain why the "selfing" of corn leads to decreased size and vigor.
6. Describe one example of hybrid vigor or heterosis.
7. Under what circumstances may inbreeding not be harmful?
8. Of what value to the owner is a race-horse pedigree?
9. With what animals has inbreeding actually proved to be beneficial?

Activities

1. The most important and the most scientific breeding of new plants and animals during the past forty years has been done at various public agencies, such as the Federal Department of Agriculture, various state experiment stations, botanic gardens, state colleges, and the larger universities. Write to your own state department to learn what has been done there, and to the Bureau of Publications in Washington, D. C., for a list of bulletins on this subject.
2. Carry out a selection experiment, with some large-seeded plant, for size and color variations. Plant the smallest and the largest seeds of the lot and then plot the curves of the seeds produced. Compare them.
3. If you have garden or greenhouse space, try cross-pollination experiments between different pure strains of flowering plants or vegetables.

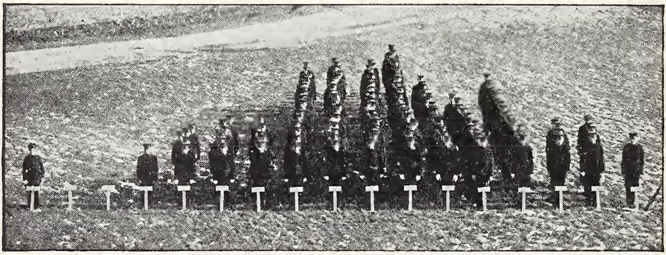
29. Human Inheritance

While there can be no reasonable doubt that in man heredity and variation follow the same laws as in other organisms, man offers the most difficult problems of all living things for the study of these phenomena. In the first place we know of no organism in which variation has so many complexities, no single species in which there are so many subspecies and varieties. Furthermore, no kind of plant or animal offers such complicated genetic material because of past crossings and mixtures. No other organism is so heterozygous in its genetic make-up, and in no other organism is there so much confusion between variations due to the environment and variations due to genes.

The Study of Human Inheritance

It is obvious that we cannot apply to man the methods we use in analyzing the variations and heredity of lower organisms. We cannot experiment at all with men, as with flies or beans. We cannot inbreed to produce more identical inheritance. We cannot operate at will to get material for the study of cell structure.

The statistical method. Sir Francis Galton, cousin of Charles Darwin, is considered the founder of the scientific study of human inheritance. He studied the problem statistically, measuring large numbers of men. On this basis he concluded that offspring inherit something less than the extremes of parental characteristics. Short people tend to have children taller than themselves, and tall people tend to have children shorter than themselves when large numbers are considered. Galton considered this fact an important principle of heredity and designated it as the "law of filial regression."



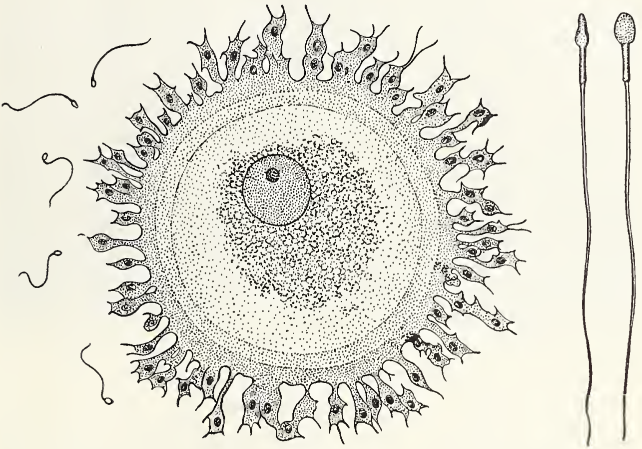
Courtesy of Dr. A. F. Blakeslee

The normal distribution curve of man according to height indicates that offspring usually inherit something less than the extremes of parental traits.

The genealogical method. Now it is realized that the fundamental laws of heredity cannot be discovered by determining average figures compiled from large numbers of people. In heredity different characteristics behave as distinct units, and as Mendel showed, it is necessary to follow the behavior of pairs of contrasting characteristics to see how they are handed down in particular family lines.

For man, then, we must first pick out characteristics which we may be reasonably sure are due to heredity and are not often changed by differences in the environment. Second, we must find some way of following the transmission of these traits through a number of generations. Third, we must examine a sufficiently large number of cases to insure valid conclusions.

Among the traits that are most certainly controlled by inheritance, and not likely to be permanently modified by the environment, are differences in color of eyes, skin, and hair and differences in hair form, such as curliness, waviness, or straightness. Of course, dark-haired people sometimes become bleached blondes through an environmental influence, but this is obviously a very temporary modification.



After Woodruff

Characteristics such as the color of the skin, hair, or eyes, and many other traits are laid down in the chromosomes, contained in human sperms and eggs. One set of characteristics comes from the father through a sperm (right and left), the other from the mother through the egg (center).

Dr. Charles B. Davenport, an American leader in the study of human inheritance, used the genealogical, or family-history, method in a study of human inheritance. One of his first studies was an investigation of the inheritance of hair color. Hair color varies from the lightest blond shade to the darkest shades of brownish black. All shades of brown tints are due to different amounts of a granular pigment, called *melanin*. Red hair is due to a fatty pigment, which is not granular. This may also exist in different shades, and may occur in the same hair with brown.

The collection of thousands of cases bearing on the inheritance of hair color provided a wealth of evidence justifying the conclusion that hair color follows a definite law in its transmission. Other characteristics that were subsequently studied followed similar patterns.

Our Present Knowledge of Human Heredity

In order to aid in the collection and filing of genealogical records, the Eugenics Record office was established under Dr. Davenport's direction at Cold Spring Harbor, New York. As time goes on, the records will become more complete, and sufficient data will become available so that more positive conclusions may be drawn regarding the inheritance of more and more human traits.

Single factors in human inheritance. The simplest and clearest cases of single-factor inheritance are found in the inheritance of certain unusual characteristics. *Albinism,* which occurs occasionally in man as well as in most other animals, is a good example. Human albinos have hair lighter than the lightest flaxen and skin and eyes without any brown. The pupils of the eye may be deep-red and the iris pink or blue. Albinism in man behaves as a simple recessive, as with other animals. Two albino parents have only albino children. An albino and a pigmented parent have all pigmented children, except when the darker parent is heterozygous.

Various abnormalities of the hands also seem to follow a simple one-factor mode of inheritance. *Brachydactyly,* or short-fingeredness, is dominant to the normal condition

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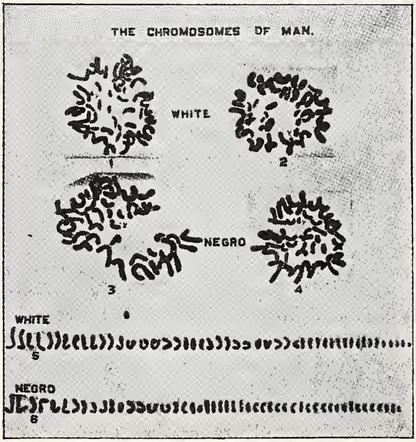
Which bones in the hands pictured here show an inherited difference from the normal?

as is *polydactyly,* the trait of having an extra finger. It is also believed that feeblemindedness is due to a single factor, and that it is recessive to normality.

Multiple factors in human inheritance. From the earlier studies it seemed to be indicated that the inheritance of ordinary differences in color of hair, eyes, and skin might be due to single-factor differences. But study of many cases brought out complications which take the inheritance of eye color out of the simplest one-factor class. In the first place, in descendants from a cross between the darkest type of brown eye and blue, there are many gradations in color. This sort of behavior is exactly what we find in experimental examples of multiple-factor inheritance, with two or more pairs of genes influencing the same trait.

In the case of skin color, where both parents are of the white race, it seems now that the inheritance follows a simple three to one ratio. The dominant trait is pigmented skin which tans in the sun but does not burn. The recessive trait is blond skin which never tans but always burns and reddens. The heterozygous condition is found in intermediate skins which burn at first in the sun, but gradually develop a protective tan.



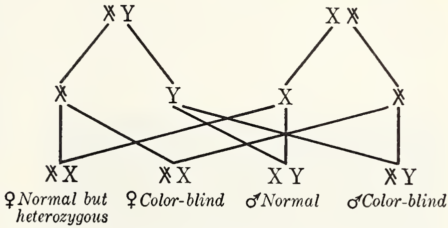
Courtesy of Professor Theophilus S. Painter

Human inheritance is controlled by the genes, or factors, in the chromosomes.

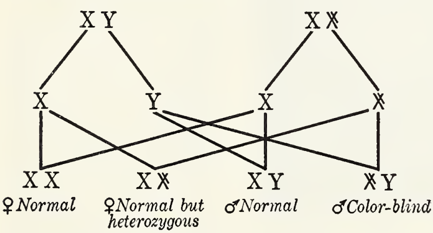
When the cross is between light-skinned and dark-skinned races, then skin color is inherited according to a multiple-factor basis, and at least three pairs of genes are involved. Hair color is also apparently due to the interaction of more than one pair of factors when the brown pigment is considered. When red hair is involved, we get a mixture of pigments. Clear red hair represents a combination of pale, flaxen, and a considerable amount of red pigment. Dark brown and dark red give a brownish red color.

The question of the inheritance of height in man is a matter of great interest and one which has been given considerable study. It is obviously no such simple condition as Mendel found with his peas, where a single factor determined tallness or shortness. Total height is a matter of the length of at least four different parts: head, neck, trunk, and legs. It is believed that the length of these parts may depend upon separate and different factors.

Sex-linked inheritance in man. Two examples of sex-linked inheritance that are well known in man are color blindness and *hemophilia,* or bleeding. The latter has been handed down in one or two of the royal families of Europe and constitutes a serious disability. Think of a condition where a slight scratch may be a source of serious loss of blood and where a nosebleed may be of fatal consequence. In its worst manifestations, hemophilia stands as almost a lethal factor.



When the father is color-blind and the mother is heterozygous, half the sons are color-blind, while the daughters, though normal, are heterozygous.



When the father is normal and the mother is heterozygous, half the sons are color-blind, and all the daughters are normal, but half are heterozygous.

In man, both color blindness and hemophilia are transmitted in the same way as in the sex-linked character of white-eye color in fruit flies (see page 500). Where, for instance, the father is color-blind and the mother normal, none of the children will be color-blind. The reasons for this are that normal vision is dominant over color blindness, and that the genes for both are attached to the X-chromosomes.

Inheritance of mental traits. Someone has made an epigram that says, "Wooden legs are not inherited but wooden heads are." It is likewise true that heads other than wooden are inherited also. Children of highly intelligent parents are very much more likely to have a reasonable degree of intelligence themselves than children of less intelligent parents. Of course, the thing that is inherited is not intelligence, as such. All that we inherit from our parents in the biological sense is our physical bodies. The physical basis of intelligence is the nervous system. A well-developed brain and a good set of neurons are essential to the development of high intellectual capacities.

©*Journal of Heredity*

Although separated most of their lives these twins are obviously identical.

The question of the inheritance of specific mental traits is a somewhat different problem from the question of the inheritance of general intelligence. It is also one about which there is less complete agreement than there is about the inheritance of such characteristics as skin color, albinism, and color blindness. Physical characteristics such as these are present at birth and are not subject to change, while mental traits are not definitely fixed and may be modified during the lifetime. For this reason, a great many people believe that environment is a more important factor in determining what a baby will grow up to be than heredity.

We have already considered certain evidence presented by identical twins, which seems to be mostly on the side of heredity. Identical twins resemble each other not only in external physical features, which make it difficult to tell them apart, but also in the internal qualities of mind, in tendencies, and in intellectual capacity. They show close resemblances even when they have been reared under very different conditions and given different amounts of schooling.

Inheritance of desirable qualities. A good line of evidence for the inheritance of mental or temperamental qualities in man is found in such a family as that of the Bachs of Germany. In eight generations, among 99 males, 50 attained distinction as musicians and composers. Ever since Revolutionary days various descendants of the Adams family have been contributing notably to American democracy. Charles Darwin was the grandson of Erasmus Darwin, himself a great naturalist and philosopher. Charles Darwin's father was an eminent physician, while his sons have continued the family interest in biology. Francis Galton, his cousin, was also a leader in biology in his day.

Inheritance of deficiencies. Besides color blindness and feeble-mindedness, other deficiencies are recognized as inherited. Deafness seems to run in family lines, due sometimes to definite ear defects. The question of insanity is more complex. In some instances it may be entirely due to the environment, but it seems just as certain that it may sometimes be a family tendency.

Diseases such as tuberculosis are not inherited, but susceptibility to this or that disease may very likely be passed along through heredity. Certain races are recognized as especially susceptible or insusceptible to certain diseases. Thus the Negro seems more likely to develop tuberculosis, under the same surroundings, than the white man. The Jew, on the other hand, has this disease much less frequently than some other white races. The Indians and South Sea Islanders showed a susceptibility to measles, which made it as dangerous to them as some of the great plagues had been to Europeans during earlier centuries.

The Improvement of the Human Species

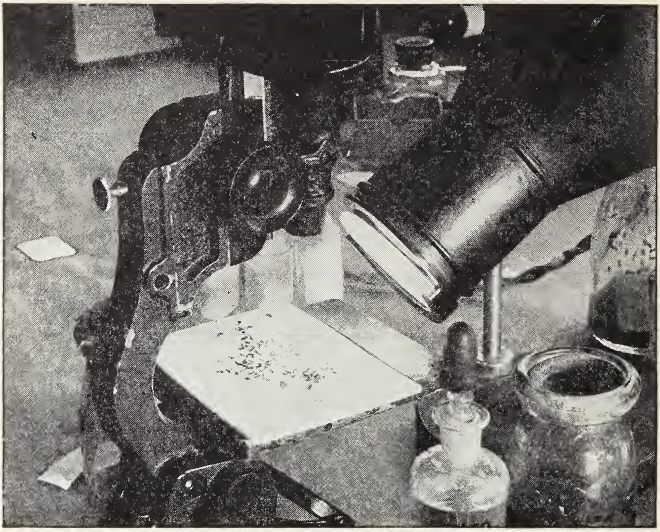
The idea that the human race can be improved is a very old one. Greek philosophers discussed the problem. Plato wrote of the perfect state where all citizens should live ideally. Some believed in the existence of gradations of perfection through which human beings naturally tended to progress. In many religions there are ideals of perfection of character toward which men have striven and which have influenced the lives of many millions of individuals. The purpose of modern universal education is the general improvement of all the citizens of a country. High civilization is impossible without educated citizens.

Eugenics. In 1883 Francis Galton proposed the establishment of a definite branch of human biology, to be called *eugenics,* which means "to be well born," or "correct breeding." Galton defined this new branch of knowledge as "the study of all the agencies under social control which may improve or impair the inborn qualities of future generations either physically or mentally."

Since the time of Galton's proposal, the world has seen the development of the science of genetics. Through this science we now believe we know and understand many agencies which "improve or impair the inborn qualities of future generations" of corn and potatoes, or rabbits, and of fruit flies. We know how variations may arise and how these may be inherited. We believe we understand the methods to be used in improving useful species. The same laws of variation and heredity apply in man as in lower animals and plants. One can understand human inheritance and variation better if he first acquires an understanding of inheritance and variation in lower species of animals.

Human inheritance is controlled by the chromosomes, and by the genes in the chromosomes. The eugenist must distinguish clearly between variations which are due to the genes and those which are caused by the environment. He must also view his problem with as little prejudice as a human being may be capable of showing.

Three methods based upon the science of eugenics have been proposed for the improvement of the human race: research, education, and legislation. These three lines are not at all separate and distinct. That which is learned through research is made the subject of education. That which has been made sufficiently clear through education may be made the basis of legislation. Eugenists are interested, therefore, in topics regarding which the facts are as yet unknown, as well as in matters which seem to be well established.

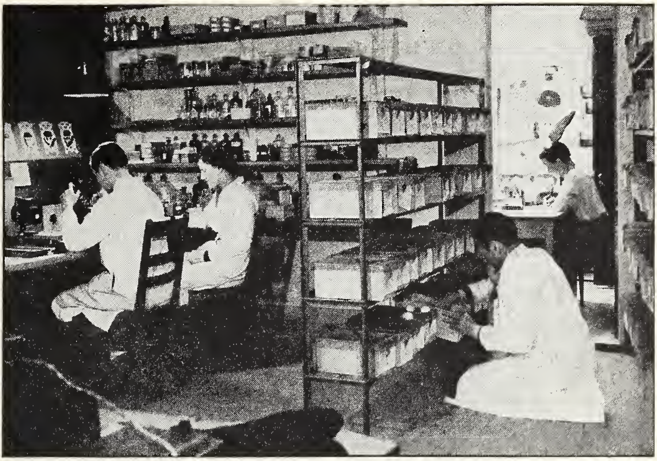


Courtesy of Carnegie Institution of Washington, Cold Spring Harbor, Long Island

The more we learn about human inheritance, the more we find it to be like that of the fruit fly, whose tiny progeny can be spread out, slightly anesthetized, on a microscope stage to be examined for their inheritance of different traits.

The importance of research. The genetics of lower animals is far ahead of that of the human species, but every new fact discovered about cells and chromosomes may become significant for human beings. The specific problems of research in eugenics are the investigations of family lines in man for the identification and verification of the laws of heredity known for lower forms. The gradual accumulation of more and more pedigrees is slowly clearing up our understanding of human inheritance and slowly bringing it in line with our understanding of inheritance in fruit flies, mice, beans, and guinea pigs.

Especially important is the discovery that certain traits

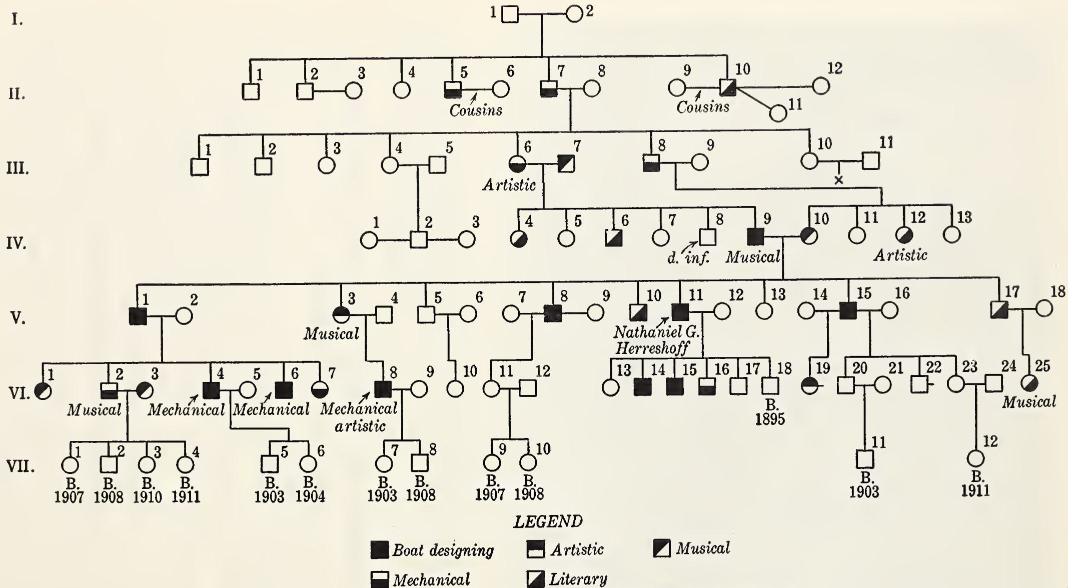


Courtesy of Carnegie Institution of Washington, Cold Spring Harbor, Long Island

We cannot study human inheritance as these workers are studying the inheritance of mice. But we can be certain that many of their findings will be applicable to man.

are inherited and that others may be controlled by training and education. When we feel sure that some particular defect is controlled by inheritance and that a possessor of this trait will be sure to pass it on to any descendants, we come into a position to make practical recommendations regarding marriages.

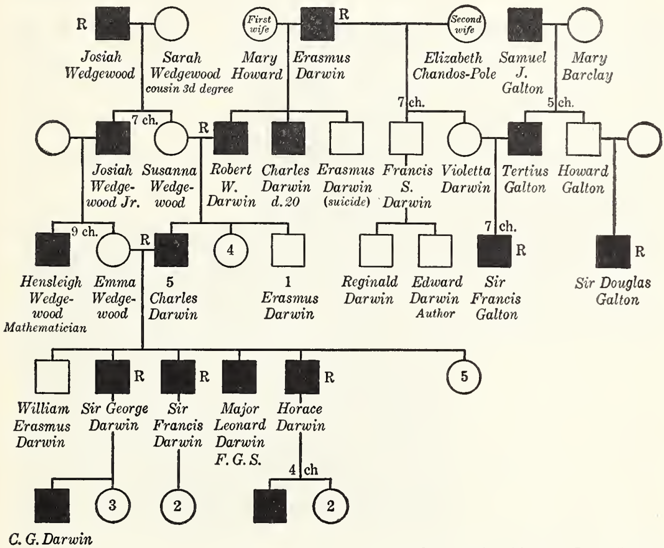
Education. A knowledge of the principles of inheritance should be included in the education of every intelligent citizen. The basic functions of the cells in reproduction, the formation of gametes, the process of fertilization, and the development of the embryo constitute a series of essential understandings with which everyone should be familiar. Every individual should be acquainted with the practical applications of genetics in the breeding of plants and animals.



Courtesy of the Eugenics Record Office, Cold Spring Harbor, Long Island

Seven generations of the Herreshoff family are shown here. In five of the generations there have been members showing marked capacity in some line. The family is noted for the success of some members in boat-designing. When the chart was made, the capacities of the last generation had not been determined.

The program of research and education has made considerable progress since Galton first launched the science of eugenics. Several international congresses of eugenists have been held, and thousands of pages have been written on



Courtesy of the Eugenics Record Office, Cold Spring Harbor, Long Island

In the five generations of the Charles Darwin pedigree, we may be sure that the qualities of the women of the family were equally important with those of the men. In human selection of a mate it is probable that like selects like more often than not.

eugenics. Through a program of education, eugenists propose to influence the intelligent members of society to avoid matings which will pass on known defects. They believe that the general program of biological education outlined in the preceding paragraph will accomplish this result with the majority of the intelligent members of the community.

Legislation. As a result of research and education in eugenics, various measures for legislative enactment have been proposed, and over a period of years a number of laws have been passed.

One of the first eugenic laws was passed in the state of Wisconsin, whereby people applying for a marriage license were required to present a physician's certificate of health and fitness for marriage. This law was framed particularly for the prevention of marriage where one or both of the contracting parties was afflicted with a social disease. These diseases are almost certain to lead to serious handicaps among children resulting from a union between people afflicted with them.

Some states have passed laws, and other states have considered doing so, authorizing the prevention of parenthood in defectives by the sterilization of individuals who are known to have serious and hopeless hereditary handicaps, such as extreme feeble-mindedness, idiocy, and imbecility. As an alternative, some people propose that all people who might be so treated be prevented from becoming parents by confining them in institutions. While to some extent this is already done, it is probably impossible for society to support properly all the people who might require such segregation.

One of the results of the development of a eugenic program has been a change in our attitude regarding immigration. For a long time the United States allowed anyone who was not afflicted with a contagious disease to enter this country for settlement. There was merely an examination at the port of entry, and people who had contagious diseases were turned back after they had reached our shores. This immigration policy resulted in some abuses. There was reason to believe that some foreign countries might be encouraging their undesirables to emigrate to the United States. It appeared also that steamship companies were encouraging immigration for the purpose of selling transportation. Finally, a committee

Photos from Ewing Galloway

Important provisions in our immigration laws require would-be Americans to pass health and other examinations in the country from which they come. Above, Ellis Island, an important receiving station for new American stock. Below, a group in Paris awaiting a train to take them to the boat for the United States.

was appointed by Congress to study the question and to report its recommendations as to a new policy. This Immigration Committee held many meetings and listened to the opinions of many different interests. Among others the committee called in as advisors several men who had achieved eminence in the field of genetics. These men who were familiar with the developments of this new science, convinced the committee of the soundness of their ideas. The result was that the immigration law enacted in 1916 contained some provisions based on the principles of genetics.

The main clause of this law limited the entry of immigrants on a national basis. Quotas were set up, fixing the number of new people who might enter from each foreign country. These restrictions were based on the numbers from various countries already in the United States. In addition, there were some provisions aimed to admit to this country only individuals with sound inheritances. In the first place, the new law transferred the place of examination in large part from our shores to the countries from which the immigrant wished to come. Those who were physically unfit were no longer allowed to spend their savings in making the trip to our shores. Instead new applicants were called upon to present their applications to our consular officers in their home countries. In the second place, the investigation of the prospective new immigrants was made more exacting than formerly. Restriction was based not only on the question of trachoma, a contagious eye disease, and other diseases, but also on the parentage of the prospective citizen. The purpose was to prevent as far as possible the entry of defective stock with records of insanity, criminality, and other defects that might be inherited.

Review and Thought Questions

1. Why is it difficult to apply to man the methods used in analyzing the variations in and the heredity of lower organisms?
2. Describe Sir Francis Galton's method of studying human inheritance.
3. What is meant by the genealogical method?

4. Evidence seems to indicate that feeble-mindedness is due to a single factor and that it is recessive to normality. What is the significance of this evidence?

5. What evidence do we have that color blindness is an example of sex-linked inheritance in man?

6. Cite evidence to indicate that we may inherit desirable as well as undesirable mental characteristics.

7. Contrast the possible effects of heredity and environment with respect to susceptibility to tuberculosis.

8. Discuss evidences that indicate the improvement or lack of improvement in man's culture, his physical structure, and his mental ability.

9. When and by whom was the study of eugenics proposed?

10. The eugenics program includes research, education, and legislation. Which of these lines of activity is the most controversial? The least controversial?

11. Why may a legislative program of eugenics be dangerous?

12. Why does research in lower-animal inheritance have bearing upon human inheritance?

13. Discuss the advantages and disadvantages of the following eugenic measures: health certification, sterilization, immigration control.

14. Explain the eugenic principles involved in two provisions of our present immigration law.

Activities

1. By observing and by asking questions concerning your own family line, determine whether there are any special physical features which have been handed down through several generations.

2. Make a chart to show how some particular characteristic is distributed in your immediate family. Note hair color, eye color, freckles, and curly or straight hair.

3. Particular organs furnish interesting subjects for comparative study, for example, the shape and curves of the ear,

the form of the nose, the shape of the teeth, and the structure of the hand.

4. Discuss the following statement: While everything possible should be done to improve the health and living conditions of all citizens, such improvement will not better the inherited qualities of the population.

5. Write to the Eugenics Record Office, Cold Spring Harbor, New York, for a sample of the blanks used.

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Unit 9

HUMAN PROGRESS

Human progress results from man's ability to study himself and the world around him from a scientific point of view—something no other animal has learned to do.

THE RISE OF HOMO SAPIENS

The Story of Human Development

How modern scientists piece together the story
Man's development traced by his tools

Species and Genera of Men

Distribution of early human species
The earliest species of men

The Biological Basis of Human Progress

How man differs from other social animals
How discoveries have led to human progress

CONSERVATION OF LIFE

Conservation of Natural Resources

Land utilization and conservation
Water resources and their utilization
Conservation of wild life
Conservation of natural beauty

Man's Control of Other Species

Insects
Fungi
Weeds
Birds
Reptiles
Mammals

Health Conservation

Causes of disease
Transmission of disease
Our defense against disease

30. The Rise of Homo Sapiens

Something like a million years ago, according to the best estimates of biologists, a new creature appeared upon the earth. It walked upright but was stooped and round-shouldered. It had a larger brain than any other animal that had ever explored our planet, and the forepart of its brain bulged out to form two enormous cerebral hemispheres. The new animal had hands, and since the hands were not required for walking, they were free to do many other things: to touch and feel, to reach for food, to grasp rocks and sticks, and to slap at insects. The hands were not entirely new, but they differed from those of the monkeys and the apes in that the thumb was extraordinarily well developed, and this permitted the new animal to do many things that were impossible for apes and monkeys.

The body of this new animal was decidedly hairy, though perhaps less so than was the case with most of the other large animals that shared its habitat. It probably lived in small family groups which worked together for protection and for securing food. Its food consisted of small animals, leaves, roots, seeds, fruits, and bark. At times, it may have attacked large animals or used its cunning brain to trap and overpower them. It uttered shrill, blood-curdling cries but could also make sounds indicating contentment, rage, jealousy, fear, joy, and tender emotion. Very slowly it learned to control its hands and its brain and to use them in new ways. After a long time it began to realize that it really was a most remarkable animal.

The Story of Human Development

Man is the only living species that is at all concerned about its own past history. We of today are very much interested in the earlier representatives of our species, because these earlier men were our ancestors. At least thirty thousand generations of Homo Sapiens have walked the earth, fought, suffered, and struggled onward to bring us here. We of today are only a link in the chain that will extend onward to countless future generations. Let us consider the past history of our species as modern scientists have fitted it together.

How modern scientists piece together the story. The science that is interested in the broad, comparative study of the human species is called *anthropology*. Anthropologists measure the heads, the jawbones, the leg bones, and the arm bones of both living and fossil men. They are also interested in the study of human culture, in the migration of ancient peoples, in the spread of prehistoric inventions, in the evolution of language, and in the development of social institutions.

Archaeology is a branch of anthropology. It has been called "pick-and-shovel history." It is interested in what took place before the time of recorded history. History deals with written and printed records, while archaeology studies the relics of earlier times, for which no other records are available. The stone arrowheads and other implements of the Indians are archaeological records. Archaeology and history thus go hand in hand, each supplementing and helping the other. But before historical records began to be made, and in those regions where writing had not yet developed, the study of human remains forms the only basis of our knowledge of earlier people.

Sometimes human relics are found buried so deep that it is necessary to turn to *geology,* the study of the earth's history as recorded in the rocks, to determine their approximate age. When the ancient Roman city of Pompeii was dug out of its covering of volcanic ashes, there were

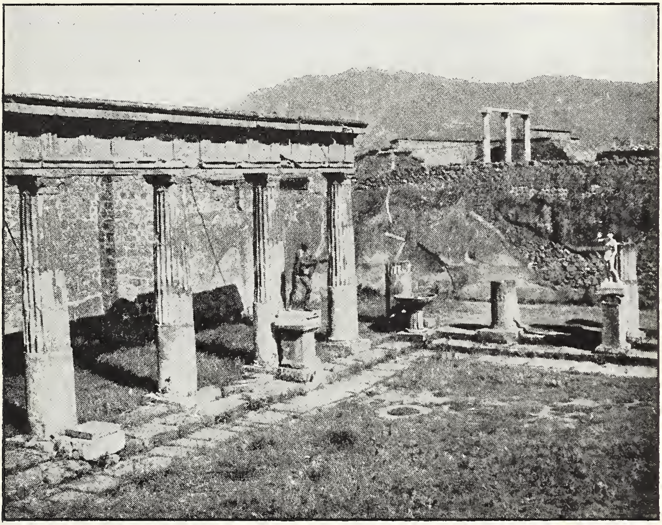


Photo by James Sawders

By digging the ruins of the large Roman city of Pompeii out of its cover of volcanic ashes, archaeologists found much to add to the story of earlier men. The city and its people were buried in 79 A.D. by an eruption of Vesuvius.

ordinary historical writings to tell us in just what year the disaster occurred, and even to tell us that the early Roman naturalist, Pliny, lost his life investigating the eruption. But when cities are found sunk beneath the surface of the ocean, as is the case along the shore of Italy, or when utensils and other human relics are dug from beneath river beds, or buried under many feet of soil, geologists must be consulted to tell us how and when the human beings may have lived. Thus, from geological studies, scientists are sure that human beings were present in Europe and Asia during the

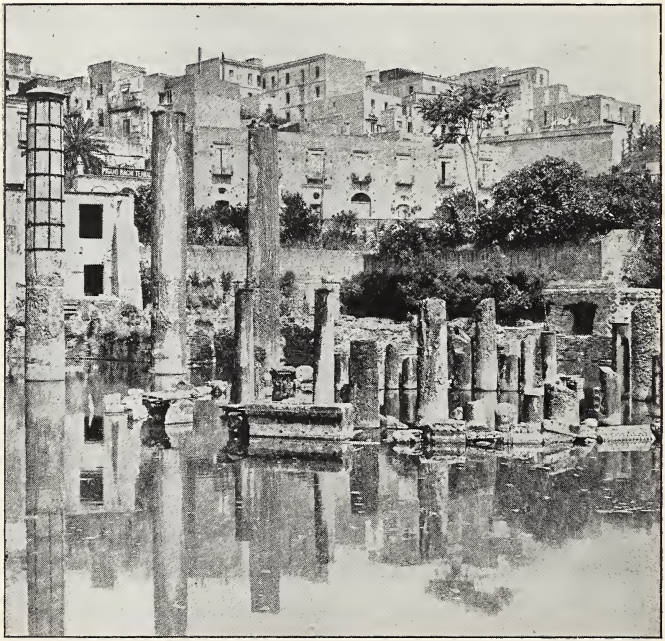


Photo by James Sawders

Ruins of man's past are sometimes found sunk beneath the ocean, as was this Temple of Serapia at Pozzuoli, near Naples, Italy. The marks of marine animals show how deeply it was once covered by the water.

Glacial Periods. It is on this geological basis that human existence is reckoned as starting at least one million years ago.

The particular kind of human record that the science of *paleontology* interprets is the bones of man and the plants and animals associated with him. The study of skeletons is the concern of the paleontologist, who may be so expert that he can read whole histories from a few bones. This kind of biological work is most important in helping us understand the early types of human beings which are known to us only in the form of bones. It has shown the existence of not one but eight or nine different species of human beings. For some of these earliest men, only a few bones, parts of a single skull, have been found. For others the records are much more complete.

From a combination of all these studies, we have a reasonably complete picture of human prehistory. The account of the archaeologists is more complete and continuous than that of the biologists, since stone implements are less perishable than human bones.

Man's development traced by his tools. The archaeologist divides early human history into great periods named after the kind of implements most characteristic of each period. For approximately the last three thousand years, we have been living in the Iron Age. Before that, there were about two thousand years of the Bronze Age. Back of that, as far as human existence can be traced at all, man chiefly used stone. Two main divisions of the Stone Age are best known: the *New Stone* Age, or *Neolithic* Age, and the *Old Stone* Age, or *Paleolithic* Age. Before the Paleolithic Age, there is a long period about which there is a great difference of opinion among scientists. Pieces of stone have been found which are so crude that it cannot be told with certainty whether they had been prepared by human hands or whether they had become broken by accident. Such stones are called *eoliths* and the period is called the *Eolithic* or *Dawn* Stone Age. In the early Paleolithic Age, whole pieces of stone, usually flint, were the only tools or implements used by man. A crude edge was formed on one side by chipping away the stone. Later it was found that flint could be flaked off in large chips, and that these chips made better implements

Photo from American Museum of Natural History

Before men built dwellings, they often lived in caves, and succeeding generations lived upon the refuse of those who had gone before. In such layers, the deeper levels may have cruder stone implements than those higher up. In the picture are shown some of the crudest tools and some of the most highly developed.

than whole pieces, and could be prepared more rapidly. Finally in the Neolithic Age men began to take more interest in the looks of their tools. In order to make them look better, they began to polish and smooth them down. The American Indians were in one of the stages of this New Stone Age when Columbus first came to these shores. Even today, however, some of the Australian natives are still partly in the Old Stone Age.

About sixty years ago, a Spaniard, Marcellino de Santuola, was exploring the deposits in the floor of a cave near his home. His little daughter was with him. While he was digging, he was startled to hear her call "Toros! Toros!" that is, "Bulls! Bulls!" In Spain bulls seem to be of particular interest but are not commonly found in dark caves. The bulls that the little girl saw were pictures drawn on the wall of the cave and hitherto unnoticed because of the dim light. They were an ancient kind of bison no longer found in Europe. When Santuola reported his find, he was at first suspected of misrepresentation; but finally it was realized that the drawings were genuine and thousands of years old. In the same cave were found layers or refuse, remains of fires, stone implements of the Neolithic Age, and human skeletons. The skeletons were identified as similar to those which had been found at Cro-Magnon, France, and so had come to be called the Cro-Magnon men. They belonged to our species, Homo sapiens, and were splendidly formed, averaging over six feet in height. Since that time, Cro-Magnon skeletons have been found in a number of different places. Another type of Homo sapiens has been found at caves at Grimaldi, France, and at other places. The skull and other skeletal features of these finds are suggestive of the modern Negro. Thanks to the artistic ability of these men of twenty-five thousand years ago, we know that their biologic environment was considerably different from ours. They drew pictures of mammoths and other animals which have been extinct a long time. We also know that the men were hunters and that they used bows and arrows, spears and knives. Since they lived at the close of the last Ice Age, when much of Europe was still covered by glaciers, it is fortunate that they knew how to make fires.

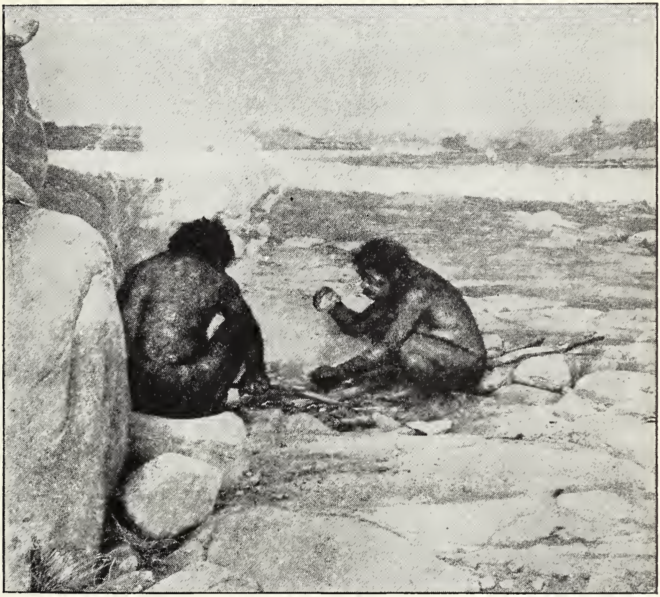
© *Field Museum*

Cave-dwelling artists among the Cro-Magnon men of about 25,000 years ago have left us pictures of animals now long disappeared. Buried, too, in the floors of the caves are found bones of long-ago animals, stone implements, and the bones of ancient men.

Species and Genera of Men

The scientist's knowledge of human types in existence before Homo sapiens is relatively scanty but eight or nine different species have been identified. One has been found many times, and on two continents. The remaining six or seven are known only from incomplete skeletons, and biologists are not agreed at all points about them.

Distribution of early human species. The most abundant material of these early species is known from



© *Field Museum*

With crude weapons, the crude earliest men contended for their living against the great beasts of their periods and the rigors of an ice age. While lions and hairy elephant-like animals have left their bones and many implements have been found, human bones of these species are few or none.

European locations. For some time biologists have been in agreement that the continent of Asia is the probable place of the origin of the human species. One very primitive type had been discovered on the island of Java more than forty years ago. Within the present century additional types have been identified, one from China, two from Java, and several from Africa. With some of the skeletons, implements have been found which indicate the cultural stage of the accompanying fossils.

So far there is no certain evidence that the American continents were ever occupied by any other species of man than Homo sapiens, represented by Indian types. The antiquity of man on this continent is estimated at somewhere between ten and twenty thousand years.

The earliest species of men. At Piltdown in Sussex, England, were found fragments of the skull of an ancient human type which is known scientifically as *Eoanthropus Dawsoni,* the "Dawn Man." A few fragments of another specimen were afterwards found not many miles away. Bones of the woolly rhinoceros, the mastodon, and crude eoliths were found with the human remains.

The Heidelberg man, or *Paleanthropus heidelbergensis,* is known from a single lower jawbone found nearly eighty feet under the surface of the sands of a river valley. An age of perhaps four hundred thousand years is indicated.

From Africa has come one certain human species, *Homo rhodesiensis,* or Rhodesian man, which is still placed in the same genus with modern man. Parts of two individuals were found; the skull and a number of bones of one, and an upper jaw of another.

In 1891 Dr. Eugene Dubois found in a river deposit at Trinil, Java, a human skullcap, a thighbone, and three teeth which he used in describing *Pithecanthropus erectus.*

This animal seems to have been a very primitive type of human being dating back perhaps a million years.

One of the most interesting and important of all discoveries of fossil human remains was named *Sinathropus pekinensis,* or the Peking man, after the name for the nearby Chinese city. It is important, both because it is very ancient and because it has been found in considerable abundance. The locality is a cave which was uncovered in limestone quarrying, and the discovery was made in 1929 by a young Chinese, W. C. Pei. The first find consisted of two skulls, but parts of nearly forty individuals have been found since. More is known about the Peking man than about any other extinct type except the Neanderthal. It has been suggested that this early type was a cannibal because some of the skulls show evidence of having been intentionally broken, as if for the brains inside. Piltdown, Peking man, and Pithecanthropus stand at present at the bottom of the scale of early human remains.

The best known of all extinct species of man is *Homo neanderthalensis,* called the Neanderthal Man because one specimen was found near Neanderthal in Germany. Neanderthal man lived during the last glacial period and was probably present in Europe after modern man of the Cro-Magnon type had appeared. Professor E. A. Hooton, of Harvard University, described him as follows:

> These Neanderthaloids were short, bull-necked, barrel-chested individuals, with many features of the bones of the trunk and of the extremities suggesting an affinity with the great apes less remote than that of modern man. The most striking features were, however, in those of the skull. The long and narrow brain cases were of moderate size or even large, but flattened down and low; their orbits were surmounted with huge bony brow ridges, behind which the forehead retreated in ignominious fashion. The

jaws were protrusive to the verge of snoutiness; the chin receded practically to a vanishing point; the teeth were massive but without canine projection.

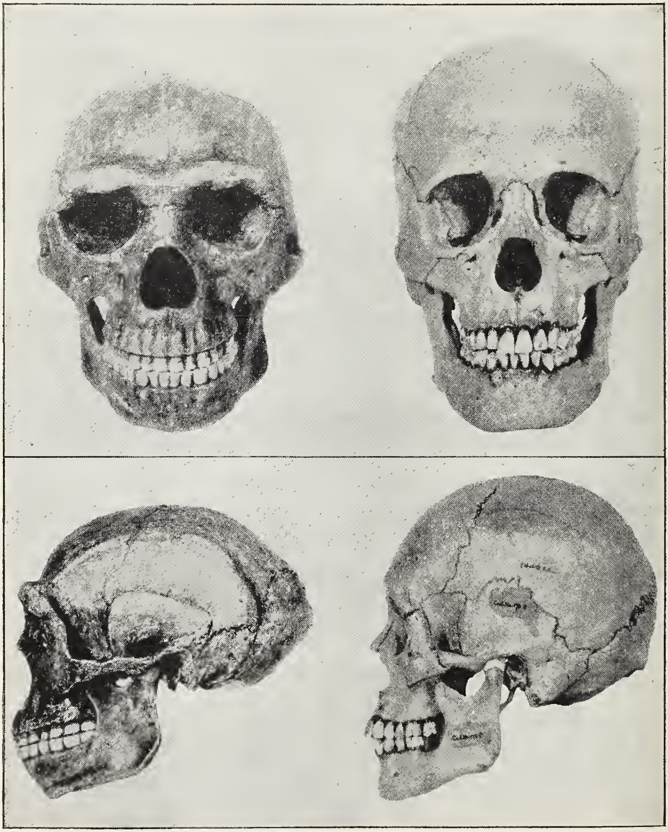


Photo by courtesy of Geological Survey of China and Dr. Franz Weidenreich

The skull of a Peking woman (two views at the left) about 1,000,000 years old was excavated during 1937. At the right are similar views of a modern Chinese. What part of the brain of the modern man is larger?

The Neanderthal man of fifty thousand years ago has unconsciously told us a number of things about himself. He used fire. He took great pains in the making of his stone implements. He had some sort of belief in a life after

© *Field Museum*

Many skeletons of Neanderthal man have been found in Europe and western Asia. He lived in crude caves, hunted with clubs and spears, and buried his dead. The skeletons found in Asia are more like Homo sapiens than those found in Europe.

death, because he buried his dead with implements for their possible adventures in the next world.

The Biological Basis of Human Progress

Our species differs from all other animals in the greater size of the brain. The human brain is more than twice as large as that of the chimpanzee, the most intelligent of the apes. Without such a brain the species Homo sapiens could never have attained its present importance.

How man differs from other social animals. Many animals have a social organization. Some animal communities function in a much more exact and efficient way than any human community. An ants' nest or a beehive is much more efficient as a social organization than any type of human-planned economy. But human social groups have a capacity for continuous progress and for

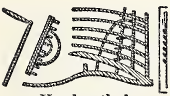
Photo from American Museum of Natural History

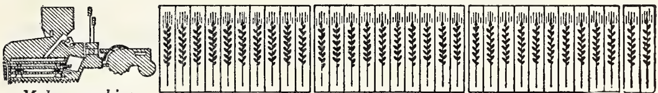
These four reconstructions are made from the bones of different human species: (from right to left) Cro-Magnon man belonging to Homo sapiens; Neanderthal man, *H. neanderthalensis;* Piltdown man, *Eoanthropus Dawsoni;* Java ape-man, *Pithecanthropus erectus.*

increasing complexity of organization not possessed by ants and bees.

That great changes and great progress have been accomplished by man does not require any proving. Men build faster ships, longer bridges, and bigger buildings than ever before. Animals with brains smaller than man's do not often get new ideas and are content to leave things much as they are.

How discoveries have led to human progress. Today, for the most part, advances in the material aspects of our civilization are the work of a relatively small percentage of the population. A few first-rate minds reach out into the unknown and bring back occasional new and significant discoveries. Sometimes it is a chemical process by which an unused substance, such as aluminum, may be produced cheaply. Sometimes it is a physical principle, from which a new industry springs, or a biological principle, such as the germ basis of disease. Only a few





The top drawing shows a cradle for cutting, a rake for collecting, and a flail for beating out the grain. The next shows a horse-drawn reaper, with a separate thrashing machine. The last shows a tractor-drawn machine which carries on all processes in one operation. The symbols at the right represent the amount of grain one man can produce by each method.

Courtesy of National Resources Board

minds make these momentous discoveries. A relatively few practical men, engineers, and health officers put them into practice. The rest of us profit from the discoveries, because it is the easiest thing to do.

Review and Thought Questions

1. How have anthropology and archaeology contributed to our knowledge of the development of man?

2. What contribution to our knowledge of early human history has been made by geologists?

3. What does a paleontologist do?

4. What expressions are commonly used to describe the Neolithic, Palaeolithic, and Eolithic Ages?

5. When Columbus discovered America, in what age were the Europeans living? In what age were the American Indians living at that time?

6. Why is it believed that Homo sapiens is the only species of man that has ever occupied the American continent?

7. How do we know that mastodons lived during the time of Piltdown man?

8. Describe the physical appearance of Neanderthal man.

9. Why do we think that Neanderthal man believed in an existence after death?

10. Scientists have classified some human fossil remains as belonging to different genera than our own Homo. Mention four and tell where such remains have been found.

11. In what respect does man's general social organization differ from that of other social animals?

Activities

1. Construct a chart of three vertical columns showing (*a*) the species of man, (*b*) the cultural epochs, (*c*) a time scale of one million years divided into ten equal parts. Consult some reference text for data.

2. In those parts of the country where arrow heads and other relics may be found, there are other evidences of prehistoric cultures. Study these, if available, or else visit a museum in order to report on the development of implements.

3. How well could you get along if you were lost in the woods and had to find food and shelter as well as discover a trail out? Make a list of the food materials you might find. If it should storm, how could you find shelter and how chart your way out?

4. Make a list of what you think have been the ten most important inventions or discoveries which man has made in his gradual progress from the days of early man.

31. Conservation of Life

In a general way, the fundamental problems of today are like those of the past. The cave man struggled for food and shelter against a hostile environment. The useful devices and implements he invented were vitally important, and their gradual improvement was one of the main factors in his cultural advance. He had various relationships with his fellowmen and with other species, either in competition and strife or in mutually helpful living. You will readily identify in your own life and that of your community these same problems in modern civilization.

There is one present biological problem, however, that is much more serious for us today than it was for our remote ancestors, a problem due to the recent increase of the world's population. Today, nearly all parts of the earth's surface which are suitable for colonization by man have been occupied, and those nations which do not wish to engage in wars of conquest must seek to make better use of the territory which they already possess. In other words, they must study the conservation of their natural resources; they must seek to utilize materials now wasted, and to make new things out of what has never been so used before.

Conservation of Natural Resources

For a long time no one in the United States worried about conservation of our natural resources. Most of the continent was only partly settled and developed. There seemed to be forests in abundance and land for cultivation beyond any conceivable needs. Men even destroyed great

Photo from H. W. Byerly

The greatest remaining supply of lumber in the United States is now in Oregon and Washington, where this forest picture was taken. What a loss when the Atlantic coast must have much of its lumber shipped from three thousand miles away!

tracts of valuable timber in order to plow the soil for corn.

About forty years ago, farsighted men began to recognize that our natural resources were not inexhaustible. It was realized then that the loss of forests meant loss of soils from the cut-over lands, and that another serious consequence was the increasing damage from floods in times of surplus water and from harmfully low water in lakes and streams at other times. It became plain to anyone who would look beyond the immediate present that this country could not go on indefinitely wasting its resources and expect that the conditions of living would continue to advance or even remain at a given level.

Courtesy of Caterpillar Tractor Company

Modern machinery has enabled one man to produce many times the amount of food he could produce a hundred years ago, but it has also helped him to deplete the soil.

Land utilization and conservation. At present the total forest area of the United States is 469,000,000 acres. The plowed land is 413,000,000 acres, and the acreage in pasture land is somewhat greater than that which is plowed.

To maintain our standard of living, an average of over two acres for each of us is needed for agriculture to produce our food supply in the United States. In Germany only one acre is required; in China, half an acre; in Japan, only one quarter of an acre. Since the first World War, Americans have used less meat, more cereal foods, and much more sugar. Figuring a total of 1,400,000 calories per person each year, this amount can be derived from the use of three acres if the food amount is in the form of pork and its products, but it would require eleven acres of crops and over two of pasture if in the form of beef. From cereals the calorie requirement could be met by the use of about three acres. If sugar alone is figured, only one third of an acre would be necessary.

According to a report of the National Resources Board in the 1930's,

> Unquestionably one of the most acute problems of agricultural land use is soil depletion, which in many parts of the country is proceeding with startling rapidity. A careful estimate made for the Land Report indicates that on our crop and pasture land there is an average loss of 322,000,000 tons of organic matter and a net loss of 222,000,000 tons. Over half of this is due to leaching or erosion. It is estimated that the usefulness for farming of 35,000,000 acres has been completely destroyed, that the top soil has been almost completely removed from an additional 125,000,000 acres, and that another 100,000,000 are starting in that direction.

In relation to the importance of forests in the present and in the future program of this country, the Report of the National Resources Board declared: "Before the depression American forests were a source of wood products valued at two billion dollars a year. In mills and in woodworking industries 1,300,000 were normally employed, who received some one and a half billion dollars of wages annually. Forests serve a number of important purposes other than the production of timber, and it is important that these purposes be kept in mind in a broad national program of planned land use."

There is every reason to believe that, with better management of our present forest areas and with the conversion of some millions of acres of worn-out farm land into

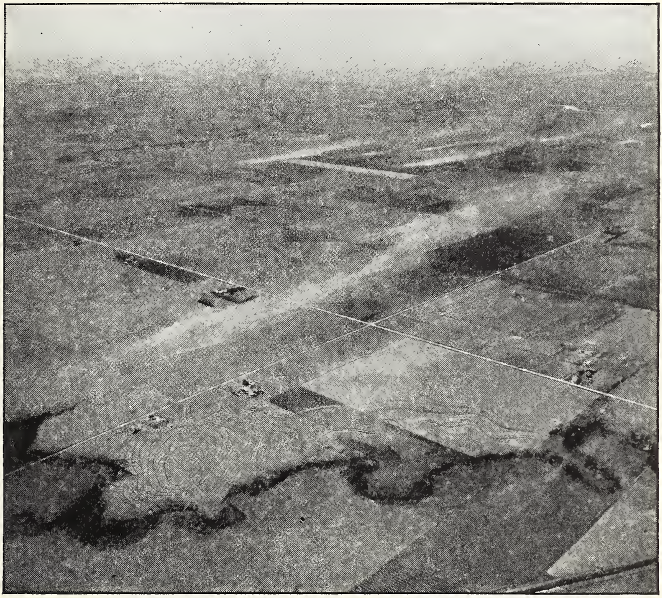


Photo from Aerial Explorations, Inc.

Dust storms in Oklahoma and other parts of the Dust Bowl area, obliging thousands of people to leave their homes, finally awakened us to the damage caused by wind and erosion.

forest areas, we may obtain not only all the lumber and other forest products we need from our own territory, but also derive other no less important benefits.

Water resources and their utilization. With all man's advances in the conquest of nature, the number of inches of rainfall per year is still a primary factor in determining where he can make his home and how he can live.

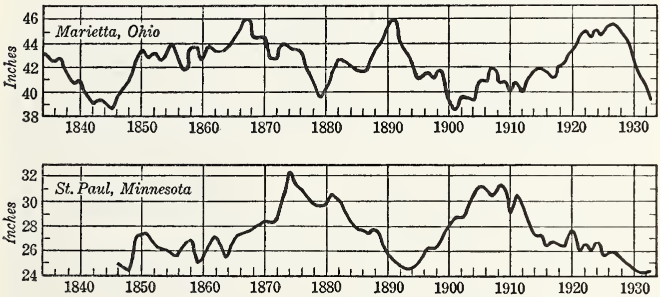
The water resources are closely tied up with land utilization, whether for farm or forest. Sometimes there is

Photo from Wide World

We should have forest land sufficient to raise all the pulpwood we need for paper but we have been importing great quantities from Canada and from Europe.

too much water in a region, and swamps are the result. Their reclamation is a question of drainage. The reclamation of arid regions is accomplished by means of irrigation. Where damages from floods are involved, the areas which suffer chiefly are often far removed from the sources of the floods and have no means of taking measures for their control. The upper tributaries of the Mississippi have long been the sources from which floods and soil erosion spring, whereas the lower reaches of the Mississippi have been the sufferers from floods and unwanted soil.

Rainfall and other precipitation range from a minimum of five inches per year to a maximum, in some localities of the Northwest, of two hundred and fifty inches. As much as fifty feet of snow falls in some regions during



Courtesy of the National Resources Board

The water resources of a country are determined by the amount of rainfall which it receives. Rainfall varies over periods of years, making the conserving of the water supply and the preventing of floods a complex problem.

a single winter. Conservation of this water supply and control of its flow is a complex problem. Reforestation of streams' sources contributes greatly toward the storing of water and the regulation of its flow. Storage dams and reservoirs are recommended for some areas. The building of great dams, such as Boulder Dam and those in the Tennessee Valley project, help prevent floods and at the same time provide a continuous supply of electric power. In other regions such dams also provide water, which can be used for irrigation purposes.

Conservation of wild life. The wild life of our country is another of its important natural resources. Game animals, game fish, fur-bearing animals, and the fish which are taken commercially in inland and in ocean waters are of considerable commercial value. Many kinds of wild life which have no immediate commercial value are of great

Photos from H. E. Ransier, Brooklyn Botanic Garden, and R. C. Benedict

Should beauty in nature be conserved? Green Lake, Jamesville, N. Y., was geologically famous, and was the home of the rarest fern in the country. A great industry wanted the limestone. That ended the beauty, although the fern has been artificially grown and distributed elsewhere.

indirect value in that they help to maintain the balance of nature and destroy harmful insects.

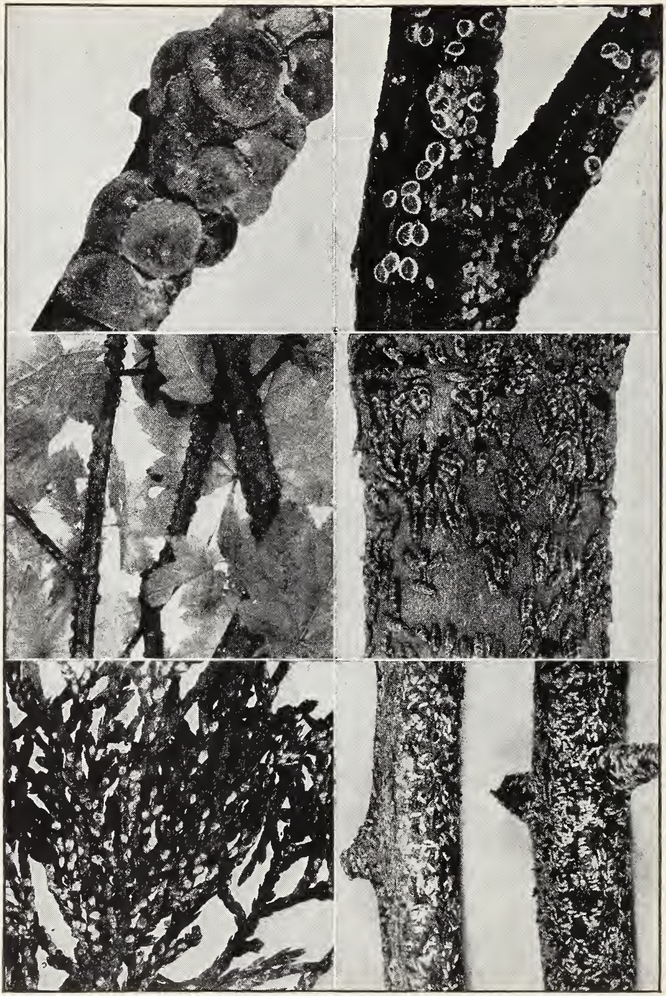
The protection of wild life is the province chiefly of two federal departments, those of Agriculture and of Commerce. In the Department of Agriculture, the Forest Service both directly and indirectly promotes the conservation of many kinds of game animals and birds through its supervision of the National Forests and the National Parks. To the Bureau of Fisheries in the Department of Commerce is especially assigned the study and conservation of the fish and other aquatic life of both our inland and coastal waters.

Conservation of natural beauty. National and state parks have been established to preserve the beauty spots of the country. Federal bird sanctuaries have been set up to maintain safe breeding places for various kinds of migratory fowl. Numerous states have enacted laws protecting particular kinds of wild flowers, not because of any commercial value in the plants protected, but simply to try to preserve from extinction various species in danger of destruction by thoughtless people.

Man's Control of Other Species

Some years ago, the interest of the public was attracted by the reports of an address entitled "Our next war." The speaker was Dr. L. O. Howard, for fifty-three years a servant of our government as a scientific student of insects. The enemies of which he told were the insects which threaten our farm crops, our forests, and our health. From the standpoint of agriculture and forestry, we might add another group of organisms, the fungi, to take their place with insects as serious competitors against man for our agricultural and timber products. The story of these plant-disease agents is not as dramatic as is that of the insects, but its importance is unquestionable.

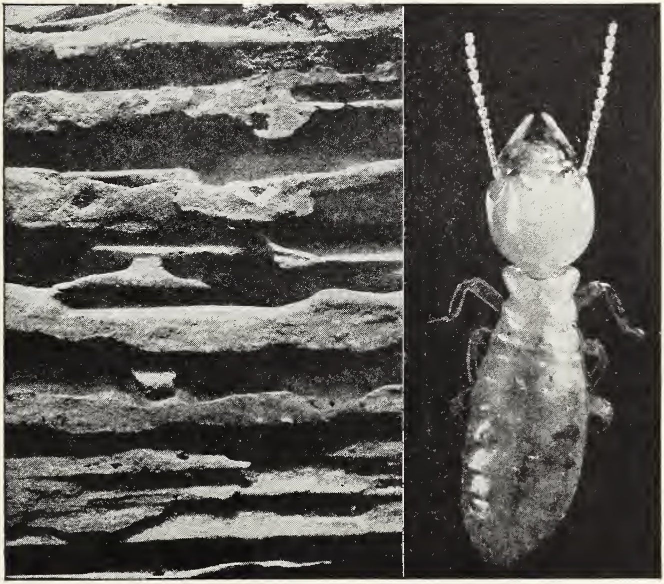
Insects. Among the most formidable of man's competitors for control of the earth's food supply are the insects. Aside from the microscopic forms of living things,



Courtesy of the Davey Tree Expert Co.

Here are six kinds of scale insects which attack woody plants while they are growing: left to right, and down — magnolia scale, European elm scale, terrapin scale, oyster shell scale, juniper scale, euonymus scale.

insects are more numerous than any other group of animals. Moreover, they are likely to continue to cause man all sorts of trouble. They eat his crops, carry diseases, spoil his foods, annoy his domestic animals, destroy his



Photos by Hugh Spencer

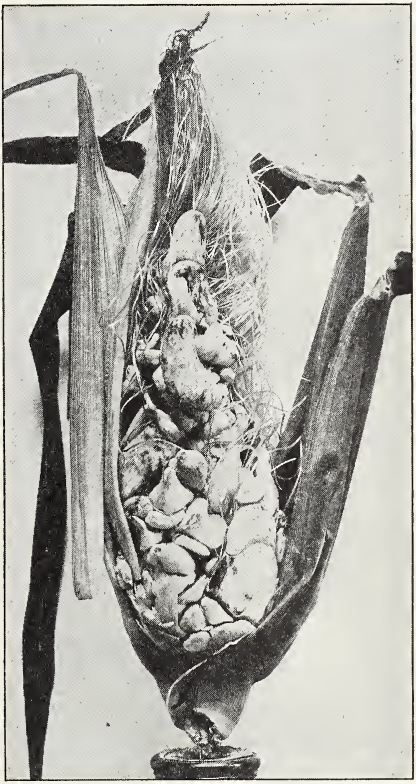
The termite bores into timber and, working unseen, riddles the wood until it no longer offers support. Over a period of years, these insects have spread widely through the country.

rugs and clothing, and sometimes use him for food. However, not all insects are harmful to human welfare. The pollination of many plants depends entirely upon insects. Without insects, most flowering plants would become extinct. The honeybee makes honey and the silkworm silk. A number of insects serve as scavengers, while others are destroyers of harmful insects. Insects also have insect parasites, and these are often useful in controlling certain insect populations.

Each kind of harmful insect presents a special problem. Each must, therefore, be studied carefully to determine at what point in its life history it may be most effectively reached and killed. The introduction of natural enemies is by far the most efficient method of insect control we have today. Chemistry has furnished the gardener with a number of chemicals in various combinations for dusting or spraying plants. The type of insecticide used depends upon the insect's feeding habits and type of body covering. Stomach poisons, usually compounds containing arsenic or fluorine, kill biting insects, such as the striped cucumber beetle, potato beetle, cabbage worm, army worm, and grasshopper. Recently, certain organic poisons, such as derris root, have been found to be more effective than inorganic poisons. Contact poisons clog the air tubes with which insects breathe, and destroy soft-bodied insects having sucking mouth parts. A kerosene emulsion of hard soap, hot water, and kerosene will destroy the common garden plant lice and the San Jose scale. Nicotine solution is another poison, which makes a good insecticide.

Early or late planting of crops may avoid the season when harmful insects are numerous. The bollworm and boll weevil are avoided to great extent by the early planting of cotton. Crop rotation and deep and frequent plowing kill or severely injure harmful insects. Plowing exposes the eggs, larvae, and pupae.

Fungi. It is a rather interesting fact that the disease and decay of plants and their products should be largely the work of fungus plants, while for animals, the disease agents are chiefly bacteria. Something of the importance of these fungus enemies may be gained by the figures for timber damage of insects and fungi. Nine billion board feet of lumber is damaged every year by insects, while three hundred billion board feet are damaged by fungi.



Courtesy of U. S. Dept. of Agriculture

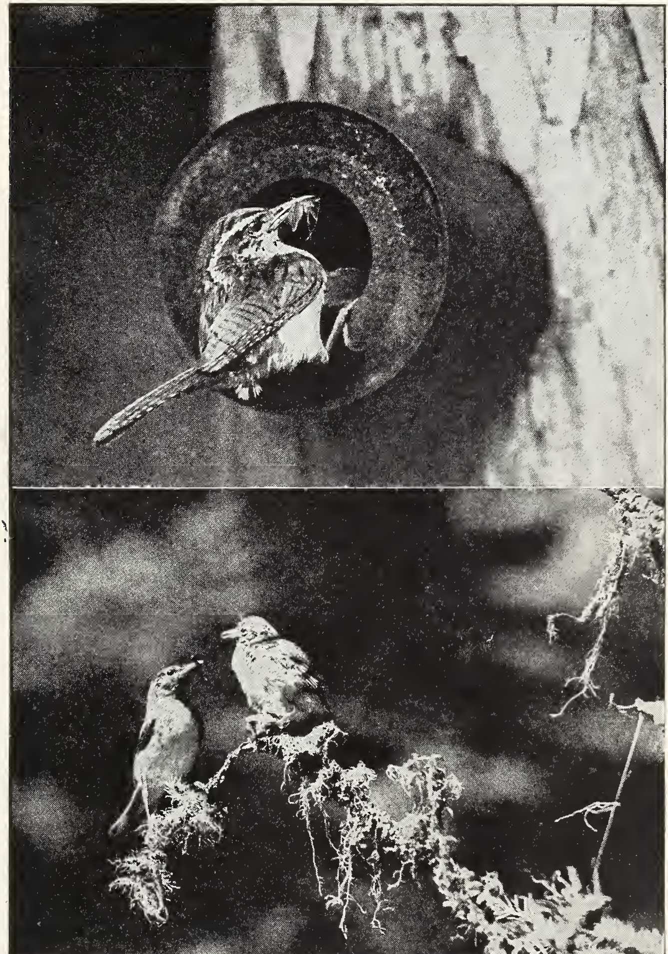
A parasitic smut fungus has invaded this ear of corn, replacing the corn kernels by black smut spores.

Some of our worst fungus pests have been brought from abroad. Once here, some have spread very rapidly. In the summer of 1933 Lindbergh collected samples of these minute organisms from currents of the upper layers of air. The cedar rust of apples, apple scab, blights of chestnut, potatoes, and other crops, smut diseases of cereal crops, leaf-spot diseases, wilts, and root-rot fungi were found in the air as far as 18,000 feet above the ground.

Weeds. Bull thistles, ragweeds, dandelions, tumbleweeds, cockleburs, wild clover, mustard, Jimson weed, wild poppies, and plantain are just a few of the weeds which have spread through the carelessness of man. These weeds invade the fields and steal the plant food, sunshine, and moisture from the cultivated plants. Weed control has become a difficult problem for the farmer, who in recent years has set about discovering the reasons for weed success and the methods which will best prevent their growth and propagation. In this task he receives the help of his state and national departments of agriculture.

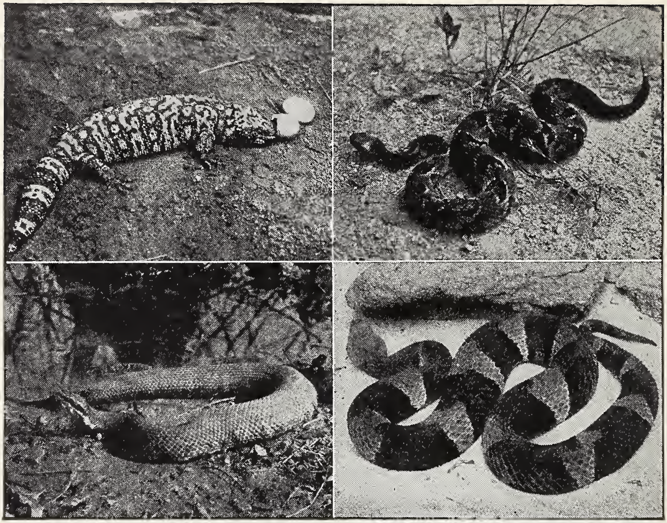
Birds. There is scarcely an insect pest which does not have its own bird enemy. The bobwhite is a constant enemy of the Colorado potato beetle. The severe epidemic of tent caterpillars in 1934–1935 in the state of New York was somewhat held in check by the cedar waxwings and Baltimore orioles. Once the meadow lark was classified as a pest. The stomachs of a large number of these birds were carefully explored and found to contain such harmful insects as grasshoppers, crickets, cutworms, wireworms, ants, wasps, flies, as well as numerous other pests. Woodpeckers were once shot for sport, yet millions of beetles that attack our pines and other trees are eaten by this bird.

The United States Department of Agriculture has investigated the feeding habits of the birds whose reputations were not too good. By careful scientific studies it was found that a surprising number of these birds killed injurious insects. The cuckoo, house wren, bank swallow, and barn swallow subsist entirely on an insect diet. The bluebird and kingbird, which eat small quantities of fruit, eat insects for the greater part of their diet. Other birds, such as the mourning dove and the bobwhite, destroy weed seeds. Most birds should be protected as valuable citizens, greatly assisting man in the control of less desirable species.



Photos from the National Association of Audubon Societies

These are valuable citizens: a California wren about to feed her young (above); a bay-breasted warbler of the eastern states, with a meal for its offspring.



Photos from New York Zoological Society

Although most reptiles are beneficial to man, poisonous reptiles, chiefly snakes, cause about 150 deaths in the United States every year. Here are four of the five kinds of poisonous reptiles of the country: (top left) the Gila monster, our only poisonous lizard; (top right) rattlesnake, of which there are several species; (bottom, left) water moccasin, of the southern states; (bottom, right) copperhead. The fifth is the coral snake, of the southern states.

Reptiles. Reptiles as a group have gained an unfortunate reputation because of the habits of some species. According to mistaken belief, all snakes are harmful and should be exterminated. Children are taught to fear snakes, although the reptile family includes many harmless species of snakes.

The reptiles do less damage, comparatively, than do the other classes of animals, and most of them are beneficial to man. The black snake and the milk snake destroy rats and mice, while other harmless snakes feed upon insects and garden slugs.

Mammals. When man emerged from the primitive stage, he was compelled to kill off his largest rivals, such as the tiger, wolf, and wildcat. They reduced his food supply; therefore, man diminished their numbers. But man has also reduced the numbers of smaller mammals which do little harm and a great deal of good. Among these are the useful insect-eating groups, such as the bats, shrews, and moles. Squirrels—even the red squirrel whose reputation has been rather sadly maligned—probably do more good than harm. Scale insects and tree insects are eaten by tree-inhabiting squirrels. Many injurious insects, as cutworms, wireworms, and grasshoppers, become food for the western ground squirrels. The armadillo of Texas and Louisiana is another great feeder on such insects as white grubs, caterpillars, and ants. Skunks destroy army worms, tobacco worms, white grubs, and grasshoppers. Some time ago hop growers in New York state requested the legislature to pass a law protecting the common skunk, because it was the most effective enemy of the hop grub.

Health Conservation

Conservation of human health is first of all the concern of the individual. Each of us has some choice between actions which may impair health and those which tend to maintain it, the choice of the right food in the right amount, and the chance to avoid injurious habits.

In many ways health is also the responsibility of the community. Individuals have no right to disregard the welfare of their fellows, either intentionally or carelessly. To prevent such disregard, we have laws requiring food inspection, health inspection of food handlers, the reporting of contagious diseases, quarantine regulations, compulsory vaccination against smallpox, and many other regulations protecting us from the spread of disease.

Scientific education and research are making a new era of health conservation possible. Medical science has

William Harvey, a famous physician of Shakespeare's time, refused to accept what men had believed for over a thousand years. Through simple tests and calculations he discovered that blood circulates through the body.

been the study from which many other sciences have developed. Most doctors of the past, as of today, have been practical men, whose days were so taken up with the care of the sick that they had little or no time for original investigation. But when men trained as physicians deserted their practical work to devote all their time to the study of plants or animals or in the field of chemistry, scientific knowledge grew rapidly. The real founders of modern medicine are the biologists and chemists of fifty to one hundred years ago, some of whom have already been mentioned, such as Schleiden, Schwann, and Schultze, who laid the foundations for our knowledge of the structure of our bodies. Virchow is counted as the founder of the science of *pathology,* the study of disease. Pasteur laid the basis for our understanding of the role germs play in human existence, and Lister applied Pasteur's findings to the field of surgery. Koch founded bacteriology by developing many of the technical methods necessary for the study of bacteria. Ehrlich contributed greatly to the advance of our knowledge of *immunity* to diseases. Claude Bernard in the same period placed the study of human physiology upon an experimental basis.

Causes of disease. Ill health may come to us from many different sources and in many different forms, but all can be reduced to a fairly simple classification. First of all, our bodies are subject to harm from definite outside agencies, from disease germs or infection, from injuries due to accidents, from harmful factors in the environment, such as industrial poisons, or such special poisons as pollen in hay fever. Secondly, sickness may result from some disturbance of bodily function or breakdown of an organ or tissue of the body, as in heart disease, kidney disease, endocrine disturbance, and illness due to improper diet or from some defect with which a person may be born. Thirdly, there are not a few sicknesses for which no cause can yet be ascribed; the physician may have a definite name for the disease and even a successful method of treatment, but may have no way of knowing what starts the particular sickness. The following table classifies the causes of 1,682 known diseases. It is interest-

A Classification of Diseases on the Basis of Cause [1]

	Total Diseases		Disease Type
EXTERNAL			
I. Living agents			
Bacteria	278		Infections
Animal parasites	207		Infestations
Animal parasites (protozoa)	70		Infections
Fungi	35		Infections
Filterable viruses	30		Infections
Rickettsia	5		Infections
Probably living but exact nature undetermined	63		Infections
Living agents alternating with nonliving causes	54		
Total	742	42.7%	
II. Nonliving agents			
Physical			
Mechanical	108		
Heat, light, and electricity	21		
Chemical			
Deficiencies	9		Avitaminoses
Poisons	57		Intoxications
Protein	9		Allergies
Undetermined congenital	120		Congenital diseases
Nonliving alternating with living	54		
Total	378	22.3%	
INTERNAL			
III. Unknown agents			
	41		Hereditary diseases
	18		Endocrine diseases
	3		Metabolic diseases
	33		Organic degenerative
	512		Unclassified: tumors, many mental and nervous diseases, blood diseases.
Total	607	35%	

[1] Dr. Frederick P. Gay, *Agents of Disease and Host Resistance*, Charles C. Thomas, Springfield, Illinois.

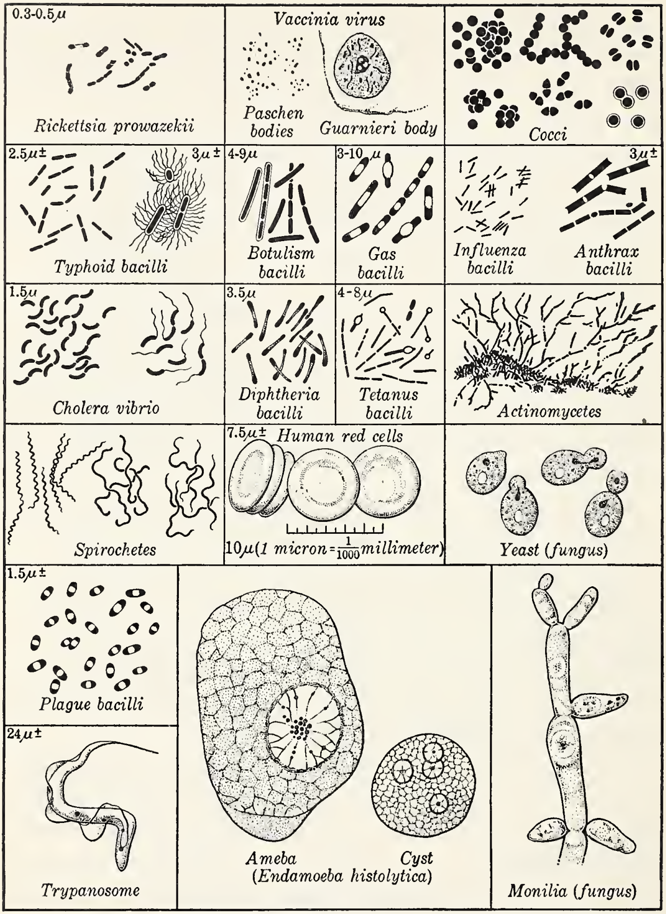
ing to note that of these, 742 are known to be caused by living agents. It is probable that many of the 607 diseases whose causes have not yet been discovered are due to living agents also.

The preceding table gives a broad view of the whole field but leaves us in the dark as to the specific cause of common diseases, some of which we may have had. Let us identify some of the agents listed and the diseases associated with them.

Living agents. Bacteria are the smallest cellular organisms, and are the living agents responsible for many common diseases. But, contrary to popular belief, not all diseases come from bacterial germs. Fungi, another type of plant, cause such diseases as ringworm, impetigo, and "athlete's foot."

Rickettsia are a type of minute granular bodies which have been recognized rather recently. They appear to be rather wide-spread as parasites in insects, but only five of them have been identified in connection with human disease, including trench fever, typhus, and spotted fever. Rickettsia are found inside the cells, thus differing from bacteria. In some respects they are intermediate between bacteria and filterable viruses.

The filterable viruses cause many rather common diseases, such as smallpox, infantile paralysis, common colds, chicken pox, cold sores, common warts, yellow fever, rabies, and parrot fever. In the case of most of the virus diseases, minute bodies have been recognized in the cells of the sick organisms. It is uncertain whether these bodies represent the disease organism or are products of the infected cells. Virus diseases are known among plants, and in 1936 Dr. Stanley of the Rockefeller Institute at Princeton reported the extraction of the virus of a tobacco

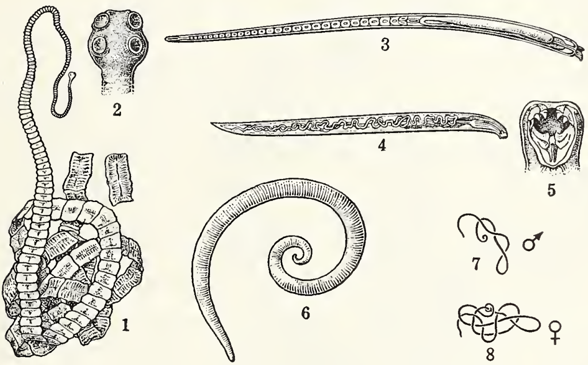


After Gay and associates, Agents of Disease and Host Resistance. Courtesy of Charles C. Thomas, Publisher

Here you can compare the general forms and sizes of disease germs, as they appear under the microscope, with those of other microscopic organisms. Note how sizes are indicated.

disease in the form of a crystal. Since then, a co-worker has identified two animal viruses as crystals.

Among the animal parasites are the protozoa, causing malaria of several types, amebic dysentery, a very serious

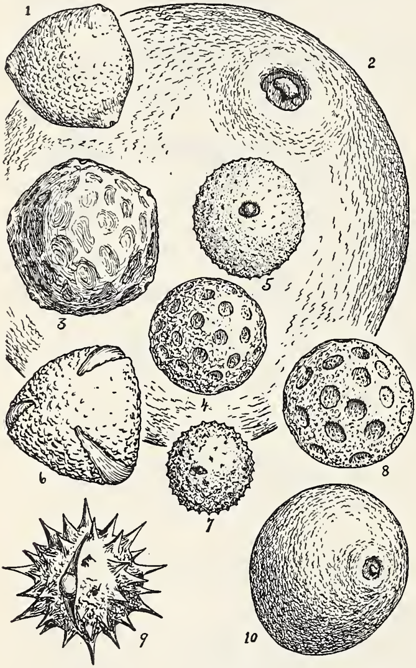


Widespread diseases are caused by these animal agents: (1) Beef tapeworm, (2) head of beef tapeworm, (3) pork tapeworm, (4) hookworm, (5) head of hookworm, (6) common roundworm, (7)–(8) filaria bancrofti-microfilaria, lymphangitis.

social disease which is prevalent all over the world, and a number of tropical diseases.

The other group of animal disease agents includes representatives of several phyla: flatworms, such as tapeworm and liver flukes; and roundworms, of which the hookworm and porkworm are the most serious. It is estimated that 23 per cent of our population harbor the hookworm, and a recent report states that porkworm infection is equally widespread.

Animal disease agents also include all types of biting and sucking insects, mosquitoes, scorpions, a few spiders, like the black widow and the tarantula, and the many kinds of stinging insects, together with poisonous snakes. We do not ordinarily think of insect bites and stings as of serious consequence but under some circumstances they may be.



Courtesy of R. P. Wodehouse

The pollen grains of these plants, most of which are wind-pollinated, and likely to cause hay fever are shown much enlarged: (1) white birch, (2) corn, (3) elm, (4) western water hemp, (5) cocklebur, (6) oak, (7), short ragweed, (8) Russian thistle, (9) sunflower, and (10) timothy.

Nonliving Agents. Among the diseases due to nonliving agents are the so-called deficiency diseases. These result from the lack of certain substances in the diet, particularly vitamins. Examples are scurvy, beriberi, ophthalmia, and pellagra. Alcoholism, lead poisoning, carbon-monoxide poisoning, mercury poisoning, and silicosis are other diseases caused by nonliving agents. Diseases classified as allergies are often caused by plant pollens, but many other substances may produce irritation. Thus some people are made sick by cats, some by horses, some by feathers of some particular kind. In such cases the poisonous agents are bits of the hair or feathers, or dandruff of the various animals.

Functional and degenerative diseases. For two thirds of the diseases listed in the chart on page 592, that is, for about eleven hundred different kinds of sickness, there is no question that the causes are external agents of one sort or another. Of the remaining six hundred to which no definite agent can be ascribed, many are among the most serious kinds of sickness and death: heart trouble, kidney disease, endocrine disturbances, diabetes, and cancer. Except for the last mentioned, these diseases represent primarily the failure of some organs or systems of the body. They are sometimes referred to as diseases of "organic degeneration." Most of them probably come as the sequels of infectious diseases. For example, it is well known that influenza, even in mild form, may leave the patient with subsequent heart trouble. Measles seems to lead to other difficulties; similarly scarlet fever, typhoid, and a whole series of other diseases may have serious aftermaths.

Transmission of disease. The diseases which afflict mankind are, with a few exceptions, peculiar to man. While it is possible to induce a variety of human diseases in lower animals by experimental means, few occur naturally. Indeed, it is difficult to find any experimental animal which can be used in the study of some of our communicable diseases.

There are four chief ways in which diseases are spread: (1) direct personal contact; (2) indirect contact; (3) human carriers; (4) insect vectors. These groups are not completely distinct, but are convenient as a basis for discussion. In the conservation of human health, knowledge of the ways by which germs are conveyed is of major importance, almost more important than a knowledge of the exact cause of the disease.

Direct contact. In this group are placed all those diseases where transmission occurs chiefly as a result of the proximity of a sick person and one who is well. Some-

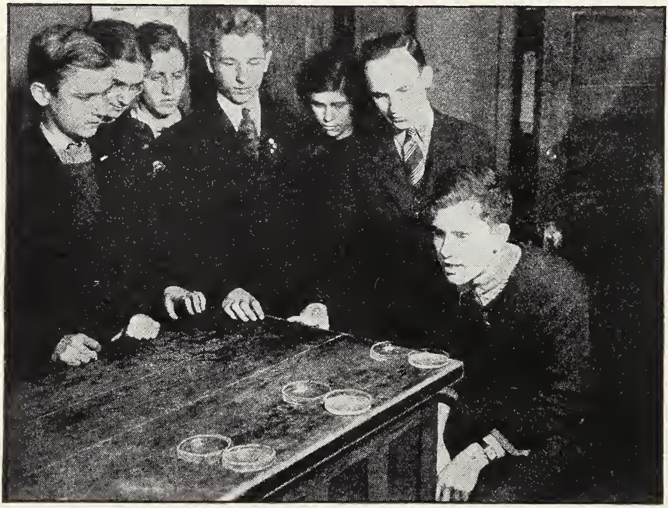


Photo by A. M. Burnham

How far does a cough or a sneeze throw germs? These students are finding out by catching the bacteria in open petri dishes containing a culture medium.

times the contact is actual, as in a hand shake or a kiss; sometimes there is no direct physical contact, but the well person is near enough so that the coughing, sneezing, or even speaking of the sick person sprays droplets of liquid into the face of the well person. There would be included also the somewhat more remote contact with things which have been contaminated by the hands or other parts of the sick person's body.

The first method of mouth and nose spray is the means by which all the so-called respiratory diseases are chiefly transmitted: colds, pneumonia, scarlet fever, tuberculosis, influenza, bronchitis, diphtheria, measles, mumps, whooping cough, cerebrospinal meningitis. These diseases have sometimes been termed "air-borne," but there is very little danger if enough air separates you from the one who is sick. Most of these infections are easily killed by heat, by drying, and by sunlight. It has been noted that various oceanic islands, and even the Arctic regions, had few, if any, of these diseases until they were visited by white men.

Direct physical contact through the skin spreads a smaller number of diseases; smallpox, chickenpox, and skin infections being the most significant. The third type of contact may be responsible for some of the above diseases, but it is particularly the means by which diseases of the intestinal tract may be carried. If hands or clothing soiled by digestive discharges later come into contact with one's mouth, such diseases as typhoid and cholera may readily be conveyed.

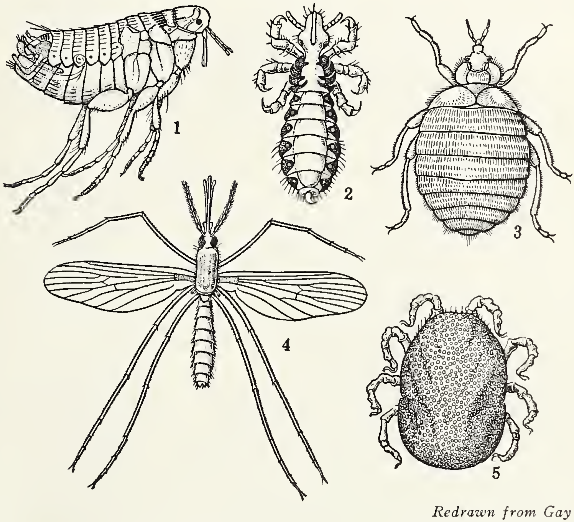
Courtesy of Brooklyn Botanic Garden

This petri-dish culture of germs shows numerous colonies of bacteria, and two or three molds. The culture medium is a seaweed product, agar.

Indirect contact. In this group are included transfers, where the sick person may have been at some considerable distance. Some intermediate means of travel is necessary, such as water, food, or clothing. Anthrax, a disease of sheep and other lower animals, has spores which are very tenacious of life, and which may cling to wool or bristles through a long route of handling until a chance for infection occurs. Shaving brush anthrax occurred a number of times a few years ago, and resulted in more careful regulation of toilet articles. Diseases of the alimentary canal are often water-borne or food-borne. Cholera and typhoid, after leaving the body of a sick person, or a carrier, may live for long periods in sewage, and from this may find their way into water supplies, into milk, through salt water into oysters and clams, and even upon some food plants, such as lettuce.

Carriers. Carriers are people who harbor disease germs without showing any symptoms of the disease. They may be naturally immune people who have chanced to receive the infection, or, more likely, they may be people who have recovered from an infection without getting rid of the bacteria. Ordinarily, following a sickness, the recovered person will eventually get rid of all the germs. There are, however, some people who remain carriers throughout their whole lives. People convalescing from an illness are likely to be temporary carriers. Among the most dangerous carriers are those who have so light a case that it is not recognized, or whose symptoms have not reached a recognizable stage. It is believed that for every recognized case of infantile paralysis, there are others so mild that the disease is never identified, and this is true for many sicknesses. It is for such conditions that boards of health follow up typhoid and paratyphoid, after the person is practically well, with several tests to determine whether typhoid germs are still being discharged.

Vectors. A vector is some kind of lower animal which regularly carries the germs of human disease, and is responsible for its transmission from one person to another. Vectors are insects chiefly, and a few of the spider group of blood-sucking parasites, the mites and ticks.



These vectors are dangerous: (1) Rat flea, (2) head louse, (3) bedbug, (4) mosquito, (5) tick.

Certain vectors, or passive carriers, such as flies and cockroaches, have been and are still extremely important in the transfer of some of the intestinal diseases. In the case of the biting insects and other similar parasites, the disease germ often has to pass through two cycles of development, one in man and one in the other host. This is the case with the malarial protozoon which undergoes sexual reproduction in the mosquito and sporulation in human blood corpuscles. In some other diseases, there is no known change in the two hosts. Three animals enter into the story with typhus, plague, and some other diseases. With plague it is the rat, and the insect is the rat flea, which ordinarily does not bother man except when

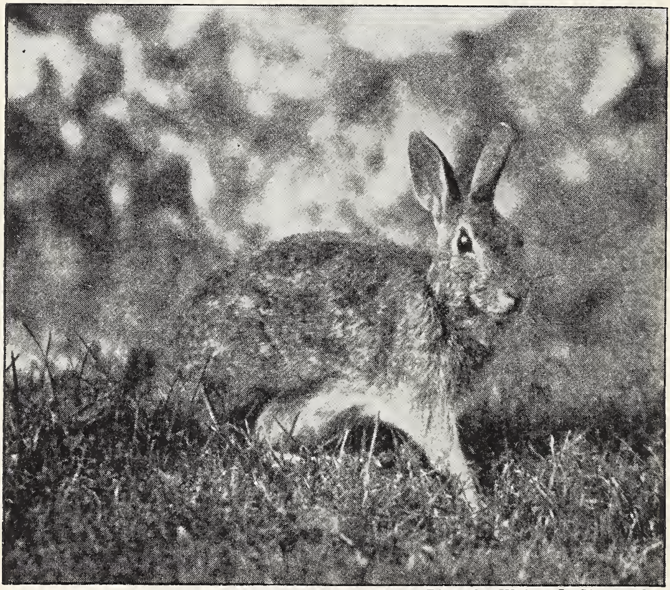


Photo by Walter J. Shoonmaker

Though this rabbit seems healthy, it may carry the disease tularemia.

the plague kills the rat host and the flea can find nothing better than man. It seems to prefer a number of smaller rodents, and has been found in certain ground squirrels in the Rocky Mountain region.

Insect vectors are not particular what kind of disease germ they transmit. In the tropics, mosquitoes transmit a worm parasite which causes a serious human disease.

Yellow fever, a virus disease, is carried by another kind of mosquito. The African sleeping sickness, a flagellate germ, is carried by a fly. Plague and tularemia are bacterial. Typhus or Rocky Mountain spotted fever and trench fever are caused by Rickettsia. It is an interesting point that in most of these diseases, the insect suffers no damage. Perhaps the only one fatally stricken is the body louse when it sucks up a meal infected with the typhus germ and dies in eight days.

Dr. Hans Zinsser, a leading authority on bacteriology, wrote a stimulating book which points out the bearing of various diseases on human history. He refers to the great plagues of the Middle Ages when many millions were killed in a single epidemic, and to the great losses caused by typhus in many of Europe's wars. He points out the difficulty involved in dealing with diseases like these and some others in which the infection may be held indefinitely in rodent hosts, waiting only an opportune time to break forth and attack man. Rodents have the fleas and lice, and the latter may have the germs, and conditions such as wars bring about, where men live with rats and fleas and typhus germs, start epidemics. Dr. Zinsser concludes one of his chapters with this interesting paragraph.

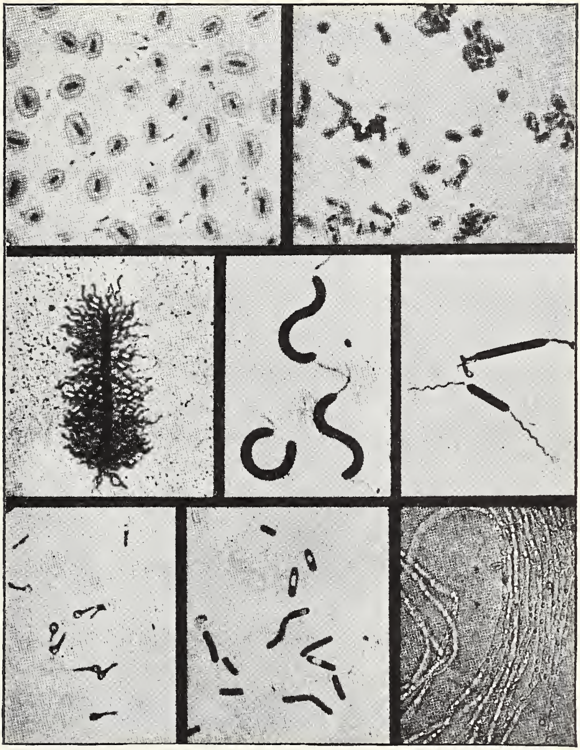
But however secure and well regulated civilized life may become, bacteria, protozoa, viruses, infected fleas, lice, ticks, mosquitoes, and bedbugs will always lurk in the shadows, ready to pounce when neglect, poverty, famine, or war lets down the defences. And even in normal times they prey on the weak, the very young, and the very old, living along with us, in mysterious obscurity waiting their opportunities. About the only genuine sporting proposition that remains unimpaired by the relentless domestication of a once free-living human species is the war against the ferocious little fellow creatures, which lurk in the dark corners and stalk us in the bodies of rats, mice, and all kinds of domestic animals; which fly and crawl with the insects, and waylay us in our food and drink.[1]

Our defense against disease. Control of the living agents of disease depends both upon an understanding of the behavior of these agents and of the reactions of the individual when its tissues are invaded by them.

Diseases caused by living organisms are classified as *communicable,* that is, transferable from one person to another. The transfer and establishment in a new host is called the *infection,* and the word *infectious* is practically a synonym for "communicable." As has been noted, there are many different kinds of organisms capable of infecting a human host and living on or in its body. Bacteria are the commonest and cause the largest number of diseases. Most of our knowledge of infection and resistance has been gained by studying bacterial diseases. We also know that there are many points of similarity between bacteria and other types of infecting agents, particularly the viruses and Rickettsia.

Only a small proportion of the total number of different kinds of bacteria and an even smaller proportion of the protozoa are ever parasitic on the human body. Moreover, not all kinds of parasitic bacteria or protozoa are disease-causing organisms. Our bodies are the homes of a variety of different microorganisms, which seem to live on or in us without causing us the slightest inconvenience. The mouth and other parts of the food canal furnish a suitable environment for a regular series of harmless parasitic bacteria and protozoa.

[1] Dr. Hans Zinsser, *Rats, Lice, and History,* Little, Brown & Company, Boston.



From Park and Williams

Here you see photographs of disease-producing bacteria. The two at the top are the rod and the coccus types, in capsules, as they sometimes grow. The middle three show bacteria with flagella; at left a large bacillus; middle, spirilla; and right, bacilli with end flagella. In the bottom row are shown spore-forming bacteria of three types.

Organisms which cause disease in some people may be harmless parasites to others, and even harmless to almost everyone under certain conditions. Most of us probably harbor in our bodies at all times a whole collection of

Photo from U. S. Dept. of Agriculture, Leaflet 95

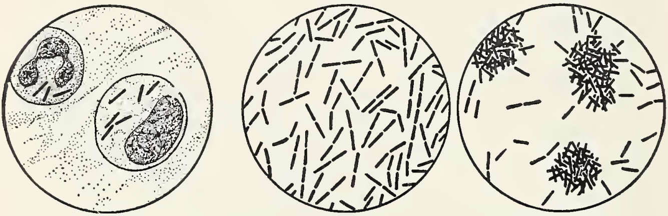
The pollen of these two species of ragweed: tall ragweed (A) and low ragweed (B), causes hay fever in some individuals. To other people it is harmless. The effect of the pollen is supposed to be due to the presence of certain proteins which are irritating to some people.

disease-causing bacteria; those of tuberculosis, pneumonia, pus infection, and others. Their harmlessness may be due to some higher degree of resistance on our part, or to a weaker condition of the particular germs. As a final step in our gradual focusing of attention on the exact basis of a disease, we find that germs vary in their capacity for invading human hosts and in their capacity for harming the host after entrance.

Biologically, an infectious disease is a reaction of the body to the growth of some harmful germ. It is a harmful condition, due either to the direct action of the infecting agent or to poisonous products produced by it. Some germs destroy body cells, as do the malarial protozoon and the tuberculosis bacillus. Others interfere with the bodily function by clogging its passages. Nearly all kinds produce poisons, called *toxins.*

Protoplasm of all sorts has the capacity to react in a defensive way to foreign and harmful substances. In resisting disease, all cells probably take some part, but certain cells are especially adapted to do so. The first practical development in the way of artificially inducing resistance to disease began with the Chinese, perhaps thousands of years ago. They were the first to induce resistance to smallpox by inoculating healthy people with material from a sick person. Then about 1800 Jenner showed that the less dangerous virus of cowpox could be used to produce immunity against smallpox without the danger of getting the real disease. But it was not until the cellular basis of infectious agents was understood that our present understanding of the nature of infection and resistance began to grow. This was less than one hundred years ago, and much still remains to be discovered.

The body is like a beleaguered city, surrounded on all sides by multitudes of enemies, some of which are constantly pressing for entrance. To meet these, there are four different lines of defense. First, the external surfaces and the membrane linings of air and food passages stand as walls against invasion. The skin is particularly strong in its resistance; very few disease germs are able to penetrate the unbroken skin. The mucous membranes are also



Phagocytosis *Check* *Agglutination*

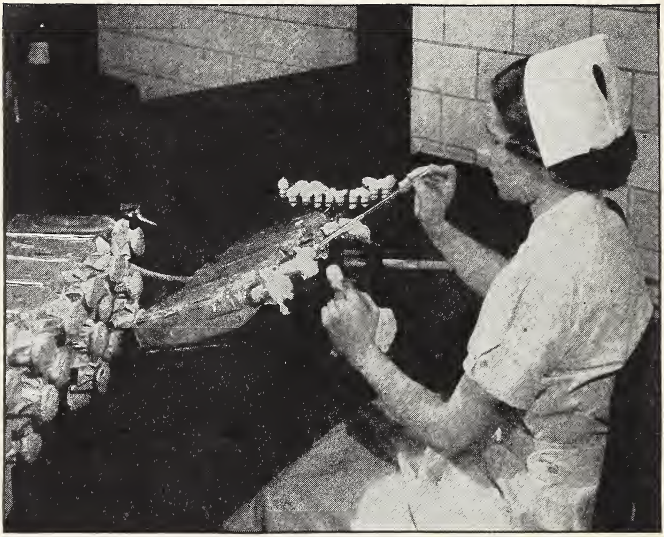
The white corpuscles, or phagocytes (left), destroy bacteria by engulfing them. Antibodies called agglutinins (right) act against disease germs in the blood by drawing them into little groups. Bacteria that may be present in the blood are shown in the center.

resistant, but with their moisture and warmth they furnish more favorable lodging places than does the dry skin. Second, the secretions which are poured out on skin and especially in the various parts of the alimentary canal are definitely antiseptic: saliva, tears, gastric juice with its hydrochloric acid, and perspiration with its salt. Third, if germs have gained entrance, they are met by positive action by certain kinds of body cells. The white blood corpuscles are able to engulf bacteria as an ameba engulfs a food particle, and cells of the spleen and lymph-nodes can also destroy germs. The fourth line of defense consists of chemical agents, the *antibodies*, some of which may act directly against the bacterial cells, and others against the poisons produced by the bacteria, the toxins.

Immunity is the capacity to resist a disease: to remain entirely well, or to show only a mild case of the infection. The opposite of complete immunity would be complete susceptibility. For some diseases, like measles and others, there probably exists no complete immunity. For others, children may at first be very susceptible, but gain almost complete immunity as they grow older. *Natural immunity* is that possessed by people who have never had the disease concerned. *Acquired immunity* is gained usually as a result of having some disease, but it may also be gained as a result of some artificial inoculation intended to create immunity.

From our discussion of the various ways in which the body fights disease, we may gain an appreciation of the basis of an immune condition. A person might be immune because of a high development of any of the separate means of disease resistance. When immunity is acquired following sickness, we know that in some cases a surplus of antitoxin remains in the blood, which protects the body although it does not destroy the bacteria. Such people are living cultures of dangerous bacteria, threatening the welfare of all with whom they come in contact, although perfectly well themselves. The most notorious case of disease *carrier,* as such a person is called, was known as "Typhoid Mary." Her employment as cook brought typhoid to scores of people, and even death to some. Other people become immune because their blood develops and retains a large amount of *lysin,* the presence of which prevents invading bacteria from getting a start.

Two kinds of acquired immunity are recognized: *active* immunity, which is gained when the body develops its own antitoxins, or other protective substance; and *passive* immunity, when the antibodies of some other person or from a protected animal are injected into the body. The best-known type of passive immunity is brought about to protect against diphtheria, or to cure a case of it. Serum of a horse which has been actively immunized against diphtheria is injected into the blood stream, and its antitoxins

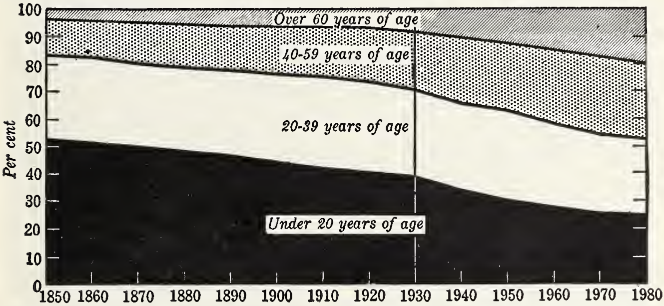


Courtesy of Eli Lilly and Company

This laboratory worker is preparing vaccines by inoculating a culture medium with bacteria.

neutralize the toxins of diphtheria. Quite recently, a good deal of use has been made of various kinds of *immune serums,* prepared from human blood contributed by persons who have recovered from the disease in question. Some diseases seem never to cause any lasting immunity; a person may suffer from repeated infections of pneumonia, influenza, tetanus, tuberculosis, pus-forming bacteria, and others. But second attacks of the following diseases rarely or never occur: typhoid, cholera, smallpox, yellow fever, chickenpox, typhus, mumps, scarlet fever, infantile paralysis, plague.

Vaccination as a means of developing immunity to smallpox has been mentioned. This is an example of what is called *protective inoculation,* which includes all sorts of inoculations for the purpose of causing the body



Courtesy of National Resources Board

Notice the changing proportion of different age groups in our population. What has brought about this change?

to acquire immunity. The word *vaccination* literally refers to the cow as a source of the inoculating material, but vaccination is often used today as a synonym of preventive inoculation. The material inoculated varies with the disease; for diphtheria, it is a toxin derivative; for typhoid, it is a mass of dead typhoid bacteria. Immunity from such inoculation is not always as lasting as that produced by the disease itself. Typhoid inoculation protects for perhaps three years, but recovery from typhoid ordinarily means permanent protection.

Every year in this country, hundreds of thousands die, whose deaths could have been prevented if they had taken advantage of the fruits of scientific discovery. Progress in health is probably the greatest achievement of the human race. But this progress has been needlessly slow. The average "man in the street" today lives a reasonably healthy life, not because he has considered and adopted all the important findings of medical science, but because of the governmental adoption of many applications of science. We may be sure that scientific research will continue to push forward and to discover for our benefit much that is still unknown. If we could be as sure that gradually the average man throughout the world would consider, appreciate, and apply scientific principles individually as well as collectively, we could feel confident that humanity would advance more rapidly than it has ever done before.

Review and Thought Questions

1. Contrast the problems of civilized and of primitive man.
2. Why are forests important in a national program of land use?
3. What connection is there between water, soil, and forest conservation?
4. Why are co-operative agreements among different states necessary in fish conservation?
5. There are state and national efforts to protect wild life for aesthetic (artistic beauty) purposes. Name some plants and animals so protected.
6. In what respects are some insects beneficial to man?
7. Describe three methods for the control of undesirable insects.
8. Ringworm and athlete's foot are fungus diseases. What other damage is caused by fungi?
9. Describe one method used to determine whether bird species are useful or harmful to man's interests.

Photo by Walter J. Schoonmaker

How do our state game laws conserve our natural resources?

10. Safety education is being introduced in school systems throughout this country. Justify this movement.

11. Why is it necessary for the community to assume responsibility for human health?

12. How did the study of medicine lead to the development of other natural sciences?

13. Name and describe four chief ways in which diseases are spread.

14. Survey briefly our resources for combating disease and name five diseases largely conquered during the past twenty-five years.

15. Microorganisms may cause harm to our tissues or to the processes of the body. Explain.

16. Describe four different lines of defense in the body for resisting disease. Contrast natural and acquired immunity.

17. Research and education are both essential to the progress of mankind. Justify this statement.

Activities

1. Compare the population per square mile of your state with that of five other states. In which state is the population

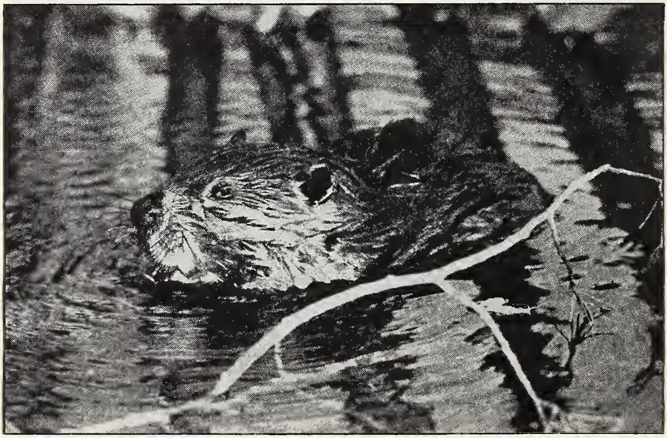


Photo by Walter J. Schoonmaker

The beaver population is now increasing. Explain.

densest, and in which is it sparsest? What influence does each of the following factors have on the density of population: (*a*) amount of rainfall, (*b*) percentage of arable land, (*c*) temperature, (*d*) mountains?

2. Find out what proportion of our population is classified as agricultural. Compare this percentage with the similar figures for Germany, Japan, and China. Can you account for the larger number of people per acre in some countries?

3. Report on a program for soil conservation, reforestation, flood control, or some other project by which your state or locality is preserving its natural resources.

4. Certain occupations are rated as much more hazardous than others. Look up five of the most hazardous occupations and tell why each is dangerous.

5. Look up one or more of the following and report on the studies made concerning them: tularemia; psittacosis; Rocky Mountain spotted fever; hookworm; yellow fever.

6. Make a list of the poisonous snakes and other poisonous animals of your neighborhood and tell how each kind may be recognized.

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Appendix

Principal Groups of Plants and Animals

I. Plant Kingdom

Phylum I

Schizophyta (single cells or at most threads, only asexual reproduction, no nuclei, no plastids)

1. Bacteria (no chlorophyll, the smallest living things, agents of most animal diseases, causes of decay of animal bodies; many useful in agriculture, soil building, industries)
2. Blue-green Algae (have chlorophyll and a blue-green pigment; in fresh and salt water, hot springs, soil)

Phylum II

Thallophyta (no roots, stems, leaves; no conducting system, no seeds; mostly water habitat; chlorophyll when present in special cytoplasmic bodies, or plastids; nuclei; from one-celled microscopic forms to giant kelps, 500 feet long; without roots, stems, leaves, or vascular tissue; reproduce by spores)

1. Algae (with chlorophyll, and in some groups, with a second pigment; brown algae, red algae, green algae, with chlorophyll alone, single cells; filaments, sheets of cells, larger bodies. Nearly all aquatic. Include rockweed, kelps, diatoms, etc.)
2. Fungi (without chlorophyll, therefore parasitic or saprophytic; agents of most plant diseases; sometimes one-celled, as in yeast, usually filamentous, *i.e.*, composed of hyphae, sometimes forming solid fruiting structures, as do mushrooms)

PHYLUM III

BRYOPHYTA (mostly land plants; without true leaves, stems, roots, vascular tissue, or seeds. Reproduce in two generations: (*a*) sporophyte, the ordinary moss plant, bearing one-celled spores, and (*b*) gametophyte, bearing eggs and sperms)

1. Liverworts (mostly flattish, scalelike plants)
2. Mosses (slender axes, thin "leaves")

PHYLUM IV

PTERIDOPHYTA (differentiation in roots, stems, leaves, conducting system; no seeds; require water for reproduction; reproducing by two generations as in mosses)

1. Ferns (broad leaves, low plants to tree ferns eighty feet tall)
2. Horsetails (*Equisetum*) or scouring rushes (scalelike leaves; mostly low, rushlike plants; stem with silica)
3. Lycopods and clubmosses (low plants with small, green, needlelike leaves)

PHYLUM V

SPERMATOPHYTA (differentiation in roots, stem, and leaves; with flowers or cones producing seeds. Reproductive process adapted for land habitat)

1. Gymnosperms (cone bearers, with naked seeds, leaves in the form of needles or scales; mostly lasting more than one growing season, *i.e.*, evergreens, yews, pines, cedars, spruces, hemlocks, firs, larches, etc. See illustration, page 69, of pine, hemlock, and cedar)
2. Angiosperms (flowering plants, with seeds enclosed; the largest number of species of any plant group)
   a. Monocotyledons (parallel-veined leaves; stem vascular tissue scattered in separate bundles; flower with parts in threes; embryo with one cotyledon. Grasses, palms, lilies, bananas, pineapples, cannas,

orchids, aroids, *i.e.*, calla lily. The illustration on page 69 shows four types, lower left, jack-in-the-pulpit and lily at top; grass and ladyslipper at the bottom)

b. Dicotyledons (net-veined leaves; stem, vascular tissue in circle or rings of bundles; flower parts usually in fours or fives; embryo with two cotyledons; many families and many species. Mustards, buttercups, roses, legumes, oaks, willows, thistles, daisies, dandelions, beets, maples, birches, horse chestnuts, cacti, spurges, potato, etc. The illustration on page 69 shows five types, lower right, reading down—morning-glory, wild rose, mustard, willow, thistle)

II. Animal Kingdom

Phylum I

Protozoa (one-celled; sometimes in colonies; ameba, paramecium, etc.)

1. Rhizopoda (ameba, and other forms with pseudopodia; some have shells, radiolaria with silica, foraminifera with lime, some with chitin, some with cemented sand grains)
2. Ciliata, (paramecium, etc.; definite shapes, and food openings; moving by cilia; two nuclei)
3. Flagellata (euglena, etc.; usually with definite shape; moving by flagella, whiplike protoplasmic threads; some with chlorophyll, some without)
4. Sporozoa (malaria germs, etc.; all parasitic, often requiring two hosts for their life cycle)

Phylum II

Porifera (sponges, mostly marine, colonies; very low degree of differentiation; some with lime spicules, some with silica, some with chitin—the ordinary bath sponge; body a simple or much-branched tube system, with walls two cells thick, feeding through many microscopic pores through the walls)

PHYLUM III

COELENTERATA (coral, hydra, sea anemone, hydroids, jellyfish; mostly marine; body a hollow bag, with walls two cells thick, and with a circle of tentacles, radial symmetry, one digestive opening)

PHYLUM IV

PLATYHELMINTHES or flatworms (tapeworms, liver flukes, planaria; all with flattened bodies, with front and rear ends, with upper and lower surfaces, that is, bilateral symmetry, with three tissue layers, with some organ systems; mostly parasitic)

PHYLUM V

NEMATHELMINTHES (porkworm, threadworm, hookworm, etc.; with rounded bodies, two digestive openings, mouth and anus; many parasitic on animals and in plants)

PHYLUM VI

ECHINODERMATA (starfish, sea urchins, sand dollars, sea-cucumbers, sea lilies; adults with radial symmetry, with hard limy exoskeleton, with distinctive organs for breathing and walking; all marine)

PHYLUM VII

ANNELIDA or segmented worms (earthworms, sandworms, leeches, etc.; with bilateral symmetry and with well-developed systems for circulation, digestion, excretion, sensation, etc.; in fresh and salt water, and in the soil)

PHYLUM VIII

ARTHROPODA (largest group of animals; jointed legs, exoskeleton; includes swimming, walking, and flying types; various habitats)

1. Onychophora (peripatus, a wormlike arthropod, and its allies)
2. Crustacea (crabs, lobsters, crawfish, and microscopic sorts; exoskeleton strengthened with lime; breathing through gills; nearly all aquatic)
3. Myriapoda (centipede, thousand-legged "worms," etc.; mostly on land; many legs, little differentiation of body)
4. Arachnida (spiders, ticks, mites, scorpions, horseshoe crabs; eight legs or more, special breathing apparatus, etc.)
5. Insecta (the largest group of organisms, more than all other animals together; flies, bees, grasshoppers, butterflies, beetles, dragon flies, plant lice, fleas, etc.; all with six legs and exoskeleton of chitin; with few exceptions winged and living on land; some aquatic types; body differentiated into head, thorax, and abdomen; breathing through spiracles, and distributing oxygen through tubes)

   Some of the more common groups of insects in this class are:

   a. Orthoptera (straight wings)
   b. Hymenoptera (lacy wings)
   c. Coleoptera (sheath wings)
   d. Diptera (two wings)
   e. Mecoptera (scorpion flies)
   f. Siphonaptera (wingless; fleas)
   g. Hemiptera (usually wingless; bugs)
   h. Lepidoptera (scaly wings)
   i. Isoptera (termites)
   j. Ephemerida (Mayflies)

PHYLUM IX

MOLLUSCA (clams, oysters, octopuses, squids, snails, etc.; bilateral symmetry, soft bodies, usually with external lime shell, appearance of foot)

PHYLUM X

CHORDATA (highest group of animals; bilaterally symmetrical, notochord vertebrae, gill slits at some stage of growth; dorsal, hollow nerve cord)

1. Fishes (perch, salmon, trout, etc.; cold-blooded; water habitat; gills, scales, two-chambered heart)
2. Amphibians (frogs, toads, newts, salamanders; cold-blooded; water or land habitats; no scales; gills in early life, air-breathing usually in later life; mostly four-limbed; three-chambered heart)
3. Reptiles (lizards, alligators, snakes, turtles; scales, cold-blooded, no functional gills, lungs, mostly four-limbed, three- and four-chambered heart)
   a. Crocodilia (alligators and crocodiles)
   b. Chelonia (turtles and tortoises)
   c. Squamata (snakes and lizards)
   d. Dinosaura (fossil reptiles; dinosaurs, etc.)
4. Birds (sparrows, eagles, etc.; warm-blooded; four-limbed, two of which are wings; feathers, scales only on feet, no teeth, four-chambered heart, and many other characteristics)
   a. Galliformes (fowls)
   b. Passeriformes (perching birds)
   c. Falconiformes (hawks, eagles, etc.)
   d. Anseriformes (geese, ducks, etc.)
   e. Ciconiiformes (storks, herons, etc.)
   f. Cuculiformes (cuckoos, etc.)
   g. Coraciiformes (kingfishers, etc.)
5. Mammals (whales, bats, cats, dogs, horses, monkeys, man, etc.; warm-blooded, hair, mammary glands,

highly developed nervous system, and many other characteristics)

a. Monotremes (spiny anteaters, duckbills)
b. Marsupials (opossums, kangaroos)
c. Insectivores (moles, shrews, hedgehogs)
d. Chiropters (bats)
e. Carnivores (dogs, cats, bears, etc.)
f. Rodents (muskrats, beavers, rats, woodchucks, squirrels, rabbits, porcupines)
g. Edentates (sloths, armadillos)
h. Ungulata (deer, cows, elephants, horses, camels, buffaloes)
i. Cetacea (whales, dolphins)
j. Primates (monkeys, apes, man)

Experiments and Laboratory Exercises

The following experiments and laboratory exercises are described in or suggested by the text. Although it will naturally be impossible for every student to perform every experiment suggested, the list should provide a valuable guide in the selection of a program of laboratory work suitable for any school situation. Fifty of the more important experiments are starred.

Pronouncing Glossary of Biological Terms

Following is a list of words which have been used in the text with special biological meaning. For some of these words, pronunciations different from those indicated below are frequently used in various parts of the country, but the pronunciations indicated follow those given in dictionaries most widely used.

Key to the pronunciation of vowels: ā, as in āle; ȧ, as in chȧotic; â, as in câre; ă, as in ădd; *ă*, as in *ă*ccount; ä, as in ärm; ȧ, as in ȧsk; *ȧ*, as in sof*ȧ*; ē, as in ēve; ẹ, as in hẹre; ė, as in ėvent; ĕ, as in ĕnd; *ĕ*, as in sil*ĕ*nt; ẽ, as in makẽr; ī, as in īce; ĭ, as in ĭll; *ĭ*, as in char*ĭ*ty; ō, as in ōld; ȯ, as in ȯbey; ô, as in ôrbs; ŏ, as in ŏdd; ŏ̃, as in sŏ̃ft; *ŏ*, as in c*ŏ*nnect; o͞o, as in fo͞od; o͝o, as in fo͝ot; oi, as in oil; t͜ů, as in nat͜ůre; ū, as in cūbe; ů, as in ůnite; ŭ, as in tŭb; û, as in ûrn; *ŭ*, as in circ*ŭ*s.

absorption (*ă*b·sôrp′sh*ŭ*n), the transfer of liquids and dissolved substances through cell membrane into the cells of an organism.

acetylcholine (ăs′ė·tĭl·kō′lēn), a chemical substance involved in the transmission of impulses between any two nerve cells.

adrenals (ăd·rē′n*ă*lz), a pair of glands located on or near the kidneys in mammals which secrete the hormone, *adrenalin* (*ă*d·rĕn′*ă*l·ĭn).

adventitious (ăd′vĕn·tĭsh′*ŭ*s), out of the usual place, as, an *adventitious bud.*

afferent nerve (ăf′ẽr·*ĕ*nt), a nerve which conducts impulses toward the central parts of the nervous system.

Ainu (ī′no͞o), a race of Caucasian origin, living in Northern Japan.

albinism (ăl′bĭ·nĭz’m), a state in which pigment is absent from the skin, hair, eyes, or feathers.

algae (ăl′jē), *singular,* **alga** (ăl′g*ȧ*), commonly meaning seaweeds, but technically, any green plants of the phyla of Thallophyta.

alimentary canal (ăl′*ĭ*·mĕn′t*ȧ*·rĭ k*ȧ*·năl′), the food canal, especially of higher animals.

allergies (ăl′ẽr·jĭz), reactions of the body to the poisonous effect of various plant and animal proteins.

alveoli (ăl·vē′ȯ·lī), air sacs in the lungs.

ameba (*ȧ*·mē′b*ȧ*), a protozoon, or one-celled animal, which moves by irregular extensions (pseudopodia) from its surface.

amino acid (*ȧ*·mē′nō ăs′ĭd), one of a number of organic acids of which proteins are constructed.

amitosis (ăm′ĭ·tō′sĭs), direct cell division; the type by which a cell is divided without the splitting of chromosomes.

Amphibia (ăm·fĭb′ĭ·*ȧ*), the class of vertebrates which includes frogs, toads, and salamanders. Members of this group are called *amphibians*.

amylase (ăm′ĭ·lās), any starch-digesting enzyme.

anal (ā′n*ă*l), related to the anus. See **anus.**

anaphase (ăn′*ȧ*·fāz), the stage in cell division in which the chromosomes move toward the poles.

annelid (ăn′*ĕ*·lĭd), any of the phylum Annelida, which includes the earthworm.

anterior (ăn·tẹ̄r′ĭ·ẽr), the forward part of an animal.

anther (ăn′thẽr), the pollen-bearing part of the stamen; **anther sac,** one of the baglike parts of the anther.

antheridium (ăn′thẽr·ĭd′ĭ·*ŭ*m), the sperm-producing organ in mosses, ferns, and some algae.

anthropology (ăn′thrō̇·pŏl′ō̇·jĭ), the study of the human species and its development.

antibody (ăn′tĭ·bŏd′ĭ), any substance produced by the body to counteract the effects of germs, of their toxins, or of a harmful substance.

antitoxins (ăn′tĭ·tŏk′sĭnz), substances in the blood produced to neutralize bacterial toxins.

anus (ā′n*ŭ*s), the posterior opening of the alimentary canal.

aorta (ā̇·ôr′t*ȧ*), the artery which leads from the left ventricle of the heart.

aphids (ā′fĭdz), or **plant lice,** small insects of the Homoptera order, which suck plant juices.

archaeology (är′kē̇·ŏl′ō̇·jĭ), study of prehistoric cultures.

arthropod (är′thrō̇·pŏd), any member of the phylum of invertebrate animals with segmented bodies and jointed limbs.

asexual reproduction (ā̇·sĕk′sho͝o·*ă*l), a form of reproduction which does not involve sex cells.

assimilation, changing food materials into protoplasm.

autotrophic bacteria (ô′tō̇·trŏf′ĭk băk·tẹ̄r′ĭ·*ȧ*), bacteria which have the ability to derive energy from inorganic substances or from light.

auxin (ôk′sĭn), a hormone found in both plants and animals which is related to growth.

axon (ăk′sŏn), the slender, fiberlike part of a nerve cell.

bacillus (bȧ·sĭl′ŭs), *plural* **bacilli** (bȧ·sĭl′ī), any rodlike bacterium; also, the name of a genus of bacteria of this shape.

bacteria (băk·tēr′ĭ·ȧ), *singular*, **bacterium,** the very small one-celled plants which include most of the human disease germs.

biennial (bī·ĕn′ĭ·ăl), a plant which requires two years to complete its life history.

blastula (blăs′tū·lȧ), the stage of an animal embryo in which it is a hollow ball of cells.

blended inheritance, the condition of an offspring in which neither of a pair of parental characters is dominant.

blood serum, the liquid of the blood free of corpuscles or platelets.

brachydactyly (brăk′ĭ·dăk′tĭ·lĭ), a condition in which fingers or toes lack one joint and are consequently abnormally short.

branching, reproduction by natural growth in the size of the living thing.

bud variations, variations arising in leaf, stem, or root of a plant.

caecum (sē′kŭm), *plural*, **caeca,** the part of the large intestine to which the appendix is attached; also blind digestive pouches in various animals.

calorie (kăl′ō·rĭ), the amount of heat required to raise a liter of water one degree Centigrade; unit of measure of heat value of foods.

cambium (kăm′bĭ·ŭm), the undeveloped vascular tissue by which the roots and stems of many plants increase in thickness.

canine (kā′nīn), the long, pointed type of tooth in man and many mammals. Also, any dog.

capillaries (kăp′ĭ·lĕr′ĭz), minute blood tubes which connect the arteries with the veins.

carbohydrate (kär′bō·hī′drāt), a compound made up of carbon, hydrogen, and oxygen in which the hydrogen and oxygen exist in the same proportions as in water.

cardiac (kär′dĭ·ăk), pertaining to the heart, e.g., the cardiac sphincter is at the end of the stomach, near the heart.

carnivorous (kär·nĭv′ō·rŭs), flesh-eating.

carotin (kăr′ō·tĭn), a yellow pigment found in all green leaves and in many vegetables and closely associated with vitamin A.

catalyst (kăt′ȧ·lĭst), a substance that speeds up or slows down a chemical reaction without itself being changed.

Caucasian (kô·kā′shăn), the "white" race; originally in Europe, in Southern and Southwestern Asia, and in Northern Africa.

cell (sĕl), the name given to a unit particle of protoplasm; the unit of structure in living things.

cell budding, cell division in which one daughter cell is at first much smaller than the parent cell.

cell fission (fĭsh′ŭn), cell reproduction which results in the division of the cell into two equal daughter cells.

cellulose (sĕl′ū·lōs), the complex carbohydrate of which the cell walls of plants are composed.

centrosome (sĕn′trō·sōm), a small body in animal cells which is located at the apex of the spindle during cell division.

cephalic index (sē·făl′ĭk ĭn′dĕks), the ratio between the width of the head and the length, expressed in per cent.

cerebellum (sĕr′ē·bĕl′ŭm), the part of the brain behind and below the cerebrum.

cerebral cortex (sĕr′ē·brăl kôr′tĕks), the outer part of the cerebral hemispheres.

cerebrum (sĕr′ē·brŭm), the part of the brain occupying the upper part of the skull in man. It controls thought and voluntary movement.

chemotropism (kĕ·mŏt′rō·pĭz′m), a tropism in which the stimulus is chemical.

chlorophyll (klō′rō·fĭl), green coloring matter found in chloroplasts and concerned with photosynthesis.

chloroplast (klō′rō·plăst), a body in the cytoplasm of plant cells which contains chlorophyll.

chondriosomes (kŏn′drĭ·ō·sōmz′), minute self-reproducing cytoplasmic bodies.

chordate (kôr′dāt), one of the phylum, *Chordata*, of animals with dorsally situated central nervous systems, to which man belongs.

chromatin (krō′mȧ·tĭn), a substance in the nucleus which stains deeply with basic dyes.

chromosome (krō′mō·sōm), one of the definite number of nuclear structures, consisting of chromatin, which appear in each cell division.

chyme (kīm), fluid contents of the stomach which have undergone gastric digestion.

cilia (sĭl′ĭ·*ȧ*), *singular,* **cilium** (sĭl′ĭ·*ŭ*m), the numerous hairlike projections of certain animal cells, capable of vibrating or lashing motion.

circulation, the distribution of materials from one part of an animal to another part by means of a liquid medium.

cleavage (klēv′ĭj), the early cell division of animal eggs.

cloaca (klȯ·ā′k*ȧ*), a waste-discharging chamber in animals.

coccyx (kŏk′sĭks), the fused vertebrae which form the lower end of man's spinal column.

coelenterate (sė·lĕn′tēr·āt), an animal, like jellyfish, hydra, etc., which belongs to the phylum Coelenterata; that is, a simple type of invertebrate animal consisting of a baglike body, of two layers of cells.

conditioned reflex, an act which is initiated by a stimulus other than that usually associated with the response.

conjugation (kŏn′jo͝o·gā′sh*ŭ*n), reproduction by the union of two similar gametes.

corpuscle (kôr′pŭs·'l), one of the separate cells found in blood.

cortex (kôr′tĕks), the outer layers of an organ as distinguished from the inner part.

cotyledon (kŏt′*ĭ*·lē′d*ŭ*n), the seed leaf.

cross-pollination, the transfer of pollen from an anther of one flower to the stigma of a flower on another plant.

Crustacea (krŭs·tā′shė·*ȧ*), a class of arthropods most of which live in the water; e.g., crabs, lobsters, and sow bugs.

cyclosis (sī·klō′sĭs), the streaming motion of the cytoplasm of some cells.

cyst (sĭst), a baglike structure within which a single cell, a group of cells, or a small organism is enclosed for protection.

cyton (sī′tŏn), the part of a neuron in which the nucleus is located.

cytoplasm (sī′tȯ·plăz'm), protoplasm of the cell, exclusive of the nucleus.

dendrites (dĕn′drīts), branching fibers on the receiving end of a neuron.

dermis (dûr′mĭs), the inner layer of the skin.

diastase (dī′*ȧ*·stās), a plant enzyme consisting of a mixture of amylase and maltase.

dicotyledon (dī·kŏt′*ĭ*·lē′d*ŭ*n), a plant with two seed leaves.

diffusion (dĭ·fū′zh*ŭ*n), the mingling of the molecules of different substances by their own movements.

digestion (dĭ·jĕs′chŭn), the process of changing insoluble foods to a soluble form which can be used in the body.

dinosaur (dī′nō·sôr), one of several types of great reptiles which lived in the Mesozoic era.

distribution, the transfer of materials between the different parts of a plant.

dominant, term applied to characteristics in inheritance which appear in hybrids.

dorsal (dôr′săl), the back or upper side of an animal. *Contrast* **ventral.**

Drosophila (drō·sŏf′ĭ·lȧ), a genus containing the common fruit fly.

echinoderm (ē·kī′nō·dûrm), a marine animal belonging to the phylum Schinodermata, including the starfish.

ectoderm (ĕk′tō·dûrm), the outer layer of cells of a simple animal or of the embryo of a higher animal.

ectoplasm (ĕk′tō·plăz'm), the clear, marginal protoplasm of the cells of protozoa.

efferent nerve (ĕf′ēr·ĕnt), a nerve that carries impulses away from the central nervous system.

eggs, female sex cells, or gametes.

element, one of the ninety-two chemical substances into which all matter may be analyzed.

embryo (ĕm′brĭ·ō), the early, dependent stage in the development of an organism.

embryo sac (ĕm′brĭ·ō săk), the structure within an ovule in which the egg cell is formed.

endocrine glands (ĕn′dō·krīn), glands which secrete hormones.

endoderm (ĕn′dō·dûrm), the inner layer of cells of a simple animal or of the embryo of a higher animal.

endoplasm (ĕn′dō·plăz'm), the inner granular protoplasm of the cells of protozoa.

endosperm (ĕn′dō·spûrm), a region of food storage in a seed, outside the embryo.

enteron (ĕn′tēr·ŏn), the food tube in animals, e.g., the branched digestive tube of planaria.

environment (ĕn·vī′rŭn·mĕnt), the sum total of all the conditions in which an organism lives.

enzyme (ĕn′zīm), an organic catalyst, that is, a substance promoting change without itself changing.

epidermis (ĕp′ĭ·dûr′mĭs), the layer of cells which provides a protective covering over plants and animals.

eugenics (ů·jĕn′ĭks), the study of all factors bearing on the improvement of the human race.

exoskeleton, a hard supporting or protective structure developed on or secreted by the outside of the body, as the shells of Crustacea.

excretion (ĕks·krē′shŭn), the elimination of bodily waste substances from a plant or animal.

eye spot, a special light-sensitive structure.

factor, a synonym for gene; thus "hereditary factors."

family, the principal subdivision of an order in classification.

feces (fē′sēz), intestinal wastes of animals.

fertilization (fûr′tĭ·lĭ·zā′shŭn), reproduction by the union of an egg and a sperm.

filament (fĭl′ȧ·mĕnt), the stalk of a stamen; also a threadlike type of plant.

filial (fĭl′ĭ·ăl), bearing the relation of child to parent.

filterable virus (fĭl′tĕr·ȧ·b'l vī′rŭs), a disease agent so small that it passes through the pores of a porcelain filter.

flagellates (flăj′ĕ·lāts), protozoa that move by means of flagella (flȧ·jĕl′ȧ).

flagellum (flȧ·jĕl′ŭm), *plural* **flagella** (flȧ·jĕl′ȧ), a long organ of motion projecting from a cell.

fluctuation (flŭk′tů·ā′shŭn), minor variations due to the environment. *Contrast* with **mutations.**

fossils (fŏs′ĭlz), remains of an organism of an earlier period, often preserved in rock.

fraternal twins (frȧ·tŭr′năl twĭnz), twins derived from two eggs, nonidentical. *See* **identical twins.**

fundus (fŭn′dŭs), the rounded, upper-left portion of the stomach serving the primary purpose of food storage.

fungus (fŭng′gŭs), molds, mushrooms, and other plants of the phylum Thallophyta, which lack chlorophyll.

galvanotropism (găl′vȧ·nŏt′rō·pĭz'm), a tropism, in which the stimulus is electrical.

gamete (găm′ēt), a single sex cell; any cell capable of combining with another gamete in sexual reproduction.

gametogenesis (găm′ē·tō·jĕn′ē·sĭs), the cell processes by which sperms and eggs are formed.

gametophyte (gȧ·mē′tō·fīt), the sexual or gamete-producing generation in plants.

ganglion (găng′glĭ·ŭn), *plural*, **ganglia,** a small, compact group of nerve cells.

gastric (găs′trĭk), pertaining to the stomach and its digestive processes.

gastrula (găs′trōō·lȧ), a stage in animal development in which the embryo consists of a two-layered sac, ectoderm and endoderm.

gene (jēn), the ultimate unit basis of inheritance, contained in chromosomes.

genetic (jē·nĕt′ik), dealing with heredity and variation.

genus (jē′nŭs), a group of similar species.

geotropism (jē·ŏt′rō·pĭz′m), the tropism for which gravity is the stimulus.

germ (jûrm), popularly, any organism that can cause a disease.

glucose (glōō′kōs), a kind of sugar.

glycogen (glī′kō·jĕn), a kind of animal starch.

Golgi bodies (Gôl′jē), specialized structures in cytoplasm believed concerned with secretion.

gonads (gŏn′ădz), the structures, either ovaries or testes, in which the germ cells develop.

grafting (gråf′ting), causing a branch of one plant to grow on another but closely related plant by placing the cambium of both in contact.

gullet (gŭl′ĕt), the tube leading inward from the mouth of an animal.

guttation (gŭ·tā′shŭn), the excretion of water in liquid form from leaves.

habitat (hăb′ĭ·tăt), the region where a plant or animal lives.

hemoglobin (hē′mō·glō′bĭn), the red iron compound of the blood which carries oxygen.

hemophilia (hē′mō·fĭl′·ĭ·ȧ), tendency to bleed which is inherited as a sex-linked trait.

herbivorous (hûr·bĭv′ō·rŭs), eating exclusively plant material.

hermaphrodite (hûr·măf′rō·dīt), an organism bearing both male and female reproductive organs.

heterosis (hĕt′ēr·ō′sĭs), the greater size or vigor often characterizing hybrids.

heterozygous (hĕt′ēr·ō·zī′gŭs), hybrid, of mixed inheritance for one or more characteristics.

Homo sapiens (hō′mō sā′pĭ·ĕnz), the scientific name for the existing human species.
homozygous (hō′mō·zī′gŭs), of identical inheritance for one or more characteristics.
hormone (hôr′mōn), a secreted substance that stimulates or inhibits activity in an organism.
host (hōst), the organism upon which a parasite lives.
hybrid (hī′brĭd), the offspring of parents which differ with respect to one or more characteristics.
hydra (hī′drȧ), the simplest multicellular animal. A fresh-water coelenterate with a slender, cylindrical body, bearing a circle of tentacles at the top.
hydrolysis (hī·drŏl′ĭ·sĭs), a chemical process in digestion, in which the food substances are combined with water.
hydrotropism (hī·drŏt′rō·pĭz'm), a tropism in which the stimulus is water.
hypervitaminosis (hī′pẽr·vī′tȧ·mĭ·nō′sĭs), a disease caused by a diet too rich in vitamins.
hyphae (hī′fē), the filaments of a fungus.
hypocotyl (hī′pō·kŏt′ĭl), the stem of the embryo plant in a seed.

identical twins, twins believed to arise from a single fertilized egg.
inbreeding, the breeding together of plants or animals that are closely related.
ingestion (ĭn·jĕs′chŭn), the taking in of food materials by an organism.
insulin (ĭn′sû·lĭn), the hormone which regulates sugar metabolism.
internode (ĭn′tẽr·nōd′), the portion of a stem between two nodes.
iris (ī′rĭs), the colored part of the eye, the circular muscle which controls the amount of light admitted.
irritability (ĭr′ĭ·tȧ·bĭl′ĭ·tĭ), the capacity to respond to stimuli.
Islands of Langerhans (läng′ẽr·häns), groups of cells in the pancreas which secrete insulin.

kelp (kĕlp), the name of large brown seaweeds.

lacteals (lăk′tē·ălz), vessels which take in digested fats and carry them away from the villi.
larva (lär′vȧ), *plural,* **larvae** (vē), the wormlike stage in the development of insects.

lenticels (lĕn′tĭ·sĕlz), openings in the bark of woody plants for the passage of gases.

lethal factor (lē′thăl), a factor or gene that may bring about the early death of an organism.

line breeding, close breeding in animals, e.g., breeding the same male to descendants.

linin (lī′nĭn), threadlike material of nucleus.

linkage (lĭngk′ĭj), the tendency of the factors or genes borne on a particular chromosome to stay together in inheritance.

lipase (lī′pās), any fat-splitting enzyme.

lymph (lĭmf), the fluid derived from the blood which surrounds the cells.

lymphatics (lĭm·făt′ĭks), a system of vessels which returns the lymph to the general circulation.

macronucleus (măk′rō̇·nū′klḗ·ŭs), the larger, nutritive nucleus in those protozoa which have more than one nucleus, e.g., in paramecia.

maltase (môl′tās), an enzyme which changes maltose to glucose.

mammals (măm′ălz), warm-blooded, vertebrate animals which have hair, and which nurse their young.

mammary gland (măm′ȧ·rĭ), the milk-secreting gland of mammals.

mandibles (măn′dĭ·b'lz), the biting jaws of insects and of some other invertebrates.

maturation (măt′ū·rā′shŭn), the development of sex cells or gametes in animals.

maxillae (măk·sĭl′ē), a pair of mouth parts in insects usually just below or behind the mandibles.

medulla oblongata (mḗ·dŭl′ȧ ŏb′lŏng·gā′tȧ), the part of the brain which is attached to the spinal cord.

meiosis (mī·ō′sĭs), the reduction division of cells in which the number of chromosomes is halved.

melanin (mĕl′ȧ·nĭn), brown pigment, found in brown eyes, brown or black skin and hair.

mesoderm (mĕs′ō̇·dûrm), the middle layer of cells of a simple animal or of the embryo of a higher animal.

mesophyll (mĕs′ō̇·fĭl), the soft, spongy tissue in the interior of leaves.

metabolism (mĕ·tăb′ō̇·lĭz'm), the sum of all the chemical changes that take place within an organism.

metamorphosis (mĕt′ȧ·môr′fō·sĭs), the series of developmental stages occurring in the life history of animals, especially insects.

metaphase (mĕt′ȧ·fāz), the stage of cell division during which the chromosomes which have split are pulled apart, arranging themselves in the equatorial plane.

micronucleus (mī′krō·nū′klē·ŭs), the small or reproductive nucleus in those protozoa which have more than one nucleus.

micropyle (mī′krō·pīl), the opening through the ovule wall leading into the embryo sac.

mimicry (mĭm′ĭk·rĭ), a type of protective resemblance in which an animal looks like some other organism.

mitosis (mī·tō′sĭs), indirect cell division by which the chromosomes of a nucleus are divided and two nuclei formed exactly like the original nucleus.

molecule (mŏl′ē·kūl), the smallest particle in which any element or compound can exist.

mollusk (mŏl′ŭsk), an animal with a soft slimy body usually protected by a shell, such as an oyster.

Mongoloid (mŏng′gŏl·oid), having the characteristics of the Mongolian race.

monocotyledon (mŏn′ō·kŏt′ĭ·lē′dŭn), a plant with a one-seed leaf.

mucus (mū′kŭs), a slimy substance secreted by small glands in the skin and in the walls of the digestive and respiratory systems of animals.

multicellular, many celled.

multiple factors, inheritance in which two or more factors are involved in the production of a single characteristic.

mutation (mū·tā′shŭn), originally any kind of inherited variation; more recently a variation due to changes in a gene.

mutation theory, explanation of evolution put forward by Hugo de Vries.

mutualism (mū′tū·ȧl·ĭz'm), a relationship resembling symbiosis in which the organisms concerned do not live in contact.

mycelium (mī·sē′lĭ·ŭm), all the hyphae of a fungus plant taken together.

Negroid (nē′groid), having Negro racial characteristics.

nematocysts (nĕm′ȧ·tō·sĭsts′), stinging cells found in jellyfish and other coelenterates.

nephridium (nē·frĭd′ĭ·ŭm), *plural*, **nephridia,** a coiled tube found in some invertebrate animals which has the function of excretion.

neurosis (nū̇·rō′sĭs), abnormal behavior not caused by an injury to the nervous system.
node (nōd), the portion of a stem to which a leaf is attached.
nucleolus (nū̇·klē′ō̇·lŭs), small body often found in the nucleus.
nucleus (nū′klē̇-ŭs), a characteristic cell structure containing chromatin, found in all cells except those of the Schizophytes.
nutrition (nū̇·trĭsh′ŭn), the utilization of food and oxygen by living organisms.
nymphs (nĭmfs), the immature stage in insects that do not have complete metamorphosis.

omnivorous (ŏm·nĭv′ō̇·rŭs), eating both plant and animal foods.
oögenesis (ō′ō̇·jĕn′ē̇·sĭs), the formation and development of egg cells.
oral (ō′răl) **groove,** a groove leading to the mouth.
order, in classification, the principal subdivision of a class.
osmosis (ŏs·mō′sĭs), the passage of substances through membranes from places of higher concentration to those of lower concentration.
outcross, breeding unrelated strains in animals.
ovary (ō′vȧ·rĭ), the egg-producing organ in animals.
oviduct (ō′vĭ·dŭkt), a tube which carries eggs away from the ovary of an animal.
ovule (ō′vūl), the structure of a flower in which the egg cell is produced.
ovum (ō′vŭm), a single egg cell.
oxidation (ŏk′sĭ·dā′shŭn), the process of combining with oxygen, producing heat and energy.
oxyhemoglobin (ŏk′sĭ·hē′mō̇·glō′bĭn), hemoglobin which has combined with oxygen.

palp (pălp), a sense organ attached to the mouth parts of insects and of some other animals.
pancreas (păn′krē̇·ăs), the gland which produces insulin and several digestive enzymes.
paramecium (păr′ȧ·mē′shĭ·ŭm), *plural,* **paramecia,** any of a genus of protozoa which possess cilia. They are usually elongated, with a mouth, two nuclei, and two contractile vacuoles.
parasite (păr′ȧ·sīt), a plant or animal which lives by getting its food from another living plant or animal, but without killing it immediately.
parathyroids (păr′ȧ·thī′roidz), small ductless glands located just below the thyroid, whose secretion regulates calcium metabolism.

parthenogenesis (pär′thē·nō·jĕn′ē·sĭs), development of an unfertilized egg.

pellicle (pĕl′ĭ·k'l), the semirigid outer layer of ectoplasm in a paramecium and in some other protozoa.

pepsin (pĕp′sĭn), a stomach enzyme which changes proteins into peptones and proteoses.

peptone (pĕp′tōn), a soluble kind of protein product formed as a result of digestion in the stomach.

pericardium (pĕr′ĭ·kär′dĭ·ŭm), the membrane which surrounds the heart.

peristalsis (pĕr′ĭ·stăl′sĭs), the wavelike contractions of the alimentary canal.

pharynx (făr′ĭngks), the throat.

phloem (flō′ĕm), the nonwoody part of vascular tissues of plants.

photosynthesis (fō′tō·sĭn′thē·sĭs), the formation of carbohydrates from water and carbon dioxide in green plants with the aid of light energy.

phototropism (fō·tŏt′rō·pĭz'm), a tropism for which light is the stimulus.

phyla (fī′lȧ), *singular*, **phylum** (fī′lŭm), the main subdivisions of the plant and animal kingdoms.

pineal (pĭn′ē·ăl), a ductless gland located in the back of the brain.

pistils (pĭs′tĭlz), the parts of a flower which contain ovules.

pituitary (pĭ·tū′ĭ·tĕr′ĭ), a ductless gland at the base of the brain whose hormones are important regulators of many body processes.

placenta (plȧ·sĕn′tȧ), in mammals, the membranes which surround the developing embryo and through which the embryo receives food and oxygen from the mother; in plants, the part of the ovulary wall to which ovules are attached.

Planaria (plȧ·nā′rĭ·ȧ), a genus of flatworms, found under stones in brooks.

plasma (plăz′mȧ), the liquid part of the blood.

plasma membrane (plăz′mȧ mĕm′brān), the outer surface of the cytoplasm of a cell. It is through this membrane that osmosis takes place.

plasmolysis (plăz·mŏl′ĭ·sĭs), the removal of water from cells by osmosis.

plastids (plăs′tĭdz), self-reproducing cytoplasmic bodies, e.g., chloroplast.

platelets (plāt′lĕts), small solid bodies present in the blood, in addition to the corpuscles.

plumule (plo͞o′mūl), the bud of the embryo in seeds.

polar bodies (pō′lẽr), small discarded nuclear bodies formed during the maturation of the eggs of animals.

pole, used in reference to the ends of the spindle figure in cell division.

pollen (pŏl′ĕn), single-celled grains produced by stamens which, under proper conditions, are capable of producing sperms in seed plants.

pollen tube, the tube which grows out of a pollen grain and passes from the stigma to the ovule.

pollination (pŏl′ĭ·nā′shŭn), transfer of pollen from anther to stigma.

polydactyly (pŏl′ĭ·dăk′tĭ·lĭ), possessing more than five fingers or toes.

posterior (pŏs·tēr′ĭ·ẽr), the rear part of an animal.

primary root, the first root which grows out of the germinating seed.

prophase (prō′fāz), first stage in mitosis, in which the spindle is formed and chromosomes appear and are split longitudinally.

proteins (prō′tē·ĭnz), complex compounds in protoplasm which contain nitrogen, sulphur, and sometimes phosphorus in addition to carbon, hydrogen, and oxygen.

proteoses (prō′tē·ō′sēs), like peptones, a product of the acid digestion of proteins in the stomach.

prothallium (prō·thăl′ĭ·ŭm), a small green scalelike stage of a fern which produces eggs and sperms.

protoplasm (prō′tō·plăz'm), living matter.

Protozoa (prō′tō·zō′ȧ), phylum of animals consisting of a single cell.

protozoan (prō′tō-zo′ăn). See **protozoon.**

protozoon (prō′tō·zō′ŏn), *plural,* **protozoa,** one of the Protozoa.

pseudopodia (sū′dō·pō′dĭ·ȧ), "false legs," extensions thrust out from ameba and other similar protozoa.

psychosis (sī·kō′sĭs), a serious mental disorder.

ptyalin (tī′ȧ·lĭn), a starch-digesting enzyme in saliva.

pulmonary (pŭl′mō·nĕr′ĭ), pertaining to the lungs.

pupa (pū′pȧ), *plural,* **pupae** (pē), a stage in the development of an insect in which it is in a case.

pylorus (pī·lō′rŭs), the valve which separates the stomach from the intestine.

quarantine (kwŏr′ăn·tēn), restriction placed on people sick with contagious diseases, or those who have been exposed to infection.

recessive (rē·sĕs′ĭv), a factor or characteristic which may not show itself in the first generation when paired with a dominant factor but which will reappear when paired with a similar recessive factor.

reduction division, the cell division during which the number of chromosomes is reduced. *See* **meiosis.**

reflex (rē′flĕks), an automatic response to a particular stimulus.

regeneration, the replacement of tissues or organs which have been lost.

rennin (rĕn′ĭn), a stomach enzyme which aids in the digestion of milk by turning the liquid protein to solid form.

reproduction, the formation of new individuals.

respiration, the release of energy in organisms, usually by means of the absorption and use of oxygen, together with the excretion of the wastes of oxidation.

response, a reaction to an internal or external stimulus.

resting spores, single cells modified by thickened walls to resist unfavorable conditions.

retina (rĕt′ĭ·nȧ), the layers of light-sensitive cells in the eye.

rickets, a serious disease which causes bone deformities in children, due to the deficiency of vitamin D.

saprophytes (săp′rō̇·fīts), plants that absorb their food directly from dead organic matter.

saprozoons (săp′rō̇·zō̇′ŏnz), animals that absorb their food directly from dead organic matter.

secretins (sē̇·krē′tĭnz), hormones secreted by cells along the walls of the stomach and intestines.

secretion (sē̇·krē′shŭn), the production by a cell of useful or waste substances usually discharged from the cell.

segment, one of the ringlike divisions of the bodies of earthworms and of many other animals.

segregation, the separation of different characters which takes place in the reduction division.

selfing, self-pollinating or self-fertilizing.

self-pollination, transfer of pollen from an anther to a stigma of the same plant.

sepals (sē′păls), the outside circle of flower parts, usually green in color.

sex-linked inheritance, the inheritance of specific traits determined by sex chromosomes.

species (spē′shĭz), the unit group in classification, consisting of similar related individuals.

sperm (spûrm), a single male cell or gamete.

spermatogenesis (spûr′mȧ·tō̇·jĕn′ē̇·sĭs), the formation of new sperm cells.

spermatocyte (spûr′mȧ·tō·sīt′), the sperm mother cell.

sperm ducts (spûrm dŭkts), tubes leading from the testes of a male animal to the exterior.

sphincter (sfĭngk′tẽr), a circular muscle for contracting and closing an opening.

spiracles (spī′rȧ·k'lz), openings which admit air into the tracheae of insects.

spireme (spī′rēm), the apparently continuous thread of chromatin found in the early prophase of cell division.

spleen (splēn), a large ductless gland near the intestine, whose function is not entirely known. It serves partly as a reservoir for red corpuscles.

sporangium (spō̇·răn′jĭ·ŭm), *plural,* **sporangia,** a spore-producing structure.

spore (spōr), a single-celled structure which is usually capable of growing to form the type of organism which produced it.

sporogenesis (spō′rō̇·jĕn′ē̇·sĭs), the series of cell divisions by which spores are formed.

sporophyte (spō′rō̇·fīt), the spore-bearing generation in mosses, ferns, and seed plants.

sporulation (spŏr′ū·lā′shŭn), a method of reproduction in which many new cells (spores) are formed within the parent cell body.

stamens (stā′mĕnz), pollen-producing organs of a flower.

sterilization (stĕr′ĭ·lĭ·zā′shŭn), in eugenics, prevention of reproduction in man by operation; in bacteriology, the destruction of life in culture media, utensils, etc.

stigma (stĭg′mȧ), the part of the pistil which receives the pollen.

stimulus (stĭm′ū·lŭs), the object or situation to which a given response is made.

stoma (stō′mȧ), *plural,* **stomata** (stō′mȧ·tȧ), openings in leaves for the passage of gases.

style (stīl), the portion of the pistil between the ovary and the stigma.

symbiosis (sĭm′bī·ō′sĭs), a mutually beneficial association between two different kinds of organisms.

synapse (sĭ·năps′), the point of nearness or contact between two nerve-cell endings.

synapsis (sĭ·năp′sĭs), the pairing and twisting of chromosomes during the preparation for reduction division.

synthesis (sĭn′thē·sĭs), the formation of complex substances from simpler substances.

telophase (tĕl′ō·fāz), the stage in cell division in which the chromosomes are reorganized into nuclei.

terminal bud, the main bud at the tip of a stem, usually referring to woody stems.

testis (tĕs′tĭs), spermary, a sperm-producing organ in animals.

tethelin (tĕth′ē·lĭn), a hormone secreted by the anterior lobe of the pituitary gland.

thermotropism (thēr·mŏt′rō·pĭz'm), the tropism for which heat is the stimulus.

thigmotropism (thĭg·mŏt′rō·pĭz'm), the tropism for which the stimulus is touch or contact.

thymus (thī′mŭs), a ductless gland located at the front of the body cavity whose hormones are important during childhood.

thyroid (thī′roid), a ductless gland in the neck region whose secretion **thyroxin** (thī·rŏx′sĭn), regulates growth and metabolism.

toxic (tŏk′sĭk), referring to the poisons produced by disease germs.

toxins (tŏk′sĭnz), poisonous substances produced by disease germs.

trachea (trā′kē·ȧ), in higher animals, the windpipe; in insects, one of the air tubes.

tracheids (trā′kē·ĭdz), elongated, pointed xylem cells, often with spiral thickenings.

transpiration (trăn′spĭ·rā′shŭn), the loss of water from leaves by evaporation.

trichocyst (trĭk′ō·sĭst), one of a layer of tiny sacs from which a paramecium may discharge a hair in defense.

tropism (trō′pĭz'm), the type of response in which the direction of the response is determined by the direction from which the stimulus comes.

turgor (tûr′gŏr), the distension of plant cells by osmotic pressure.

unicellular, one-celled.

urea (ū·rē′ȧ), a nitrogenous compound excreted by the kidneys.

ureter (ū·rē′tēr), a tube which conducts urine away from the kidney.

uterus (ū′tēr·ŭs), *plural,* **uteri,** the organ in which the embryo is developed in all higher animals.

vaccination (văk′sĭ·nā′shŭn), the introduction into the body by inoculation of any substance which will cause the body to develop active immunity to disease.

vaccine (văk′sēn), originally, material from a calf used to produce immunity to smallpox; now applied to any material containing dead or weakened disease germs, which can be inoculated into the body to produce active immunity.

vacuoles (văk′ū·olz), parts of a cell containing droplets of water or other substances which are not actually protoplasm.

variation (vâr′ĭ·ā′shŭn). Two kinds are distinguished. (*a*) Genetic variation is the process in reproduction whereby offspring different from the parents are produced. (*b*) Acquired variation is the development of differences during the life of an organism due to environmental influences.

variety, a group in classification which is a subdivision of a species.

vascular (văs′kū·lẽr), tubular, referring to structures such as blood vessels in animals and veins in leaves.

vectors (vĕk′tẽrz), disease carriers among lower animals which may carry disease to man.

vein (vān), a blood vessel which carries blood toward the heart.

ventral (vĕn′trăl), pertaining to the belly or lower part of an animal.

vertebrates (vûr′tē·brāts), animals with backbones.

vessel, a tube formed from a row of originally separate wood or xylem cells.

vestigial (vĕs·tĭj′ĭ·ăl), applied to structures of no apparent use, but which are explainable as persisting from some ancestral form.

villus (vĭl′ŭs), *plural,* **villi** (vĭl′ī), a microscopic projection in the walls of the small intestine.

virus (vī′rŭs), the contagious matter causing a disease.

vitamin (vī′tȧ·mĭn), one of a group of accessory food materials which are necessary for proper metabolism in animals.

xylem (zī′lĕm), the woody part of the vascular tissue of plants.

zoogloea (zō′ō·glē′ȧ), dense masses of bacteria held together by a gelatinous secretion.

zygote (zī′gōt), a cell formed by the fusion of two gametes as in fertilization or conjugation.

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