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THIS LIVING WORLD

This Living World

A College Course in Science

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DRAWINGS BY LOUISE WALLER GERMANN

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PREFACE

THE REMARKABLE progress in the natural sciences since the beginning of the last century has greatly increased man's understanding of the living world. The practical application of this knowledge has contributed many material advantages to human welfare, providing for the maintenance of health and the treatment of disease, markedly affecting the development of our institutions, and even influencing our ways of thinking. Thus the natural sciences have become a major social force. For this reason, the essentials of a good education today require some general knowledge of the natural laws governing the phenomena of everyday life.

The aim of this book is to present, in a form that combines accuracy with pleasant reading, the gist of modern knowledge about the living world, with special reference to the physical development of man and the structure and functioning of his body. The volume is designed as a text for college students who are taking a course in science for its cultural and exploratory value. In the selection and organization of the subject matter, the authors have been governed by considerations of what they believe to be the best approach to satisfying the needs of students who are not specializing in science. The presentation is an outgrowth of the senior author's long practical experience in presenting science courses to students who are nonscience majors.

In attempting to select appropriate reading material to accompany the cultural science courses offered by the authors, it was found that while there are well-written accounts that are suitable for many of the topics considered, these are nowhere suitably gathered into a single volume. The existing texts that adequately cover the separate fields of the biological sciences are in general too detailed and specialized to meet these students' needs and interests. It is the authors' belief that the use of these

special texts tends to defeat the purpose of survey courses, since where too much emphasis is placed upon detail the student fails to gain the more comprehensive insight which he is seeking. One of the primary purposes in producing this volume, therefore, has been to treat the natural sciences on a sufficiently comprehensive basis to give a broad understanding of the nature of living things and of the underlying principles governing their behavior and interrelationships. This basic requirement has been the guiding one in the selection of subject matter. In organizing the material the authors have kept in mind the object of presenting a logical and connected story of life on the earth.

The physical environment which supports life and the general characteristics of living things are discussed in the first few chapters of the book, since these topics are thought to be essential to understanding the more complex forms of life and their relation to each other. The succeeding chapters give an account of the development of life during the geologic past and the relationship of early forms to modern creatures, including man. Following this broad treatment of the development of living things and their more fundamental characteristics, special emphasis is placed on the complex physical organization and functioning of the human body, since to the individuals for whose use this volume is intended the human animal is of primary interest among living creatures. The text is concluded with a chapter on the prehistoric cultural development of man, a discussion that seemed necessary in order to complete the picture of man's early activities on the earth and to give some insight into the origins of modern culture. This approach has been found to be one that gives the most satisfactory understanding of the world of life and man's place in it, in that it presents a logical story with a theme or continuity running through it.

Throughout the book an attempt has been made to introduce the different topics by reference to common knowledge and then proceed to a discussion of pertinent material that may not be so generally understood. Wherever possible, illustrative examples have been selected from animal life, choosing in particular animals that might have some human interest or familiarity. The language of the text has been kept as nontechnical as is consistent with clear exposition. Some of the terms of science

are included, as they must necessarily be, for clarity and definiteness. However, these terms have been limited to cases where more common language could not be effectively employed, and they have been explained in the body of the text when first used. In order to make for interesting reading, the style of writing has been made descriptive and narrative where the subject matter could be clearly explained by so doing.

An annotated list of references for additional reading has been given at the end of each chapter for those whose interests may extend beyond the discussion of this text. In selecting the references, some popularly written books and magazines have been included that are suitable for general reading, and some more technical books and professional journals are listed for the specific and detailed information which they contain.

It is a pleasure to acknowledge the help and cooperation the authors have received from a number of persons during the preparation of this volume. The authors' thanks are expressed to their colleagues in the general science courses in the School of Commerce, Accounts, and Finance, New York University, for their valuable assistance in organizing and teaching the courses which led to the writing of this manuscript; to Dr. William R. Duryee, Biology Department, New York University, who helped prepare three of the chapters in their original form; and to Louise Waller Germann for her devoted interest and skill in making the artistic and technical drawings. We are especially obliged to Professor D. T. O'Connell, Geology Department, College of the City of New York; to Professors L. G. Barth, J. H. McGregor, A. W. Pollister, and H. Burr Steinbach, all of the Department of Zoology, Columbia University; to Mr. James Peskin of the Department of Biophysics, Columbia University; and to Professor H. A. Charipper, Biology Department, New York University, for reading parts of the manuscript and offering many timely and valuable suggestions for its improvement.

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New York City,
August, 1940.

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THIS LIVING WORLD



1: CHANGING CONCEPTS

Regarding the World of Life

IN 1564 an Italian philosopher, Giovanni Maffei, wrote an extended document of one hundred and forty leaves on the nature of the world and addressed it to the Count of Altavilla. It was a beautifully bound manuscript, written in the quaint old Italian script of the times. In it the author informs the count that the world consists of fourteen parts, namely, four elements and ten heavens. These are arranged in consecutive order from the center outward in concentric spheres. They may be considered in the form of a great stairway, he says, and he invites the count to ascend this progressive stairway of spheres in order to learn what is to be encountered on each step. The various steps include an explanation of a wide range of subjects, from those dealing with the immortality of the soul to why man has

two feet instead of four, and why stones sometimes have the forms of animals.

While the "Scala Naturale" of Maffei is considered to be one of the minor scientific classics of medieval times, the amount of misinformation which it contains is remarkable. It illustrates, nevertheless, how extensively our knowledge of natural science, particularly that relating to the phenomena of life, has increased during the last four centuries.

Since the days of the early Greek and Egyptian civilizations, man's knowledge of the animate world has been increasing. It is as if mankind had been climbing an ever-expanding stairway of understanding. It is true that his progress has not been steady; in fact, during certain ages it has been slow or even backward down the stairway. During all these centuries many attempts have been made to get some insight into the nature of living things and to formulate some concept of man's place in the world of life and his relationship to the material universe.

At the present time mankind has accumulated a large body of knowledge regarding the make-up of the living world. He has worked out a number of interpretations of this knowledge and formulated a number of beliefs regarding the nature of life, which greatly influence our thinking and behavior. The beliefs and habits we now have in this respect are somewhat different from those of previous centuries. They are founded upon more adequate knowledge than earlier man possessed. In this respect our concepts are more complete and more accurate. It would be satisfying, indeed, if we had the perfect understanding of life; however, this not being the case because of our lack of a complete knowledge of living things, mankind will continue to seek after information, and the future will no doubt see modifications of some of our present concepts. While this treatise is primarily concerned with getting some general understanding of man's present information regarding the phenomena of life and his interpretations of that information, it is of importance and perhaps of interest first to inquire briefly into the increasing knowledge and changing concepts of mankind in this respect throughout past human history.

Attempting to Understand the Universe

The earliest and most successful attempts at the time to organize man's knowledge of the universe and to formulate an explanation of man's relation to it were made by the ancient Babylonians, perhaps two thousand years before the time of Christ. Their early priests pictured the universe as a closed box or chamber with the earth as the floor. In the center of this floor were the snowy regions from which came the waters of the Tigris and Euphrates rivers. Around the earth was a moat of water and beyond it were celestial mountains supporting the dome of the sky. The sun, moon, and some of the stars moved over this dome, while most of the stars were fastened to it. The priests kept a record of the movements of the sun, moon, and planets and from these movements eventually learned to predict the occurrence of the seasons, a feat that was of inestimable practical value to a people whose very existence depended upon knowing the time of the rising and subsidence of the rivers' waters.

This study was the beginning of scientific astronomy. However, flushed with such success in predicting the seasons from movements of the sun, moon, and stars, the Babylonians erroneously reasoned that these celestial bodies exercised minute control over human actions and affairs of life and death. A whole fantastic scheme of magic was built up, and the astrologers acquired very real power over the minds of men. Their rites and ceremonies involved mimicking many acts of nature and assigning to the forces of nature the properties and forms of living creatures, which were to be worshiped and to which sacrifices were to be made. They held that man's destiny was ruled by the stars; hence all was governed by an inhuman and inexorable fate. Within such an atmosphere, neither science nor any rational philosophy of life could well be expected to develop further. It was several centuries before any new ideas were added to man's concept of the nature of life and the universe. This time the advancement originated in early Greece.

One of the most renowned of early Greek philosophers was Plato, who lived during the fourth century B.C. He was a great

exponent of what is known as idealism and reasoned that the universe must be perfect. Holding that the sphere was the most perfect of forms, he pictured the heavens as composed of spheres. The heavenly bodies were carried in cycles which had a circular motion, and the apparent motions of the sun, moon, and stars about the earth as the center sphere of the universe could be explained by a combination of these cycles. He loudly condemned experimentation and careful observation of nature as being either impious or a base mechanical art. Plato never asked questions; he answered them with a dogmatism that was decidedly unscientific. If he had had an experimentalist type of mind, he probably would have discovered that the earth revolves around the sun, and not the sun around the earth, as he taught. Most of his science was fantastic, but in many respects it had a profound effect upon human thinking for many centuries. This was brought about mainly by his influence on one of his pupils, Aristotle.

Aristotle formulated in a more definite manner a great many of Plato's ideas regarding life and the universe. He was the greatest collector and systematizer of knowledge the ancient world produced. Some of his scientific work was a contribution to an understanding of nature; however, some, particularly that relating to the nature of the physical universe, was inaccurate and influenced by a belief in the magical. His great importance to science was that he treated a great variety of subjects and so systematized all knowledge that it could be comprehended by succeeding generations. His great hindrance to scientific advance was that for centuries his teaching became authority and laws unto themselves, so that there was no distinction between what was correct and what was wrong. It became the mode to accept all things upon authority from either Aristotle or others and to disregard entirely research and observation. Although Aristotle himself referred to his work as the first step that should be improved upon, his ideas came to be unreservedly accepted for fifty generations.

He extended the idea that the universe was a series of spheres, because a sphere was the most perfect shape. In the center were the material and perishable spheres. They were the earth, water, air, and fire, which by their opposing and corrup-



Aristotle was the "greatest collector and systematizer of knowledge the ancient world produced."

tible principles of hot and cold, wet and dry, produced generation and destruction. Beyond these were the spheres in which moved the heavenly bodies, perfect and incorruptible. Seven of the spheres were to account for the movement of the sun, moon and the five planets known in those days. Altogether there were fifty-five of these hollow, transparent balls, one within the other. The outer and largest was by its very nature the most perfect, Aristotle reasoned. There resided the supreme and perfect creator of the universe, the Divine Being who ruled all. These ideas became involved in much of the theology and religious teachings of succeeding centuries and as such became established as authority that could not be disputed or contradicted.

When an observing scientist discovered that some detail of the scheme was incorrect, he was immediately ridiculed or persecuted out of existence because it would mean that the entire system was imperfect. To maintain this was impious and blasphemous. For example, when Galileo, some eighteen centuries after Aristotle, constructed his first crude telescope, the senators of Rome were delighted to look through it to see ships at sea

which their eyes failed to reach; but when he pointed it to the planet Jupiter at night and discovered four moons revolving around it, the learned men of the age refused to look. By this time the number seven had become sacred; there could be no more than the original seven moving heavenly bodies which were a part of the whole system of thought of the times. To disturb a single part of the system would destroy the whole. Yet Galileo was saying that his telescope revealed four additional moving bodies. He was forced to deny what he had seen through his telescope in order to escape with his life.

Thus man's knowledge and concepts of the universe had become fixed and static. His entire reasoning and thinking processes were based upon authority rather than upon experimentation and careful observation. Then in 1543 in Nuremberg, Germany, an old Polish astronomer by the name of Copernicus, lying half-conscious on his deathbed, received a copy of the book he had spent a lifetime in preparing. It was called "Revolutions of the Heavenly Bodies" and was the result of his quiet and careful observations over many years. Copernicus had discovered, and so stated in his treatise, that the sun was the center of the solar system and that the earth revolved around the sun as did the other planets. Furthermore the earth was rotating on an axis, thus producing the apparent rising and setting of the sun each day.

So well documented a paper as this could not be brushed lightly aside. Instead, it challenged the whole system of an earth-centered universe and all the dogmas that had been established upon this idea. The earth had been removed from its realm of importance and reduced to the insignificance of a revolving planet. Likewise, it was reasoned, man had been dethroned from his place on the summit of creation. Thus the Copernican system affected the human mind and human beliefs in many ways. To accept the idea was intellectual revolution.

While Copernicus had passed beyond the realm of human punishment, some of the contemporary philosophers who championed the idea were dealt with severely; the most notable of these was Giordano Bruno. He not only abandoned the idea that the earth was the center of the universe, but taught that the stars were scattered throughout an infinite space rather than

fixed in constant and finite spheres. For his philosophy and zeal he was burned at the stake in 1600.

The discoveries of Copernicus were slow in being accepted. As time went on, the later studies of Tycho Brahe, the profound reasoning of Johannes Kepler, who formulated the laws of planetary motion, as well as the discoveries of Galileo, which would not be silenced even though he denied his findings, finally established the Copernican system as the true picture of the universe. Any discussion of the many discoveries that followed the time of Brahe, Kepler, and Galileo is not in place here, but during the last three centuries careful scientific study has come into favor again. Throughout that time most of our present and much more rational understanding of the universe was attained.

Increasing Knowledge of the Human Body

Second only to man's attempt to develop a concept of the nature of the universe has been his attempt to understand his physical body and to place himself in proper relationship to the entire scheme of life. This, too, presents an ever-changing picture. The earliest beliefs and deductions that have come down to us represent man as the highest form of animate creation. This idea is supported at present by an immense wealth of scientific information, but the present concept of the relationship of man to the rest of life is quite different from that held in ancient and medieval ages. Furthermore, as the centuries have passed there has been an added accumulation of knowledge regarding the physical body of man. With this greater knowledge has come a better understanding not only of the physical structure and functioning of the human body but of the significance and meaning of human life.

One of the first important efforts to understand the nature of the human body was made by Hippocrates about the end of the fifth century B.C. His chief interest was the healing of the sick, and he has long been revered as the father of medicine. He set for himself a high standard in obtaining the most expert knowledge and maintained a high degree of ethical conduct in his practice of medicine. Even today the Hippocratic oath is taken by every person entering into the medical profession. Hippocrates

was familiar with a great variety of diseases and with a number of remedies that were helpful in curing some of them or in relieving pain. His policy was to be considerate of the patient and to encourage him. He knew that the body itself had large healing powers, if given proper care and attention. He apparently made a number of dissections, had a considerable knowledge of anatomy, and, it is said, performed many successful operations. He demonstrated that disease was not dependent upon supernatural causes and for a time liberated medicine from the magical.

Five hundred and thirty-two years after the death of Hippocrates, a young stranger entered Rome. He was destined to become the most gifted physician of the second century A.D.—and of some fifteen centuries thereafter. Having been trained at the school of medicine at Pergamum in Asia Minor, an institution that made even the learned center of Alexandria envious, and having a thoroughly inquiring mind, the physician Galen (for he was the stranger) soon became well established in the imperial city. Eventually he became physician to the Roman emperor.

Galen was remarkably well founded in human anatomy, having made dissections and studied human skeletons at Alexandria. Whoever today speaks of anatomy pays tribute to Galen. He described many of the muscles of the body and their functions. He described most of the bones of the skeleton, and in these descriptions he made few errors. Also, he discovered many things about the central nervous system. He knew that the brain was its chief organ and that the spinal cord was of next importance. He made a series of cross sections of the spinal cord and brain, which were some of the most important experimental demonstrations of antiquity.

Galen, however, seemed to have learned little about the nature and causes of the great plagues that spread over Europe from time to time. It has been charged by some that he never studied them because of the fear of becoming a victim. Whether this be true or not he did leave Rome on one occasion for a year, presumably to collect medicinal ores and herbs along the seacoast to the east and to study the drugs of the Phoenicians. It was at this time that one of the worst plagues of ancient Europe

was raging in Rome. At another time, he was requested by the emperor Aurelius to accompany him on one of his campaigns. On this occasion one of the plagues was not only thinning the Roman army but also doing more to reduce the opposing peoples than were the Roman legions. The physician informed his ruler that he had been warned in a dream to remain in Rome and attend the emperor's son, who would become sick. Of course, the young boy did soon become ill of some childhood disease and was promptly cured by Galen. For apparently saving the life of a future emperor, the physician received the blessings and favor of the empress as well as a substantial reward from the emperor.

In addition to practicing and teaching medicine in Rome, Galen wrote prolifically. Some of his writings contain his best medical information and have been exceedingly valuable to succeeding generations. However, some were nonsensical and speculative assumptions or vituperative tirades against his contemporary medical colleagues. These parts had a profoundly adverse effect in later times, as succeeding generations made no attempt to distinguish between established truth and misinformation.

Galen's mind seemed to have detested doubt; he craved for finalities. In his writings, all questions regarding the physical structure of the body and medical practice were answered. He solved all problems, and everything was catalogued and tabulated. He sought to make medicine a closed science with his own knowledge and speculations, an absurdity that would have been appropriate to a much less capable mind. His effectiveness, however, was greater than he could have hoped for. After this last of the learned Greek scholars had passed from the earthly scene, there was little progress in the study of human life and human disease for many centuries.

Even during Galen's time it was generally regarded as improper to dissect a human body. The Roman government as well as theological authority soon established laws and canons against such dissections, even though for centuries the wholesale destruction of human life in wars, games for the amusement of the rulers, or feudal disputes rendered it cheap and uncertain. The battlefields and arenas might be strewn with corpses, but everyone shrank from the anatomist's knife. By the time the

Middle Ages had been reached there were centuries when not a human skeleton for study was to be found in all the medical schools of Europe. The belief became established that whoever dissects a cadaver is guilty of sin. It is, therefore, obvious under such conditions that little progress could be made in understanding the nature and functioning of the human body or in the treatment of disease.

As the centuries from about A.D. 600 to 1300 rolled on, the teachings of Hippocrates and Galen were forgotten. Treatment of disease was first reduced to prescribing obnoxious concoctions of such things as bitter herbs, emasculated insects, and dirt from wagon ruts; often these were administered with the repetition of words of magic or with supplications to some deity or demon. Later it became the fashion to prescribe magical treatments. One of the most famous of such formulas was the magic word "abracadabra." This word was written, rewritten, and again rewritten, one letter at the end being dropped with each rewriting until only an *a* remained. The shortened word was written each time immediately beneath the one above it, in such a way as to produce an inverted cone. The piece of paper on which it was written was tied about the neck of the patient with a flax string and was supposed to cure or prevent disease. The Dark Ages of the study of human life had been reached.

Of course, such practices were eventually reduced to the ridiculous. In later centuries, the monks in the monasteries rediscovered the writings of Hippocrates, Aristotle, and Galen. These writings were learned and recopied so extensively that they eventually developed into a sort of authoritative law. Some of their teachings were widely and blindly followed to the extent that they were accepted as true upon authority and hence were not subject to contradiction by any man. Even at the University of Paris, which had become the medical center of the Middle Ages, surgical operations and bedside examinations were outlawed. These customs along with the widespread belief in divine healing constituted most of the medical practice of the later Middle Ages. In these times the physical body came to be looked upon as unworthy of high regard or understanding. It was taught and widely believed that the body was vile clay, imprisoning the soul.

Then in 1543, a young Belgian by the name of Vesalius published a book entitled "Fabric of the Human Body," and it is noteworthy that it appeared in the same year as did Copernicus' treatise on the heavenly bodies, which changed our whole thinking regarding the make-up of the universe. Vesalius made a clear and lucid description of the structure and functioning of the human body, one that he had learned from actual experimentation. It was beautifully and accurately illustrated by excellent drawings made by a competent artist. In it Vesalius challenged and corrected about two hundred incorrect statements made by Galen some thirteen hundred years before, which by this time had become such authority that to dispute them was blasphemous.

For example, Galen had said that venous blood mixed with arterial blood through pores in the heart. Every anatomist since Galen's time had imagined that he had seen such openings. Vesalius showed there were none. He was immediately attacked by the professional and ecclesiastical men of his day as being mad and dangerous. But as his thoroughness in teaching increased, his fame spread. Many followers were attracted to him in order to have revealed to them the wonders of the human body.

Finally, a nobleman of Italy died, and Vesalius performed a dissection on his body in the presence of many spectators. To the surprise of Vesalius and the rest, the heart was still beating, and the unpleasant story spread fast and far. One unauthenticated report has it that Vesalius' untimely end came when his enemies charged him with impiety and murder and condemned him to death. Gradually, however, his teaching became widely accepted. It produced revolutionary ideas regarding the significance of the human body and the life that courses through it. His anatomy and his evaluation of experiment have become modern practice.

Another discovery, made about the middle of the nineteenth century, revealed much about the functioning of the body, particularly as it relates to disease. This time it was a French chemist by the name of Louis Pasteur who was the master mind. He established what is usually referred to as the germ theory of disease, and this discovery constitutes one of the greatest single



Pasteur's discovery "constitutes one of the greatest single achievements of mankind."

achievements of mankind. Before Pasteur's time the causes of disease were unknown, and its treatment was primarily a trial-and-error process. Since his discoveries medicine has become an exact science, and many of the plagues of mankind have come under human control.

Pasteur began his epoch-making work by a study of the fermentation of wines. He finally discovered that fermentation was produced by microscopic organisms acting on the grape juice. Further, he demonstrated that there were many types of fermentation and that each type was caused by its own specific organism. Then, in 1865, he was approached by some silkworm raisers whose silkworms had a serious disease, called pébrine, which threatened to destroy the silk industry of southern France. He accepted the challenge to find the cause of the disease and a remedy for it. In a few years, after a prodigious amount of work by Pasteur and equally as much ridicule by the medical profession of his day, he had found that certain microorganisms within the bodies of the silkworms were producing the disease. He isolated these germs and found how to control them, and thereby saved the silk industry of France.

He then reasoned that the contagious diseases of man and other animals were caused by the presence in their bodies of various specific types of small organisms. However, his results and judgment were in no wise generally accepted. A few faithful colleagues, notably Joseph Lister of England and Robert Koch of Germany, continued investigations into the causes and control of disease. Finally, Pasteur's own work in 1877 was the turning point in establishing the germ theory of disease. He demonstrated that splenic fever, a devastating cattle and sheep disease, was caused by a type of microorganism known as anthrax bacteria and that these bacteria could be killed and the disease cured by a vaccine he had prepared.

The demonstration had a dramatic staging. His medical and veterinary opponents induced him to perform a public experiment. They hoped that his failure, which they believed inevitable, would discredit him and leave them to the pursuit of old methods that they understood. However, the plan proved to be a veritable boomerang. A number of sheep were collected amid a large public gathering and divided into two groups. The first group Pasteur inoculated with his anthrax vaccine; the other group was left without vaccination. Fourteen days later all the sheep were injected with a virulent culture of the anthrax microbes which Pasteur knew caused the disease.

During the day and night following, the unvaccinated sheep began to get sick. As the news spread, more people collected at the demonstration farm. Those were anxious moments. The question in everyone's mind was whether or not the vaccinated sheep would succumb to the disease. That night Pasteur received a staggering note to the effect that one of the vaccinated sheep was dying with the disease. However, it proved to be erroneous. When morning came he went to the experimental lots amid cheering and grateful people who had already learned the results. Not a thing had gone wrong. The sheep that had not been vaccinated lay dead from the disease, while the vaccinated ones browsed in their lots with perfect health. The cause and control of splenic fever had been established.

In 1880, Koch found the bacteria causing tuberculosis and in the following year discovered the bacteria causing cholera. Within the following fifteen years most of the diseases caused by

microorganisms had been successfully studied. The germ theory of disease has become an established fact. We now have vaccines and serums that prevent or cure smallpox, typhoid fever, yellow fever, lockjaw, diphtheria, and many other contagious diseases.

Changing Concepts of Life's Relationships

On the earth today there are something like a million different kinds of living creatures that are known to man. A great many of these different forms, or species, were observed by the peoples of ancient times; this number, however, was much smaller than that known at present. It is now known that many of these species are closely related to each other and that others are more distantly related, some only remotely. Early man knew of no such specific relationships. Today it is well established that all living creatures have certain fundamental things in common. All life has apparently arisen from one common source and through the ages has separated into the great diversity of modern forms. This concept of life is one that has been developed only in recent times. It marks a distinct change from man's thinking of a great many centuries past. It has come about as a result of the accumulation of a great amount of information regarding the structure of the physical bodies of different animals and their life processes and development.

The first attempt at a definite classification of animal life and a study of their relationships was made by the early Greek natural philosophers. One of the foremost of the natural research workers was Democritus, who lived during the fifth century B.C. He must have studied and observed the bodily structure of a great many creatures, both large and small. He distinguished between the vertebrate and invertebrate animals and believed that even the smallest creatures observable to the unaided eye possessed many body organs. These organs, he held, increased in complexity and number with the larger animals until the body of man was reached, which represented a sort of world in miniature. He believed that there was a decided relationship between cause and effect both in animals and in inanimate nature and that different animals had different body forms and functions because of some influence that had been exerted upon them.

The first great systematizer of biological knowledge was Aristotle, who lived from 384 to 322 B.C. He had observed a large number of species and collected in his writings all contemporary knowledge of animal life. He held that animals may be classified according to their way of living, their actions, their habits, and their bodily parts; that is, they were divided into land animals and water animals. Then, the water animals were divided into groups that could swim, those that could only creep, and those that were adherent to rocks or ocean bottoms. The land animals, also, had certain similar characteristics in regard to their habits and ways of living.

However, his most important basis of classification was the parts of animals bodies. This, of course, is the most significant criterion in modern biology; but, Aristotle was handicapped in knowing little about such body structure except what he could observe from outside appearances. Thus, he separated the animals into such groups as mammals, birds, fishes, whales, shellfish, and crayfish. Each of these large groups constituted a sort of genus, according to Aristotle's scheme. Within each large genus there were many individual forms, such as the horse, lion, or dog in the mammal group. It is seen, therefore, that he began a kind of system for grouping animal life, even though his classifications were often erroneous because of a lack of definite knowledge of body structure.

He also studied reproduction among animals and was remarkably familiar with the embryonic development of the chick. He was familiar with it to the extent that he was able to give clear statements of the structure of the embryo and the development of the body parts at different stages in embryonic growth. In particular, the growth of the heart, blood vessels, eyes, and legs was carefully explained. He used reproduction as a means of differentiating between animals, including three divisions, those that reproduce by sexual means, those that reproduce asexually, and those that arise from spontaneous generation, for he believed that many small forms arise out of decaying substances. Thus his system became more and more complex. Perhaps its greatest merit was that it was better than no system.

In addition, Aristotle drew up a scale in which the animals were placed according to their development and pointed out

that those animals are highest which have a warm and moist nature and not an earthy one. The most perfect animals were those provided with lungs, which possessed warmth, and whose young were born alive; of these man was held to be the highest. Then he developed a complicated scheme in which the male was placed in superior position to the female. Likewise, the next lower animals were the land forms which laid "complete" eggs, such as birds and reptiles. These were followed by the cold and earthy animals that lay "incomplete" eggs, such as frogs and fish. And the lowest of all were the smaller creatures of other groups. It is seen that there was a definite and decided separation of animal life into these various groups. Later generations added the idea that there was little or no connection between them.

Aristotle, therefore, became the founder of systematic biology, and his teachings were the dominant note in biological thought for more than fifteen centuries. They became adopted in many of the ecclesiastical laws as well as being considered standards for intellectual discussions. In this manner they came to be accepted upon authority to such an extent that they produced stagnation in biological work for a great many centuries. Under such circumstances the biology of antiquity, in spite of its splendid beginnings, never advanced beyond Aristotle's conception of the phenomena of life.

About the middle of the eighteenth century a work on the classification of plants and animals was completed that was of inestimable value in reducing to order a wealth of disconnected information regarding plant and animal life and in showing many of the relationships that exist between them. This was the system of classification developed by the distinguished Swedish botanist Carl Linnaeus. While still a young man, Linnaeus developed a keen interest in botany and found little satisfaction in the pursuit of the academic studies of his early schools. He finally accepted the advice to study medicine and went to the university at Upsala. His first year there was spent in dire poverty; however, he had a remarkable quality of attracting admiration and sympathy from many of his acquaintances. Soon he acquired friends among the faculty of the university and gained one success after another.

The following year as an undergraduate he obtained permission to lecture on botany and attracted large audiences. He received a number of grants on which he traveled to different parts of Sweden to collect material for research on natural objects. On one of these trips he met his future wife, the daughter of a wealthy physician. With the financial assistance of his father-in-law to-be he traveled and studied in Holland, eventually receiving the degree of doctor of medicine. While there and while still in his twenties he published his epoch-making work, the "Systema Naturae," which brought him immediate fame. He later returned to Upsala and was made professor of botany, where from the day of his arrival he became the foremost member of the university. His later publications followed each other in rapid succession. He founded many schools and sent some of his pupils on research expeditions to remote parts of the earth. In organizing work and reducing an enormous amount of biological knowledge to order and system he has had few equals.

His biggest contribution probably consisted in establishing the species as the basis of classification of living creatures and in giving to each species a double scientific name. In his system a species consisted of all examples of creatures that were alike in minute detail of body structure. During his lifetime he described many thousands of species of plants and animals. The species most alike were organized into genera, while collections of similar genera constituted different orders. All the similar orders were grouped into larger divisions, the classes. With a few modifications, this system is still used in classifying plant and animal life, and it has been of inestimable value in reflecting the relationships that exist in organic life. The scientific name for each creature consists of its generic and specific title. For example, the domestic house cat is *Felis domestica.*

It was Linnaeus' theory, however, that each species of creatures was created by some special act in the very beginning as it now exists and that creatures of each species were unchangeable. He held that one single pair, one of each sex, had originally been created, and that each one then reproduced its kind through the ages in all respects like the parents and thereby accounted for all the different species now existing. There was

no room for spontaneous generation in such a theory, neither was there any possibility for the seeds of one plant to give rise to a different kind or for any animals to produce species other than those of their own parents.

It is not known whether Linnaeus actually formulated in any positive fashion such a theory or merely accepted the prevailing ideas of his time in this respect. However, these ideas appear repeatedly and forcibly throughout a great deal of his work. They had a profound influence in encouraging the continued acceptance of these concepts for a century following his death.

In 1831 a young Englishman twenty-two years of age sailed on a five-year voyage around the world. He was the unsalaried ship's naturalist on H.M.S. "Beagle," which was to circumnavigate the globe, mainly in the interest of map making. The naturalist in question was Charles Robert Darwin. The voyage of the "Beagle" not only did much to map the oceans of the earth, but was also the beginning of a long and prolific life's work by Darwin, which did much to change man's concepts of the nature and relationships of all living creatures. The three years previous to the sailing of the "Beagle," Darwin had studied theology at Cambridge after having given up the study of medicine at Edinburgh because of boredom with the medical teaching of his day. He was advised against the trip by his parents and nearly rejected by the ship's captain because of the shape of his nose. However, his father gave his consent upon the recommendation of an uncle, and, as Darwin himself remarks, the voyage was the most important event in his life.

During the five years of the trip, Darwin sent home copious notes and large collections from every stopping point. After returning to England he spent many years in working over the material he had collected and set a great many experimental studies for himself. At the age of thirty he married his cousin, Hanna Wedgwood, of the family of ceramic fame, and her considerate helpfulness and wealth enabled him to lead the quiet life of a scholar. This became an absolute necessity because of increasing ill-health that had been started by his almost continual seasickness on the extended exploration. It is said that his bodily existence, so full of suffering, was compensated for throughout his life by a freedom from passion, hate, envy, and

ambition. His ideas came to be unreservedly praised or violently attacked. He met the attacks with calm steadfastness and always took note of and answered material objections. These qualities won for him great personal esteem, and when he died at the age of seventy-three he was mourned by the most distinguished scientific and social people of his time.

His studies showed him that there are many variations within different species of plants and animals. These variations, he found, increased gradually as distance and isolation from the native home of the species increased. For example, he found that on the desolate Galápagos Islands situated off the coast of South America was a fauna of distinctly South American genera although of different species. Many other variations were noticed on the voyage. One instance was that certain insect forms on islands in mid-ocean have restricted powers of flight as compared to the same species on the mainland. In studying the changes that had been produced in breeding domestic animals in England and on the Continent, Darwin observed that new species had been developed; that is, the bulldog and greyhound, both of which had been developed from the wild canine type, differed from each other more than the variations he had found in many wild life forms that were considered one species.

On the basis of such observations and as a result of long study, he finally formulated his theory regarding the variation and development of species, which was published in 1859 under the title, "The Origin of Species by Means of Natural Selection." In this work he explains that in the struggle for existence those life forms which are less capable of adapting themselves to their environment are destroyed, while the individuals which have certain variations suitable to prevailing conditions survive and reproduce themselves. The environment itself comes to favor the differences brought about by variations in the offspring in relation to their parents, until a new species may arise.

Thus, the restricted powers of flight of insects on mid-ocean islands resulted from a selection of that characteristic as best suited to survival in that environment. The wide-flying varieties of the species were held to have been blown out to sea by the strong winds and to have perished. This condition of nature is not encountered on the mainland, where the flying varieties of

the species are found. Similarly, the life forms on the Galápagos Islands developed from the South American forms that were isolated in the islands because of the natural selection of certain variations in the offspring that were suitable to the different environment there, while the old forms perished in the struggle for existence. Consequently, the struggle for existence induces natural selection that operates to produce the origin and development of new species. Darwin maintained that the idea of natural selection operating in life tended to produce higher and better forms until perfection was reached.

This was a concept of life that was of a marked difference from the old idealistic natural philosophy, in which it was believed that each species had been produced by a special act of creation and that the species possess an independent and immutable existence. However, it was not only a concept that brought order into the attempt to account for the great varieties of living creatures, but also one that had an optimistic outlook on life processes.

Darwin's work, for the first time in history, established the general idea that all living things are related—that existing forms, as well as many extinct ones, have arisen through descent with change from preexisting forms. Many of the detailed facts on which the original theory was based have since been shown to be of secondary importance. Darwin's theory of the origin of species, at least as originally stated, has long since been abandoned. Thus, it is now known that the principal factors controlling the production and propagation of new varieties and species of plants and animals are inherent in the hereditary mechanism itself. The theory of natural selection is retained in principle, but its application is known to be restricted owing to the limits imposed upon variation by the physical nature of the hereditary process. The essential idea of the theory of evolution has become well established as the central concept of natural philosophy. Not since Newton's formulation of the gravitational law has a scientific theory so deeply influenced man's general conception of life as Darwin's has.

One of the important results of Darwin's work, and of the controversies which have raged over it, has been to introduce into biology the modern spirit of scientific research and to

establish man's freedom to base his views of living processes upon the results of that research. During the half century since Darwin's death a wealth of information has been obtained which gives us not only a better understanding of the processes and relationships of life, but also a greater appreciation of life's values and significance.

The pages which are to follow contain a general survey of some of the conditions and characteristics relating to living things that are well understood today. Particular emphasis is placed upon the physical structure of the human body and the nature of the living processes within it. The first chapters may be regarded as a kind of introduction, in which certain physical conditions of the earth's surface are described which make life possible and to some extent pleasant. This is followed by an examination of the characteristics of living things, the development of life on the earth throughout the geologic past, and some account of modern forms with special reference to man himself.

REFERENCES FOR MORE EXTENDED READING

NEEDHAM, JOSEPH, and WALTER PAGEL: "Background to Modern Science," The Macmillan Company, New York, 1938.

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LOCY, W. A.: "Biology and Its Makers," Henry Holt & Company, New York, 1908.

This is a well-written history of biology that is developed around the lives and works of the men who have contributed most to it.

VALLERY-RADOT, RENÉ: "The Life of Pasteur," Doubleday, Doran and Company, Inc., Garden City, 1923.

The English translation of this French biography is an interesting and detailed account of Pasteur's life work and the contributions he made to biological and medical science.

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A concise and authoritative discussion of the development of such scientific knowledge of the early and immediate past as is necessary to explain the philosophic thought of those times.

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NORDENSKIOLD, ERIK: "The History of Biology," translated by Leonard Bucknall Eyre, Alfred A. Knopf, Inc., New York, 1928, Chaps. III, V, Part One; Chap. VII, Part Two; Chaps. VIII, XVII, Part Three.

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WOLF, A.: "A History of Science, Technology and Philosophy in the 16th and 17th Centuries," The Macmillan Company, New York, 1935, Chaps. I, II, VI, XVIII.

These chapters include a comprehensive treatment of the advances made in astronomy and biology during the sixteenth and seventeenth centuries. Most of these chapters is written around the work and discoveries of the leading scientists of these two centuries.

WOLF, A.: "A History of Science, Technology and Philosophy in the 18th Century," The Macmillan Company, New York, 1939, Chaps. I, XV, XVII, XVIII, XIX.

Included in these chapters is an account of advances made in the study of geology, botany, zoology, and medicine during the eighteenth century. A companion volume to the earlier publication.



2: SOLID SURFACES

Or a Consideration of Some of the Features of the Earth's Crust

SOME understanding of the nature of the earth's crust has been of great advantage and importance to man. Upon its surface he lives and exerts his activities. From it he digs his fuels, building materials, water, salt, and minerals. The plants, which get their substance from the soil and air, provide him with food. This thin surface, including the air above it, provides a home for life on the earth. So far as we know, it is the only place in the universe where such life exists.

While we have some knowledge of the structure and density of the interior of the earth, it is chiefly the relatively thin outer layer known as the earth's crust that has been extensively studied. It is the only part of the earth that is directly accessible to man and, therefore, the only part that can be thoroughly investigated. This outermost layer is a shell of rock about twenty to one hundred miles thick. It is a small covering, indeed,

compared to the eight thousand miles of expanse through the entire earth. However, it contains the continents and ocean beds and because of this it is the most important part of the earth to us. Many remarkable changes have occurred in the earth's crust during past geologic ages. These have not only brought about the present geographic features of land and sea, but also made for conditions that have profoundly influenced life here.

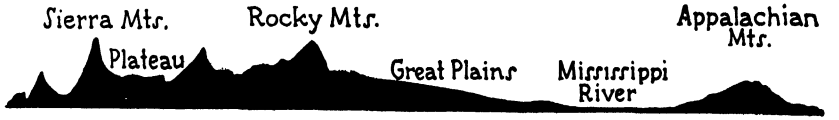
Earth's Relief

To a person traveling over the earth, its surface seems very irregular. The land part has valleys, hills, and mountains. The oceans seem very deep. These irregularities of the surface, or the relief form of the earth, are great or small only by comparison. A person on foot finds them very great, one in an automobile less so; a person flying in an airplane finds them much less. As Howard Hughes and his four flying companions recently winged their way around the earth in less than four days, they probably noticed little of its up-and-down surface beneath them.

Compared to the total size of the earth, its relief is very small. In this sense it may be considered a smooth ball, much smoother relatively than the surface of an orange. The highest elevation of the land, Mount Everest in The Himalaya, is approximately 29,000 feet above sea level; the deepest known point in the ocean, in the Pacific, is about 35,000 feet below sea level. This makes a total difference in elevation of some 64,000 feet, or about 12 miles. Between these extremes exist all the relief elevations. However, about ninety per cent of the earth's people live in a narrow elevation extending from the level of the sea to about one-fifth of a mile above sea level. The mean height of all land areas above sea level is approximately 2,900 feet. In North America the average is less, about 2,400 feet. The average depth of the oceans is 13,000 feet, it being greater for the Pacific than for the Atlantic.

The main features of the land consist of plains, such as the Atlantic Coastal Plain; plateaus, such as the Colorado Plateau; and mountains, such as the Appalachians. One thing that is relatively characteristic of the relief form of continents is that they tend to have mountain chains as coastal rims with interior

plains or basins. The North American continent is especially typical of this condition. The major relief divisions of this con-



General relief divisions of North America found in the United States. Vertical scale greater than horizontal scale.

tinent, all of which extend through the United States, are the Atlantic Coastal Plain, Appalachian Highlands, the Interior Plains, Rocky Mountain System, Intermountain Plateaus, and Pacific Mountain System.

Within these relief divisions are found most of the varieties of rocks, soil, and geographic features that constitute the land surface of the United States.

Rock Materials

There are three principal classes of rocks which make up the earth's surface, including the continents and ocean beds. They are igneous, sedimentary, and metamorphic rocks. These constitute the bedrock that forms much of the outer portions of the earth's solid masses. In addition to the bedrock, there is spread over most of the land part of the earth's surface a sort of rock debris called mantle rock. This debris is in various stages of disintegration and decomposition. It is not a separate class of rocks from those mentioned above, but it consists of broken fragments of them.

Mantle rock consists of sand, soil, pebbles, and boulders, together with decaying remains of organic tissue. At most it consists of a very thin skin over the rocks beneath and in some areas it does not exist at all. However, it is this exceedingly thin skin that supports most of life on the land, including man himself. Without it, life here would be quite a difficult process. Mantle rock is continually being shifted about by winds and water and being used up to form some of the more permanent rocks mentioned above. However, its supply is ever replenished by the same forces which produced it originally.

Great areas in the United States are covered with mantle that has been produced by weathering of older rocks. In regions

of plentiful rainfall this rock debris usually becomes covered with a layer of soil. The soil and mantle often show a gradual change downward into the bedrock beneath, and this gradation indicates that the mantle rock has been slowly built up from the rock it covers. Such a formation is referred to as residual mantle. In other regions the weathered debris has been deposited by running water, wind, or other agents of transportation. Old river valleys and flood plains are likely to contain layers of this mantle. The same is true of regions that were once covered by glaciers. This kind of rock debris is known as transported mantle.

In the northern part of North America and Europe millions of acres are covered with drifts of mantle rock which have been deposited by glaciers in past ages. They consist of sand, pebbles, and boulders spread out in rolling sheets and covered with soil. This is the unsorted debris that was carried along with the glacier, then dropped as the ice began to melt and the glacier to recede, the soil being formed during later times. What is often found is a great ridge of unbedded material piled up by the melting glacier. Extending out from such a ridge will usually be a series of outwash plains of sand and gravel that have been carried away by the running water. The ridges are called terminal moraines. Such moraines have greatly added to the fertility of the soil, and particularly to the features of the landscape. Many of the low-lying hills of New England and the Middle West were formed by glacial deposits. The many small lakes of Wisconsin, Michigan, and Minnesota that make those states popular vacation lands had their origin in the same process.

Igneous Rocks

One of the great divisions of rocks making up the earth's surface and much of its subsurface are the igneous rocks. These are the so-called fire-formed rocks; at least, that is the meaning implied by the term "igneous." Those formed on the earth's surface were produced by the solidification of molten masses, called "magma," that have come up from within the earth. The magma may be discharged from volcanoes or flow out of fissures in the earth's crust as streams of lava. While volcanoes are the more spectacular and better known examples of lava

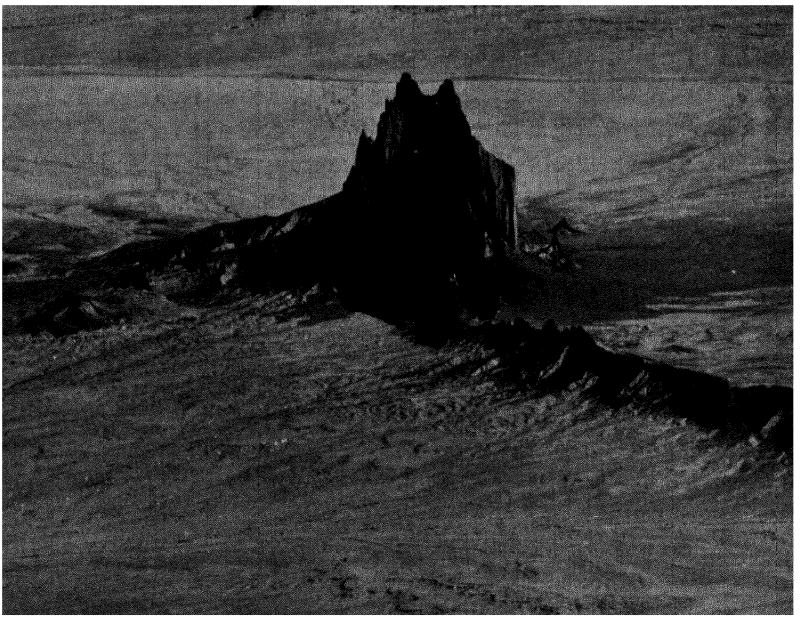
flow, other greater movements of this molten rock have occurred to form large areas of the earth's surface bedrock.

The formation of igneous rocks has occurred in two general ways. In one instance the magma rose from the depths of the earth to higher levels but was stopped before it reached the surface. By a slow process of cooling, the magma gradually hardened into masses known as igneous intrusions. These rocks may be seen on the surface only where erosion or other forces have removed the overlying formations and exposed the intrusions to view. In the other case the rising magma has reached the surface, where the lava flowed out, either violently or smoothly, to form deposits that cooled more rapidly than the intrusions. Such rocks are called igneous extrusions. They form the well-known volcanic cones and great lava beds or thick deposits of basaltic rock that cover large areas of land.

Igneous Intrusives

On the relatively flat landscape of western New Mexico just south of the Mesa Verde National Park is a curious elevation known as Shiprock. It was so named because it resembles a sailship on a flat ocean surface. An examination of its structure shows it to be a volcanic neck standing some 1,300 feet above a wide expanse of sedimentary sandstone formation, and extending out from it for several miles is a low-lying, narrow, igneous dike. By reconstructing the picture of the formation of this unusual feature of the flat country, it is known that it originated from a mass of lava that was forced up along a fracture in the sandstone, which at the time had a much greater thickness than at present. The flow of the lava was arrested before it reached the surface, and slowly it solidified into igneous rock. A later erosion of the softer sandstone through many hundreds of feet has left exposed the more enduring igneous rock, and its contour is evidence of the general shape of the vertical fracture into which the lava was forced.

This formation and many others similar to it are examples of smaller intrusions of once molten lava into fractures in the overlying rocks, the flow of which was arrested before the lava reached the surface. Perhaps the best known example in



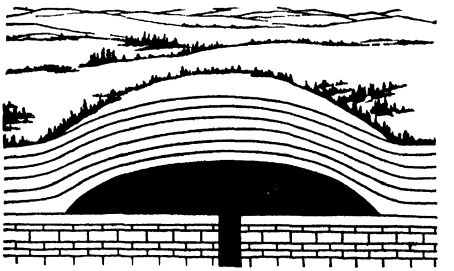
Airplane view of Shiprock near Farmington, N. M., a volcanic neck projecting about 1,300 feet above the surrounding country. (Photograph by Barnum Brown, American Museum of Natural History.)

America of a lava intrusion between horizontal layers of overlying rock are the Palisades along the west side of the Hudson River.

Examples of other intrusive actions on a larger scale are seen in certain dome-like mountains known to the geologist as laccoliths, the classic example of which are the Henry Mountains in Utah. The Henry Mountains are elevations that project some 5,000 feet or more above the surrounding, deeply eroded, sandstone formations and highly inaccessible country. The mountains are covered with strata of sandstone, and it is only along the sides, where a long period of erosion has enabled running water to cut through the overlying layers, that the igneous core beneath them is revealed.

The Henry Mountains, and others similar to them, are really great "blisters" on the earth that were formed by lava intruding itself between the layers of strata and arching it up into great domes. Without breaking through to the surface, the lava hard-

ened and formed the igneous cores of the mountains. In such cases the lava has apparently come up from below through a relatively narrow fissure and then spread itself out horizontally as it pushed up the strata above it.



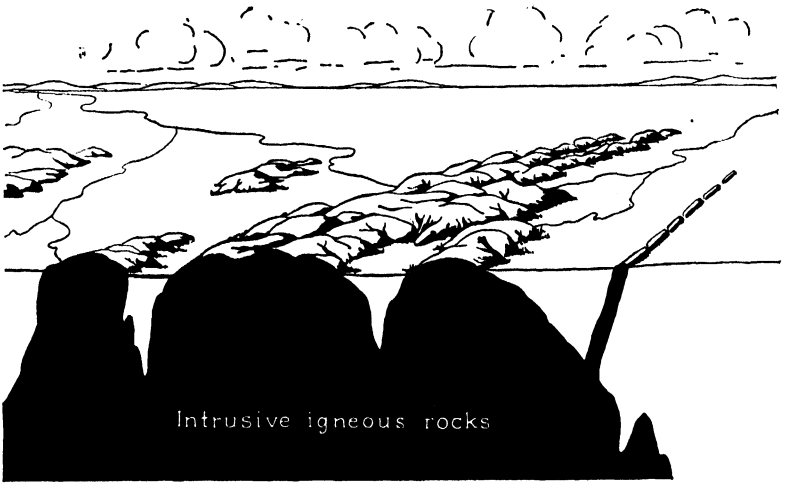
The Henry Mountains and others similar to them, known as laccoliths, were produced by lava intruding beneath layers of overlying strata, and arching it up into great domes. Without breaking through to the surface, the lava hardened and formed the igneous cores of the mountains.

The formation of igneous intrusives on a grand scale is seen in some of the great mountain belts of North America and other continents. They have become visible through exposure by erosion, or elevated to the surfaces by processes of mountain making. These intrusives are enormous bodies of igneous rocks that seem to extend downward indefinitely into the earth's crust and are the main units in the structure of great areas of its surface. They are technically known as batholiths, and they consist chiefly of granite, this being an igneous rock formed by magma cooling beneath the surface.

The largest batholith in the United States is the one in Idaho, which is exposed over an area of about 16,000 square miles. The Sierra Nevada Mountains is another example of such a formation on a large scale. Here elevation of the mountains has exposed great areas of granite. In some places high mountain peaks have been formed, one of which is Mount Whitney, the highest point in the United States. Just to the east of Mount Whitney the Sierra elevation drops rapidly into Owens Valley, and it is revealed that the granite layer is at least 8,000 feet thick. From this peak extend in all directions for many miles, even hundreds of miles in some directions, great ranges of granite which are silent evidences of former great movements of magma.

Igneous Extrusives

One of the most spectacular scenic views in Northwestern United States is the Seven Devils Canyon in the Columbia



Many great mountains of Western North America and other continents consist of enormous bodies of intrusive igneous rocks which seem to extend downward indefinitely into the earth's crust. They are known as batholiths. The illustration represented above is about 20 miles wide. (Redrawn from Longwell, "Physical Geology.")

Plateau. Here the Snake River has cut a winding trail more than three thousand feet deep in an enormous bed of lava flow that covers an area of more than 200,000 square miles. The structure of the igneous rock as well as the sedimentary deposits now covering it, except where they have been removed by erosion, reveal that this area was once covered with great seas of molten lava that flowed to the surface, where it cooled relatively fast. The lava that once deluged this wide expanse of country must have flowed over the land without any explosive activity, as it has formed broad plains, the beds of which often show horizontal layers. The chief rock of this formation is basalt, which is a hard and enduring type of igneous rock that is often formed by lava cooling on the surface.

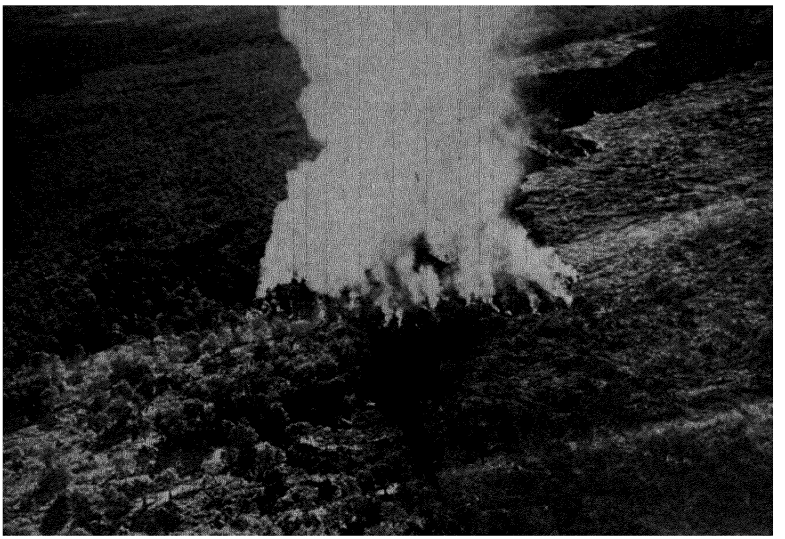
Another example of mass eruption of lava is to be found in western India. There an area equally as large as the Columbia Plateau is covered with basalt which reaches a maximum thickness of about six thousand feet. Likewise, the bedrock of the northern part of the British Isles as well as the islands to the north is remnant of a basalt plateau which has been deeply eroded by the sea since its formation. It may be that this plateau once extended as far north as Iceland.

Volcanoes are a form of magma flow that is more generally known than any other process of igneous rock formation. This is so primarily because of their quickness of action, spectacular displays, and visible evidences of damages done. One of the more recent volcanic eruptions that received wide notice was the activity of Mauna Loa in Hawaii in 1935. During this year there was an outpouring of lava which exceeded in volume any other similar activity witnessed by modern man. A sea of molten rock flowed down the side of the great cone from an elevation of about nine thousand feet, where it erupted, and threatened to destroy the town and harbor of Hilo at the seacoast near its base. A series of bombings by the U. S. Army Air Service diverted the flow from its course toward the town, and some of it finally spilled into the sea at a safe distance before the eruption ceased. The volcano itself is a mass of igneous rock that has been built up to an elevation of nearly fourteen thousand feet by former eruptions, and it is the largest of all modern volcanoes. These recent eruptions have added another layer of lava rock to its expanding sides and base.

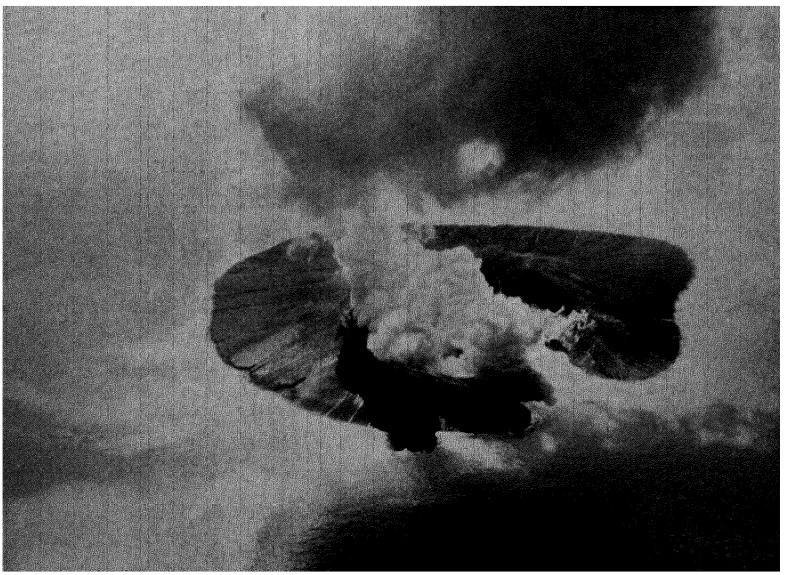
Perhaps the most violent volcanic eruption of modern times is the one that occurred in 1883 at a volcano in the Indian Ocean near Java, known as Krakatao. The volcanic cone exploded and the entire island was blown to pieces. Dust from the explosion was thrown upward for many miles and carried by the winds over the entire earth, producing in many places such brilliant sunsets as had never been seen before. The force of the explosion caused waves in the sea some fifty feet high which swept away the coastal villages in near-by Java and Sumatra.

It is not to be implied by these two examples that all volcanoes either pour forth great volumes of lava or erupt with explosive violence. In many cases volcanic activity may consist primarily of the escape of water vapor and carbon dioxide gases, accompanied by smaller quantities of other gases, such as hydrogen chloride and hydrogen. In all cases, it is generally believed that such gases come from the magma itself, being discharged when the pressure on the magma is released as it moves through the vent to the volcanic cone.

Many different-shaped volcanic cones may be built up, the size and shape depending upon the nature and materials of the

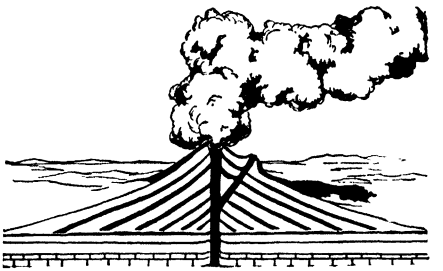


The flow of lava from Mauna Loa, Hawaii, in 1935 destroyed the forests in its path and threatened the town of Hilo on the nearby coast. A river of the lava is shown in the upper right corner of the picture. (Science Service photograph.)



Recent airplane view of Krakatao, showing the stump of the neck that remains today. The volcano blew up in 1883, producing the loudest noise modern man has ever heard. (Life Magazine photograph, courtesy of N.E.I., Army Air Corps.)

eruptions. These vary from the relatively symmetrical cones with a small vent or opening at the top, to the large and irregular-shaped ones, some of which may have many vents of different ages. Crater Lake in Oregon is on the summit of a volcanic mountain of basalt that has long since ceased to be active. Apparently the entire top of the old volcano "caved in" to form a great pit some five miles in diameter and about four thousand feet deep. It is now about half filled with water of a beautifully blue hue, making this lake one of the most spectacular in all America.

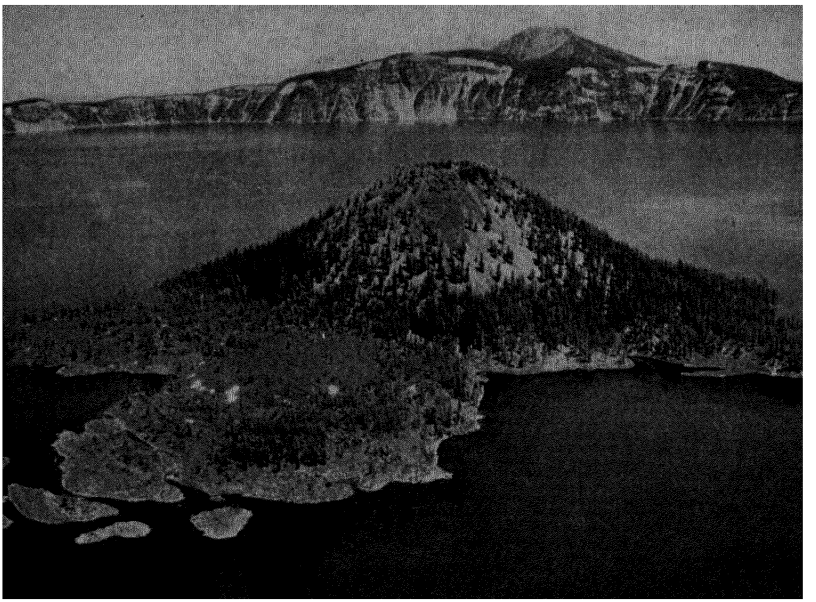


Volcanic cones are built up in various shapes and may consist of a variety of rocks. The one illustrated above has two vents that have been active. The cone is built up of strata of solidified magma, represented by the black lines, and strata of other materials, such as volcanic ash and wind-blown sediments. The magma producing volcanoes rises through a vent in the strata below the cone from some reservoir at a greater depth.

The source from which such great quantities of magmas come which produced the volcanoes and other greater flows of lava is still somewhat undetermined, especially as regards magmas of different types and different chemical composition. However, it is likely that the parent lava from which all diverse forms are produced is basalt and that the other forms result from chemical changes which occur in the basalt as the magma is pushed upward. The ample source of basaltic magma is believed to be a deep layer of basalt that underlies all the earth's crust. This basalt is probably in a rather solid state at the pressures exerted upon it, although it is very hot. When this pressure is lessened by some weakening in the crust above, the basalt becomes somewhat liquid and begins to flow toward the surface through some vent, fissure, or crack in the overlying rocks.

Sedimentary Rocks

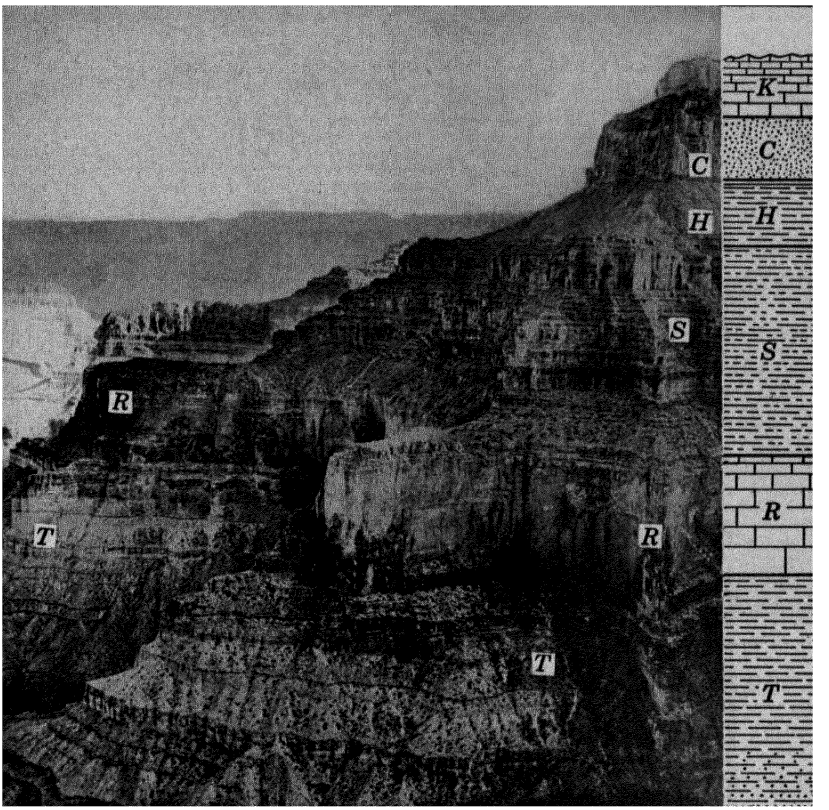
The Grand Canyon of the Colorado River is widely known to the peoples of the earth because of its ever-changing beauty and gigantic size. Here the river has cut its way into the earth to a depth of about one mile and to a width of twelve to fourteen



Crater Lake, Oregon. The lake's surface is six miles long, four miles wide, and 6,293 feet above sea level. (Photograph by Ewing Galloway.)

miles. In addition to the scenic grandeur of the mighty chasm, its eroded walls have exposed in one great picture geologic processes throughout many millions of years. The upper four thousand feet of these walls consists of nearly horizontal layers, or strata, of sedimentary rock that have been cut through and laid bare by the eroding river. These rocks have been formed as a result of thick beds of sediments that were deposited in past geologic ages. Some of these sediments were laid down when the area was beneath an inland sea, and others were deposited at times when it was elevated above the water. A slow elevation in relatively recent geologic ages has caused the river to cut deeper and deeper as the surrounding country has been raised.

The lowest formation shown in the accompanying picture of the canyon wall consists of shale and sandstone more than one thousand feet thick. Above it is a five hundred-foot layer of Redwall limestone whose massiveness causes it to form many steep cliffs and some of the most interesting scenery of the canyon. The next overlying layer is a thick series of shales and



South wall of the Grand Canyon of the Colorado River near El Tovar, showing six sedimentary formations. They are lettered to correspond with explanations in the text. (Photograph by N. W. Carkhuff, U. S. Geological Survey.)

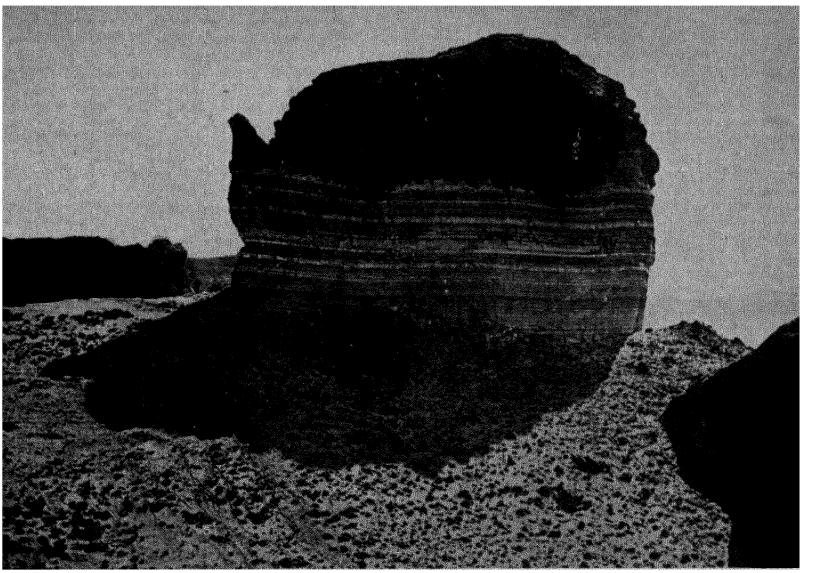
sandstones. Above these is a layer consisting entirely of shale. On top of this is a layer of white sandstone known as Coconino sandstone. Above this and forming the top layer is the Kaibab limestone that was deposited under a sea that flooded this country.

The formations that are shown on such a large scale at Grand Canyon are examples of sedimentary rocks. These rocks underly large areas of the entire land part of the earth. In some places these sedimentary rocks extend to depths of forty thousand to fifty thousand feet. In other places they may be very thin and, of course, in still others they do not exist at all. These are formations that were once sediments which have since changed into rocks. They constitute a second group of the earth's bedrocks.

One of the most noticeable features of sedimentary rocks is that they usually consist of layers or strata. These layers may vary greatly in thickness from a fraction of an inch to many hundreds of feet. In most cases the strata differ from each other in some manner, such as a difference in color, texture, composition, or all of them; and the rock may split easily along the place where the strata join each other. In many places the strata may be horizontal or nearly so, as is the case at Grand Canyon. In other places they may be vertical or inclined at a large angle from the horizontal. Since all strata were deposited originally as horizontal layers of sediments, it is concluded that present stratified rocks which are inclined at some significant angle or warped into twisted designs have had their positions altered by some geologic forces acting upon them.

The strata, when present, have been produced by the manner in which sedimentary rocks are formed and by the composition of the sediments laid down. The ceaseless actions of erosive forces continually produce fragments of the older rocks, or reduce such rocks to chemicals that are held in solution in the water draining from the land. For the sake of clarity we may think of the materials that eventually form the sediments as divided into two classes; first, those that consist of broken bits of rocks which are carried along by moving water, winds, or glaciers and, second, those that are dissolved out of soil and rock and held in solution in water to be later deposited by some process of separation from the water. The fragmental materials consist of mud, silt, sand, and gravels while those in solution are mainly calcium carbonate and silicates.

The separation of the fragmental materials into mud, silt, sand, and gravels is primarily a division of such materials according to size. Mud and silt consist of the finest particles of the insoluble sediments, usually so small as to be distinguishable only under a high-power microscope. They are usually flaky minerals that have a great tendency to float and therefore remain suspended in the water for long periods of time. They settle out only after long standing in relatively quiet water. They are likely to be deposited over flood plains during times of decreased flow of water and on oceans and lake beds at some distance from the shore, where the water is relatively quiet.



One of the most noticeable features of sedimentary rocks is that they usually consist of layers or strata. This is remarkably well shown in the Teapot Dome Rock in Wyoming, famous in oil and legal history. (Science Service photograph.)

Thus, in time, layers of fine-grained clay material are deposited which upon long standing may produce strata of sedimentary rock of the characteristics of the finer sediments.

The fragmentary materials consisting of particles about the size of refined table salt are considered as sand. These grains are likely to become more or less rounded in their process of transportation by water and wind. Wind-blown sands become rounded most, and those in desert areas may become almost perfect spheres. The sands of oceans and lakes will be less rounded than the wind-blown ones, and river sands are usually the most angular of all. Since the sand grains are larger than silt particles they will settle out of the water or air somewhat sooner than the silt, and beds of these deposits are formed at the mouths of rivers, relatively near ocean and lake shores of moderately quiet waters, and in land areas of high sand content where prevailing winds blow. Eventually these sediments may form strata of sedimentary sandstone.

Fragmentary materials of larger particles constitute the gravels. These coarser materials also become somewhat rounded

in transportation by water and glaciers, the amount being roughly a measure of the distance carried. Such larger particles, of course, are dropped first by the transporting agents, and they may form thick layers of deposits. This has particularly been true at the ends of melting glaciers, where low-lying hills or moraines have been built up. Gravel deposits often contain finer-grain materials that have been caught by the gravel and prevented from removal unless the transporting water has a fairly rapid flow. These smaller particles as a rule are sands or similar materials that do not easily go into solution or suffer chemical decay.

Of the second type of materials forming sediments, that is, materials in solution, calcium carbonate and the silicates are the most abundant. These materials are dissolved out of land areas and transported to the oceans or inland seas of no outlet, such as Great Salt Lake or the Dead Sea. After long accumulation in sea water, parts of these materials are removed by various processes and form sediments at the sea bottoms. Continued evaporation of the inland, or "dead," seas results in concentration of the solution to the point where sediments begin to form. However, most of the sediments from these materials in solution are accounted for in other ways than by evaporation; particularly is this true of calcium carbonate.

Calcium carbonate in solution is particularly sensitive to the amount of carbon dioxide dissolved in the water. Where the temperatures of the sea water are highest more carbon dioxide will be driven off by the heat and consequently less remains in the water. These areas, of course, are near the surface of the sea, and especially in shallow portions of the oceans along continental margins and in shallow submarine banks in tropical regions. As the content of carbon dioxide becomes less, the calcium carbonate becomes more concentrated, and it will be precipitated out when saturation is reached. Often in such places, great beds of calcium carbonate are deposited. These beds eventually form strata of limestone rocks, and the thickness of the strata will be determined by the length of time elapsing before some change of conditions occurs and by the concentration of calcium carbonate in solution. In some places, beds of

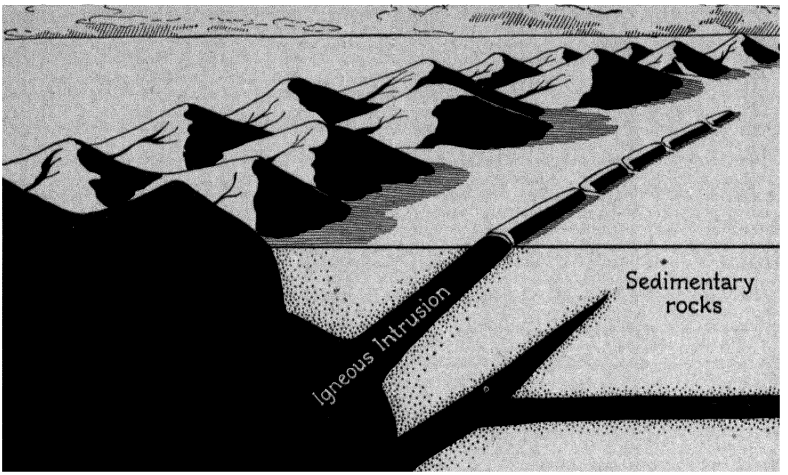
limestone thousands of feet thick have been formed by processes of this character.

Marine animals and plants are also active agents in removing calcium carbonate, as well as other chemicals, from sea water. These materials are withdrawn from the water in the course of the life processes of the organisms to form shells or other mineral parts of the organic body. At death of the organism these hard parts drop to the bottom to become a part of the sediments. Shells of marine animals may be deposited in such quantity as to form beds of limestone rock consisting almost entirely of such shells. Limestone beds of great thickness that contain shells or other calcium carbonate remains of once-living marine creatures are not uncommon. Limestones containing such remains, known as fossils, were used in building King Solomon's Temple, as well as the Pyramids of Egypt, and they are found extensively over the earth in regions that once were the bottoms of shallow seas.

Sediments of the various types mentioned above become converted into rocks by the action of numerous forces upon them. One of the most important of these forces is pressure from overlying deposits. The sediments may become cemented by the actions of certain minerals that are present in them or percolate through them in ground water, which harden when this water is removed. Upon hardening they form a sort of mineral "gel" in the spaces between the sediment particles which holds these particles tightly together, thereby binding them into sedimentary rocks. As a result of these forces and other less important ones not mentioned here, the various sediments eventually form rocks. Thus, calcium carbonate produces limestone, silt forms shale and mudstones, sand results in sandstone, and gravel produces conglomerate rock and glacial till.

Metamorphic Rocks

There still is a third general type of rocks included in the earth's surface that must claim our attention, even in such a brief discussion as this. These are a highly distinctive group of rocks that are neither igneous nor sedimentary and are known



Contact-metamorphosed rocks, shown in dotted areas, may be produced by igneous intrusions into older sedimentary rocks.

as metamorphic. The term itself means changed in form, and rocks so named are those that have been transformed from older rocks, both igneous and sedimentary, so that their original character is partly or completely altered. This transformation is in reality the result of the original rocks adjusting themselves to a new and different environment from that in which they were formed. Rocks are subject to change when different conditions are imposed upon them. When they have adjusted themselves to a given set of conditions, they are said to be stable for that environment. Upon a change of these conditions they become unstable, and a new equilibrium demands that an alteration in the original minerals be made. During the process of becoming stable in the new environment metamorphic rocks are produced.

Let us consider a simple example. A body of limestone that is deeply embedded beneath the surface is subjected to magma penetrating the cracks and fissures of the strata. The heat of the magma will raise the temperature of the adjacent limestone. The limestone is unstable under such conditions and profound changes take place in it. It may become somewhat fluid in character, and when it has resolidified new types of crystals will be formed. The physical appearance will be changed. Any fossils

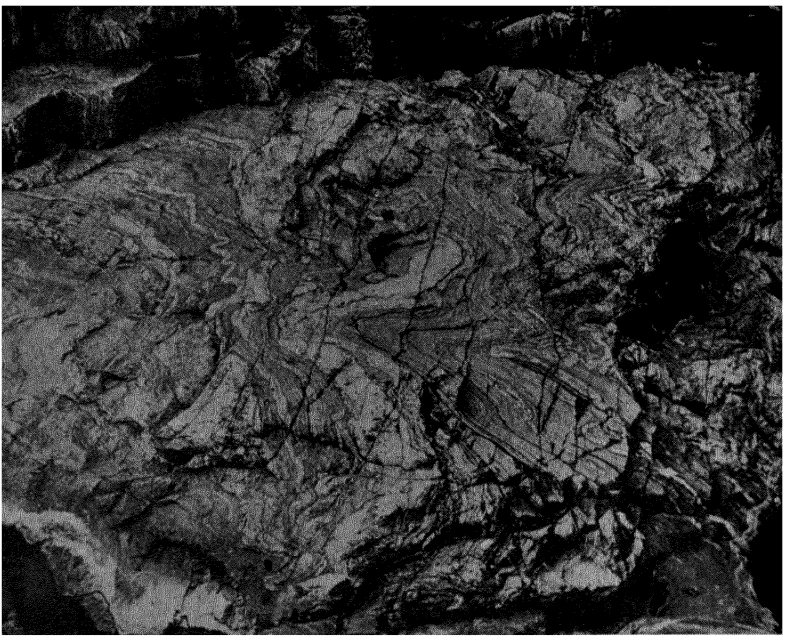
that may be present are likely to be entirely destroyed. When the limestone has reached a stable state under the new conditions, metamorphism has converted it into marble. Should there also be vapors escaping from the intrusive magma, these vapors and some silica of the magma will penetrate the pores of the sedimentary rock. They are likely to combine chemically with the calcium carbonate of the limestone, producing calcium silicates and many other compounds. As a rule they become beautifully crystallized and may form many new minerals.

Heat and a swarm of chemical mineralizers from magma constitute, then, agents that may bring about alteration of the rock into which the magma intrudes. Other forces bring about metamorphism of rocks on a much wider scale than the contact with intrusive magmas just mentioned. One of these is pressure, and its accompanying heat, that is produced by a movement of great areas of existing rocks. Such movements come about as a result of folding of the earth's crust or elevation of mountains through long periods of time. The changes that take place in rocks under such pressures are quite complex, and only in general can they be considered here.

Rocks ordinarily break into fragments when they are subjected to sudden pressure or blows. However, when they are confined on all sides and the pressures applied over long periods of time, quite different effects are produced. The rocks become plastic, and may even be made to flow, just as a block of ice can be made to flow through an opening in its container when a great and continuous pressure is exerted upon it. It is in this manner that the ice on the underside of a glacier actually flows down a mountain valley.

Rocks that have been subjected to mountain-building pressures may be metamorphosed into new structures and new chemical combinations. It is generally true that when rocks become metamorphosed they take on forms to suit the new environment, in which both the crystal structure and the chemical composition become denser and the new rocks usually harder.

Without mentioning any of the details of metamorphism, a general type of summary may be stated. Considering first the sedimentary rocks, sandstone is metamorphosed into quartzite,



This injection gneiss, in the inner gorge of the Grand Canyon, near Bright Angel Creek, shows the white intrusive masses and the dark masses of metamorphosed sedimentary rock between. Both the metamorphic and igneous materials have been twisted and bent by the motion of the deep strata in which they were once contained. (Science Service photograph.)

shale into mica schists, and limestone into marble. Among the important igneous rocks, granite is metamorphosed into gneiss, while lava and basalt may produce serpentine and soapstones. If we remember that metamorphic rocks include a great variety and complexity of forms, the above simplified grouping may be of value in clarifying our thinking without misleading us.

Within the narrow confines of Manhattan Island there are two interesting illustrations of metamorphic rocks. One is mica schist, the other is marble. At Morningside Heights is a high elevation overlooking the Hudson River to the west. The rocks are mica schist and they were metamorphosed from a former shale. They have resisted much of the weathering of past geologic ages. As typifying their endurance man has built at this location some of his most permanent structures—the Cathedral of Saint John the Divine and Columbia University. Just to the east and

at the foot of a steep cliff are the Harlem flats, eroded almost to sea level. The underlying rocks here are the less resistant marbles that were metamorphosed from sedimentary limestones. Even these less enduring rocks seem to have exerted an influence on man. The Harlem section is covered almost entirely with low-type tenements, in marked contrast to the lofty spires of the cathedral towering above them.

Earth's Shifting Surface

One general opinion man has of the earth is that it is solid, stable, and enduring. The notion of a terra firma that has been so long and universally held would seem to fortify our ideas of its rigidity and permanence. However, the earth's surface is continually being shifted about, a fact that is evident enough to the inhabitants of an earthquake country. The former idea of an "unshakable earth" is now outmoded. The earth, even with its immensely long history, has not yet reached a static and stable condition. It probably never will.

Earth-crust movements vary from those that are quick and violent, as manifested in the most pronounced earthquakes, to those that are so slow as to be imperceptible. These movements may effect only small, local areas, or they may represent uplifts or downwarps of a large portion of a continent or ocean basin. Sudden movements are more impressive and significant to the popular mind than the slow movements because of the destruction they produce and the evident shifting of local land areas. However, the crustal movements which take place more slowly and on a larger scale are of much greater importance in producing profound geographic changes in which large areas may sink beneath the sea or similar ones be elevated into mountain ranges over long periods of time. A single word has been invented to denote all the diverse and complex movements of the solid parts of the earth. It is well worth knowing, and we pause to note it here. This word is diastrophism. There are many evidences that diastrophism has occurred on the earth in recent times as well as in past geologic ages.

One of the points of interest to many tourists in Naples is the ruins of the temple to Jupiter Serapis on the seacoast near by. This temple was built before the time of Christ on the shore

overlooking the blue waters of the sea. By A.D. 1200, the land had sunk and the floor of the temple was beneath the sea to a depth of twenty feet. During the eighteenth century the land was elevated again. Three of the forty-six old columns were still standing. These shafts were pitted over the twenty feet that had been beneath the water by the borings of marine mollusks. Today the floor of the old court is again slightly under sea water, and the three columns still stand as monuments to a glorious past, and as a recorded history of the rising and sinking of the land in that area.

There is direct evidence that a part of the southern coast of California has been elevated from below sea level. This consists of terraces along the shore that were formed when part of the present land was below water. At San Pedro Hills, near Los Angeles, is a succession of such terraces cut by the waves of the Pacific that are plainly marked. The highest and oldest of these terraces are over a thousand feet above sea level at present, while the lowest, which contains many seashells, is about one hundred feet above the water.

On the eastern coast of North America are many "submerged" river valleys and small lakes near the shore which indicate that the eastern coast of this continent has been sinking. In some places this subsidence has occurred to the extent of hundreds of feet. For example, the Hudson Valley of New York is a good illustration of a "drowned" river. A regional subsidence of hundreds of feet now allows tide waters to flow up this river for a hundred miles above its mouth. Soundings of the sea bottom to the east of New York City seem to show that in former geologic times the Atlantic Coast was much higher than at present and that the Hudson River flowed a hundred miles farther out to sea and probably emptied into the ocean over a waterfall.

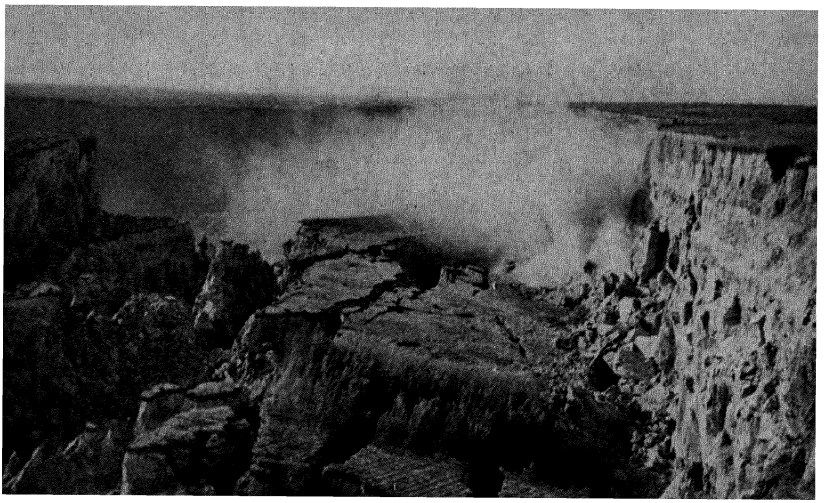
Diastrophism is in no sense confined to shore lines, as might be inferred from the illustrations just given. There are many examples of earth-crustal shiftings in the wide expanse of the continents themselves. Most of these have occurred during the geologic past; however, there are evidences that some are going on at present. One example of a change in land levels that is evidently in progress at present is in the Great Lakes region;

and this has had its repercussions in human affairs within recent years.

Many people still remember the highly publicized controversy a few years ago regarding the Chicago Drainage Canal, which permits some of the waters of Lake Michigan to drain into the Mississippi rather than follow the present natural outlet through the other lakes and the St. Lawrence River. It was argued pro and con that the Drainage Canal would produce a disastrous lowering of the water levels of the Great Lakes. However, it appears likely that in future ages Lake Michigan will drain through the Mississippi, regardless of man's opinions or efforts. A far greater force than any which he controls is at work to change the level of the shores of the Great Lakes. The land to the northeast of this region is slowly being elevated, as is evidenced by the fairly rugged shore lines to the north of the lakes. The area to the southwest of the lakes is sinking, the low-lying coast and submerged valleys being witnesses to this fact. The net effect of this is to tip the lakes toward the south. If nothing happens to change the present tendency of this tipping, Chicago is eventually destined to find itself marooned on a low island or completely submerged as the waters of Lake Michigan and Lake Superior find their outlets to the Gulf of Mexico.

Mountain Building

However, much more pronounced examples of diastrophism on a large scale are to be found within the mountainous regions of North America and other continents. These are great elevations of land that have been uplifted, for the most part in the remote past. In certain parts of the Rocky Mountains are strata of sedimentary rock that now exist at elevations from one to two miles above sea level. Many of these strata contain shells of sea animals. These sediments were unmistakably laid down beneath the surface of the sea, and a later upheaval raised the sedimentary rocks to their present levels. In The Himalaya sedimentary strata containing marine fossils have been found up to heights of four miles. These two examples and others similar to them are definite evidences of broad uplifts of land areas which have produced in some cases extensive mountain ranges.



An action photograph showing the collapse of a wall of "Sinking Canyon" near Buhl, Idaho. The slump of the canyon along a geologic fault began in 1937, and parts of the canyon wall give way from time to time. (Photograph by Ewing Galloway.)



Airplane view of Death Valley, California, and the block mountains on each side that were formed by faulting. (Photograph by Stephen H. Willard.)

The movements of the crustal rocks have taken place in various ways, as indicated by the structure and form of the mountains produced. One significant way has been by faulting on a large scale, or breaking and displacement of rocks along a line for a considerable distance. Another has been by a deforming of the rocks into great folds, giving rise to what are called fold mountains. In many places these two types of movements have taken place concurrently, producing mountains that are complex in their structure.

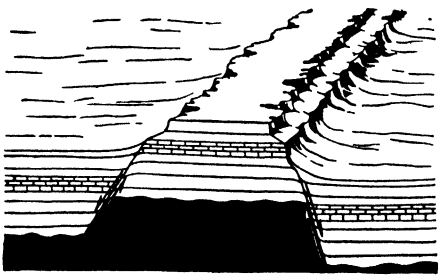
Many of the north-south ranges of eastern California, Nevada, and Utah are mountains that have been formed by faulting of great blocks of rock. The magnificent Sierra Nevada range is a single, somewhat tilted, fault block of granite over 500 miles long and about 75 miles wide. It has been sharply upthrusted on the eastern face to elevations of 14,000 feet in some places. The western slope, however, decends gradually for distances of about 75 miles into the Great Valley of California only a few hundred feet above sea level, thus indicating the tilt of the entire mountain block.

These mountains evidently were formed by a granite mass of large dimensions slipping upward along a fracture several thousand feet deep that extends in a general north-and-south direction. This fracture no doubt developed from some weaknesses in the bedrocks which yielded when the forces exerted upon them exceeded their breaking point. Later forces have produced upward movements along this old fault to form the present mountains.

Many other mountains as well as valleys are the results of upward or downward movements of the earth's crust along faults in the rocks. An idealized situation is represented in the drawing on the following page to illustrate how forces that act largely in a vertical direction may elevate some areas into mountain heights and depress others into valleys, the movements taking place along great faults in the earth's crust.

Mountains in which the rocks are strongly folded and broken are also common examples of crustal rock movements. Where these folds, or their eroded remnants, consist of sedimentary strata it is possible to determine the processes whereby the mountains have come into existence, even though the complete

history of the mountains may have been quite complex. Such is the case with the Appalachians of Eastern United States. A brief consideration of these mountains may give a general insight into certain processes of diastrophism that have extended over many geologic periods.



Many mountains as well as valleys are the results of upward or downward movements of the earth's crust along fractures or faults in the rocks. An idealized mountain range with a deep valley on each side is represented above. There was a relative moment of the bed rocks along two faults, as indicated by the arrows.

Even a casual trip across the Appalachians would reveal that most of the exposed rocks are the commonest kinds of sedimentary strata, such as sandstones, shales, and limestones. Many of these rocks contain marine fossils of the type which indicate that the strata were laid down on the floor of a relatively shallow sea. Careful examinations have shown that these strata were deposited to thicknesses of 25,000 to 35,000 feet. Since the strata are of shallow-water origin, it is evident that the sea bottom must have been sinking during times when the sediments were deposited. Such a slow sinking can be accounted for by the great pressures exerted on the lower strata by the weight of the accumulating sediments above.

These deep deposits are now known to have been laid down gradually in a large subsiding trough, extending in a general north-and-south direction, about 100 miles wide and several hundred miles long. Such an elongated trough is known as a geosyncline. The Appalachian geosyncline was filled in during much of its history by an inland sea which at times extended to the west probably as far as is the Mississippi River, and at other times was reduced to great swamp areas.

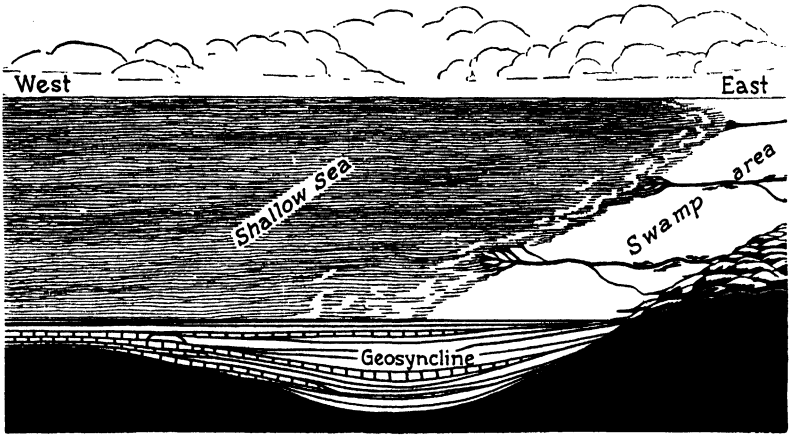
The geosyncline was bordered on the east by a belt of old rock near the present Atlantic Coast. This ancient land of unknown extent must have reached far to the east and out into the present ocean. Much of the sediments that were deposited in the geosyncline are known to have been eroded and transported from this eastern belt of land. A study of the Appalachian

strata shows that the coarser materials are on the east, with finer materials grading westward into marine shales and limestones. Only a general drainage from the east would sort the sediments in this fashion on the bottom of the inland sea.

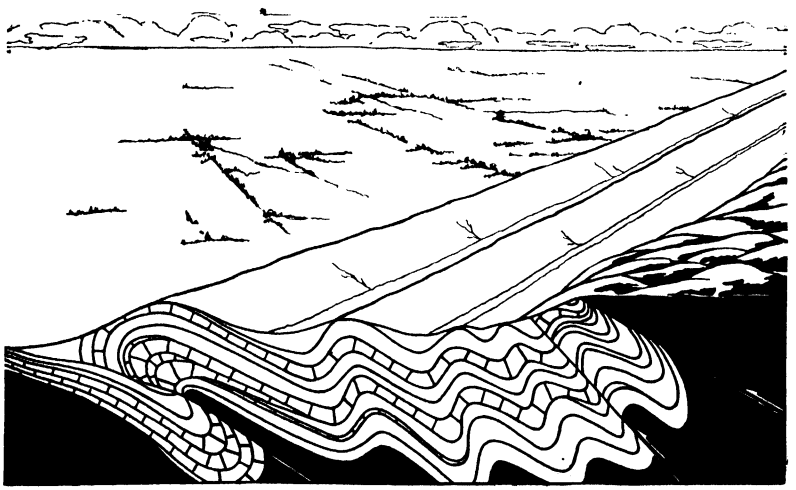
This high plateau to the east and its western geosyncline is known to have existed for six geologic periods of about fifty million years each in order to account for the types and depths of the strata formed in the subsiding trough. As this enormous volume of sediments was being delivered into the geosyncline, the bordering eastern belt must have been rising either continually or intermittently to cause erosion in this fashion to continue until such great deposits were made. This evident rising of the eastern belt was certainly the result of some vertical upward force, and it may have been aided by the belt's becoming lighter as the eroded materials were removed.

As these processes of plateau erosion and deposition of the materials in the geosyncline to the west were going on, we have evidences of one of the remarkable procedures of nature. Tremendous horizontal compressive forces were brought to bear on the sedimentary strata and their eastward coast line. The strata were warped into folds, and a mountain chain was literally raised out of the inland sea. The structural features of the Appalachians indicate that just such folding took place in several stages to produce the mountains from the old geosyncline. These folds were pushed up to great heights. In some places the folds were severely compressed, and in others there were great fractures and a faulting of strata over the original overlying beds. A later erosion has reduced these great folds and fault thrusts to the feeble old mountains of the present that present little more than a reminder of their former glory.

The folding took place entirely in the strata of the geosyncline. This trough was the area of the greatest weakness in the rocks, and it would be, therefore, the one that would be affected most by the horizontal pressures applied in the earth's surface. Furthermore, extensive folds would take place in deeplying strata when horizontal forces were applied, since the great pressures from overlying beds would render the rocks somewhat plastic. It is only where the folding has become extreme, or less plastic conditions exist, that fractures and faulting take place.



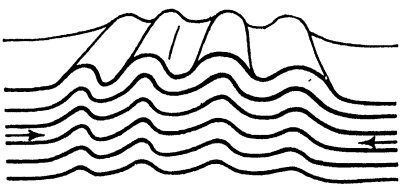
During the first stage of the formation of the Appalachian Mountains, deposits of sedimentary rocks were formed in a subsiding basin, known as a geosyncline. These sediments were eroded and transported from an ancient highland of unknown extent that reached far to the east.



At a later geologic time great compressive forces were brought to bear on the sedimentary strata and their eastern coast line, producing a folding and fault thrusting of the rocks in the geosyncline. Later erosions produced the feeble old mountains of the present from these folds and the Atlantic Coastal Plain from the eastern highlands. (Redrawn from Longwell, "Physical Geology.")

It may be stated as a general rule that in mountains produced by folding, one side of the range will consist of much older rocks which were the source of the sediments that formed the strata of the mountains. Bordering these older rocks on one side

was a geosyncline and shallow sea which received the sediments that were later warped into the mountain range. This has been the history not only of the Appalachian range, but also of much of the Rocky Mountains at a vastly later period. The Rocky Mountains developed from a great geosyncline that stretched north from the Gulf of Mexico to the Arctic, with highlands to the west.



A shrinking of the earth would set up horizontal forces in the earth's crust that would produce folds in the weaker rocks.

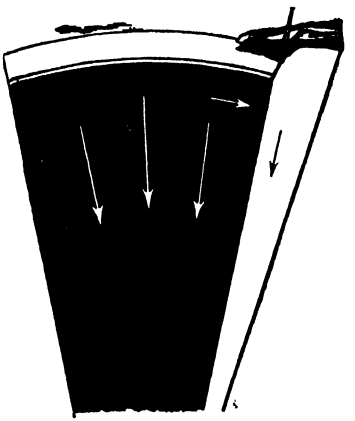
Why These Earth-crust Movements?

To explain why and how such movements of the earth's crust take place is much more difficult than to ask the question. There are several theories to account for the enormous forces involved in diastrophism. While there are many lines of evidence that point to these general conclusions, it should be kept in mind that the detailed causes of crustal movements are not known. One of the ideas that is generally agreed to is that the earth is shrinking, and that this shrinking probably brings about a wrinkling and fracturing of its crust. Another idea held by some is that a sort of mechanical balancing of heavier and lighter areas brings about crustal adjustments.

It is fairly well known that the earth's interior, although rigid, is very hot. This being true, slow cooling would cause a shrinking below the comparatively shallow depth of the cooler crust. This condition would bring about a buckling of the outer surface. In general a reduced size of the earth sphere would produce forces applied horizontally in the buckling crust. Thus the rocks, particularly the weaker or more plastic sedimentary strata, would be pushed up into folds, somewhat the same as one may produce folds in a sheet of paper by properly pushing on its sides.

It was suggested about 1890 that some of the movements of the earth's crust may have occurred through a general process of mechanical balancing. Let us see what this means. All parts of the crust are pulled toward the earth's center by the force of

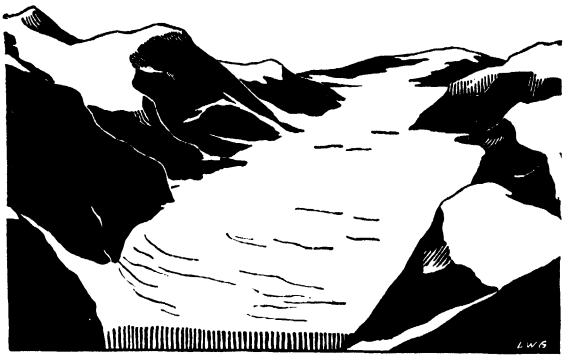
gravity. This force will be in direct proportion to the masses of different areas. Some parts of the earth's crust are heavier than others. The oceanic portions of the globe are denser than the continents; volume for volume they are heavier. Especially is it true that there is a considerable difference in density between ocean beds near the margin of the continents and the continental areas. The ocean beds tend, therefore, to be pulled more strongly toward the earth's center than the continents, thus setting up strains and stresses.



A greater sinking of the denser ocean beds near continental margins than that of the land areas would produce a relative uplift of the shore; also the sinking wedge would exert horizontal, squeezing forces on the continents.

The tendency will be for the land to be uplifted relative to the ocean bottoms. During the actual yielding the oceanic segment may settle downward with respect to the continent somewhat as a sinking wedge. Such action would tend to squeeze the continent with horizontal forces as well as to produce a relative elevation. While the idea of balancing great areas by a sinking of the heavier and rising of the lighter areas is highly speculative, such processes do explain in part the formation of certain deep ocean beds and of some mountains that resulted from faulting. Likewise, they would account for some broad shifting of land levels where mountain building has not occurred.

In terms of this theory, we can get some explanation of the changes taking place around the Great Lakes. During the ice ages large glaciers covered Canada and the northern part of the United States. The enormous weight of this ice caused the land beneath it to sink. The land to the south was elevated to balance this pressure. The glaciers have long since melted and the water flowed back to the sea. The higher lands to the south were unbalanced by the sunken lands to the north with their glacial weight removed. So, the process has reversed itself. The lands of southern Canada are being pushed up again while those to the south are sinking. It is a sort of giant geologic seesaw.



Glaciers constitute one of the agencies that wear away the land.

Wasting of the Land

Another type of change of the earth's surface which is continually going on is erosion and the distribution of the eroded materials to other areas. Erosion is the mighty chisel of nature that is always operating to sculpture the land and to reduce it to broken fragments. As soon as mountains are elevated they begin to be worn down again. Forces are at work which can destroy the hardest hills and reduce them to the level of the sea. Chief among the agencies that wear away the land are winds, freezing water, chemical action, glaciers, ocean waves, and running water. The eroded materials are then transported and deposited, usually to lower elevations, by such agencies as winds, running water, waves, and glaciers.

Winds are an active force in weathering the surface of the earth. Dust particles carried by winds are blown against exposed bedrock and pebbles and boulders on the ground. Additional particles are worn from the rock by an abrasive action. This action is most pronounced in arid and desert regions, where large quantities of dust and sand may be picked up by the moving atmosphere. The effects of wind-abrasive action are pronounced in the Mojave Desert, where much of the sand and silt has been cut away by the wind. Many of the deep canyons and large caves in the Great Basin of Arizona and Utah have been partly formed by such sand-bearing winds.

Winds are active, also, in transporting eroded materials and depositing them in other localities. In some of the dust storms which occurred during recent summers, finely divided particles

of soil from the prairie states west of the Mississippi River were carried as far as the eastern seacoast and out into the Atlantic Ocean. This was small in amount, however, as compared to the great volumes of dust deposited in areas closer to the dust-storm centers. In many instances houses and barns were partially or completely covered with the deposited dust. In desert countries and along the shores of some lakes great quantities of sand are carried by the winds and deposited as sand dunes. These dunes usually are continually shifting. The sand dunes along the south end of Lake Michigan, for example, cover many square miles of territory in northern Indiana.

It has been the experience of many people to have water pipes or automobile radiators cracked by the force of freezing water. The fact that water expands when it freezes is generally known. This principle operates to crack rocks in favored climates as well as to burst water pipes. Water seeps into their pores and crevices, and upon repeated freezing and thawing exerts forces that are capable of disrupting the rocks. This process is usually confined to relatively thin-surfaced layers of the rocks and tends to break off small pebbles or fine grains. Eventually large amounts of the hardest as well as softer rocks may be reduced to minute particles in this manner. This is particularly noticeable on steep slopes and in high mountains, where the loosened material is removed by gravity and new surfaces are exposed so that the process may continue.

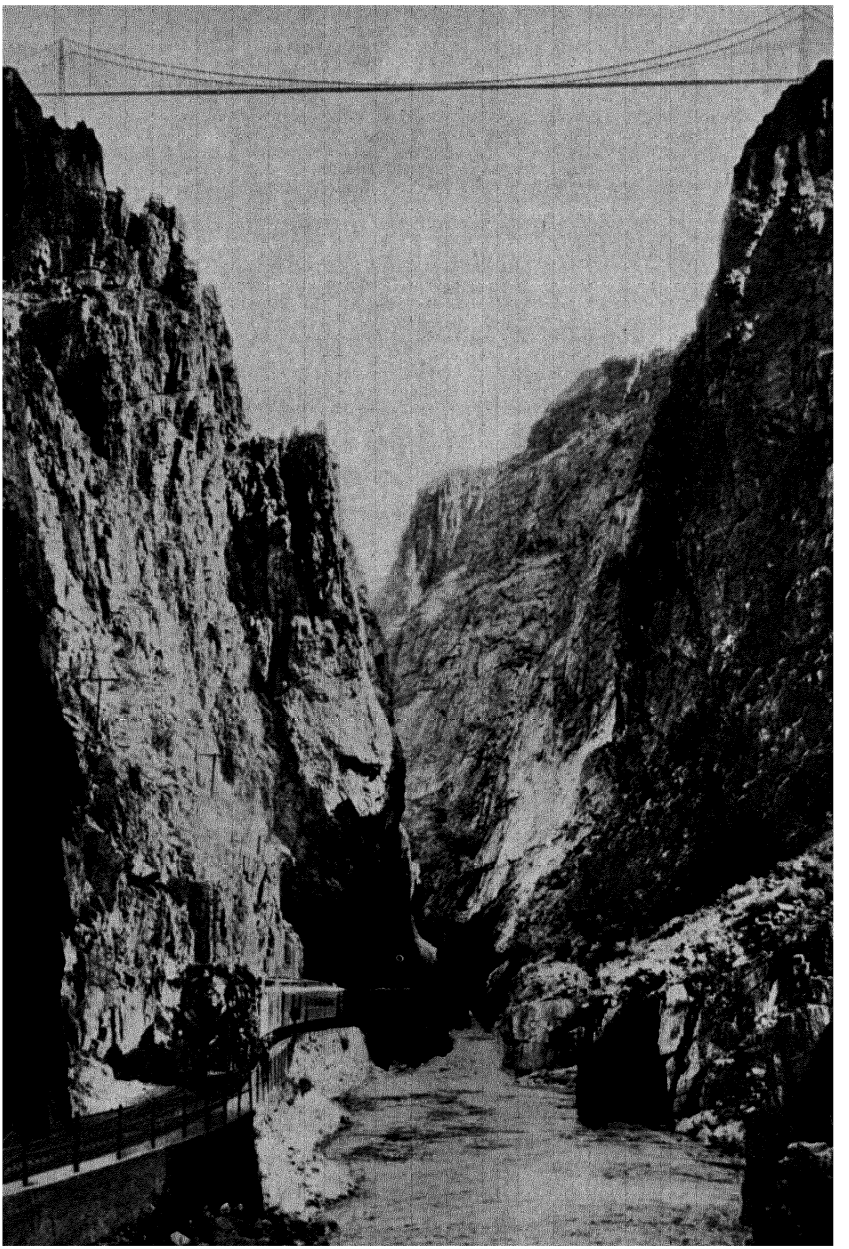
The mechanical forces of running water, ocean waves, and glaciers are also effective in wearing away the land. Moving water and ice exert powerful forces against land areas, which break away fine particles from the rocks or loosen the particles of rock debris and soil. When fine sediments are carried by the water, the erosion is accelerated by the scouring action of the suspended particles. The incessant beating of waves along a seacoast results in wearing away the shore. The water, which usually has in it an abundant supply of sand and gravel, sweeps back and forth along the coast and wears it down to a depth somewhat below the general water level. As these forces cut farther and farther into the land that has an original high elevation, the shore eventually becomes terminated as a sea cliff. The waves act to cut a notch at the water level, and thus under-

mine the land above. This causes the overlying rocks to break off and form relatively steep or ragged cliffs. Out beyond the sea cliff the surface that has been cut away usually forms a gentle slope seaward beneath the water, producing what is called a wave-cut terrace.

However, a far greater erosion than that affected by all the waves of all the oceans is produced by running water. The average annual rainfall over the land part of the earth is about thirty-six inches. Even allowing for evaporation and seepage into the ground, a considerable portion of this total rainfall flows off the slopes, forming streams that eventually reach the seas. This running water wears away an enormous amount of rock debris and soil. It cuts the hardest rocks, particularly after being collected into streams and rivers. Much of the country in the Great Basin of Arizona and Utah has been eroded into thousands of canyons primarily by running water, the most spectacular of all being the Grand Canyon. The same type of erosion is repeated throughout the world, although in most places it may be less conspicuous.

The smaller streams and runoff water continually carry away some sediments wherever rain falls. Soil surfaces are also loosened and carried away. In many areas where farming has been carelessly practiced or the climate is particularly arid, runoff water reduces the land to a series of outwash gullies and wasted fields. It has been estimated that the United States as a whole is being lowered by the action of running water at the rate of one foot in about seventy-five hundred years. At this rate it would be entirely reduced to sea level in fifteen million years were there no other forces operating in the earth's surface.

Simultaneously with the mechanical weathering of rocks by the agents mentioned above, chemical agents act upon them and reduce them to different materials. In some cases these new products are soluble in the water passing through the rocks, and they are thereby dissolved out and carried away. One of the most active agents in chemical weathering is carbon dioxide. When this gas is dissolved in water it forms a weak acid, known as carbonic acid. Carbonic acid reacts readily with the mineral salts of calcium and magnesium to form the soluble carbonates of these elements. Carbonates thus formed as well as native



Royal Gorge near Canyon City, Colorado, has been eroded to a depth of 1,060 feet by the Arkansas River. A transcontinental railroad passes through the canyon, and the highest suspension bridge in the world crosses it. (Photograph by Ewing Galloway.)

calcium carbonate, or limestone, are slowly dissolved by the water percolating through rocks that contain these compounds. This process accounts for the caves in limestone regions. The Mammoth Cave in Kentucky, for example, is one of the well-known caves which was formed in this manner. Some of its caverns are several miles long, and one contains an underground stream large enough for canoeing and boating.

Water produces chemical weathering of rocks in a manner other than that of dissolving carbonates and similar soluble constituents. That is, the water molecule becomes an essential part of the molecule of the rock substance. The chemical composition of the rocks does not change; however, their molecules increase in size by the addition of the water molecule. This process is known as hydration. It produces a swelling of the new molecules and thereby an expansion of the parts of the rocks so affected. As hydration takes place irregularly in rocks because of unequal evaporation, the resultant expansion will also be irregular. Even the hardest rocks give way under the forces of unequal expansion, and there will be a spalling off of slabs and flakes until the rock material is reduced to fine particles.

Thus the various agents of weathering, acting through long periods of time, bring about rock decay. Winds and running water transport this debris from the high places and deliver it to the sea. The "eternal hills" are not everlasting, but are eventually worn down. However, during the same time other great forces are operating to elevate other land areas and to push up large and small mountains. Changes are taking place everywhere, in most cases slowly. The processes go on and on.

Soil Surfaces

The various changes in the earth's crust have produced a thin layer of mantle rock, from which soils are developed. Soil, water, and air constitute the earth resources necessary to plant growth. It should be kept clearly in mind that all animals are dependent either directly or indirectly upon plants for food. The development of soils is a slow, gradual process. It results from mineral substances and organic compounds, along with microscopic living organisms, being brought together in proper condition to support plant life.

The minerals are supplied by the soil mantle, while the organic matter is derived from plant and animal remains. Organic remains when reacted upon by certain microorganisms living in the soil are broken down into complex compounds that go into solution, producing a substance known as humus. The humus furnishes some of the food for plants, produces organic acids also required by plants, and, in addition, gives the soil a high capacity for dissolving water. Much of the water retained in soils is held in these microscopic humus particles. They also produce tiny air sacs and provide the soil with sufficient air to support the microorganisms and to aid in plant growth.

Any prolonged condition that tends to upset this balance of mineral substances, humus, and water in soil composition is destined to produce an unfertile area for plant growth and therefore a poor habitation for animal life.

There is a great variety of specialized soil types, the discussion of which is beyond the scope of this book. However, there are four general types that cover great areas of the earth's surface, and are worthy of a brief consideration here. One of these is the acid soils of little or no humus found in the tropical forests. Another is the low-humus soils found in evergreen forests in temperate or frigid climates. A third is the high-humus soils of areas in the temperate zones, where there is moderate rainfall, and the fourth is the gray desert soils.

In the great forest lands of the humid tropics, the soils generally take on a decided character. Although they support dense forests, the refuse vegetation collects mainly on the surface. This material oxidizes rapidly under the influence of high temperature and abundant microorganisms, which are stimulated by the hot climate. As a result, little or no humus is formed. If no humus is present, the water from the heavy rainfall, by percolating through the soil, is exceedingly effective in dissolving out certain critical mineral elements of soil fertility. The absence of humus and a scarcity of these critical minerals make these soils poor for ordinary field crops and many kinds of natural vegetation.

In climates that have cold winters and only moderate summers, other forest areas are found. However, these forests usually consist of evergreen trees such as pines, spruce, and the like.

These colder climates favor the accumulation of a thick layer of raw humus material that has only partially decomposed because the lower temperatures retard bacterial action in reducing organic material into mature humus. This spongy material retains much water and becomes definitely acidic as a result of the slow humus decay. These acid waters, by percolating into the soil, render it acidic and many desirable soil microorganisms are destroyed. Further, the acid waters dissolve out much of the iron minerals and give the soil a whitish appearance. Such soils are usually unfavorable to agriculture and the growth of smaller vegetation.

In other large areas in the temperate climates somewhat reduced rainfall has prevented the growth of dense forests. These are what might be called the grass lands, as represented, for example, by much of the central part of the United States. Scattered trees and a dense and luxurious growth of grasses predominate. A wealth of humus is formed, and mineral and moisture content are usually sufficient to render the soil fertile for agriculture and a great variety of food-bearing plants.

The other great division of soils we should take note of here are the gray deserts. These are arid lands in relatively hot climates. Only widely spaced desert grasses and scrubs grow there. These soils are, therefore, light in organic matter. As a result, such soils usually are scarce in nitrogen compounds. Lime and other alkali minerals accumulate near the surface, giving the soils a decidedly alkaline character. The desert sands contain considerable amounts of undecomposed rock materials, as a rule. All these conditions tend to prevent any luxuriant or sustaining plant growth. Wide areas are subject to rapid erosion and they support only a reduced amount of life of any kind.

Landscapes and Life

The different types of soils and the plants which they produce have a decided effect upon the animal life which inhabits an area. This is particularly noticeable when the areas are relatively large and when no artificial conditions, such as irrigation, exist. These interrelationships constitute what is usually referred to as the biotic conditions existing within a given community. This interdependence of plants and animals, and their absolute de-

pendence for existence upon soils and climatic elements, is one of the fundamental conditions of life on earth.

These biotic relationships may be illustrated in a general way by considering one small area of country that has been thoroughly studied. This area has within narrow geographical boundaries a variety of soils and a considerable range of climatic conditions. The area in question is Zion Canyon in southwestern Utah. For much of this information we are indebted to the work of Dr. Angus M. Woodbury of the University of Utah.

Zion Canyon is a picturesque gorge about twenty miles long, a half mile or so wide, and about 3,000 feet deep. It has been carved out of the Colorado Plateau by the Virgin River. This river begins in the mountains just to the north of the canyon at an altitude of about 10,000 feet and drops down rapidly through the canyon onto the desert plain at the south end of the canyon, where the altitude is approximately 3,500 feet. Within this short course of the river there are forest-covered mountains, where the climate is relatively humid and cool, the arid top of the plateau, the nearly perpendicular bare rock walls of the canyon, the cool humid floor of the canyon bottom, and the hot desert at the canyon's mouth. Let us consider these briefly.

On the desert plain there is only scattered vegetation of scrub plants such as mesquite, yucca, and cactus. Animals there are limited to the small and hardy types that can endure the rigors of desert climate and food supply. They are the smaller insects, a few reptiles, a scattering of birds, and such small mammals as the desert wood rat and ground squirrel. The insects feed upon roots of the desert plants and microorganisms. The reptiles subsist upon the insects and probably eggs of the birds. The birds live upon the insects and upon the seeds and fruits that are available. The ground squirrel feeds upon such vegetation as it can find, while the rats probably consume a mixed diet of any organic material that can be secured.

Farther up the canyon and along the rock walls are to be found the beginning of soil development and its accompanying life forms. This is on the bare rocks and fallen boulders. Where there is a trickling of water over such rocks, algae and mosses begin to grow. Soon they cover the rocks, and, when sufficient humus has been formed by their decay, ferns get a start. These

are followed by seed-bearing plants, such as orchid and columbine. Thus a plant community becomes established. Animal life keeps pace with this development, often assisting the plants to get a foothold. Spiders, including the black widow, are found here, as well as other smaller insects. Certain insect-eating lizards soon move in, to be followed by the canyon wren, hummingbird, and a few other species. Bats inhabit the rock areas, and usually at least one species of the field mouse will soon make its appearance.

In the canyon bottom are to be found extensive biotic communities. Here the abundant moisture from the river and numerous springs has produced luxuriant plant growth. This soon makes a rich soil. The climate is generally mild, the area being protected from much of the intense sun's rays by the steep canyon walls. In addition to a great variety of flowering and seeding plants, small trees of oak, willow, and maple are to be found. Such communities support many species of insects, a variety of mollusks, fish in the river and ponds, several varieties of snakes, numerous birds, and many kinds of mammals. Many of the mammals are vegetarians, and some are carnivores. Rock squirrels, chipmunks, porcupines, cottontails, and mule deer find food in the roots, grasses, seeds, and berries. Such carnivorous mammals as the ring-tail cats, skunk, and badger live regularly in the canyon and depend upon the above-noted animals for food. The mountain lion inhabits the cliffs or the mountain slopes high above, but once or twice each week may descend to the canyon bottom to kill a deer or some domestic animal for food.

Above the canyon walls is the table land of the plateau. It is subjected to a relatively dry and hot climate. The most prominent vegetation features are the juniper and piñon pine trees. Such smaller scrubs as sage, manzanita, and silverberry are to be found along with scattered grasses and other seeding plants. The largest native vegetarian mammals are mountain sheep and the mule deer. They, along with smaller mammals, furnish food for the mountain lion and bobcat which make their homes in the canyon cliffs or near-by mountains.

Thus, it is seen, physiographic and climatic factors largely determine the types of plants which can develop within an area.

The dominant plants along with these same factors in turn control the animal life that can use these areas as natural habitats.

REFERENCES FOR MORE EXTENDED READING

SCHUCHERT, CHARLES, and CLARA M. LEVENE: "The Earth and Its Rhythms," D. Appleton-Century Company, Inc., New York, 1927.

This is a popularly written story of the rocky framework of the earth. Chapters IV to XI inclusive give an account of factors producing change in the earth's surface, such as running water, chemical action, glaciers, and winds. Chapters XVI to XIX inclusive are a discussion of the action of earthquakes and volcanoes and the processes of mountain making.

CRONEIS, CARY, and WILLIAM C. KRUMBEIN: "Down to Earth," University of Chicago Press, Chicago, 1936, Chaps. V to XXII inclusive.

The book is written in an informal and readable style and profusely illustrated with drawings and many photographs. The chapters referred to include an account of the changing features of the earth's surface, the nature of its rocky crust, and the action of volcanoes.

HEIM, ARNOLD, and AUGUST GANSSER: "The Throne of the Gods," The Macmillan Company, New York, 1939.

This is a thoroughly interesting and authoritative account of an expedition conducted by two geologists for the Swiss Scientific Society for the purpose of studying the formations of the Central Himalaya Mountains. The book is illustrated with over two hundred very remarkable photographs; also there is a relief map of The Himalaya.

LOBECK, A. K.: "Geomorphology, An Introduction to the Study of Landscapes," McGraw-Hill Book Company, Inc., New York, 1939, Chaps. II, III.

These two chapters include an exhaustive discussion of rock structures and processes of weathering. They are illustrated with analytical drawings and a number of remarkable photographs. The illustrations are so excellent that the reader's interest will not be confined to the two chapters referred to here, once the book has been examined.

LONGWELL, C. R., A. KNOPF, and R. F. FLINT: "A Textbook of Geology," John Wiley & Sons, Inc., New York, 1939, Chaps. V, VIII, IX, XI, XII, XIII, XIV, XVI, XVIII.

This is a well-written and extensively illustrated elementary text in geology. The chapters referred to provide interesting and instructive material on the earth's surface formations and the various natural processes which affect changes in them.

FINCH, V. C., and G. T. TREWARTHA: "Elements of Geography," McGraw-Hill Book Company, Inc., New York, 1936, Chaps. XIV to XXI inclusive.

These chapters are a discussion of the processes of erosion and transportation of earth materials and the formation of soil surfaces. The topics are fully treated in a readable style and are well illustrated.

WOODBURY, ANGUS M.: "Biotic Relationships of Zion Canyon, Utah," Contribution from the Museum of Vertebrate Zoology, Ecological Monographs 3: 1933, University of California, Berkeley, Calif.

A carefully documentated and well-illustrated account of the biotic relationships in Zion Canyon with specific reference to succession of life in relation to soil and climatic environment.

The National Geographic Magazine, published by National Geographic Society, Washington, D. C.

A monthly magazine devoted to the increase and diffusion of geographic knowledge. It contains articles, all of which are profusely illustrated, on a great variety of explorations and studies of unique places and peoples.

Journal of Geology, published by University of Chicago Press, Chicago.

This journal of eight issues per year contains illustrated research articles on geological formations and other articles and news of interest to the geologist and inquiring laymen.



3: LIFE'S DOMAIN

In Turbulent Oceans of Water and Air

AS THE earth pursues its long journey around the sun, it goes wrapped in a flimsy garment of a gaseous atmosphere. Transparent and mostly invisible this garment offers a protective covering against extremes of heat and cold. Endowed with oxygen, it provides the breath of life. Beneath this outer coat three-fourths of the earth's surface is covered with a flexible film of water. This film projects itself into the air above and then down onto the land, providing there a considerable amount of its liquid covering. Air and water are integral parts of the earth's surface.

These conditions not only affect the physical characteristics of the outer portions of the earth, but they also make it possible for life to exist here. Life is dependent upon water for drinking

and upon oxygen for breathing. All life must have some flexible lubricant in which to move. Water serves as this medium. Even for the higher forms of land life, including man, the same is true, the water being carried around as a part of the body. Oxygen is a substance necessary for most living forms on the earth. Most plants and animals must have it for breathing. Most of this oxygen is in the air. This air may be either in the gaseous envelope above the earth or dissolved in water of the oceans, lakes, and soil. Without air and water, the earth would be dead and barren.

Furthermore, these oceans of water and air are constantly in turbulent motion. Such motions result from the unequal heating of the earth's crust and from the rotation of the earth on its axis. They are greatly modified by the presence of oceans, plains, and mountains. They are all mixed up by forces that are continuously at work and over which man has little control. Such complex movements of air and water produce for us that much-discussed phenomenon, the weather.

The average succession of all weather conditions over a period of years constitutes climate. Climate, then, gives a more general and complete picture of atmospheric and temperature conditions for a location or country. It includes not only the average of weather but also the extreme variations of weather elements. Climatic conditions are more decisive factors than weather in influencing the course of life as well as the physical conditions of the earth. It is a well-known fact that the climate of different sections of the earth has modified living conditions and life during the present and past historical times. It is equally well known that great changes in climatic condition during the remote geologic ages have had a profound effect upon the development of life on the earth.

Let us, therefore, give some brief consideration to these conditions of water and air and their effects in producing weather and climates.

Earth's Waters

The water constitutes a sort of envelope surrounding the earth's solid crust. In the beginning of the earth's long history, the atmosphere probably contained in the form of vapor all the



" . . . about seventy per cent of the earth's surface is covered by oceanic waters."

water now in lakes, oceans, and rivers. As water vapor began to condense when the earth was cooling and forming its present shape, the liquid collected, mostly in the low places of the earth's surface. This formed the oceans. The first oceans were no doubt mostly fresh water. We know with certainty that the salt now in the sea has been washed into it from the dry land.

Slightly more than half of the water of the earth is now in the oceans. When it is realized that about seventy per cent of the earth's surface is covered by oceanic waters, this is not unexpected. The average depth of the oceans has been estimated to be about 13,000 feet, while some of the deepest points of the ocean bed go down to 30,000 to 35,000 feet. The deepest point yet recorded is off the east coast of the Philippines and is 35,433 feet below sea level. It has been possible to calculate the volume of water in the ocean, and it is approximately 300,000,000 cubic miles. This is far greater than the volume making up all the continents and islands.

Water in lakes, inland seas, and rivers makes up a volume somewhat less than half of this amount. Also, the amount of ground water in the crust of the earth is enormous. This water is

held below the surface of the ground in the soil and rocks in depths ranging from a few inches to several thousand feet. It furnishes the water for many growing plants, springs, wells, mines, geysers, and an immeasurable volume which man cannot tap. There is no way of measuring the total amount of such underground water. However, it has been estimated from the best data available to be about one-third the amount of the oceanic waters.

These three sources—oceans, inland surface water, and underground water—constitute somewhat less than the grand total of the earth's waters. To them must be added the ice sheets that cover much of the Arctic and Antarctic zones as well as the present existing glaciers. This is more than most people realize. Should all this ice melt, the ocean level would be raised 150 feet, and New York City would be submerged beneath the sea, as would most of the Atlantic Coast line and a part of the Mississippi Valley.

Some water vapor is always present in the atmosphere. This water vapor goes through an endless circulation of evaporation from land and sea water, and precipitation again as rain and snow. The annual precipitation of water from the atmosphere, if averaged for all the earth, would be about thirty-six inches for its entire surface. Of course, it varies enormously in different areas. The extremes range from 0.02 inch per year for a spot in Chile to 451 inches in Kanai, Hawaii. These figures are averages based upon many years of observation. However, the great areas of extreme dryness are in the Sahara Desert and a great stretch of Asia from the Caspian Sea to China. Large areas of excessive rainfall are to be found in the Amazon Valley and in India, considerable portions of which exceed 100 inches per year.

Ocean waters have one thing in common that is quite in contrast to the air or land; this is that their temperature remains much more constant than does the temperature of the air or the dry land. Water absorbs relatively a large amount of heat. This heat is radiated slowly. Therefore, large bodies of water contain exceedingly great amounts of heat energy. As the ocean warms, some water is evaporated into the air. The heat required to evaporate a given quantity of water is over five times the amount required to increase the temperature of the same

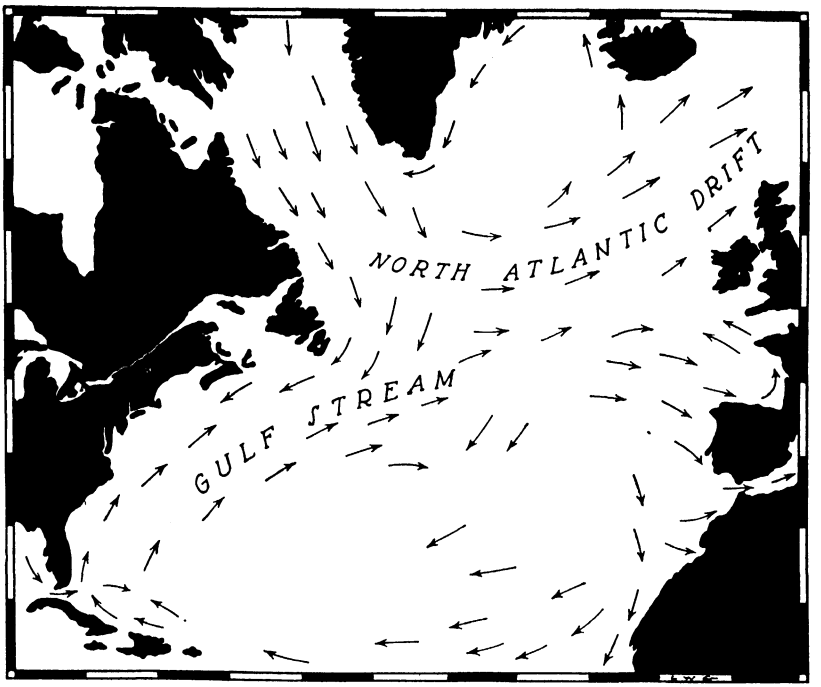
volume from freezing to boiling. Some of this heat for evaporation comes from the water itself, thus tending to cool it. These two transfers of heat operate to keep the oceans relatively constant in temperature; also they make water a great storehouse of heat energy from the sun.

There is, however, some variation of ocean temperatures. The temperature of the surface of the ocean near the equator is about 80 to 90°F. It gradually gets cooler as the polar regions are approached. The Arctic and Antarctic oceans vary in temperature from 28 to 50°F. The variation of daily temperature changes is about 1°F., while the yearly variations at any one point may be as high as 40 to 50°F. in oceanic waters.

The temperatures mentioned above are for the surface waters of the oceans. At depths of about 1,500 to 2,000 feet the ocean waters remain constant. At 1,200 feet the temperature is 50°F. throughout all the oceans, at 6,000 feet it is 36.5°, and at 9,000 feet it is 35.3°F. This is brought about because water is a poor conductor of heat. At those depths little heat from the sun penetrates, and what heat is there is retained by poor conduction and the lack of movements of the water. Ocean water freezes at lower temperatures than fresh water because of the salt dissolved in it. Even at the low temperature of the Arctic Ocean the water beneath the ice sheet does not freeze, as normal sea water freezes at a temperature slightly below 28°F.

Moving Oceans

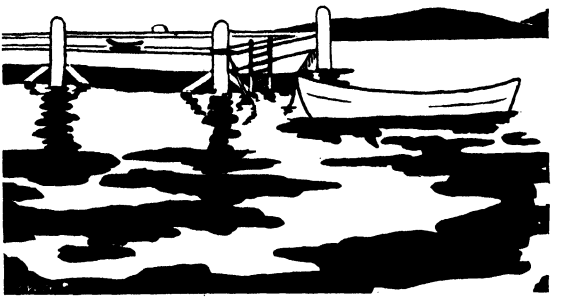
There are many large movements of surface water in the ocean, setting up ocean currents and drifts. One of these currents, for example, is the Gulf Stream. It flows northeast along the east coast of the United States, then east across the Atlantic to the west coast of Europe. The movements of ocean waters are brought about by a number of different factors. Some of these are inequalities of water level, unequal temperatures, variations in barometric pressure, tides and constantly blowing winds. Winds blowing constantly in one general direction drive the water along with them. The actual path of the water will be determined somewhat by the shape of the shore line. Thus, the northeasterly trade winds and the shape of the eastern shore of North America produce the Gulf Stream.



Important oceanic currents in the North Atlantic.

Let us see how this takes place. Just north of the equator the trade winds blow continuously from the northeast. This tends to push the ocean water along in this direction. Thus water of the Atlantic is piled up along the northeast coast of South and Central America, where it is warmed. Of course, it cannot remain piled up in any one place. It begins to flow north along the coast line. The shape of the east coast of North America is such as to give the water also an easterly direction as it flows north. This warm water follows, therefore, the well-known path of the Gulf Stream out into the northeast Atlantic and across to Europe.

Added to the Gulf Stream there is a general movement of the ocean waters of the north Atlantic toward the northeast; this is referred to as the North Atlantic Drift. Such movements of ocean waters have a very definite and important effect on the climate of many lands. For example, Scotland and Norway are as far north as the Hudson Bay and frozen Labrador in North America; yet they have a relatively mild climate as a result, primarily, of warm, moist, winds blowing from the warm sea



High tide at a Hudson River wharf.

that comes to those shores. The prevailing westerly winds of the North Temperate zone force other waters of the north Atlantic to follow this same northeasterly direction. Therefore, warm currents continuously bathe the coasts of Europe. Here they are deflected southwest and the circuit begins again.

This drift is slow. It is about four months before the warm waters off South America reach the Straits of Florida. Some eight to ten months later this same water, still retaining some of its warmth, arrives in the vicinity of the European coast and influences European weather. Thus, unusually strong winds, in mid-Atlantic blowing away from England to the southwest might produce unusually warm weather in England a year or so later. Should such strong winds persist for several months, a period of extreme coldness would follow this warm period in England as colder waters from the north would be drawn down and less time allowed for the warming of the Gulf Stream. However, no such cycle has ever been observed. It is quite likely that the change of temperature of the Atlantic waters would serve to check the strong winds producing the cycle.

A striking example of a change of ocean currents producing a change of weather of near-by lands is reported for the coast of Peru from January to April, 1925. Ordinarily a current of cold water from the south flows north along these shores. The cool air blowing off the ocean current lessens the heat there, but the air is warmed so much in passing over the land that its relative humidity is reduced and no precipitation can take place. Rainfall rarely occurs, and the country is mostly a desert land. However, during the early months of 1925 the ocean current changed for some unknown reason. A current of warm water



Low tide at same wharf.

from the north set in and continued for about four months. During this time warm, moist air from over the ocean current blew inland, was cooled somewhat, and its relative humidity thereby raised. Remarkable changes in the weather occurred. Great floods spread destruction over the land. However, there came a quick and luxuriant growth of grass, giving the half-starved animals such a feast as they had never known before. By the end of April the ocean current had returned to normal, the rains ceased, and the country reverted again to its arid type.

While we have dwelt upon the movements of ocean waters of the Atlantic, it must be remembered that similar currents exist in other great sea areas. The ocean current flowing along the eastern coast of Asia, which makes a mild climate for Japan, is produced in much the same way as the Gulf Stream.

One thing about oceanic water movements that frequently puzzles people is the tides and their causes. The raising and lowering of the water two times in about one day is a condition common to all seashores. From a bird's-eye viewpoint these are two great waves separated by about twelve hours that circle the globe in approximately one day of twenty-four hours. Tides are caused by the earth's daily rotation under the gravitational attraction of moon and sun. The moon pulls up water on the side of the earth toward it. That much is generally understood by most people. However, a bulge or ridge of water also rises on the side opposite from the moon. This is not so generally understood.

The explanation of these conditions is that on the side nearest the moon, the moon attracts the water more than it does the

solid ball of earth, thus tending to separate the water and the earth. On the farthest side of the earth the moon shifts the earth ball more than it does the water, causing the water to be left a few feet behind. Again, there is a tendency for a separation of earth and water. There are, therefore, two separations of water and earth, or two high tides, that flow around the earth as it rotates on its axis each day.

Tides make themselves felt in many rivers which empty into oceans. They extend up the Hudson River to Albany, up the Delaware River nearly to Trenton, and up the James River to Richmond. In many harbors, especially where the water is shallow, the rise and fall of tides is enough to have an important effect on navigation. Vessels arriving at such harbors at low tide are often compelled to wait for high tide before entering. The current of tides through narrow openings to harbors sometimes is so strong as to interfere with navigation. The current through Hell Gate near New York City is an illustration of this point.

Atmosphere

There is an old saying to the effect that "seeing is believing." Even though we have come to rely upon sight to such an extent that we consider it the most important of all the senses, we do not depend upon it exclusively. While we cannot see the atmosphere under ordinary conditions, no one doubts its existence. Shakespeare in his "Richard III" refers to it as "the empty, vast, and wandering air." The atmosphere is one of the great and important divisions of the earth's surface. The present atmosphere is composed of the gases which have not yet condensed as the earth has cooled. If the earth cooled to a much lower temperature than it now is, these gases would condense to a liquid. In that instance the oceans might be filled with liquid air. Water would then be in a solid glass-like rock form, or ice. It is not unlikely that such conditions do exist on some of the outer planets, which are much colder than the earth.

The air is a mixture of its several gases, rather than being a gaseous compound. The largest per cent of the atmosphere is nitrogen gas, the next largest per cent is oxygen, there being about seventy-eight and twenty-one per cent of each, respec-

tively. There is present about three hundredths of one per cent of carbon dioxide, nearly one per cent of argon, and traces of other rare elements. These are the constant elements of the air, and in any discussion regarding the composition of the air they are considered as composing it entirely. However, in addition to these elements, the space occupied by the air contains other materials that are somewhat variable, mainly dust particles and a considerable amount of water vapor. These are finely divided particles or molecules which are in the space of the atmosphere around the molecules of oxygen, nitrogen, and other constant gases. The beautiful color effects which are often observed in the sky at sunset and sunrise are produced by the water vapor and transparent dust particles refracting sunlight into its different colors.

The atmosphere at present is at least three hundred miles thick. There is some evidence to indicate that traces of it extend as high as 600 miles above sea level. However, it decreases rapidly in density as the height increases. At least half the weight of the air is below the elevation of three and one-half miles. At five miles above sea level the air is too thin to support human life. Aviators and balloonists who ascend to these heights must take an oxygen supply with them. Even larger mammals that inhabit mountain slopes above three miles elevation must descend below that level in order to breed and raise their young, so thin is the atmosphere of the higher elevation.

We may think then of a sort of ground floor of the air. It is the layer around the earth up to about seven miles, the height varying considerably for different localities. Although not very high, relatively speaking, this layer nevertheless contains most of the oxygen. Here are the whirling storms, the cold currents, the hot ones. Here gentle breezes may blow or hurricanes and tornadoes devastate the earth. Here clouds form, producing rain, thunder, and lightning. This ground layer is in a state of turbulence. However, here it is that all higher forms of land life exist.

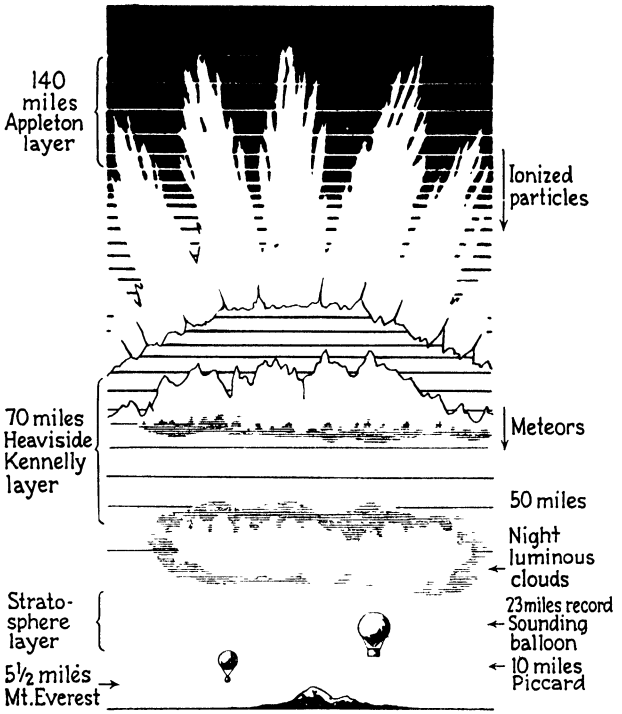
Above this floor is a second layer, called the stratosphere. It is a region or layer of the atmosphere with its lower surface about six to eleven miles above the ground, the exact height depending primarily upon the latitude. It is highest above the

equator and gradually sinks toward the earth in the direction of the north and south poles. From this lower surface upward to heights of twenty to thirty miles, the temperature remains practically the same. Without any change in temperature there is obviously no convection current in this layer, and it is in a stable equilibrium. Here, then, is a region of the atmosphere that is in marked contrast to the ground layer below. No violent winds blow, and there are no storms. At most only general drifts proceed in a given direction.

Temperatures in the stratosphere are very low compared to those prevailing at the earth's surface. Above the equator the temperature in the stratosphere layer is about 110° below zero Fahrenheit. It gets somewhat warmer as the poles are approached, the temperature above the North Pole being about 46° below zero Fahrenheit. As would be expected at such high altitudes, the atmospheric pressure is low. Recordings that have been made by sending balloons into the stratosphere show that the barometric pressure in the stratosphere is about one-thousandth that at sea level. Should this region ever become the highway for airplane travel, it will be necessary to carry oxygen for crew and passengers and probably to get a new method for propelling the plane.

Above the quiet, cool region of the stratosphere and extending up to about one hundred miles is a third layer of the atmosphere that has some marked differences from the stratosphere. For one thing, it probably is much warmer than the stratosphere or even warmer than the earth's surface. But this warmth would seem unreal to us, as the air is exceedingly thin. For all practical purposes it is as rarefied as a vacuum. However, some air does exist there. It is in this region that the incoming meteors first encounter enough resistance to heat them to incandescence, producing for us the streamers of "shooting stars" across the sky as the meteor is burned to dust. It includes what is called the Heaviside layer of ionization, which reflects certain radio waves back to the earth. However, it should be remembered that we have little accurate information about conditions so high up.

Even above one hundred miles traces of atmosphere exist. These upper reaches contain sufficient ionized or electrified



Layers of the atmosphere. (After Dorothy Fisk in "Exploring the Upper Atmosphere.")

particles of the air to provide for us those beautiful northern electrical displays, the aurora borealis. Here, also, are other ionized layers of the atmosphere, known as the Appleton Layer, that reflect certain radio waves back to the earth and permit our long-distance radio transmission around the earth. Such traces of ionization must extend up to approximately six hundred miles, based upon the data of these reflections. Beyond this the atmosphere shades off into nothingness, and the story from there out becomes astronomy.

Heat Blanket

The atmosphere acts to trap the heat from the sun and to keep the earth warm. If there were no air, there would be extreme daily variations in the temperature of the earth's surface. The temperature at noonday would probably approach that of boiling water; at night it would probably be far below freezing. The dry land heats rather rapidly, particularly near

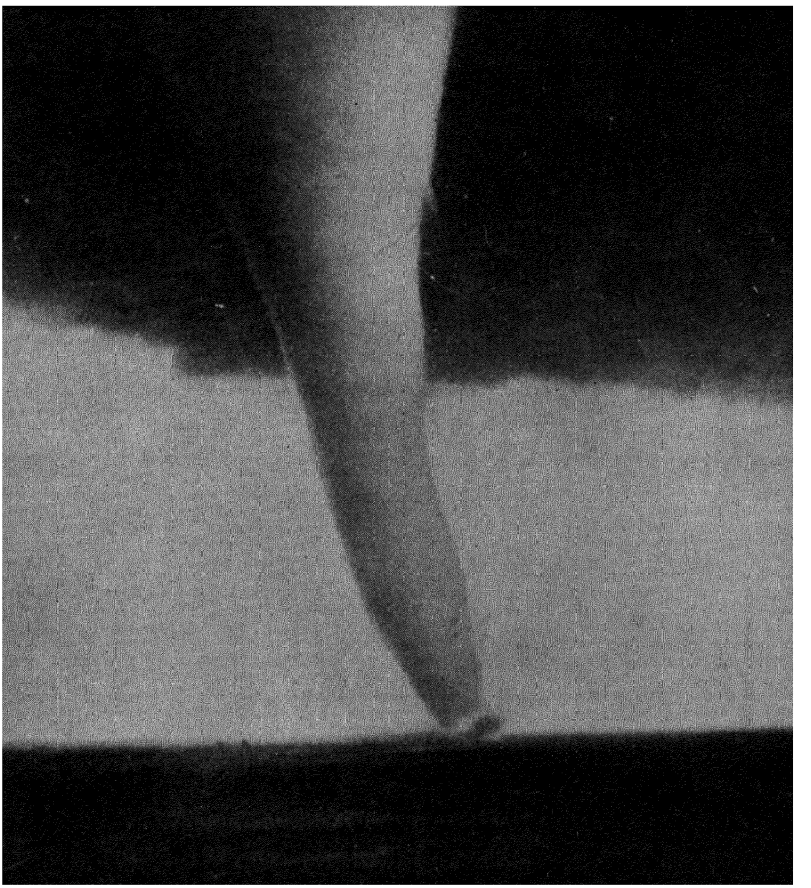
the surfaces, and loses its heat quickly. The full intensity of the sun's rays would make the earth very hot during the day, if there were no atmosphere. After sunset this heat would soon be radiated and the temperature would drop to a very low point, probably as cold as dry ice. Under such conditions life here would be strenuous, if not altogether impossible.

The atmosphere acts as a blanket to regulate the heat of the earth because of the way it transmits heat waves. During the day some of the heat from the sun is absorbed by the atmosphere, and thus the earth escapes extreme temperatures. However, most of the heat waves go through to warm the land and water. At night this heat is radiated in the form of longer heat or infrared rays. These longer heat waves do not pass through the air, being absorbed principally by the carbon dioxide and water vapor present. The air next to the ground thus is kept warm during the night and keeps the land from cooling off rapidly. This warm blanket of air acts exactly the same as the glass roof of a greenhouse. It lets some of the sun's heat in but prevents longer heat waves from being reradiated from the earth.

Movements of the Atmosphere

Winds are winds. Gentle breezes and violent tornadoes are different intensities of the movement of the atmosphere. We complain when no breezes blow and we suffer from the destruction wrought by tornadoes, yet breezes and tornadoes result from the same general forces. So long as the physical conditions of the earth remain what they are, each must occur to torment men's souls and to manifest the changeableness of weather. The catalogue of things that keep the winds blowing begins with the sun's heat and includes the temperature and pressure of the atmosphere, the irregular distribution of land and water over the earth, the rotation of the earth on its axis, the presence of mountains and valleys on the continents. It ends with winds, just where we started at the beginning of the paragraph.

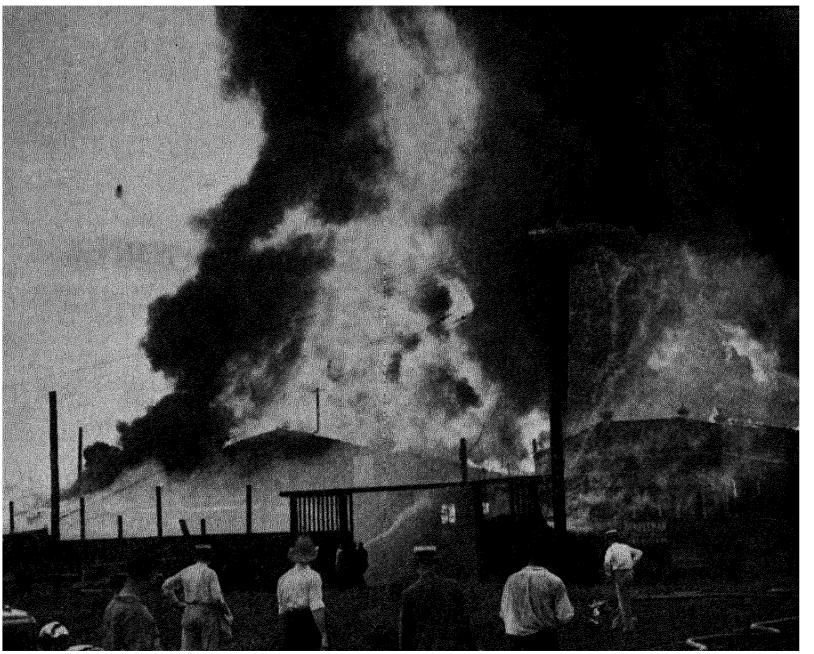
Great circulations of the atmosphere over the earth are set up by unequal heating of the earth's surface at different places; that is, the force that started winds blowing in the beginning and has served to keep them blowing ever since is the sun's heat. Anyone who has ever watched the flames leap up from a burning



Tornadoes are revolving movements of the air of small diameter and destructive violence. A funnel-shaped cloud extending downward from a heavy cloud mass may have revolving winds of 300 miles per hour and an updraft of 200 miles per hour at the center. (Science Service photograph.)

building, has seen on a small scale a condition similar to the great circulations of the atmosphere. The heated gases of the flames go up; they do not spread out over the ground. These gases are lighter than the surrounding air, and they are thus pushed upward by heavier air rushing in to equalize their pressure and, incidentally, to fan this fire to greater burning.

When great bodies of air are heated they expand and become lighter than cooler air. This difference in weight, while generally imperceptible, is really enormous. Suppose we consider two



Flames leaping upward in lumber yard fire at New Orleans. (Photograph by Ewing Galloway.)

cubic miles of air adjacent to each other. Each of them is a layer of air one mile thick over one square mile of surface. It is not so large a volume after all. If the two cubes differ in temperature by 1°F., the colder cube weighs about 10,000 tons more than the warmer. Should the difference in temperature be 20°F., their difference in weight is approximately 200,000 tons. With such enormous forces unbalaneed something must take place. The cooler, heavier air flows in and pushes up the warmer, lighter air until their weights are balanced. Should the incoming air become likewise heated, it too is subject to the same upward push by other layers of cooler air. If the heating continues, the process goes on ad infinitum.

Strangely enough this does take place on certain areas of the globe. Where would we expect to find such a place? It is, of course, over the equator. In the equatorial belt the earth is warmest, in fact continually warmest, and the air is heated most. Here it rises, probably up to near the stratosphere, where it cools

and overflows toward the poles. Therefore, the chief movements of the air on each side of the equator are slow vertical drifts. Since the vertical drifts are generally imperceptible, the area constitutes a belt of calms, known as the "doldrums." The doldrums are characterized by only light winds and heavy rainfall.

The doldrums, then, are areas of heated air which have expanded and become lighter. The cooler, heavier air from each side the equatorial belt flows in to balance this reduced pressure. This flow is near the surface and from the region of the temperate zones to the north and to the south. North of the equatorial belt the flow is toward the south. South of this belt it is toward the north. These rather gentle and constant winds are called "trade winds." The name has nothing to do with commerce, but is derived from an older English meaning of the word signifying a straight path.

Now, if the earth were all sea or flat lands and not spinning on its axis, the trade winds would blow directly north and south, and such breezes would probably be the only pronounced ones we would know. Weather would be simple, but probably uncomfortable and uninteresting. However, the earth is not all seas or flat plains and it does rotate. Therefore even the large general movements are complicated somewhat and smaller ones much more, as we shall note presently.

As the earth rotates on its axis, it carries the air along with it. Every school child who has played "crack the whip" knows that the speed in a circle is much greater near the circumference or at "the end of the line" than it is at the center or the "pivot" of the school game. The air, then, that is circulating around the earth in the temperate zones is traveling with much less speed than it is at the surface of the equator, since the circumference of the earth is greater at the equator than nearer the poles. The surface speed of the rotating earth at the equator is about one thousand miles per hour while at Mexico City, for example, it is about nine hundred miles per hour. At the north pole this speed would be, of course, exactly zero or imperceptible.

The air moving into the region of the equator from the latitude of Mexico City is traveling into faster territory. It has no innate ability to increase its speed. In fact, like all material bodies, it possesses inertia and tends to remain at its present



Great prevailing air movements of the earth's surface.

condition of motion. Consequently, it lags behind the faster moving surface of sea and land of the equatorial regions. The eastward motion of the earth is too great for it, and this lag causes the air to drift to the west as it flows south in the Northern Hemisphere and north in the Southern Hemisphere. Therefore, the trade winds blow toward the southwest and the northwest in the two hemispheres, rather than directly north and south.

Let us not forget the air that has been displaced above the equator. It cannot remain perpetually aloft. These upper winds spread out to the north and south above the trade winds. When they have cooled and contracted sufficiently, they sink back to the surface. Just north of the north trade winds and south of the south trade winds this sinking will be greatest, producing two other belts of little horizontal movement, giving us two other regions of calms, known as the "horse latitudes."

Some of the air from aloft spills over the horse-latitude calms to the north and the south before reaching the surface. It should be kept in mind that this atmosphere still retains its surface speed of rotation approximating that at the equator. However,

now it is in higher latitudes, where surface speeds are much slower. When this air approaches land and sea level it is literally running ahead of the surface beneath it. As it spreads out to the north in the North Temperate zone, it also flows to the east, since it is outdistancing the surface speed of the rotating earth there. Such winds, then, blow rather constantly toward the northeast. In the Southern Hemisphere the same condition holds, and winds blow toward the southeast. These are called the "prevailing westerlies."

Such are the great prevailing winds of the earth. These are, however, in no sense the total atmospheric movements, particularly in the North Temperate zone, where continents and mountains and irregular seas and ocean currents operate to upset this well-ordered scheme. The prevailing westerlies are greatly altered by the unequal heating and cooling of land and water. This air, being swept over high mountains into low-lying plains, is churned in all sorts of fashions. Some of it comes in contact with cold air from the polar regions, which also adds to the turbulence.

Under the influence of the sun's heat the land is warmed quickly during the day. It cools off some at night. However, the water of the ocean heats much less quickly and cools off much more slowly, as we have seen. This unequal heating of air above land and sea causes unequal expansion of the air. It thus brings about areas of high pressure adjacent to areas of low pressure. These are in truth as well as name "centers of action." During the winter months, for example, low temperatures and high pressure tend to prevail over the land, while over the ocean higher temperatures and low pressures prevail. This is particularly true of the North Pacific along the coast of northern United States and Canada. Unequal conditions are so marked there that great seasonal circulations of air are set into motion.

Local movements of air thus get started. These movements travel east under the general influence of the prevailing westerlies. The air may be deflected sharply upward over mountains, where it cools quickly and precipitation begins. Should the winds come in contact with a cold layer from the north, other disturbances are produced. All is turmoil. Weather begins.

Weather

Until a few years ago people took the weather pretty much for granted and did not worry a great deal about solving its complexities. As Charles Dudley Warner (not Mark Twain as usually stated) once said, "Everybody's talking about the weather, but nobody's doing much about it." However, today it may be said that we are doing a great deal about understanding the sources of weather, making short-time, accurate predictions, and regulating our activities accordingly, with great advantages to many people.

And what is weather? A rather comprehensive and complex set of phenomena are all put together under this one word. It includes temperature changes, rainfall, snow, sleet, humidity, atmospheric pressure, wind direction and velocity, clouds, and electrical disturbances. These things are all so variable that even the Weather Bureau, with its technical staff and far-flung set of observation posts, cannot fathom all their secrets. "As fickle as the weather" is an axiom with significant meaning. However, the weather experts have solved many of the problems relating to atmospheric movements and the physical changes that accompany them. We can decipher some of the physical factors involved in producing weather changes and thus get some insight into weather phenomena and the reasons for such complexity and fickleness.

For example, rainfall is so commonplace that we never think about it unless it upsets some of our best laid plans. However, a complex series of events must take place before water is lifted from the earth's surface and returns as rain.

Water vapor is removed by evaporation from the oceans and inland surfaces containing water. The sun's heat is the energy that converts water into a gas and brings about its escape into the air. Heat energy when absorbed by the water sets the molecules of the liquid into a more rapid state of vibration, and, having acquired this additional energy of motion, they break away from the surface. This process goes on continuously, and great quantities of water vapor are raised to considerable heights above sea level. It has been calculated that the weight of water vapor necessary to produce rainfall of one inch over the entire state of Georgia, for example, is about four billion tons. The tremendous

energies of solar heat provide the only forces on earth capable of doing such great amounts of work.

The source of most all water vapor is the ocean. After being removed from the oceans by the expenditure of solar energy, water vapor is carried over the continents by winds and diffusion methods. Moist land surfaces, vegetation, and inland bodies of water contain much water and provide a significant amount of evaporation. Plants give off more water vapor than does dry ground, but not so much as a freely exposed water surface.

Water vapor gives us humidity, a condition that is the despair of summer residents of New York City and many other low-altitude sections of the country. The water vapor is always present in variable amounts in the space not occupied by the constant elements of the air. That is, the molecules of the constant elements are not in actual and continued contact with each other, and as a result there is considerable space between them. It is this space that is occupied by the molecules of water vapor. It should be kept in mind that any reference to water vapor in the air means that the water vapor occupies the space not occupied by the other molecules; it does not mean that the water vapor molecules are actually a part of the molecules of the constant elements of oxygen, nitrogen, carbon dioxide, argon, etc., or that they are an integral part of the regular atmospheric composition.

When people generally speak of or complain of humidity, they are usually referring to conditions brought about by relative humidity. By relative humidity is meant the amount of water vapor in the air at a given time compared to the amount this same space could hold without condensation at the same temperature; that is, the capacity of the atmospheric space for water vapor depends very largely upon its temperature. As an illustration, this space at 90°F. has a capacity for moisture about fifteen times greater than it does at 20°F. The hot, dry winds of the Mojave Desert may actually contain more water vapor than the drizzly December atmosphere of a New England coast, but the latter place always has a higher relative humidity. The maximum water vapor capacity of air at 90°F. is about fifteen grains per cubic foot while at 20°F. it is about one grain per

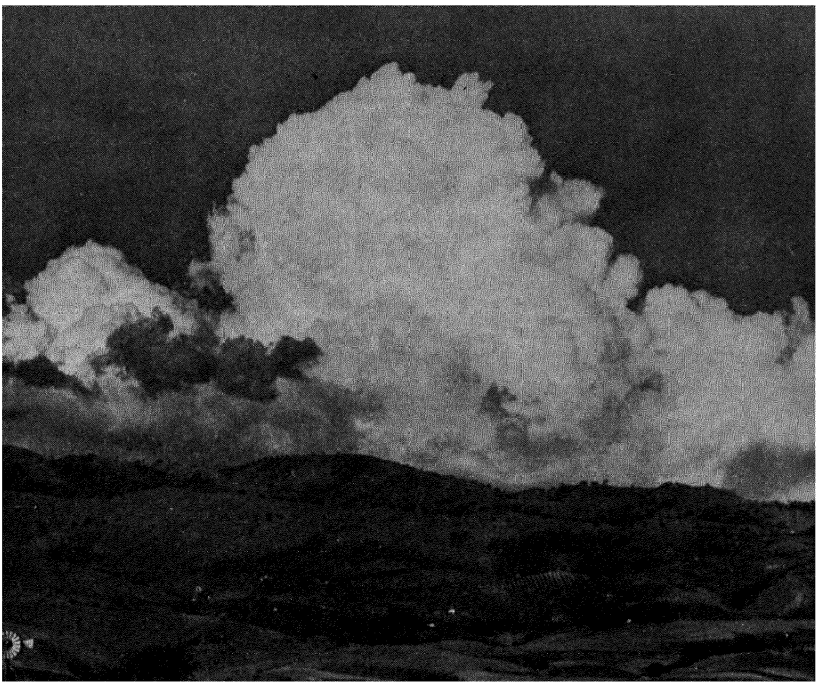
cubic foot. Should the air over the Mojave contain one grain of moisture per cubic foot, the relative humidity would be one-fifteenth or about seven per cent. However, with the same amount of moisture in air at 20°F. over the New England coast, the relative humidity would be one hundred per cent and the air would be saturated at that temperature.

The water vapor that is present in the air must condense and form into raindrops before it will fall back to the earth as rain. Condensation will occur only when saturation (or a relative humidity of 100 per cent) is reached at a given temperature. It is obvious, therefore, that condensation depends upon the amount of water vapor present and the temperature of the vapor which is, of course, the same as the surrounding air. With a given amount of moisture present in the air condensation occurs when the temperature drops to the point just below that at which this amount produces saturation. Thus, cooling of the air is the main factor in producing condensation.

Most cases of cooling great masses of air are brought about by expansion of the air in rising currents. When air rises, it expands because there is less weight upon it than at the lower altitudes. Rising currents may be produced by convection when air in one area is heated more than that in an adjacent area. Air may be forced upward also by the movements of winds over a mountain range. No matter what the reason for the upward rush of air and its consequent expansion, cooling inevitably results and condensation is likely to occur.

Should condensation take place, clouds are formed and float above the surface. However, before the moisture can condense, it must have something on which to condense. In the air this medium is either ionized air particles or fine dust particles, usually the latter. These solid particles cool quicker and to a lower temperature than the water vapor, and thereby form small nuclei around which water vapor condenses. Someone has said that the heart of every raindrop is a dust particle. A continued rising of these fine droplets produces more condensation, thus adding to their size. Eventually they become large enough to be visible, and clouds are formed.

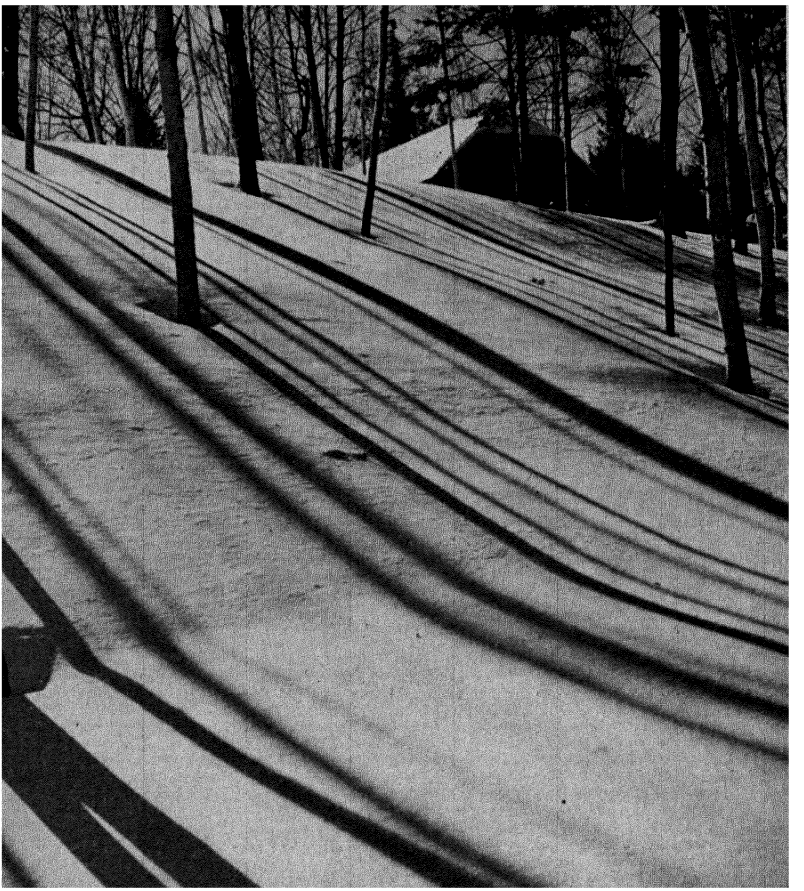
In fair summer weather it is not uncommon for local areas to become heated and give rise to ascending air currents that pro-



Cumulo-nimbus clouds result from updrafts of heated air. (Photograph by Gale Pickwell.)

duce clouds with flat bases and beautiful, towering, cauliflower tops. These are called cumulus clouds. They are usually well isolated in a blue sky, attesting that the rising air currents are very much localized. Another type of cloud that produces beautiful effects in the sky are similar fair-weather ones of localized heating, known as cirrus clouds. They occur at altitudes of from five to ten miles, where the temperatures are low enough to freeze the condensed water. Thus they are composed of minute ice crystals and they assume various forms, sometimes appearing like white curls, ringlets, or wisps of hair. Clouds which are formed by a large-scale cooling of the air and which usually extend from horizon to horizon constitute some form of stratus clouds. Often they form a gray ceiling to the sky, or they may be thick and dark masses from which rain or snow falls.

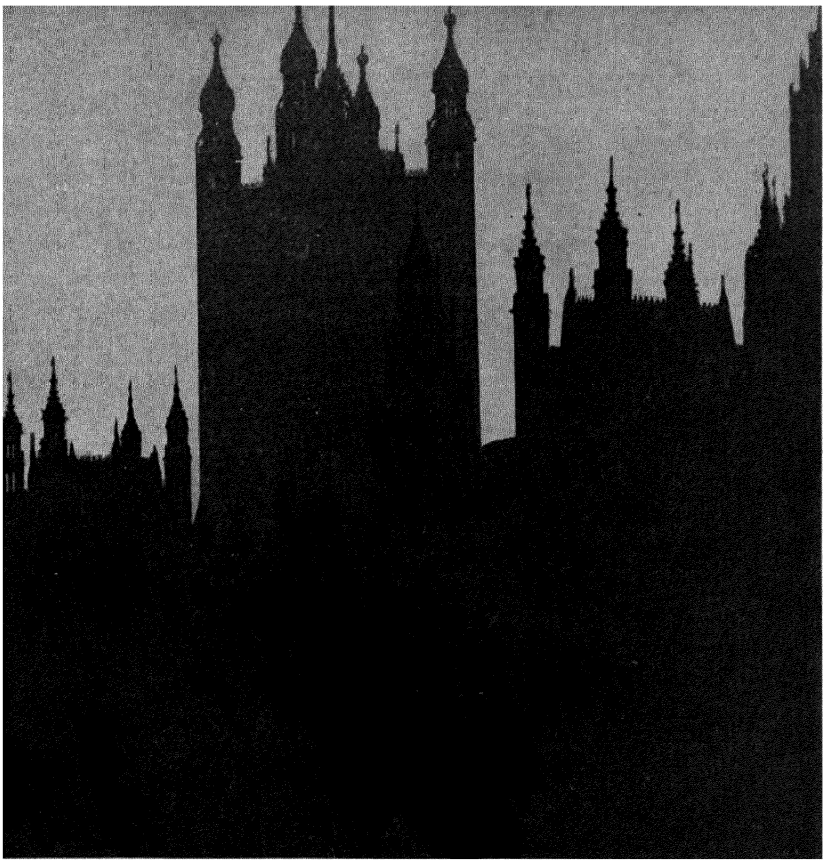
Clouds will produce rain when the air continues to ascend well above the condensation level, where further condensation



When the expansion of the upper atmosphere is such as suddenly to lower the temperature below the freezing point of water there will be a simultaneous condensation and freezing of the water vapor, producing snow. (Photograph by Ewing Galloway.)

takes place around the minute drops of water. When these drops grow large enough to overcome the upward movement of the ascending air, the force of gravity pulls them downward and they eventually reach the earth. And so the rain falls.

Precipitation may occur in other forms than raindrops. The moisture in the clouds may freeze as it condenses. If the expansion in the upper atmosphere should suddenly produce temperatures below the freezing temperature of water, this will always happen. Such simultaneous condensation and freezing produces



Houses of Parliament and Westminster Abbey in a fog over London. (Life Magazine photograph.)

snow. The delicate crystals of ice thus produced are of infinite design and unsurpassed artistic beauty. No more remarkable sight is in store for anyone than that of some flakes of new-fallen snow under a microscope.

On the other hand should the raindrop freeze after condensation, it might fall to the earth as sleet. Such freezing may be brought about even in summer if the raindrops in the clouds are violently blown upward by rapidly rising air. Thus these raindrops cool more and may freeze. However, when this happens in the summer, they will eventually fall back to the cloud, where more condensation of water occurs around the frozen center.

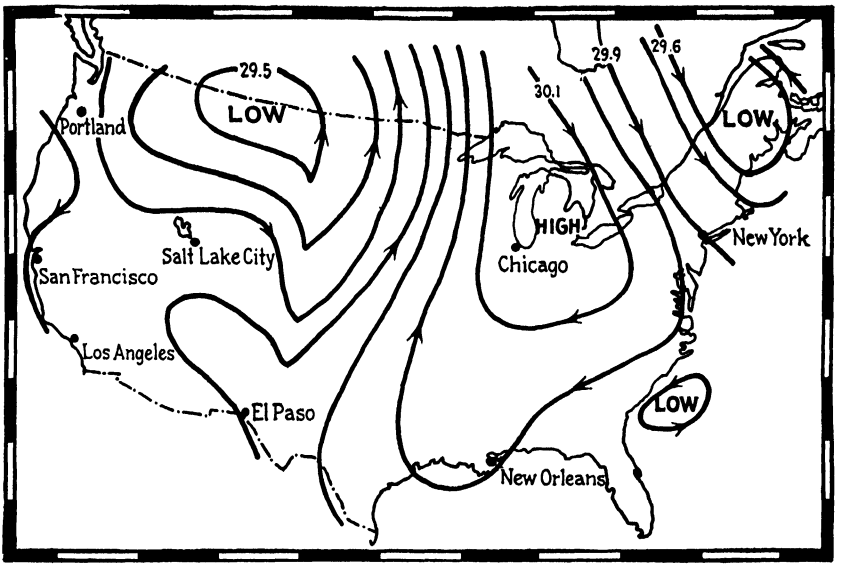
Then without being able to fall to the ground, they are hurled aloft again by the rising air, and the outer layer likewise is frozen. Should this up-and-down condensation and freezing repeat itself enough times the frozen sphere may build itself up to an inch or even more in diameter. Eventually, of course, it becomes so heavy that it breaks through the cloud and falls to the earth as hail. Hailstones in August as large as hen eggs are not unheard of.

Condensation may occur near the surface of the earth rather than at higher altitudes. In such an event fog is produced. Ideal conditions for this type of cooling are a clear sky, no wind, and a relatively long night. Radiation of heat from the earth cools the surface rapidly, and the thin layer of air next to it has its temperature reduced below the point necessary to produce a saturation of the moisture present. These conditions are also aided by the presence of large quantities of dust particles composed partly of organic materials, a condition that is common around many large cities. These particles absorb water vapor easily, and thus produce persistent fogs. These fogs are more common in areas near seacoasts, where the moisture content of the air is likely to be high. This accounts in part for the intense fogs of London.

Thus expansion, cooling, freezing, and condensation of moisture on microscopic solid nuclei furnish us with some of our weather phenomena.

Cyclones

The large-scale condensation and precipitation that is common to much of the country in the North Temperate latitudes takes place around storm centers. These are areas where great volumes of air are lifted and consequently cooled. The uprush of the air in such magnitude occurs in well-established regions of low barometric pressure, where the air has been warmed somewhat and thereby becomes lighter because of expansion. These areas are known as "lows," and they constitute the centers of great revolving cyclones that move across the United States and many other countries of the north latitudes every few days from west to east. They are so large in area and mild in wind velocity that they rarely are considered as "cyclones" in the popular connotation of that word. They produce much of the weather



Simplified weather map of September 11, 1939, for the United States, showing lows and highs, and their general path eastward across the continent.

changes common to the northern part of this country. However, these cyclones are definitely not to be confused with tornadoes or hurricanes.

These revolving storms range in diameter from about 100 to 2,000 miles, the average diameter in the United States being 1,000 miles or more. Quite in common with the general tendency of the air to whirl because of the effect of the earth's rotation, the cyclones revolve in a counterclockwise direction. They usually form over the North Pacific and more majestically eastward across the country. The transcontinental journey across the United States requires from three to five days.

The path they follow is generally southeast to about the center of the United States, then a turn to the northeast along the south part of the St. Lawrence drainage and out into the Atlantic. To be sure, they often take different routes but almost always in an easterly direction. Frequently the cyclones dissolve after getting far out to the sea. However, many of them cross the Atlantic to Europe. Most of these, together with those which begin in the North Atlantic, move northeastward across the British Isles into Northern Europe and Russia. A few of them

have been followed entirely around the globe. They reflect the workings of the earth's gigantic weather machine. A glance at the weather map of the United States for any day will usually show one or more lows or centers of such cyclones.

The cause of these cyclones is not definitely known. However, the best explanation is that they are caused by a polar front. It is well known that great masses of cold air accumulate in the polar regions, and likewise masses of warm air accumulate in the warmer zones. In areas of the prevailing westerlies, these masses of warm and cold air are driven together. There is a well-marked and distinct surface of separation between the two. This surface is the polar front. Since the earth's atmosphere affecting weather is several miles thick, this front is not a line but a surface, ranging from an inclined plane to an almost vertical wall.

Across this front there is a marked change in the temperature and humidity of the air. The front is a sort of battleground on which there is a ceaseless pull and tug between these two mountainous masses of air. The irregularities of air movement along the polar-front set up eddies and swirls which initiate the depressions in barometric pressure that form the lows of the cyclones. When this occurs, weather gets started. There are storms and cold spells, rains and droughts, winds and dust storms.

The winds of a cyclone blow in certain definite directions around a low. This is easily understood, if it is remembered that the cyclones revolve in a counterclockwise direction around the center, looking down on it from above. Therefore, east of the center of such a storm the winds blow north. West of the center, they blow south. This means that as a whirl approaches New York City, for example, from the west or northwest, warm moist air from the Southern Atlantic Ocean is drawn northward or northwestward toward the city. Accordingly, as such a whirl approaches, the weather is likely to be warm. Some condensation is likely to occur because of the slight cooling of this air, producing cloudy skies.

As the center of the whirl passes, which it usually does at some distance to the north of the city, the warm air from the south, which has been drawn northward on the east side of the whirl, is forced upward by cold, heavier air from the north,

which is being carried southward on the west side of the whirl. This updraft of the warm air brings about its expansion and cooling. Condensation and precipitation of the water vapor is likely to occur, producing rain or snow. The rains or snows, therefore, usually come to New York City when the whirl is north or northwest of the city, so that the city is in the southern half of the whirl.

As soon as the center has passed entirely, so that New York is in the western half of the whirl, cold northern air, with strong winds, blows in from the northwest. Cold air drawn into a warmer climate has its humidity reduced, and clear weather results. That is why such cold, clear days usually follow promptly rains or snows. The usual succession as a whirl approaches and passes is (1) warm, moist weather; (2) cloudy, warm weather; (3) rain or snow; (4) relatively sudden change to clear, colder weather with strong northwest winds. This succession follows about every four or five days.

About ninety per cent of all weather experienced in New York City and in many other parts of the United States can be interpreted on the basis of the passage of cyclonic whirls, as explained above. The chief exceptions, which cannot be so interpreted, are continued cold spells in winter, caused by persistent areas of high air pressure in Western Canada; and persistent hot spells in summer, caused similarly by persistent areas of high pressure over the South Atlantic Ocean.

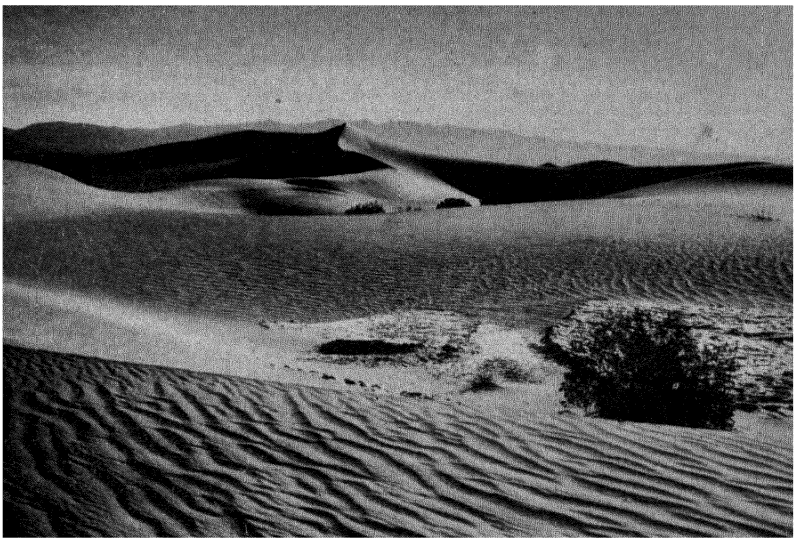
Earth's Climates

A summation of the factors and conditions producing weather gives a general picture of climate, since climate is the average succession of weather conditions for a considerable period of time. Climatic conditions, therefore, usually refer to large areas or zones of the earth's surface; they involve long stretches of time. Climate does have and has had throughout the past a material effect upon life on the earth. Climates are referred to as warm or cold; hot or dry. Temperature and precipitation are without doubt important elements. In addition, such things as relative humidity and winds are hardly less effective in determining climate, and in affecting life conditions.

One classification of climates relates to climatic zones. Those commonly recognized are the torrid or Tropical zone, which is centered about the equator; the Temperate zones, which occupy areas both north and south of the Tropical zone; and the frigid or polar zones, which surround the poles. The boundaries of these are designated in various ways. One that serves as well as any is the system which uses lines of average temperatures as boundaries. Usually the temperature lines of 68°F. (one on each side of the equator) are taken as the limits of the Tropical zone, while the temperature lines of 50°F. for the warmest month are respectively the northern boundary of the North Temperate zone and the southern boundary of the South Temperate zone. The polar zones extend from these two boundaries to the North and South poles. The temperature lines around the earth are somewhat irregular, since the presence of oceans and continents has considerable effect upon average and seasonal temperatures. The general result is that on the western boundaries of continents in the Northern Hemisphere the warmer temperatures will extend farther to the north, while on the eastern boundaries the opposite is true.

The leading characteristic of the tropical climate is a relatively high temperature; uniformity of winds and high humidity are also typical. So long as the winds blow over low lands they are usually dry. Many lands in the path of such winds are desert areas, the most notable ones being the Sahara and Australian deserts. However, when such winds blow over mountains or plateaus the moisture in them is precipitated by an uprising of the air, producing heavy rainfall. The abundant rain on the tableland of Brazil, on the east slope of the Andes Mountains, and on the higher parts of the Hawaiian Islands is produced in this manner.

In addition, the Tropical zone includes some areas where strong monsoon winds blow. These are winds which are produced by a greater heating of the land than of the bordering oceans and which blow in an opposite direction to the prevailing trade winds. Monsoons are the most active agent in bringing heavy rainfall to India. In the Tropical zone near the equator the convection currents of the doldrums give almost daily rains, such as are common to the Amazon Valley and the central part of Africa.



Rhythm in sand dunes in the sun-scorched desert basin of Death Valley, California, 210 feet below sea level. (Photograph by Ewing Galloway.)

Thus high temperatures and abundant rainfall or high temperatures and extreme dryness predominate in tropical climates. In some sections, then, there will be abundant vegetation and dense forests, in other sections there will be the most pronounced deserts on earth. The forest areas are conducive to the extensive existence of varied animal life, particularly some larger forms of mammals, reptiles, and amphibians. It is there that we find the natural homes of many specialized types, as for example, the great apes and monkeys of the primate group.

The range of temperatures is much greater in the North Temperate zone than in the Tropical zone. The result is that the summers may be relatively hot and the winters cold. Rainfall is partly influenced by the prevailing westerlies. These winds blowing from the oceans over the continents will have only a moderate precipitation of rainfall. This does not hold true in winter, when the land is colder than the oceans, nor on the west side of mountain ranges bordering the west side of continents.

In North America the Sierra and Rocky Mountains produce an upward movement of the prevailing westerlies on the western slopes. Thus an expansion of the air with resultant cooling pro-

duces abundant rainfall on the slopes. To the east of the mountains the drier air will be warmed again by descending to lower altitudes, resulting in little rainfall. There we find the semidesert areas of Utah and Arizona, and the arid regions of the Western Great Plains. In Europe there are no great mountain ranges on the western coasts. Consequently there are no great areas of excessive rainfall or extreme dryness. The prevailing westerlies produce a somewhat warmer climate in Europe than in inland North America of the same latitudes, as has been previously noted.

Life conditions in the temperate zones are more varied and often rather extreme. An enormous variety of living creatures finds its natural habitat there. These are mainly mammals, birds, and insects that can live under changing climates. Creatures that can move about easily, and often migrate long distances, flourish best; at least this is true for the larger animals. Here, too, are found both plants and animals that can subsist upon small amounts of moisture during the dry seasons and those that can withstand the rigors of relatively low temperatures.

In the polar zones the temperatures are uniformly colder than in lower latitudes. Much of the surface is covered with snow or ice-cold water. Precipitation is usually not heavy, and much of it falls as snow. Only in certain areas, where local conditions produce warmer temperatures and greater rainfall, are there exceptions to this general condition. Life in these zones must be adapted to this colder, drier climate. The important mammals are the furbearing mammals. Reptiles are scarce, and native birds have made special adaptations to these conditions.

Climatic conditions in the different zones do not change rapidly. Only such minor variations as are produced by periods of sun spots are clearly established. Within a generation of human life or within a century, actual records show little climatic fluctuation. However, over longer intervals of time, such changes may be quite large. From about A.D. 600 to about 1100 the climate of Arizona was apparently different from that at present. There is much evidence to show that there was more abundant rainfall and a lower average temperature. It was during those centuries that the extensive Pueblo Indian civilization developed there. Furthermore, there was a more luxuriant vegeta-

tion and a more extensive animal life than at present. This is also the case in Southwestern Asia and Northern Africa. Within early historical times these areas supported great civilizations and a fairly abundant plant and animal existence. Now they are arid countries, supporting only a meager distribution of life.

Climates in Geologic Times

Farther back in the earth's history there were great climatic changes. These resulted from widespread changes in the earth's surface, such as the elevation of mountain ranges or the covering of large continental areas by inland seas; and probably from some long-time fluctuations in the amount of heat received from the sun.

There is conclusive evidence that the earth is now emerging from the glacial climate of the Pleistocene epoch. About twenty thousand years ago these glaciers receded from most of North America, Europe, and Asia. Within the period beginning at about this time and extending back about one million years, at least four great glaciers crept down over a good part of the North Temperate zone. At the maximum these ice sheets of several hundred feet thickness covered most of North America as far south as the Ohio River, Europe nearly to the Mediterranean Sea, and Western Asia into the southern part of India.

The development of such great ice fields and the reduction of temperature produced great areas in which little or no life could exist. The forms which previously inhabited these lands and seas had to migrate south or perish. Even in the southern climates the pace of life was quickened, and there was keen competition for space and food. Only those forms best suited to the more rigorous conditions survived. Thus reindeer, moose, walruses, and woolly mammoth were found as far south as South America and Africa. During the interglacial times the climate became much milder, and tropical conditions existed as far north as Canada and into Northern Europe. At such times lions, saber-toothed tigers, horses, elephants, and sea cows were distributed over practically all the United States, for example.

During still earlier geologic times there were long periods of uniformly mild climate. This was the condition that existed during most of the Mesozoic era. Great inland seas covered

much of Central North America. Such mild climates and large areas of swampy land favored the development of the large reptiles. In the latter part of the Mesozoic era the great dinosaurs inhabited most of the United States. Following this, the Rocky Mountains began to be elevated, and the inland seas subsided. These changed conditions brought about cooler and drier climates. It is unlikely that the dinosaurs could withstand such changed conditions. At least they have all perished from the earth, and in their place other animals have come into existence and flourished.

There have been many other periods in the earth's history when mountains were upheaved or oceans were pushed in over large areas, each period bringing about marked changes in humidity and temperatures. Such times were especially dangerous to plants and animals that were highly adapted to exist under the old conditions. Great groups of flora and fauna would be blotted out. Some small and probably insignificant types would be best suited to the new conditions; they, in turn, would develop into the predominating forms.

For example, in Central Africa today, the fauna consists primarily of animals that were common over the earth in the tropical climates of the Pliocene epoch, which just preceded the Pleistocene. These are the elephants, giraffes, lions, monkeys, and the like. Should this country become cold or dry, or should a glacier move down over it, these creatures could not possibly continue to exist, even if man did not continue to destroy them in wholesale fashion.

Thus, the climates of the ages have exerted a profound effect upon life on the earth.

REFERENCES FOR MORE EXTENDED READING

FREE, E. E., and TRAVIS HOKE: "Weather," Robert M. McBride & Company, New York, 1928.

The authors have discussed and illustrated in this book many of the practical, dramatic, and spectacular facts about the weather. It includes lively written answers to a great many questions which people generally yearn to know regarding this much-discussed subject.

PICKWELL, GALE: "Weather," McGraw-Hill Book Company, Inc., New York, 1938.

A popularized elementary discussion of weather phenomena, the chief merit of which is a large number of remarkable photographs that are unusually well reproduced.

SHAW, SIR NAPIER: "The Drama of Weather," Cambridge University Press, London, rev. ed., 1939.

This is a somewhat dramatized account of weather changes which is aided considerably by a number of well-chosen photographs and neatly made charts.

TANNEHILL, I. R.: "Hurricanes," Princeton University Press, Princeton, 1938.

This book, written in popular language, is an account of the nature and history of tropical cyclones of the West Indies and the southern coasts of the United States. Vivid descriptions are given of the great hurricanes of these regions. The book includes a large number of maps and some remarkable photographs of hurricane destruction.

BLAIR, T. A.: "Weather Elements," Prentice-Hall, Inc., New York, 1937.

This book presents systematically and in some detail the science of meteorology and the physical processes underlying observed weather phenomena. Written by the senior meteorologist of the U. S. Weather Bureau, it contains much information that has been secured in studying the weather and used in making weather predictions.

FINCH, V. C., and G. T. TREWARTHA: "Elements of Geography," McGraw-Hill Book Company, Inc., New York, 1938, Chaps. VIII, IX, X, XI, XII.

The chapters referred to include a readable and explicit discussion of the earth's climates, their classification, characteristics, and weather changes.

KENDREW, W. G.: "The Climates of the Continents," the University Press, Oxford, England, 1937.

This English text is an extended account of the climate conditions of the different continents of the earth. It includes a wealth of material regarding weather, rainfall, temperature changes, winds, and other meteorological conditions. Many maps and tables of data of interest to aviation and to students of climatic phenomena are recorded.



4: LIVING CHEMICALS

The Nature and Physical Basis of Life

IN THE mythology of the ancient Norsemen the most glorious of all cities was Asgard, the shining home of the gods. Only one person within this city was given the secret of life. This was Iduna, the lovely goddess of youth. When she smiled, it was always spring. When the triumph of the evil giants of Jotenheim saddened her, icy winter set in. Iduna had a magic casque filled with wonderful apples which the Fates had allowed her to pluck from the Tree of Life. Whoever partook of these apples gained immortal youth and loveliness.

Once upon a time Loki, the god of mischief, conspired to steal Iduna and her life-giving apples away from Asgard. For refusing to give any of her fruit to the giant, Iduna was imprisoned in a cave. The gods and people of Asgard grew old and

gray and tired. At last, learning of Loki's perfidy, they forced him to rescue Iduna and return her to them. Eating again of her apples, they at once grew young and strong. Then the goddess leaned over the wall of Asgard and smiled with pity on the cold white earth below. Soon the grass sprang up, the trees turned green, the birds came back, and men, too, gave thanks for her return.

The story of Iduna and her magic casque of apples, indeed the whole fabric of Norse mythology, like that of the early Egyptians, Greeks, or Romans, represents an attempt to explain the mysteries of the animate world. Seeing the raging elements, the procession of the seasons, the awesome panorama of nature with its cycle of life and death, the ancient peoples tried to explain these phenomena in terms which were understandable to them. The riddle of existence has fascinated and challenged mankind since the very dawn of thought. Still no satisfactory answer to it has been found.

It is true that everyone of us can tell a living plant or animal from a stone. Yet no one can say exactly what makes the one alive, the other not. No simple solution to such a stupendous problem as the exact nature of life should be expected. But, while no one has succeeded wholly in formulating a definition of life, biologists in the last 250 years have reached some definite conclusions regarding the characteristics which set apart the living from the inanimate world.

Characteristics of Living Things

When an animal or a plant is broken down into the chemical elements which make up its substance, it is found that these are the same elements that go to make up the composition of inanimate bodies. It is possible to go a step further without arriving at a fundamental distinction between the living and nonliving. A great many chemical compounds which occur in living matter are also found in nonliving things. Many other compounds, although not normally occurring except in the bodies of plants and animals, can be made artificially in the chemical laboratory. By mixing these compounds in a definite manner, or by further combining some of them, it is possible to produce substances

that have some of the manifestations of living things. That which we have produced, however, is but an imitation of life.

What is the difference between our mixtures and true living matter, aside from an obvious one in their degree of complexity? The difference seems to lie in the organization of the latter, in the way in which the various constituents of living substance are combined and possibly also in the way in which they are arranged in space. In recent years biochemists have come to recognize that the intramolecular arrangements which a substance possesses in the stable form with which we are familiar in the laboratory do not necessarily hold for the structure of the same compound as it actually occurs in a living animal or plant. The first characteristic, then, in which living things differ from nonliving ones is in the organization of their substance.

We have spoken of living matter as though its composition were fixed and unchanging. As a matter of fact, nothing could be farther from the truth. The stuff which constitutes the physical basis of life is continually changing. Like the flame of a candle which retains its general form although its burning molecules decompose and are replaced by others, living matter, while maintaining its essential characteristics, is never the same from one instant to the next. In every living organism chemical reactions are continuously taking place. Some of them lead to the breakdown of materials to provide energy for carrying on the vital activities of the body; others result in the formation of new body substance, either for growth or for repair.

The sum total of all these chemical reactions is termed metabolism. The ability to carry them on constitutes a second fundamental characteristic which serves to distinguish living things from inanimate ones. Metabolism is the very essence of life. It implies an orderly set of reactions and interactions which at death become uncontrolled, some of them slowing down or ceasing while others speed up to the point of destruction.

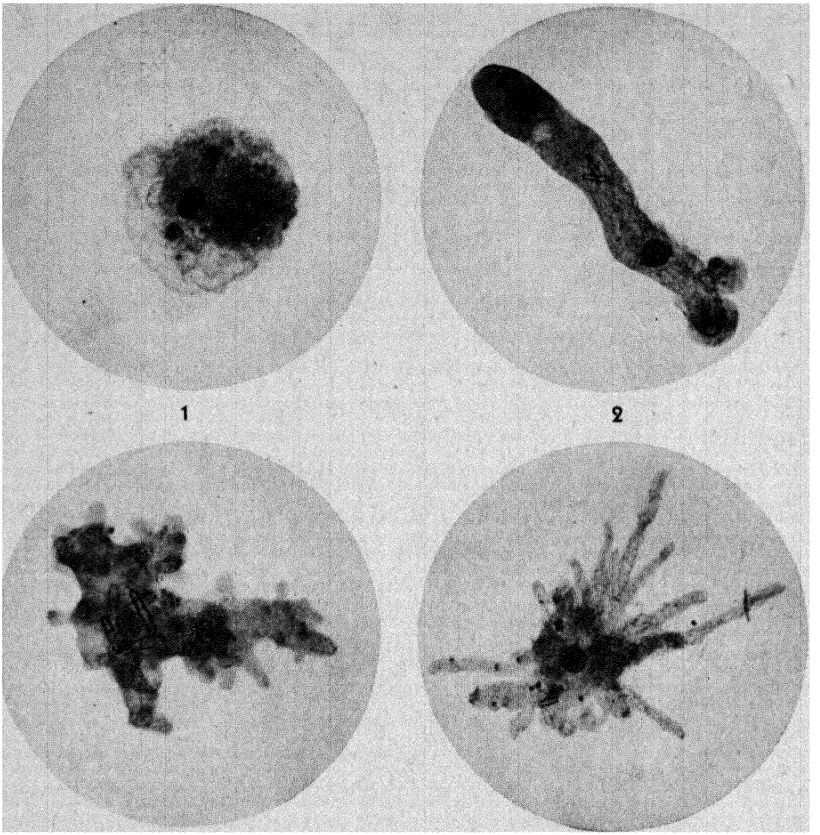
Growth, or increase in size, is one of the most obvious features of living things. We can all remember a time when we were much smaller, some perhaps more vividly than others. Some of us have seen a rather indefinitely shaped bundle of fluff develop into a fine big police dog. Others have watched a spindly seedling grow to be a tall shade tree. But increase in

size is not alone a property of living plants and animals. A tiny crystal of copper sulphate dropped into a saturated solution of the same substance will give rise to a great, branching "copper sulphate tree" in the course of a relatively few hours. In this case, the new structure is always built up by the addition of molecules of copper sulphate withdrawn from solution.

In a living organism, however, growth takes place from within. In the process many different types of raw materials are converted into the specific stuff which makes up the body of the individual. This growth of a plant or an animal is orderly. As it grows, moreover, each living thing preserves not only its own individuality but also the characteristic shape and structure of others of its kind. It takes materials of various chemical compositions and converts them into the substances of its own body. This ability to form new specific substances from nonspecific materials distinguishes the growth of living organisms from that of nonliving systems.

Perhaps one of the most remarkable features of living things is the power of adaptation. In general, adaptation is the modification of a part or the whole of an animal or plant to meet the needs of special living conditions or to perform a special function. The wing of a bird is a modification, which is an adaptation for flying, of the forelimb of other four-legged types of animals. A different type of modification for the same purpose is seen in the wing of a bat. The brain of man is an example of another adaptation. Remarkably free from other structural modifications, except those necessitated by the assumption of an erect posture, man has developed in his brain the most remarkable adaptation known. The power of reason confers on human beings the greatest survival value among living things, for the ability to think gives mankind a greater capacity to adjust himself to changing conditions than any other form of life possesses. Nonliving systems do not exhibit any characteristics comparable to the power of adaptation.

Another characteristic of living things is illustrated by an experience which probably every person has had at some time during his life. If someone aims a blow at our eyes we instinctively blink and duck our heads. Our subsequent actions depend upon many complex factors, among them, perhaps, the size of



Series of photographs illustrating responses of amoeba to various environmental changes. (1) In the absence of stimuli, for example, in darkness and cold, the amoeba rounds up into a ball. (2) In rapid movement a single large pseudopod is formed and the amoeba flows into it. The large dark nucleus is clearly visible, also the smaller, clear contractile vacuole. (3) Among slime-covered algae the amoeba throws out numerous short, blunt pseudopodia to support it in its slippery surroundings. (4) In clear, moving water, amoeba forms many long thin pseudopodia which help to buoy it up. (Photomicrograph by Roy Allen.)

our opponent or our own aggressiveness. In any case, our behavior exemplifies the power of living creatures to respond to stimuli. This power is termed irritability. It is manifested by even the simplest kinds of plants and animals, but not by inanimate bodies.

Any change in the environment of an organism may serve as a stimulus for some kind of response. Thus, a sudden drop

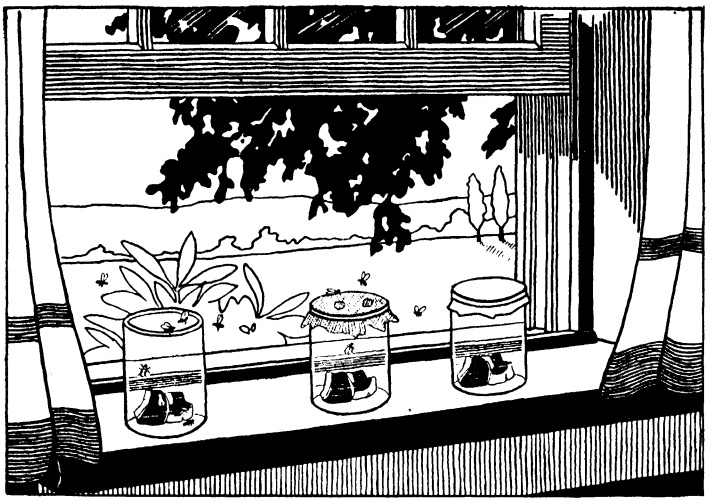
in temperature soon brings on shivering if we are not properly clothed to withstand it. After strenuous exercise we perspire. Under different types of conditions the same stimulus is capable of eliciting quite different responses; that is, the nature of the response is subject to intrinsic control. Our reaction to the odor of cooking is apt to be different when we are hungry from when we are not. It is in this respect that the response of a living organism to a stimulus differs from the response of an inanimate object to the application of a force. A billiard ball has no choice of motion when hit with a cue. It always moves in a direction and with a speed which are determined by the direction and angle of incidence of the cuehead and the force with which it is applied.

We have reserved until the last the discussion of what is perhaps the most striking characteristic which serves to distinguish living things from nonliving ones. The ability to reproduce their kind is exhibited by all forms of life but in general is not manifested by inanimate objects. The so-called filtrable viruses and the bacteriophage are borderline cases which possess the power of reproducing themselves, although not yet properly referable to the class of living matter. The essential feature of the reproductive process is the faithfulness with which every structure of the parent is duplicated in the offspring down to the most minute details. Horses can give rise to nothing except other horses, and an acorn will produce nothing but an oak.

The Stream of Life

The title of the current discussion embodies one of the most fundamental concepts of modern biological thought, namely, that life is continuous and has been so since its origin. The concept is summed up in the celebrated aphorism "Omne vivum ex vivo." In its simplest terms it states that living things are always descended from other living things through the exercise of the fundamental process of reproduction.

This concept has not always enjoyed the scientific reputation or widespread acceptance which it does at present. No less eminent an authority than Aristotle, writing in the fourth century B.C., described the spontaneous origin of insects from the dew which falls on the leaves on warm spring and summer evenings.



" . . . maggots developed only in the jar which was left uncovered. . . . "

This idea that some forms of life are constantly generated in some such mysterious fashion proved scientifically acceptable until the latter half of the eighteenth century. It persists even today in the folklore of uneducated people, who believe that horsehairs falling in a barrel of rain water are transformed into worms or that maggots arise directly from decaying meat.

That the latter is not true was shown by Francesco Redi, an Italian physician, in 1768. Redi, in one of his experiments, allowed meat to decay in a series of jars placed near an open window. One of the jars was left uncovered, a second was covered with gauze, while a third was sealed with parchment. He found that maggots developed only in the jar which was left uncovered, although flies laid their eggs on the gauze covering the second jar. He concluded quite correctly, therefore, that the maggots came from eggs laid by the flies on the meat to which they had free access. Since no eggs were laid on the parchment, which is impervious even to the odor of meat, he also concluded that flies when about to lay their eggs are attracted by the odor of decaying meat.

The theory of spontaneous generation received its deathblow about the middle of the nineteenth century, when Louis Pasteur demonstrated that even bacteria do not arise *de novo*. Pasteur showed that beef broth can be indefinitely prevented from undergoing putrefaction by the simple expedient of boiling it in a

vessel which can be sealed off from direct contact with the air. Under these conditions no bacteria appear in the broth, although the latter still is capable of supporting bacterial growth on exposure to air which contains bacteria or their spores. If this had been Pasteur's sole contribution to scientific knowledge, he would still rank today as one of the greatest benefactors of mankind, for this one discovery has made possible the cultivation of single species of bacteria in pure strains and so opened the door to recognition of the causes, prevention, and cure of infectious diseases.

The Physical Basis of Life

In considering the remarkable manifestations of living organisms which distinguish them from inanimate matter, we are led to wonder of what sort of stuff living things are made. What enables living plants and animals to carry on the activities which are so essential to their existence? The answer to this question has already been mentioned in part. Living things differ from nonliving in their organization; that is, in the manner in which their chemical constituents are combined and possibly also in the way in which these constituents are arranged in space. Only the physical substances which show this complex type of organization possess the peculiar properties of living things.

The essential part of every living organism, from the smallest bacterium to the largest whale, is a unique substance, called "protoplasm." It occurs nowhere in the inanimate world, a fact first recognized during the eighteenth century by the German botanist, Hugo von Mohl. He not only recognized the significance of this substance and gave it its name but also began a systematic study of its complexities that has continued until the present. Somewhat later, Thomas Henry Huxley, the great English naturalist, defined protoplasm as the "physical basis of life." In its chemical composition and physical properties it surpasses in complexity any other substance or mixture of substances known to man.

The Chemical Composition of Protoplasm

Of the ninety-two known chemical elements thirteen are almost invariably present in protoplasm. They may be divided roughly into four groups in the order of their abundance. The

first group, comprising about ninety-nine per cent of the living substance, consists of carbon, hydrogen, oxygen, and nitrogen, occurring in the order named. In the second group are potassium, phosphorus, sulphur, and chlorine, making up nine-tenths of the remaining one per cent. The third group comprises sodium, calcium, and magnesium. Iron, iodine, and fluorine make up the last group. Occasionally also there are traces of a few other elements such as copper, vanadium, and silicon. With the exception of chlorine, the elements comprising the first two groups are essential to all organisms. Curiously, sodium and chlorine apparently are not essential for plants, while calcium is not essential to certain lower animals. The proportions of these different chemical elements in the human body are aptly set forth in a short article from *Reflector* entitled, "What Are Little Girls Made Of?"

> Chlorine, enough to sanitate five swimming pools; oxygen, enough to fill 1,400 cubic feet; thirty teaspoons of salt, enough to season twenty-five chickens; ten gallons of water; five pounds of lime, enough to whitewash a chicken coop; thirty-one pounds of carbon; glycerin, enough for the bursting charge of a heavy navy shell; enough gluten to make five pounds of glue; magnesium, enough for ten flashlight photos; fat, enough for ten bars of soap; enough iron to make a sixpenny nail; sulphur enough to rid a dog of fleas; and only one-fourth of a pound of sugar.

The chemical elements which we have listed as components of protoplasm do not exist here in elementary form. They occur partly in combination with one another as chemical compounds and partly as electrically charged particles, called "ions," formed by the action of water in dissolving them. Thus, most of the molecules of salt (sodium chloride, NaCl) appear as positive sodium ions, Na^+, and negative chlorine ions, Cl^-. Many of the processes peculiar to living matter are possible only because of the existence in it of ions.

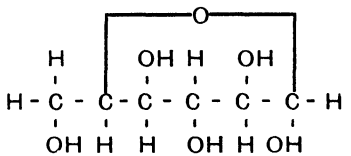
Water is the most abundant single chemical compound occurring in protoplasm, comprising from seventy to ninety per cent of its substance by weight. Water is not itself ionized to any great extent although, as we have seen, it is responsible for the ionization of compounds dissolved in it. It is not only the most abundant constituent of living matter; it is essential to life. In the

absence of water we cannot even imagine any kind of life remotely resembling what we see on earth.

The remaining compounds of protoplasm are the organic compounds, so called because they occur naturally only in living organisms, although many of them have been synthesized artificially in the chemical laboratory. These substances all contain the element carbon and usually also hydrogen and oxygen. On the basis of their structure and elementary composition they are divisible into four classes: carbohydrates, proteins, fats, and lipoids.

The Carbohydrates

These are the simplest organic constituents of protoplasm, being composed of carbon, hydrogen, and oxygen alone, the latter two in the proportion to form water. An example is cane sugar or table sugar, $C_{12}H_{22}O_{11}$, the molecules of which are formed by the union of two molecules of a simpler sugar, glucose, $C_6H_{12}O_6$ with the elimination of a molecule of water. Glucose is the simple sugar formed by green plants from carbon dioxide and water, using the energy of sunlight. The structure of the glucose molecule is represented by the chemical formula presented below.



The arrangement of the hydroxyl (OH) groups and hydrogen (H) atoms on opposite sides of the carbon atoms (C) in glucose confers upon its molecules in solution the peculiar property of rotating the plane of polarized light rays. This is so characteristic of carbohydrates as they occur in living matter that it has been regarded as a key to the understanding of life processes. Glucose rotates the plane of polarized light to the right. Other naturally occurring sugars rotate polarized light rays to the left.

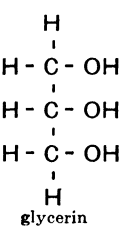
Carbohydrates are particularly important as foods, since they constitute the most readily available energy source and since they are stored in the body to a considerable extent for

this purpose. The process by which the energy of the carbohydrate molecule is released is a straightforward combustion, similar to the burning of wood. In fact, wood, or its principal constituent, cellulose, is a carbohydrate. Another typical example of this group is starch, $(C_6H_{10}O_5)_n$, the chief storage substance of plants. The starch molecule is formed by the combination of an indefinite number (n) of simple-sugar molecules with the elimination of a molecule of water between each uniting pair. The starches are very complex substances, sometimes composed of as many as 200 simple-sugar molecules.

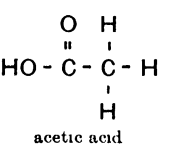
The Fats and Lipoids

The fats and lipoids are oily and waxy substances which are insoluble in water and occur in protoplasm either as granules or globules, depending upon whether they are solid or liquid at the temperature of the organism. Like the carbohydrates, they are made up of carbon, hydrogen, and oxygen, but the lipoids may contain sulphur, phosphorus, and nitrogen in addition. Unlike the carbohydrates, the proportion of oxygen in both fats and lipoids is less than that required to form water. As a result of this fact, the combustion of fat molecules yields a greater quantity of heat and chemical energy than does that of carbohydrates. The fats are therefore important as energy sources as well as being one of the chief storage bodies of animals.

The true fats are formed by the union of molecules of simpler substances, called fatty acids, with glycerin ($C_3H_8O_3$). One of the simplest fatty acids is acetic acid ($C_2H_4O_2$), found in vinegar. These two substances have these structural formulas:

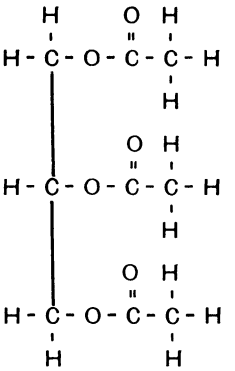


glycerin

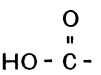


acetic acid

One of the simplest possible true fats would be glycerin triacetate, which has the structure:



The molecule of glycerin triacetate is formed by the union of three molecules of acetic acid with a single molecule of glycerin, as indicated above, with the elimination of three molecules of water. It will be noted that the union takes place by the sharing of a common valence bond between the acid



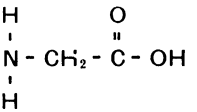
carbon atom of each acetic-acid molecule and one of the three oxygen atoms in the glycerin molecule. As a matter of fact, the simplest naturally occurring fats are usually of mixed composition with respect to their fatty acid particles and contain fatty acids of much higher molecular weight and complexity than acetic acid. The structural formula of glycerin triacetate is given to illustrate the way in which fats are formed.

The lipoids are of the utmost importance as constituents of semipermeable membranes in living organisms. They are also apparently concerned in many types of activities which take place in living protoplasm. Evidence of this is seen in the close correlation between the distribution of lipoids in the various organs of the body and the degree of activity displayed by the latter. Thus, the brain, which has the greatest variety and extent of function, has the highest lipoid content. The liver exhibits the next highest percentage of lipoid, then the pancreas, kidney, and lung in order.

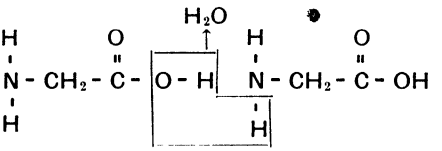
The Proteins

The presence of protein has been stated to be "the most characteristic chemical property of a living system." Certainly,

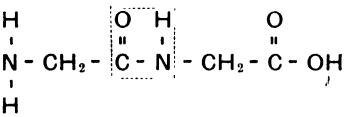
next to water, proteins are the most abundant components of protoplasm, where they occur either as microscopic granules or in colloidal solution and make up about fifteen per cent by weight of its bulk. They are the most complex organic substances known. In addition to the carbon, hydrogen, and oxygen of carbohydrates, all proteins contain nitrogen and sulphur, many contain phosphorus, and a few contain iron or other elements. Certain of the properties peculiar to living matter are attributable to the relatively tremendous size of protein molecules. The simplest known proteins have a relative molecular weight of about 17,000 as compared to hydrogen, with an atomic weight of about 1.0, or water, with a molecular weight of approximately 18.0. These complex molecules are built up of many simpler molecules of *amino acids*—simple substances containing carbon, hydrogen, oxygen, nitrogen, and occasionally also sulphur. There are twenty-one amino acids that are important as components of protoplasm, of which the simplest is glycine ($C_2H_5O_2N$), having the structural formula:



Two molecules of glycine may be combined by splitting out a molecule of water between them in the following manner:



When this is done the result shown below is obtained, the two molecules being linked together at the point indicated by the broken-line box.



The resulting compound is an example of a simple dipeptide, the first step in building up a complex protein molecule. The portion of the structural formula enclosed in the broken-line box repre-

sents the so-called "peptide linkage." This type of linkage makes possible the formation of exceedingly complex molecules from relatively simple substances.

A single protein molecule may contain as many as fifty amino-acid groups and over 50,000 individual atoms. Even as the number of combinations of the twenty-six letters of the alphabet to form words seems inexhaustible, so the number of different kinds of proteins made possible through different combinations and arrangements of the twenty-one common amino acids is infinite. It is this diversity of chemical composition of the protein molecule which makes possible organic diversity itself, that is, the great variety of the forms of life. It is well known that the protoplasms of no two kinds of living things are exactly alike with respect to their protein constituents, a condition which has been found to be one of the most important bases of the body's defense against disease. There seems to be at least one specific protein corresponding to each kind of living creature.

The Enzymes

A special class of proteins of great importance to living things are certain enzymes, some of which have recently been isolated in pure crystalline form. One of the most striking characteristics of living systems from the point of view of the chemist is the great variety of reactions which take place in them at ordinary temperatures and pressures and which cannot be duplicated in the laboratory under these conditions. This remarkable chemical activity of protoplasm is made possible by the enzymes occurring in it and produced by it, some of which are now known to be complex protein substances. Enzymes are organic catalysts. It will be recalled that catalysts are substances which possess the peculiar ability to alter the speed of a chemical reaction without themselves being used up in the process and without changing the point at which the reaction stops.

An example is *amylase*, the enzyme of the human pancreatic juice which greatly accelerates the conversion of starch to the simple sugar known as maltose:

$$\underset{\text{starch}}{(C_6H_{10}O_5)_n} \xrightarrow{\text{amylase}} \frac{n}{2}\underset{\text{maltose}}{C_{12}H_{22}O_{11}}.$$

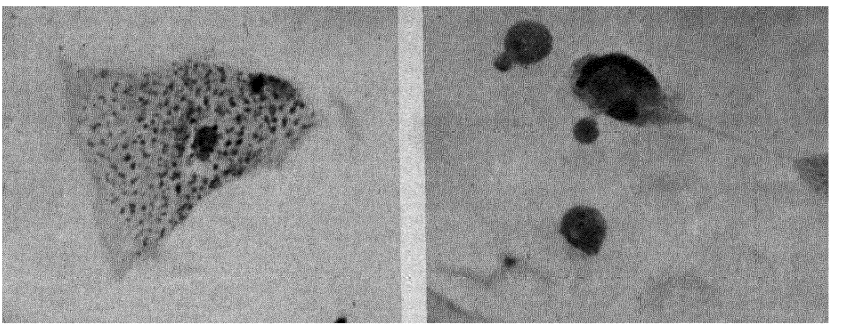
In the equation, n signifies an unknown number of starch units ($C_6H_{10}O_5$), and $n/2$ represents one half of this number. A very small quantity of pancreatic amylase is capable of bringing about the rapid conversion of many times its own weight of starch to maltose. Moreover, the same small quantity of amylase may be used over and over again in changing successive portions of starch to sugar without losing its power.

Enzymes differ from inorganic catalysts in several important respects. One of these is that enzymes are generally specific in their action; they catalyze one and only one definite kind of reaction. Thus, pancreatic amylase accelerates the change from starch to sugar and only that change. This specificity is so rigid that enzymes are identified and named according to the material upon which they act. Moreover, there are a large number of different enzymes, each capable of catalyzing only one type of chemical reaction, even in a single kind of living organism. Another feature in which enzymes differ from inorganic catalysts is that the enzymes are destroyed by heating above relatively moderate temperatures (140 to 176°F.). Inorganic catalysts, such as finely divided platinum, are not affected in this manner by heating.

The Borderland to Living Things

In the preceding paragraphs the chemical composition of protoplasm has been discussed in a manner to bring out the peculiar tendency of living matter to build up ever more complex substances. Reference has been made to the fact that protoplasm itself is the most complex of all substances, combining in its organization molecules of carbohydrates, fats, lipoids, and proteins. The enzymes have been described as a special group of proteins tremendously important in the economy of life. Bridging the gap which formerly was thought to exist between living and nonliving things is another group of protein substances. These are the *filtrable viruses*, so called because they will pass through the pores of the finest porcelain filters and because they are associated with diseases such as yellow fever, smallpox, infantile paralysis, influenza, and the mosaic diseases of plants.

The viruses are so small that they are beneath the limits of visibility of the microscope. It is their small size that accounts



The picture at the left is of an epithelial cell from a person with a sub-acute throat infection. The dark spots are accumulated virus bodies. The picture at the right shows a tissue culture from a patient with measles. In this disease the virus bodies often collect in a crescent formation within the cells as shown by the dark area. (Photomicrographs by Dr. J. Broadhurst, Columbia University.)

for their ability to pass through filters which will hold back bacteria. The virus of smallpox is made up of particles estimated to have a diameter of 0.00017 millimeter, whereas microscopically visible typhoid bacteria are approximately 0.002 millimeter across. This is about the limit of the resolving power of the microscope, and typhoid bacilli are among the smallest bacteria known. Yet, *Vaccinia virus* of smallpox is nearly a thousand times smaller.

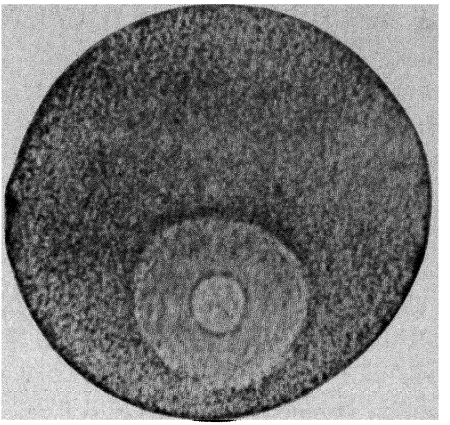
Because of the extremely small size of their particles, obviously not much can be determined about the structure of the filtrable viruses at present. They are chiefly known by their physical and chemical properties, which place them among the largest known protein molecules. They exhibit many of the properties of enzymes, but unlike these they possess the ability to reproduce themselves, although the process by which they do so is believed to be more closely analogous to the growth of crystals than to the multiplication of living organisms. The so-called "mosaic disease," important in the curing of Havana tobacco leaf for cigars, is caused by a filtrable virus. Recently, Dr. W. M. Stanley of the Rockefeller Institute for Medical Research in Princeton, New Jersey, has succeeded in reducing to a dry crystalline form several grams of pure tobacco mosaic-disease virus, a treatment no living substance has ever been able to survive. The crystals can be weighed, analyzed, and redissolved

in the same way as other crystals, such as those of sugar and salt. Nevertheless, on being injected into the leaves of a living tobacco plant, they will resume their activities and reproduce themselves with astonishing rapidity. They are in a sense chemicals at the threshold of life, standing on the border line between the living and nonliving. No one has yet succeeded, however, in cultivating a filtrable virus in the absence of living matter.

There is another group of substances, intermediate between living and nonliving things, which closely resembles the filtrable viruses in certain respects although differing markedly from them in others. These are the *bacteriophages*, so named from the fact that they possess the ability to destroy and feed upon bacteria. Like the filtrable viruses, the bacteriophages are submicroscopic in size and are capable of self-propagation. They likewise resemble enzymes in their physical and chemical properties and are placed among the larger protein molecules. On the other hand, unlike the filtrable viruses, bacteriophages have not been obtained in pure crystalline form. They are so small that they are known only from their action upon the bacteria on which they feed. They cannot be grown in the absence of bacteria but appear to be able to survive for considerable periods of time in mediums from which bacteria have disappeared.

The Physical Properties of Protoplasm

By examining a bit of protoplasm under a high-power microscope and by manipulating very fine glass needles in it, something may be learned of what this living substance is like. Under high magnification it is a grayish transparent material not unlike the uncooked white of an egg in appearance, except that it frequently is full of tiny bubbles or granules which give it a foamy structure. When these particles are carefully watched, they are seen to be constantly moving back and forth, around and around, without evident purpose or direction. This vibration is called Brownian movement after its discoverer, Robert Browne. Brownian movement is not peculiar to protoplasm but occurs wherever fine particles are suspended in a liquid. This movement is due to the bombardment of the particles by the molecules of the liquid. It is evidence of the fact that molecules



An ovum cell of a starfish shows the granular nature of protoplasm. Within the cell the nucleus is clearly visible, and within it is the smaller nucleolus. (Photomicrograph by G. C. Grand, New York University.)

possess mass and motion sufficient to impart a visible force to the suspended particles. It is also evidence of the fluid consistency of protoplasm. Further evidence of this latter fact is obtained by carefully pushing a fine glass needle about in a bit of protoplasm. Most of it is quite liquid, although more viscous than water; however, certain portions are more solid, like a soft jelly. On withdrawing the needle the stuff is found to stick to it, stretching out, and, on finally breaking loose, snapping back. Thus, protoplasm resembles unhardened glue in that it is sticky, elastic, and has a rather high degree of tensile strength.

If the bit of protoplasm is surrounded by a watery medium, it will be found to behave like a drop of oil in that it does not mix with the water but preserves a sharp boundary between itself and its environment. When this boundary is investigated with the glass needle it is found to be a true membrane which may be punctured, stretched, and otherwise distorted, showing that it has thickness, elasticity, tensile strength, and a semisolid consistency. Thus, protoplasm always surrounds its tiny units with a true containing membrane.

The Colloidal State

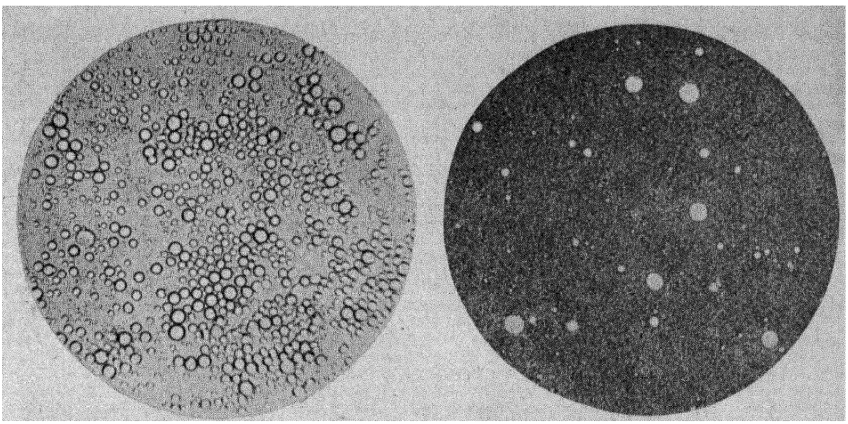
As a result of observations and experiments similar to those just described, scientists have concluded that protoplasm is an

extremely complex colloidal emulsion. What is a colloidal emulsion? The word colloid is derived from the Greek, meaning "glue-like." It was first used over ninety years ago by the English chemist Thomas Graham to refer to peculiar and at that time little understood substances such as egg white. A *colloid* is now known to be a mixture of very fine particles of one substance suspended against the force of gravity in another substance, neither one of them dissolving in the other. In such a system the suspended particles are referred to as the *dispersed phase*, while the substance in which they are suspended is called the *continuous phase*.

In an *emulsion*, both the dispersed phase and the continuous phase are liquids. The mayonnaise used as salad dressing is an example of a simple emulsion in which the dispersed phase is fine droplets of a solution of vinegar in water, while the continuous medium is oil. In other types of colloids the suspended particles may be solid and the continuous medium gaseous, as is the case of smoke in air. India ink is a colloidal mixture of solid carbon particles in water. These are examples of the simplest kind of colloidal system, in which there are but two phases.

In more complicated systems there may be more than one kind of particle suspended in the continuous phase, and the dispersed particles may themselves be colloids. Such a colloidal system is said to have many phases or to be *polyphasic*, and protoplasm is the most complex polyphasic colloid known.

An extremely important property of colloids is their ability to undergo reversal of phase; that is, the suspended particles may coalesce to form a continuous phase, in which the former continuous phase becomes broken up and in turn suspended. An excellent example is the change which takes place when cream is churned to make butter. Cream is an emulsion of oil and fat particles in a watery solution. During the churning process the suspended fatty and oily particles coalesce into the continuous phase, while the water solution breaks up into fine droplets which become suspended. In this way butter is produced. Since fats and oils are much thicker and more viscous than a watery solution, and since the continuous phase is the more important in determining the properties of a colloid, butter is more like a solid or *gel*, while cream is more like a liquid or *sol*.



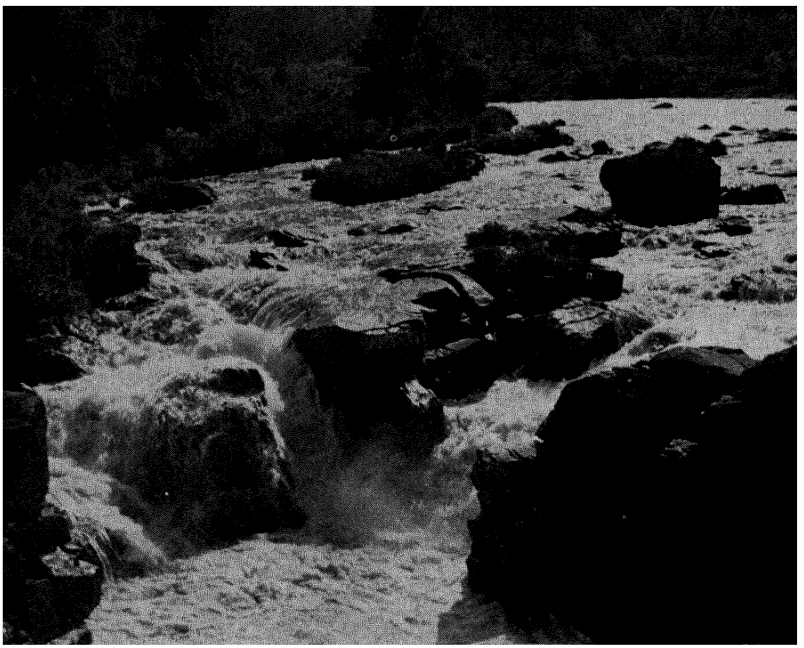
Milk is an emulsion of fat and oil droplets in a watery solution. In the left photograph the fat and oil droplets are shown as bright spheres, while the watery solution forms the gray background. In making butter, when the milk is churned and the phases are reversed, the watery phase breaks up into droplets, which appear in the right photograph as light spheres scattered in a darker background, representing the fatty material which has coalesced to form the dispersed phase. (Photomicrograph by Roy Allen.)

Many biologically important colloids can change rather freely back and forth between a *sol* and a *gel* state. Indeed, a very large number of the peculiar properties of protoplasm may be traced to its colloidal organization and to this ability to change from the gel to the sol state and back again.

The Energy of Life

In order to understand the phenomenon of life it is necessary to think in terms of energy as well as matter. The business of living does not depend upon some mysterious force; in the strictest physical sense it involves work and energy, the capacity for doing work. In the first section of this chapter metabolism was pointed out as one of the distinctive characteristics of living organisms in comparison with inanimate objects. The chemical reactions referred to collectively as metabolism constitute a unique system of energy changes associated with life.

Physical and chemical processes involving inanimate matter tend to take place in such a way that energy is dissipated throughout space. Thus, water always tends to run downhill, and moving bodies tend to come to rest or to lose their kinetic energy by encountering other bodies. A hot body tends to lose



"Physical and chemical processes involving inanimate matter tend to take place in :h a way that energy is dissipated. . . . water always tends to run downhill." (Photograph by Ewing Galloway.)

heat by radiation or conduction, and ordinary chemical reactions yield energy to their surroundings. Living organisms, however, possess the singular ability of storing energy in particular masses of matter to a greater or lesser extent.

The principal differences among living things relate to the degree in which they have developed this ability to store energy. With certain exceptions, the plant kingdom comprises a group of organisms which are able to store large quantities of energy in chemical form, making use of common inorganic substances from the soil and from the air as raw materials. The animal kingdom, on the other hand, is made up of organisms which are directly or indirectly dependent upon plants for their energy sources.

The great majority of plants utilize inorganic substances as energy sources, either directly or in the synthesis of other energy sources, without the aid of other living things. Among these, the forms with which we are most familiar are the green plants.

Such plants are green because of the presence in their protoplasm of a mixture of substances known as "chlorophylls." These are among the most important substances in nature. The chlorophylls comprise a system having the not altogether unique property of converting light energy into chemical energy. The chemical energy available in this process is utilized by green plants in the manufacture of carbohydrates, in which form the energy is stored. The first step in this process is the formation of a simple six-carbon sugar from water and carbon dioxide. In chemical language the process is represented by the following equation:

$$6CO_2 + 6H_2O + \text{light energy} = C_6H_{12}O_6 + 6O_2$$

A synthetic reaction is one in which two or more simpler substances are combined to form a more complex one. The term "photosynthesis" is applied to the process in green plants because the energy utilized is received as light. The carbon dioxide is taken from the air, while the water is taken up from the soil through the roots of the plant. This photosynthetic process is the very foundation of life. It is the principal process whereby organic substances are built up from inorganic compounds. Without it, life as we know it on the surface of the earth would be impossible.

Among the plant-like types of organisms, certain bacteria are able to obtain the energy needed for carrying on their vital activities from the oxidation of simple inorganic compounds found in the air and in the soil. Among these are the nitrogen-fixing bacteria, which utilize the energy released in the conversion of ammonia and the ammonium of ammonia compounds to nitrites and in the conversion of nitrites to nitrates. Another example are the sulphur bacteria, which obtain energy from the oxidation of hydrogen sulphide to sulphur.

The process of oxidation mentioned in the preceding paragraph is as fundamental in the economy of nature as is photosynthesis. In order that the energy stored in photosynthesis may be useful to living things, providing them with the energy necessary to life, it must be released. The process of oxidation provides the mechanism for releasing stored chemical energy and transferring it. Oxidation is defined as the loss of electrons.

It is always accompanied by reduction, which involves the gain of electrons. Oxidation really involves the transfer of electrical energy, in the form of negative electric charges, from one atom, which is thus oxidized, to another, which is thus reduced. It is not a case of creating energy, since energy can neither be created nor destroyed under the conditions existing on the earth.

The processes of oxidation and reduction may be illustrated with a simple example such as the conversion of ammonia to nitrous acid. In chemical language the reaction is written as follows:

$$2NH_3 + 3O_2 = 2HNO_2 + 2H_2O$$

For the *oxidation* of nitrogen:

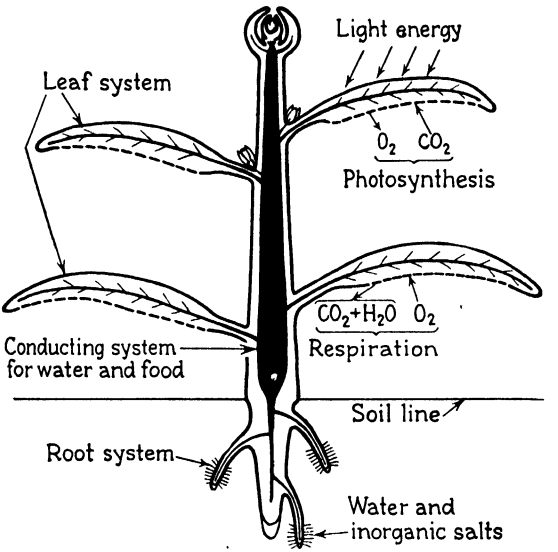
$$N^{---} = N^{+++} + 6 \text{ electrons}$$

For the *reduction* of oxygen:

$$3O + 6 \text{ electrons} = 3O^{--}$$

The nitrogen atom and three hydrogen atoms are held together in the compound ammonia by the transfer of one electron from each hydrogen atom to the nitrogen atom. Therefore, the nitrogen atom has three extra negative charges, and may be written N^{---}. When ammonia is oxidized to nitrous acid (HNO_2), the nitrogen not only gives up its three extra electrons, but also releases three additional ones. Having lost these three additional electrons, the nitrogen atom becomes charged positively, and may be written N^{+++}. Oxygen is the element which gains the electrons released by the nitrogen. It so happens that the oxygen atom can take on only two additional electrons. When it gains two electrons, it may be written O^{--}. In order to take up all six of the electrons released by the nitrogen atom, three oxygen atoms must be used.

The reactions which are chiefly utilized by living organisms as energy sources ultimately involve the oxidation of carbon and hydrogen and the reduction of molecular oxygen. As a result, the principal waste products of metabolism are carbon dioxide (CO_2) and water (H_2O). The utilization of molecular oxygen and the production of water and carbon dioxide by living plants and animals is called "respiration." When the material which is



Green plants use the energy of sunlight in manufacturing carbohydrates from atmospheric carbon dioxide taken in through the leaves, and soil water taken up through the roots.

oxidized is a simple sugar, the process is just the reverse of photosynthesis, as indicated below:

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

Photosynthesis and respiration are carried on simultaneously by green plants in the light. The rate of photosynthesis considerably exceeds that of respiration. As a result, in the daytime a plant will use up more carbon dioxide from the air than it puts back in, and will return more oxygen than it removes. At night, or in darkness, photosynthesis ceases, but respiration continues. Consequently, at night the metabolism of a plant is like that of an animal. Oxygen is used up from the atmosphere and carbon dioxide is given off to it. Animals do not possess chlorophyll and consequently are unable to carry on photosynthesis. Respiration of both plants and animals is closely analogous to the burning of fuels such as wood, coal, or oil. This was first demonstrated by a French chemist, Lavoisier, in 1774. Lavoisier's discovery, more than any other, has been responsible for the development of the modern interpretation of vital phenomena in purely physical and chemical terms.

Respiration and photosynthesis are examples of two different and opposing kinds of metabolic activity. Photosynthesis is a constructive process which results in the storage of energy in forms which are useful to living organisms. The sum total of metabolic activities by which living organisms store energy is called "anabolism." The other phase of metabolism, termed "catabolism," is necessary for the release of the stored energy and is typified by respiration. Life depends upon a nice balance between these opposing tendencies, for catabolism is a destructive process which leads to the wasting away and death of the individual if not properly compensated by anabolic activities. This is what happens when a person starves. When food is not taken in, the body draws upon its own substance to provide the energy needed for carrying on those fundamental processes which are essential to the maintenance of life. The starving individual not only grows thinner, but actually shrinks, since water plays an important part in many of the chemical reactions upon which the body depends for its energy. Catabolism predominates also during the old age of living organisms. During youth, on the other hand, a preponderance of anabolism finds its expression in growth and high vitality.

The Interdependency of Living Things

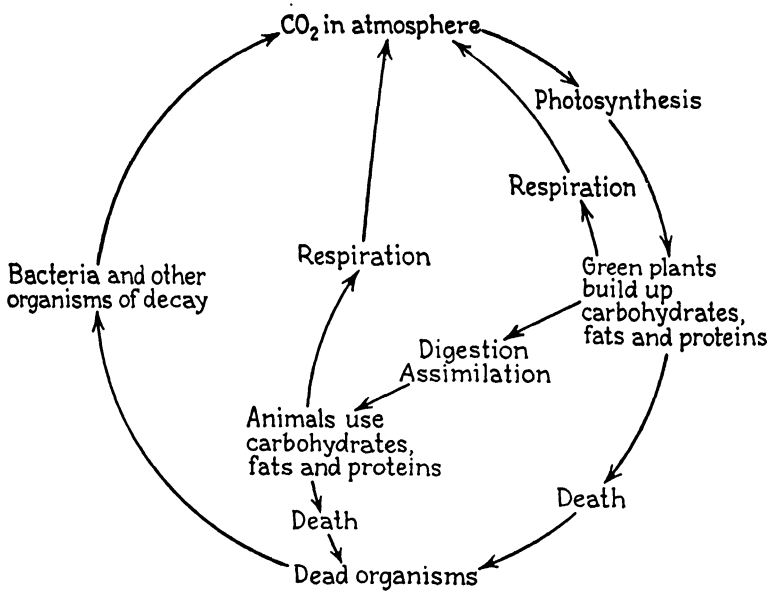
With the exception of the independent types of plants which we have discussed, all living organisms are dependent in some degree upon other living organisms. Even some plants depend upon others for their energy sources. Thus, the yeasts require sugar, which, as we have seen, is manufactured by green plants. The putrefactive and fermentative bacteria utilize dead organic material of both animal and vegetable origin. These are examples of plants which live on materials produced by other living things. Among the most interesting of all plants are the carnivorous ones, such as the pitcher plant and Venus's-flytrap, which feed upon insects.

We have already indicated the dependency of animals upon plants. This is rather obvious in the case of a large group of animals, called "herbivores," which feed exclusively upon vegetable matter. It is not so apparent for the "carnivores," or flesh-eating animals, yet it is only necessary in the case of these

meat-eaters to trace the food chain back a little further and ultimately some inconspicuous plant feeder will be found. The voracious shark feeds upon other fishes which in turn feed upon smaller ones, until finally we come down to the forms which eat plants, sometimes microscopic plant life. The great agricultural industry attests man's dependency upon other living things. The linking of animal and vegetable life is closer here, moreover, than in the case of the carnivores, for man is an "omnivore"—his diet includes both plants and other animals, chiefly strict herbivores.

Perhaps no better way could be found to illustrate this interdependency of living things than to trace the paths of an individual carbon atom and an individual nitrogen atom in the energy cycle at the earth's surface. Let us begin with an atom of carbon forming part of a molecule of atmospheric carbon dioxide. Eventually our carbon atom will encounter a green plant and will enter into the process of photosynthesis, becoming part of a molecule of simple sugar. The sugar molecule may be broken down to provide energy for other processes in the plant, or it may be used in the synthesis of starch or new protoplasm. In the former instance our carbon atom is returned to the atmosphere as carbon dioxide. Although the pathway may not be so direct in the case of sugar molecules used in the synthesis of starch and protoplasm, we shall see that the net result is the same. When the plant dies, decay usually sets in through the activities of putrefying bacteria, with the result that the carbon atom may become incorporated in the protoplasm of the bacteria. Ultimately, however, it is returned to the atmosphere in the same form as it was removed, namely, as gaseous carbon dioxide.

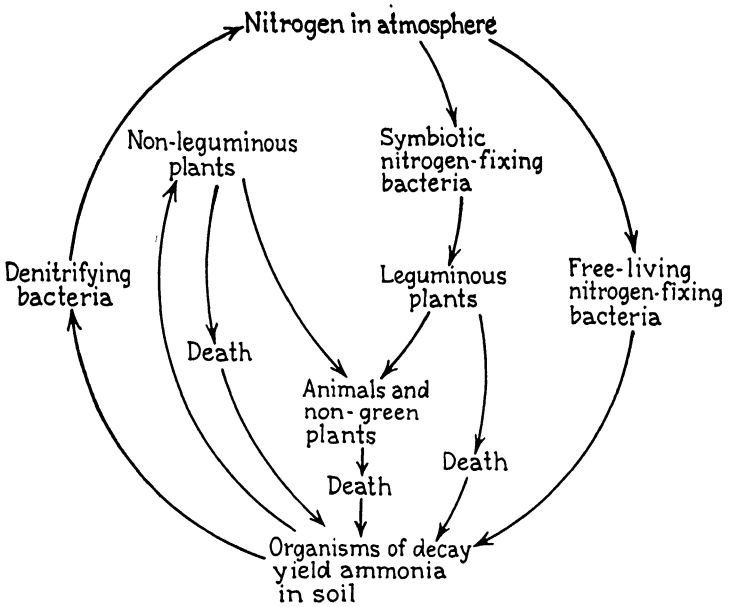
If, on the other hand, the plant is eaten by an animal, the carbon atom may participate in many interesting and varied reactions. As part of a simple sugar molecule, it may be oxidized to carbon dioxide at once to provide energy utilized by the animal in finding and devouring other plants; or, as part of a complex glycogen molecule, it may be stored in the liver of the animal. It may be utilized in the formation of new protoplasm in the body of the animal. If the animal is eaten by still another animal, the cycle may be repeated with some variations. Even-



Living organisms are characterized chemically by the predominance of carbon compounds in their makeup. Perhaps no better way could be found to illustrate the interdependency of living things than to trace the path of a carbon atom in the energy cycle at the earth's surface.

tually, however, the carbon atom again reaches the atmosphere as carbon dioxide, as is shown in the accompanying diagram. Here the travels of the carbon atom are represented as occurring in a closed cycle, although, as we have seen, the pathway is quite likely to be much more devious and complicated.

Nearly four-fifths of the total volume of the earth's atmosphere is made up of nitrogen in elementary form. A part of this is rendered available to living organisms through the activities of the so-called "nitrogen-fixing" bacteria, which are able to use atmospheric nitrogen in the formation of complex organic compounds. These organic compounds are decomposed by other bacteria into ammonia and ammonium compounds, in which form the nitrogen is oxidized by nitrifying bacteria to form nitrates and nitrites. These are deposited in the soil. Green plants in turn utilize the nitrates of the soil in synthesizing their protoplasm. Through the processes of decay the nitrogen of the plant tissues is returned to the soil, and the cycle is repeated endlessly. The soil nitrates and nitrites may also be broken down



The wanderings of an individual nitrogen atom, like those of the carbon atom, may be represented by a closed cycle.

by denitrifying bacteria, their nitrogen being returned to the atmosphere.

Among the nitrogen-fixing bacteria is an interesting group that lives in small nodules or tubercles on the roots of certain plants, chiefly the legumes, which include beans, peas, and clover. These nitrogen-fixing bacteria render invaluable service to their plant hosts in making available to them the nitrogen which they require. In return they receive other materials from the plant which they are unable to synthesize themselves. The relationship is an example of a mutual benefit association between living organisms, called "symbiosis." Soil which has been depleted of its nitrogen through cultivation of other crops may be replenished by growing leguminous plants upon it and plowing them under, as has long been practiced in scientific farming.

If plants are eaten by animals, the nitrogen may be excreted as ammonia, urea, or uric acid, or it may enter into the formation of animal protoplasm. Eventually, however, it reaches the soil or the atmosphere once more, either through excretion or on death and decay. The wanderings of an individual nitrogen atom,

like those of the carbon atom, may be represented by a closed cycle, as shown in the accompanying diagram, but with the same reservations which were made in the case of the carbon atom.

REFERENCES FOR MORE EXTENDED READING

MASON, FRANCES: "The Great Design," The Macmillan Company, New York, 1934.

This book consists of a number of articles by distinguished English scientists. The primary objectives seem to be to summarize the scientific facts in a number of fields and in each case to indicate to what extent there is some great design of nature underlying the universe. The sections "The Earth as the Home of Man," "The Oneness and Uniqueness of Life," and "The Chemical Romance of the Green Leaf" should prove interesting and not too difficult reading in connection with the present assignment.

KERMACK, W. O., and P. EGGLETON: "The Stuff We're Made Of," Longmans, Green & Co., New York, 1938.

This book is admirably designed and clearly developed to interpret biochemistry to the public. The authors explain how the complex molecules of living things are built up from the chemical elements. Enzymes, hormones, and vitamins are entertainingly discussed, and substances which fall in the borderland between the living and nonliving are adequately treated.

PLUNKETT, CHARLES R.: "Outlines of Modern Biology," Henry Holt & Company, New York, 1931, Part I: Protoplasm, Chaps. I, III, IV, VI.

An excellent general account on the elementary level, one of the best texts in the field.

HOLMAN, RICHARD M., and WILFRED W. ROBBINS: "Elements of Botany," 2d ed., John Wiley & Sons, Inc., New York, 1936, Chaps. II, III, IX.

A standard introductory account of the principal phenomena of plant life.

BAYLISS, W. M.: "An Introduction to General Physiology," 1st ed., Longmans, Green, & Co., New York, 1919, Chap. VII.

This is practically a classic in the treatment of the physical basis of life.

BEUTNER, R.: "Life's Beginning on the Earth," Williams & Wilkins Company, Baltimore, 1938.

The author presents herein his theory that life originated on the earth after a gradual development of preparation processes necessary to life. He tells in plain words how science today understands single life phenomena and the working mechanisms of life and presents scientific evidence which indicates that life originated gradually through chemical and physical processes.

CRILE, GEORGE: "The Phenomena of Life," W. W. Norton & Company, Inc., New York, 1936.

A physician and scientist sets forth in this book his interpretation of life phenomena; this being mainly that the phenomena of life are due to radiant and electrical energy. The discerning reader will find many points for thought in this extensive discussion.

CALKINS, GARY N.: "The Smallest Living Things," The University Society, New York, 1935.

A brief survey of microscopic forms of life written in essentially nontechnical language. This little book contains only 116 pages, and it would pay everyone interested in microbiology to read it at least once.

SEIFRIZ, WILLIAM: "Protoplasm," 1st ed., McGraw-Hill Book Company, Inc., New York, 1936.

A standard reference book for those interested in a detailed study of protoplasm.

The Scientific Monthly, published by The Science Press, Lancaster, Pa., for the American Association for the Advancement of Science.

This is an illustrated monthly magazine containing a variety of articles of general interest to scientists and inquiring laymen.

Journal of General Physiology, published by Rockefeller Institute for Medical Research.

A bimonthly technical journal that is devoted to research articles relating to the explanation of life phenomena on the basis of physical and chemical constitution of living matter.



5: THE PATTERNS OF LIFE

Organization and Development of Living Things

IN THE "Rubaiyat" of Omar Khayyam the great Persian scholar of the twelfth century compares the creator of the heavens and earth to a potter who molded the hollow shape of a man and then breathed into it in order to give it life. The poet must have marveled at the skill of the fingers of his imaginary potter, which fashioned the human form from a shapeless mass of wet clay by bending and folding it, stretching it here and pinching it there. Even more marvelous to us today is the intricate process of embryological development by which a human being actually arises from a fertilized egg cell. In a flat, three-layered mass of cells produced by successive divisions of the egg, the precise sequence of bending, folding, stretching, and pinching takes place as growth proceeds which a potter might follow in molding a clay vessel or the model of a man.

But we are getting ahead of our story. In the preceding chapter we learned something of the nature of living matter. Here we

shall see how protoplasm is organized into units called cells, how these units divide, and how they become highly differentiated and associated to form the bodies of complex animals and plants. In the growth and development of every creature on earth, the process begins with a single cell. By cell division, cell differentiation, and cell specialization a new individual is formed. This differentiation and this specialization of cells produces the patterns of organs and body systems. A given specific set of patterns brings about the production of one specific kind of adult creature, such, for example, as a starfish. A different set of patterns produces a different type animal, say an elephant. Still other patterns would produce other life forms, such as mice, cats, fish, roses, or cedars.

Let us trace here the history of the individual from the time of conception through the various stages of growth. We shall see that the individual's development is a brief and sketchy history of the evolution of his ancestors. This is not surprising when we realize that the problems of the race and those of the individual are really identical. Some two thousand million years were required for the development of present life forms from the first protoplasm, and into this struggle have gone the efforts of countless individuals to survive and to adapt themselves to the changing conditions of the earth's surface.

Cellular Organization

Viewed from a distance, a modern skyscraper appears to be carved from a single large mass of stone. Closer inspection reveals, however, that it is made up of many kinds of smaller units, including stone blocks, brick, steel girders, rivets and nails, plate glass, sections of pipe, and various other materials. Just so, minute examination of a large animal or plant shows that its body is not a single large mass of protoplasm. One of the outstanding characteristics of living matter, and one which sets it apart from nonliving colloids, is that it is organized into tiny, individual, and self-perpetuating units called cells. A typical cell is a bit of protoplasm surrounded by a thin partition wall, the cell membrane, and differentiated into nucleus and cytoplasm. The nucleus is a centrally located, characteristic organ provided

with a membrane of its own, while the cytoplasm is the rest of the cell contents.

Upon this type of organization depends the orderly and controlled sequence of activities which take place in protoplasm and which are essential to life. Indeed, the cell is the unit of life. An entire group of animals, the protozoa, comprising about 15,000 kinds of organisms, and a similar group of plants are unicellular; that is, their bodies consist of a single cell. The bodies of multicellular plants and animals are made up of from a few hundreds to many billions of cells forming a coordinated whole. The single-celled plants and animals are capable of an independent existence. Within each cell there are all the conditions necessary to life. On the other hand, the cells of the larger and more complex plants and animals have usually become so specialized and dependent that they cannot continue to live when separated from the parent community or body.

It is only where some special environment is provided that the cells comprising the body of a multicellular organism are capable of a limited degree of independent existence. If a small fragment from such an animal or plant is removed and placed in a suitable nourishing fluid under proper conditions, although the crushed or injured cells soon disintegrate, the intact ones will go on living, growing, and multiplying as long as they receive proper care. One of the most famous experiments in modern biology is that carried on by Dr. Alexis Carrel of the Rockefeller Institute for Medical Research. In 1921 he took a living fragment of a chicken's heart and placed it in a medium that provided food, air, and the proper environment for living conditions. During the years that have followed, this tissue has lived and grown. It probably will continue to live indefinitely so long as properly cared for. Without such care, however, the isolated cells of complex animal bodies soon die. Death is the penalty which they must pay for the specialization they have undergone in order to perform particular functions in the economy of the great community of which they once formed a part. In a somewhat similar manner, a civilized man if left to his own devices in a primitive world would most probably be unable to survive.

The word "cell" was first applied in a biological sense by an English amateur microscopist, Robert Hooke, who used it to de-

scribe the structure of cork, which is composed of dead cell walls of the bark of the cork oak. The great French biologist Felix Dujardin first drew attention to the contents of the cell in 1835, but it was Hugo von Mohl who first recognized the importance of protoplasm. The cell principle, which states that living organisms exist only through the reciprocal action of the cells of which they are composed, was enunciated by two Germans, Jakob Schleiden and Theodor Schwann, one hundred years ago in 1839. Today this concept has been established by a great body of experimental knowledge. In addition, it has been extended to include many cell products, substances formed by the action of living cells, as, for example, the cellulose walls of plant cells, bone, lymph, blood, and elastic fibers. Thus, it is now well known that protoplasm, which is the very physical basis of life, is universally organized into these small but complete units, the cells. It is only because of the delicate adjustments made possible by this cellular organization that life continues.

Typical Cells

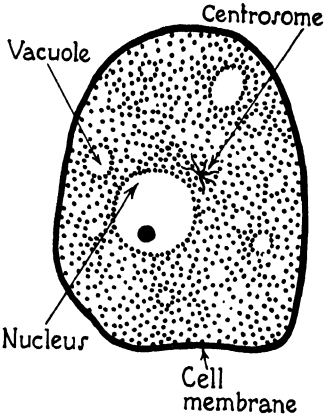
What, then, are the special features and details of living cells that make them capable of maintaining this unique place in nature? We have seen that a typical cell is composed of nucleus, cytoplasm, and cell membrane. Of these, the nucleus is in many ways the most important. That it is an organ essential to the life of the cell is readily demonstrated by microdissection experiments. If a cell is cut into two parts in such a manner that one of these contains all the nucleus, this fragment will form a protecting membrane at the cut surface and continue to live and multiply in a perfectly normal fashion. The other portion, having no nucleus, never multiplies and usually disintegrates and dies almost immediately. The experiment proves not only that the nucleus is an indispensable organ of the cell, but also that it plays a role in the ordinary cell activities. If this were not so, the fragment with no nucleus might be expected to survive for a longer period.

Chemically, the nucleus is composed largely of a peculiar kind of protein substance, called "nucleoprotein," a material found nowhere else in the cell in such great quantities. At times this

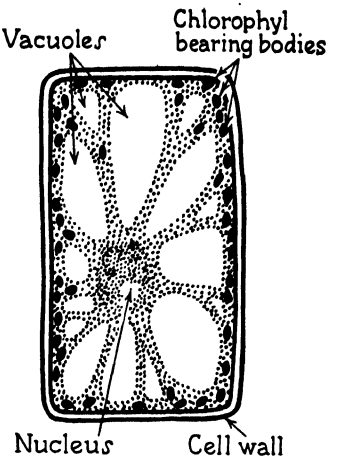
extraordinary substance behaves as though composed of many separate and distinct bodies. These bodies are the units that have come to be called "genes." The genes, therefore, are exceedingly small units within the nucleus. Just how large they are is not definitely known, but they are probably of the same order of magnitude as protein molecules. Even though extremely small, these units are exceedingly important, as they constitute the physical basis of heredity. Each and every kind of living thing has a specific and different aggregate of genes, numbering up to many thousands. The genes determine the exact body patterns and characteristics to be transmitted to the offspring. They might be considered as a sort of blueprint in the cell nucleus which causes the offspring to be the same kind of creature as the parent.

Genes are believed to be similar to enzymes, since they control various chemical reactions which take place in the living cell without themselves being altered or destroyed in the process. A specific gene tends to regulate a particular kind of reaction in a particular way. It is in this manner that the genes exert their controlling influence in heredity. The genes in the nuclei of human body cells, for example, direct the activities of the cells in such a way that they have the composition and perform the functions which characterize human organisms and not some other type of animal life. Even those qualities which serve to distinguish human individuals from each other are ultimately traceable to the action of genes.

The genes have the property of becoming organized in chains or strings, called "chromosomes." Chromosomes are typically rod-like in shape and are clearly visible in the nuclei of most cells under a high-power microscope. They undergo certain definite changes during cell division. The number of chromosomes in the nuclei of the cells of any given kind of organism is specific and constant; this number, however, is much smaller than the number of genes. The cells of the human body ordinarily contain forty-eight chromosomes in their nuclei. Those which make up the body of a fruit fly contain eight chromosomes, while the nuclei in the cells of a frog's body have twenty-six. Other creatures have from two to several hundred chromosomes, but this number is in no way related to the size of the animal or plant.



A typical animal cell is a bit of protoplasm surrounded by a thin membrane and differentiated into nucleus and cytoplasm.



The cell membrane of a plant cell is surrounded by an outer wall of cellulose.

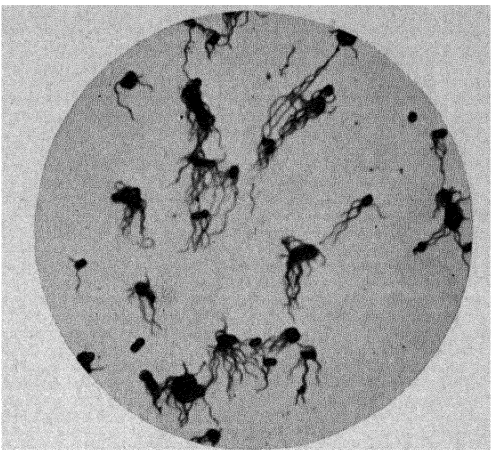
Although the nucleus is perhaps the most important organ of the cell, it is very nearly rivaled by the cell membrane. The very organization of protoplasm into cells depends upon the presence of such a structure, as may be demonstrated very readily by disrupting it. If the injury to the membrane is sufficiently extensive that the cell itself is unable to repair it, the entire cell contents will flow out and almost immediately disintegrate. The cell membrane is essential, therefore, for preservation of the cellular organization, which in turn is necessary for the very existence of protoplasm. Careful experiments have demonstrated that the cell membrane serves to preserve and protect the cell contents not only by preventing mixture with the external medium but also by regulating the influx and outgo of materials into and out from the cell. For the cell membrane is one of the finest examples of what is known as a semipermeable membrane. Such a membrane permits the passage of certain materials through it while preventing the passage of others.

Chemically, the cell membrane appears to be a film or layer of protein and lipoid substances just one molecule thick. The thin cell membrane often builds up a coating around itself to give it protection or rigidity. Most plant structures are rather rigid. This condition is brought about by the fact that the cell mem-

brane of each plant cell is surrounded by a second, rather thick, outer wall of cellulose. Cellulose is a complex carbohydrate substance manufactured by the plant cell. The production of cellulose cell walls is an ingenious adaptation on the part of plants which enables them to grow to great sizes and to endure under a great variety of conditions. On the other hand, the membrane of animal cells is frequently uncovered, giving the cell greater pliability and motility. Most muscle cells, nerve cells, and other body cells have naked cell membranes. However, the membranes of animal cells may be reinforced by hard materials secreted by the cells themselves or deposited from the outside. Such materials may form bone structures, cartilage, horn, and similar substances.

The cytoplasm of cells frequently contains numerous granules and vacuoles, each surrounded by its own membrane, presumably of a semipermeable character. Examination of the contents of these vacuoles in certain large plant cells has shown that they are capable of storing materials against a relatively tremendous osmotic pressure. The conspicuous vacuoles in the cells of Valonia, a marine plant, contain potassium at a concentration many times that in which this element occurs in the surrounding sea water. In order to store materials in this manner, it is necessary to do work against the osmotic pressure built up within the vacuoles and against the hydrostatic pressure of the sea water.

Osmotic pressure is the pressure exerted by the molecules of a substance in solution against any barrier to their free diffusion. When two solutions of different concentration are separated by a membrane which is impermeable to the dissolved substance, there is a difference in osmotic pressure on the two sides of the membrane. In order to equalize the pressure there is a tendency for the liquid in which the material is dissolved to pass through the impermeable membrane from the more dilute to the more concentrated solution. The extra liquid thus makes the concentrated solution more dilute and tends to balance the pressure on the two sides of the membrane. The passage of the liquid through the membrane is known as osmosis. The construction of osmotic systems—that is, systems surrounded by semipermeable membranes—provides one of the mechanisms by which cells are enabled to store energy and to do work. It is a straightforward



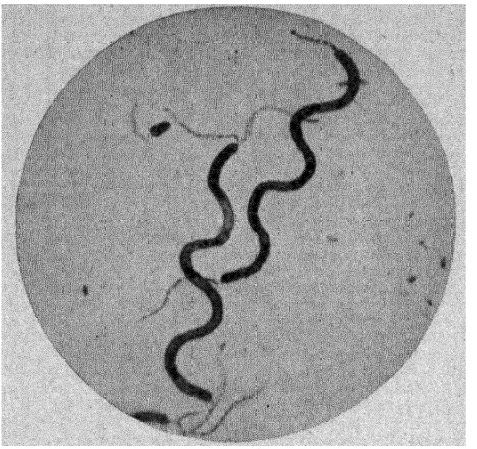
The paratyphoid bacillus, illustrating a rather complex type with flagella. (Photomicrograph by Roy Allen.)

physical process which provides living cells with some of the energy of life.

The Smallest Living Things

The smallest things generally conceded to be alive are the bacteria. Although millions of these tiny colorless plants can occur in a single drop of water and although their very existence was unknown until after the perfection of the microscope, they are relatively large compared with the largest known molecules. Some of the very largest of them can just be discerned with the naked eye, but the great majority fall within the size range of objects which must be examined microscopically. Because they are so small, not much is yet known about the internal organization of bacteria. They cannot be described as true cells since they do not possess a nucleus as a distinct organ, although the presence of scattered granular masses of a nucleoprotein substance has been demonstrated by delicate microchemical tests. In common with true cells, bacteria possess a semipermeable limiting membrane and their protoplasm contains vacuoles and granules surrounded by similar structures. Some of the more elaborate forms resemble the simplest algae, or lowest plants.

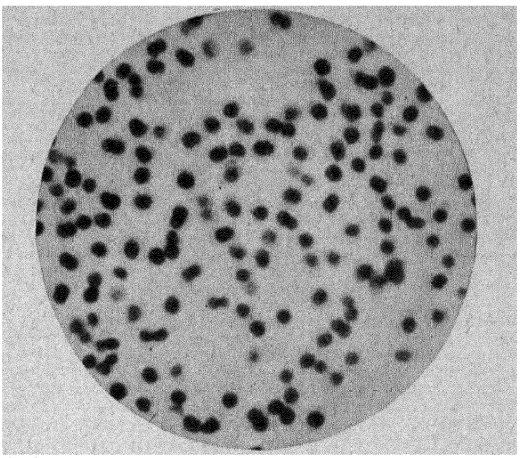
Because of their relative simplicity of organization, it is generally recognized today that bacteria can be more efficiently



Spirillum volutans, a free-living type found in stagnant water. Scattered nuclear granules are clearly visible and the flagella are well shown. (Photomicrograph by Roy Allen.)

characterized and distinguished by chemical means and by culturing them than by simple microscopic observations. Indeed, bacteria are little more than packages of enzymes with hulls or sheaths of lipoid, protein, and carbohydrate materials. They may be compared to chemical factories equipped to carry on a limited number of operations, for one of the outstanding characteristics of bacteria from the chemical viewpoint is their specificity of action.

We all know that one kind of bacteria produces tuberculosis, another typhoid fever, another syphilis, and so on down through a long list of diseases to which mankind is heir. Actually, there are at least three kinds of tubercle bacilli which look exactly alike. One of these will grow only in cows, another only in birds, and the third only in human beings. Again, certain bacterial organisms will ferment lactose, or milk sugar, to butyric acid, one of the simpler fatty acids found in butter. Other bacterial organisms will convert lactose to lactic acid, which is a constituent of sour milk. This specificity of growth and effect is accounted for by the specificity of the enzymes found in each type of bacterium. The lactic-acid-forming bacteria do not possess the enzymes for converting lactose to butyric acid, while the butyric-acid-forming types do not have the enzymes needed to form lactic acid. Truly, bacteria act like keys in locks one set of

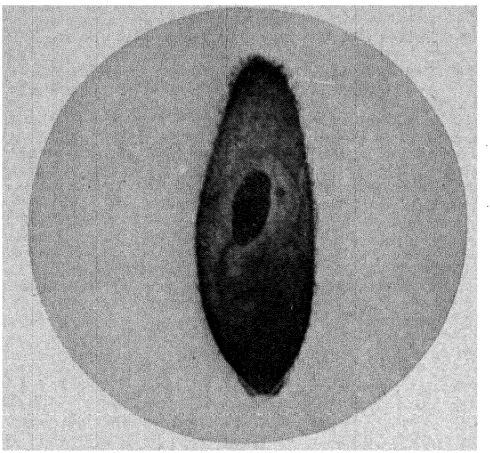


A very unusual photograph of Neisseria gonorrhea, the causitive agent of gonorrhea, taken with practically monochromatic light (the sodium line). A large nuclear granule appears in the center of the cells, some of which appear to be in stages of division. (Photomicrograph by Roy Allen.)

internal properties fitting only a certain set of external environmental conditions.

Cell Differentiation

The large number of different kinds of bacteria gives us some idea of the enormous range of differentiation and specialization manifested by living cells. They differ not only in structure, shape, and function, but also in size. A one-inch square drawn on the back of a man's hand would circumscribe about six million cells. A cubic millimeter of human blood contains about five million of these protoplasmic units, and the total number making up the body of one person is an astronomical figure. However, some particular kinds of cells may be rather large. The single-celled animal, Paramecium, is large enough to be seen without the aid of a microscope, and the marine protozoan, Porospora, may reach a length of over half an inch. Unspecialized types of cells tend to assume a spherical shape when not restricted by conditions of their environment. However, nearly every other conceivable shape may occur, from the long thread-like cells of the human spinal cord to the snowflake design of the pigment cells on the scales of fishes. Torpedo shapes and flattened pancake types are common. Plant cells are often compared to a shoe box.

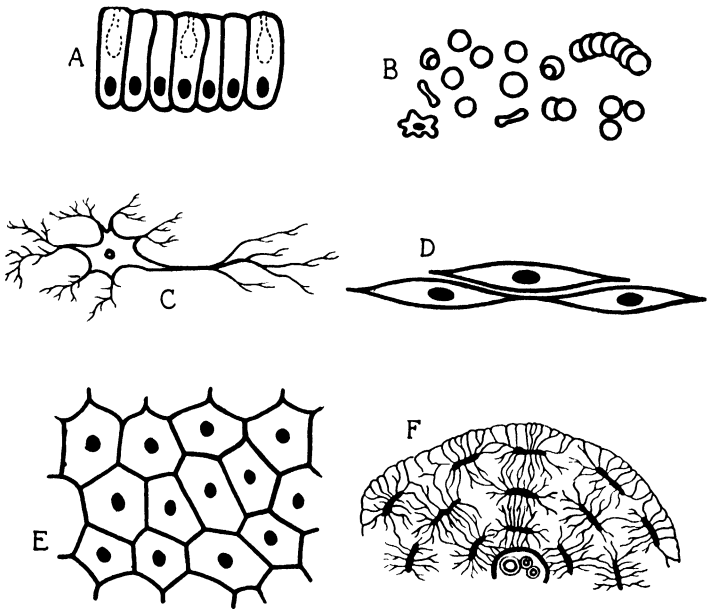


Paramecium. A large nucleus can be seen in about the center of the cell, and near it, a small nucleus. The surface of the cell bears numerous cilia. (Photomicrograph by Roy Allen.)

Many different kinds of cells that are specialized for performing different functions occur in the bodies of multicellular plants and animals. Here there is a close analogy to the structure of a mechanical device with its many different parts, each assembled from different types of materials and differently shaped units. The tissues of living things are made up of groups of cells specialized in structure for performing similar functions. For example, the exposed surfaces of plants are covered by epidermal tissue, comprising a layer of flattened protecting cells. The supporting tissue of plants is made up of thick-walled cells, which give rigidity to the plant structure. Finally, water and food materials are transported to the various parts of a plant by conducting tissue made up of tube-like cells.

In animals, both the internal and external surfaces of the body are covered by epithelial tissue composed of thin, flattened cells. The supporting tissues of the animal body, including bone and cartilage, are largely made up of products secreted by cells. There are elastic and collagenous fibers that form a framework upon which or within which the softer tissues are suspended. Muscle tissue is composed of greatly elongated fibrous cells specialized for contracting, and nervous tissue is made up of rounded or flattened nerve cells and their filamentous processes specialized for transmitting impulses.

The various tissues of animal and plant bodies are often combined in the structure of organs for performing definite functions.



Some kinds of animal tissue cells: A, glandular epithelium; B, mammalian blood cells; C, nerve cell; D, smooth muscle cells; E, pavement epithelium; F, bone.

The leaf is an organ of a plant, while the liver, heart, and lungs are examples of organs found among animals. Organs are in turn often grouped into systems concerned with the same functions. The foliage of a green plant as a whole forms such a system, as do the roots. Likewise the brain, spinal cord, and nerves form a complex system of communication within the bodies of higher animals.

Growth and Division of Cells

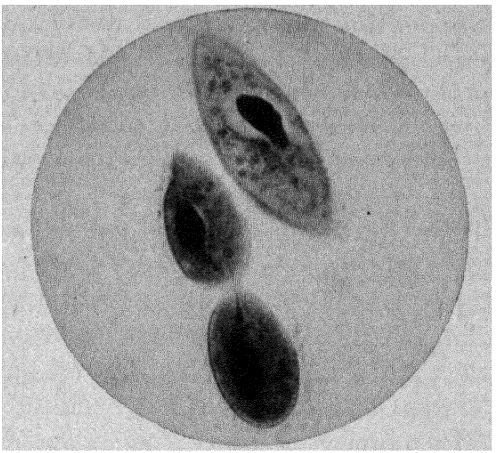
One of the distinguishing characteristics of living things is growth, or increase in size. The conscious desire of every boy and girl to grow into adulthood is but one manifestation of an unconscious condition that pervades all animate nature. All creatures with multicellular bodies grow by an increase in the number of cells making up their physical structures rather than by an increase in the size of the cells. Cells themselves grow by adding to their protoplasm and to their storage materials. This

process does not continue indefinitely, however. If it did, there soon would not be room on the earth's surface for more than a single cell. The rate of growth of protoplasm is so enormous that even one cell would increase sufficiently within a few days to cover the entire earth were it not checked somewhere along the line.

The limits of growth for a given type of cell are governed in part by intrinsic factors, such as the influence of the genes contained in the nucleus; and in part by extrinsic factors, such as the pressure exerted by adjacent cells, and particularly by the factors controlling the exchange of respiratory gases. Oxygen is taken up and carbon dioxide is given off at the surface of the cell, and the rate of exchange of these gases is controlled by their diffusion rates and by the amount of cell surface available. In order to insure an adequate supply of oxygen at all points in the cell and proper elimination of carbon dioxide from all points, the ratio of cell surface to cell volume must be kept within certain well-defined limits. As a cell grows, its volume increases as the cube of its radius, while its surface increases only as the square. It is not difficult to see that the surface-volume relationship soon becomes unbalanced in the growth process. This would be detrimental or even destructive to the cell if it were not corrected.

This difficulty is corrected by one of the most unusual processes which living organisms manifest. When a cell reaches a certain size, it usually divides into two parts, called daughter cells. In this complex and quite remarkable process a favorable ratio of cell surface to cell volume is restored. After a period of growth, each of the daughter cells in turn may divide, and the process continues indefinitely. In this manner, a single cell can give rise to many thousands in a relatively short period of time.

The rate of increase of a population of cells is a geometrical progression. The number of individual cells produced by equal division (barring accidental death) after a given number of generations, designated by the letter n, is equal to 2 raised to the $n-1$ power (2^{n-1}) multiplied by the initial number of cells. For example, suppose there are 20 bacteria in a bottle of milk. Suppose, also, they are permitted to remain there long enough for 15 generations to occur by cell division. How many bacteria are now adding life to the bottle of milk? Two raised to the



Paramecium, dividing. The division of the large nucleus and of the cytoplasm is well shown. Numerous food vacuoles are visible in the cytoplasm. (Photomicrograph by Roy Allen.)

fourteenth power is 16,384. This figure multiplied by the 20 starting bacteria produces a total of 327,680 cells! Should the growth be allowed to continue for 15 more generations, the number would be increased to over 21 billions. The growth of a multicellular animal or plant is the result of cell division and growth. Likewise as a multicellular organism grows larger, its component cells increase in number in geometrical progression until adulthood is reached or some other limiting factor comes into operation.

When it is realized that so far as is known every living cell in the universe arose by division of a preexisting cell, it is apparent that the process of cell division is of fundamental importance in the scheme of life. If we could know all about it, we should go far toward understanding the riddle of existence. Incidentally, we would have discovered the cause of cancer, which always involves abnormal division of cells.

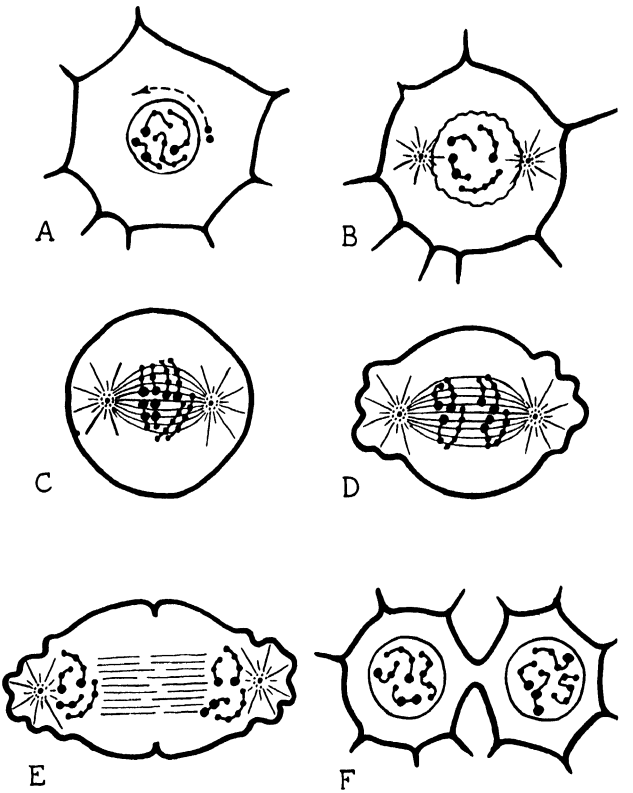
The way in which one cell becomes two is important for several reasons. It is the way in which the torch of life has been handed down through the ages and is continuing to be handed down at present. Moreover, it provides the mechanism by which multicellular forms of life are believed to have arisen from single-celled organisms, through the formation of colonies and application of the important economic principle of division of labor.

Finally, it provides the physical basis for the phenomena of inheritance, by which the integrity of each kind of living organism is both preserved in future generations and permitted to vary in such a way as to account for the great diversity of organic forms.

The ordinary method by which cells divide is called indirect division or "mitosis." It is not surprising that this is a rather complicated process when it is considered that in it the complex structure of the parent cell is preserved in each of the resulting products. Of singular importance is what takes place inside the nucleus when a cell divides by mitosis. A series of complicated and invariable steps is followed. In the nucleus of a cell in the resting state, the material of which the chromosomes are composed appears to be scattered irregularly upon a framework of material of a different sort. When the cell is about to divide, this material, called "chromatin," becomes aggregated to form the chromosomes. The appearance of the chromosomes marks the first step in the mitotic process. This is followed by contraction and thickening of the chromosomes and by the disappearance of the nuclear membrane.

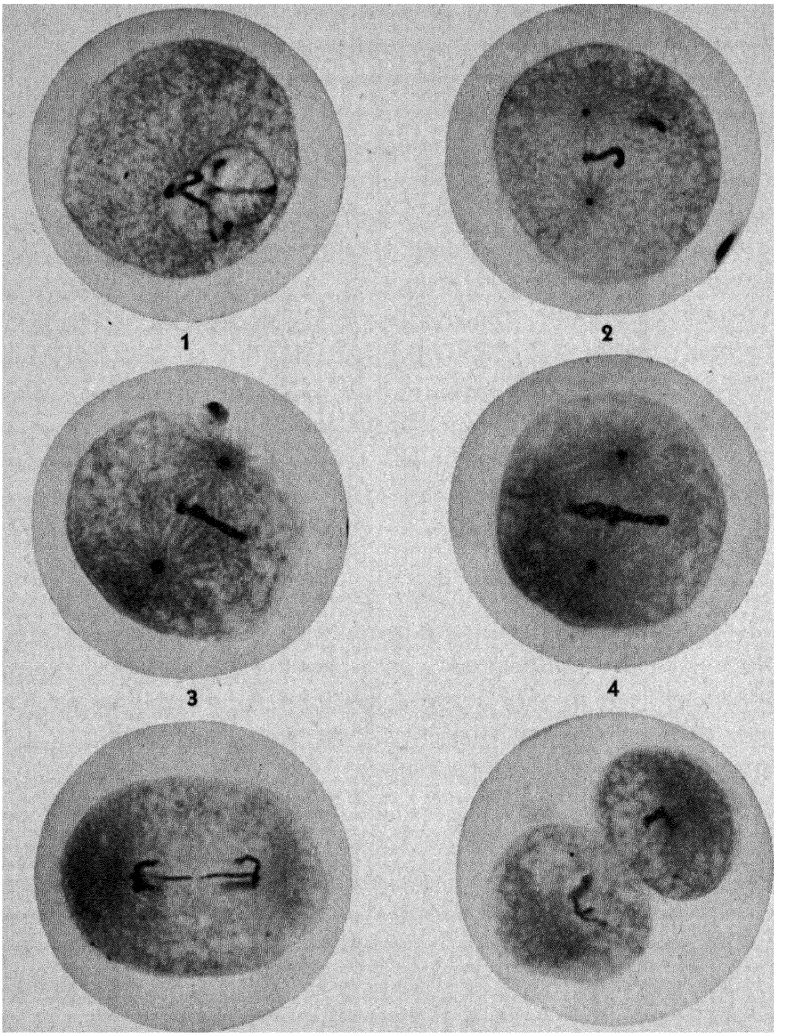
In the next step the centrosome divides, one half migrating around the nucleus and taking a position at the opposite side from its sister half. It should be noted here that the centrosome is a tiny granule resting on or near the nucleus. It is surrounded by a larger zone of clear protoplasm from which numerous fibrils, or rays, extend out in all directions, forming an aster or star. Centrosomes generally are present in the cells of higher animals and many lower plants, although they are absent in the cells of higher plants. When they do occur, they play a prominent role in the division of the cell. After the two centrosome halves have taken their positions on opposite sides of the nucleus, a cigar-shaped structure is formed between them, called the "division spindle." It is made up of fibrils derived from the astral rays and partly formed anew. In cells which lack a centrosome, the spindle represents an entirely new structure formed at every division. Certain of the spindle fibers begin to invade the nucleus and appear to become attached to the various chromosomes at specific points.

In the meantime, another step in the division of the cell has occurred. Each chromosome has divided longitudinally, or dupli-



When a cell divides by mitosis, a series of complicated steps is invariably followed: A, the centrosome divides and one half moves to the opposite side of the nucleus; B, the nuclear membrane begins to break down, and the cytoplasm begins to coagulate around the centrosomes; C, each chromosome divides longitudinally, the nuclear membrane has disappeared, and the chromosomes have become arranged about the equator of the division figure; D, the division figure elongates with the cell and the sister chromosomes separate, moving toward opposite poles; E, the chromosome groups reach the opposite poles, the elongated cell body begins to constrict in the equator, and the division figure begins to disintegrate; F, two daughter cells nearly completely separated.

cated itself. The genes or gene strings which make up the chromosomes have been doubled. During the next step a remarkable phenomenon takes place. The corresponding halves of each original chromosome begin to move in opposite directions, as if drawn by the fibrils of the centrosome. One half goes toward one pole of the division spindle, the other half toward the opposite



A photographic record of cell division. The first cleavage division of the fertilized egg of Ascaris, a worm having only two meiotic chromosomes. (1) When a cell is about to divide the nuclear chromatin becomes aggregated to form the chromosomes. (2) The nuclear membrane disappears, the centrosome divides and one product migrates to the opposite pole of the cell. The division figure appears, made up of the two asters and the spindle fibers. (3) The chromosomes line up at the equator of the spindle. (4) The chromosomes divide longitudinally and the corresponding half-chromosomes begin to move in opposite directions. (5) As each group of daughter chromosomes approaches its centrosome, the spindle fibers disappear. The dividing cell elongates in a plane parallel to the long axis of the division figure. (6) The cell constricts in a plane passing through the equator of the division figure. The asters begin to disappear. (Photomicrographs by Roy Allen.)

pole. During this process, the traction fibrils attached to the chromosomes shorten and eventually disappear.

As soon as each group of chromosomes reaches its centrosome, the spindle fibers appear to break at the mid-point and the cell begins to constrict in a plane passing through the equator of the spindle. A membrane soon forms in this plane, and the cell is divided into two daughter cells, each one of them by this process containing the equivalent of half of the original. The chromosome groups in each daughter cell presently become reorganized, forming a nucleus for the cell and secreting a nuclear membrane.

The significance of this complicated process of mitotic cell division lies in the careful manner in which the hereditary factors are distributed among the products, so that each daughter cell receives an exact duplicate of the set of genes contained in the other and both of them have an exact duplicate of those in the original parent cell.

Production of a New Individual

The process, just described, by which one cell becomes two, together with cell differentiation, forms the basis of biological development. The production of a new individual occurs by division of the cells constituting a preexisting individual or a part of it, and, in the strictest sense, this is the only method of reproduction.

In order to see completely the moving picture of early embryonic development, it is necessary to view it in the sequence of the acts as they occur. This sequence of development may be described in eight more or less arbitrary steps. These are artificial in that they are not sharply marked off from one another, but they are useful in untangling and understanding the patterns of life in the growing embryo. In another sense, however, each of these steps constitutes a distinct act of form building. Each one leads to the production of visible organs and special structures in the embryo, which to early outward appearance is not differentiated into special organs. In our own lives they cover the first twenty-one days of existence, up to the time we are about an eighth of an inch long.

The first stage in early embryonic development is cleavage, or cell division, leading to the production of many cells from a single

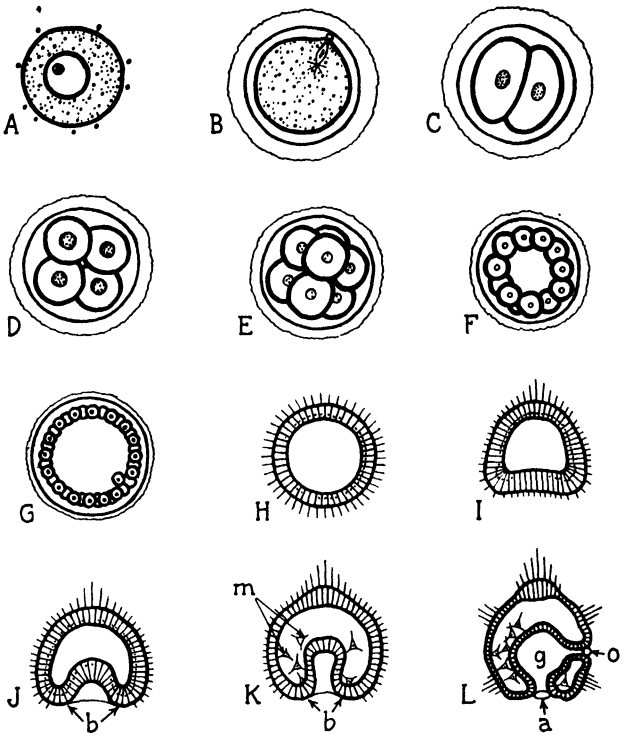
fertilized egg. The second stage is blastulation, in which the cells become arranged in a hollow sphere. The third is gastrulation, or the infolding of the hollow sphere of cells to form a multiple-layered embryo. In the fourth stage, evocation, the primary axes of the body are set up. The fifth stage is induction, or organization of the embryonic cells into organs and organ systems. The sixth is differentiation, by which the cells become specialized for future jobs. The seventh is the stage of interaction, in which the various systems begin to exert their effects upon each other. The eighth stage is that of coordination and growth, when the parts of the body begin to grow and to become adjusted to one another in function. All these steps are now objects of careful experimental research, most of them being well understood. Embryology has become one of the exact sciences.

Normal Development

In any great theatrical production, the scenes follow one another in orderly sequence. First, the background and the plot are laid. The acts of the drama then unfold until the climax of the story is reached. Finally, an ending results from the natural order of events which have preceded. A developing embryo likewise presents a moving picture which should be viewed in the sequence of the scenes presented. The growth of a new individual from a fertilized egg is in reality a continuous and moving process which begins with the laying down of certain fundamental structures and continues with the development of all the complex patterns which make up the adult body.

In order roughly to chart the course of normal development, let us follow the embryological history of a simple animal such as the sand dollar. Some of the critical scenes in the story are shown in the drawings which accompany this text. The first scene is cleavage. When an egg has been fertilized by a sperm, a set of age-old forces is unlocked anew; they proceed in orderly, neat, and perfect fashion. About an hour after penetration by the sperm, the egg divides by mitosis into two smaller cells, that is, the egg "cleaves." The two cleavage products soon divide to give four, and the process is repeated until several hundred small cells are formed. As shown in the drawings, the individual cells be-

come smaller as they increase in number during cleavage. Growth is another and different matter, which comes later.



The embryo sand dollar develops from a fertilized egg by an orderly series of events involving the growth, division, rearrangement, and differentiation of cells: A, immature unfertilized egg; B, polar spindle formed; C, two-cell stage, after first cleavage division; D, four-cell stage following second cleavage division; E, eight-cell stage following third cleavage division; F, optical section of thirty-two cell stage; G, optical section of early blastula; H, optical section of ciliated blastula; I, optical section of blastula, flattened at antapical pole; J, optical section of early gastrula showing inpushing of endoderm (b, blastopore); K, optical section of later gastrula showing beginning of mesoderm (m); L, optical section of free-swimming embryo with mouth (o), anus (a), and complete primitive gut (g). (Drawn from sketches of living embryo sand dollar by W. R. Duryee.)

The first act in laying the groundwork for the critical scenes which are to follow is blastulation. In this process the cells arrange themselves to form a hollow sphere, called the "blastula." Each cell moves into its little niche with all the precision of a dancer performing an intricate routine in a musical revue. The wall of the hollow sphere, as shown in the accompanying drawings, is a single layer of cells in thickness. This layer is called the

"blastoderm," or "germinal skin." It will be noted that the cells comprising it bear hair-like or whip-like structures called cilia.

In the next scene, known as "gastrulation," a unique movement begins to take place. Within about twenty-four hours after the blastula is formed, one side begins to sink inward in much the same way as one side of a soft rubber ball sinks in when one pushes his finger into it. The infolding continues until the embryo sand dollar acquires an inner sac-like structure, termed the "primitive gut." This sac-like structure is its first elementary organ, becoming later the digestive tract. It is easy to see that a two-layered condition has now been reached. The outer blastoderm remains as before, but a new layer has been formed by the infolding. This layer forms the gastric cavity or stomach. It is made up of cells which have passed over the rim of the opening made by the infolding. These cells lose their cilia and become differentiated to form a new body layer, called the inner skin or "endoderm." The hole leading to the gastric cavity from the outside remains open, forming what is known as the "blastopore." The blastoderm may now be called the outer skin, or "ectoderm."

As the infolding of the wall of the blastula continues, the endoderm gradually extends across the cavity of the blastula, until it touches the ectoderm at a point opposite the blastopore. At this point, where the two layers touch, a thin membrane is formed, consisting of both endoderm and ectoderm tissue. It is a temporary structure, called the oral plate. Eventually, it breaks through to the outside, giving rise to an opening which becomes the mouth of the embryo. It is, perhaps, significant that the mouth of every known vertebrate, including man, is formed in this way. Equally important is the fact that the blastopore, the original opening into the gastric cavity, becomes the anal opening. With the formation of the mouth the primitive alimentary canal is completed, forming a straight tube passing through the embryo from the forward to the rear end. The embryo at this stage is called a gastrula.

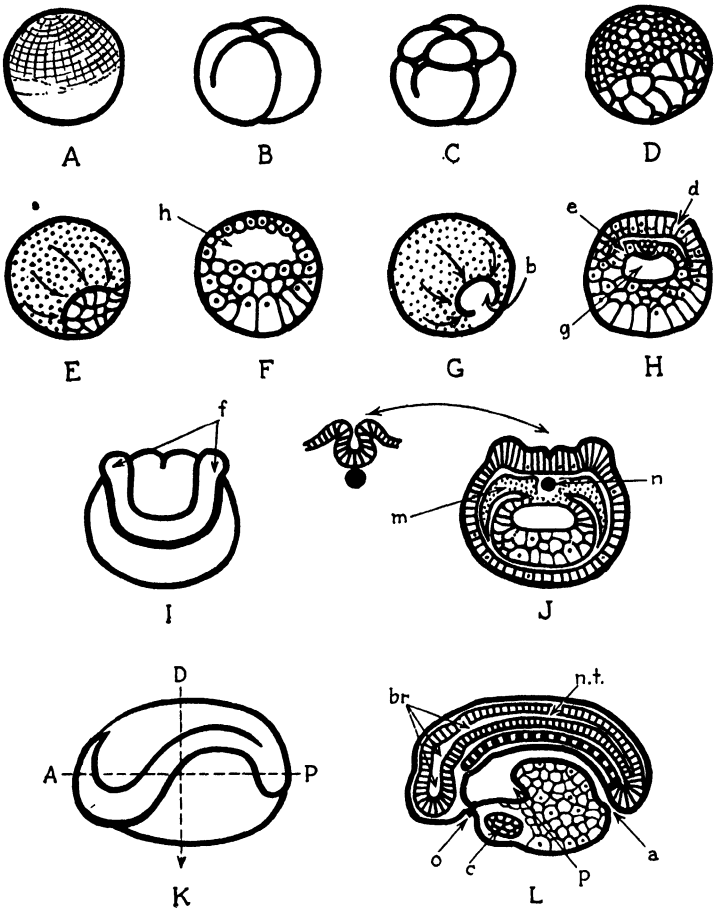
During the later stages of gastrulation a third important body layer begins to form. This is the middle skin, or "mesoderm." It appears first as a few cells which bud off between the outer ectoderm and inner endoderm in the region of the blasto-

pore. Gradually they extend across the cavity between these two layers, forming two layers of mesoderm tissue. In the formation of the mesoderm the original cavity of the blastula is completely obliterated. In the embryo sand dollar, the mesoderm forms a new cavity which becomes the principal body cavity of the adult animal.

These three basic layers of tissue, the ectoderm, endoderm, and mesoderm, are known as the primary germ layers. They are the raw materials out of which all the organs and organ systems of the body are made. It might be said that they constitute the fundamental parts of the plot of embryonic growth from which all future acts are developed. For example, the ectoderm later gives rise to the skin and nervous system. From the endoderm are derived the alimentary canal, digestive glands, reproductive cells, and lungs. The mesoderm produces the skeleton, the muscles, and the circulatory and urinogenital systems.

The next scenes in the drama of embryonic development produce the climax of the story. They present the immediate circumstances underlying the shaping of bodily patterns. They will be better understood in relation to the reproduction of a new human individual if their sequence in the development of a simple vertebrate type is followed. For this purpose, the embryo of the salamander or the frog provides the best example, as more is known concerning the developmental processes in these forms than in any others.

The first of the crucial scenes to be dealt with here is evoction, or the determination of the main body axis. In this process the locations of the head and the tail ends of the embryo are established. An imaginary line passing through the centers of these fixed regions of the body constitutes the principal axis around which and along which the organs and organ systems will develop. Up to the time when the position of this imaginary line is determined the cells of any particular layer of the gastrula have nearly equal potentialities. Under certain experimental conditions, all the cells of a given germ layer are eligible to enter into the structure of any or all of the organs and organ systems which normally would be developed from that layer. Like that of schoolboys who are eligible for any trade or profession of their choosing, the fate of the cells is not yet fixed.

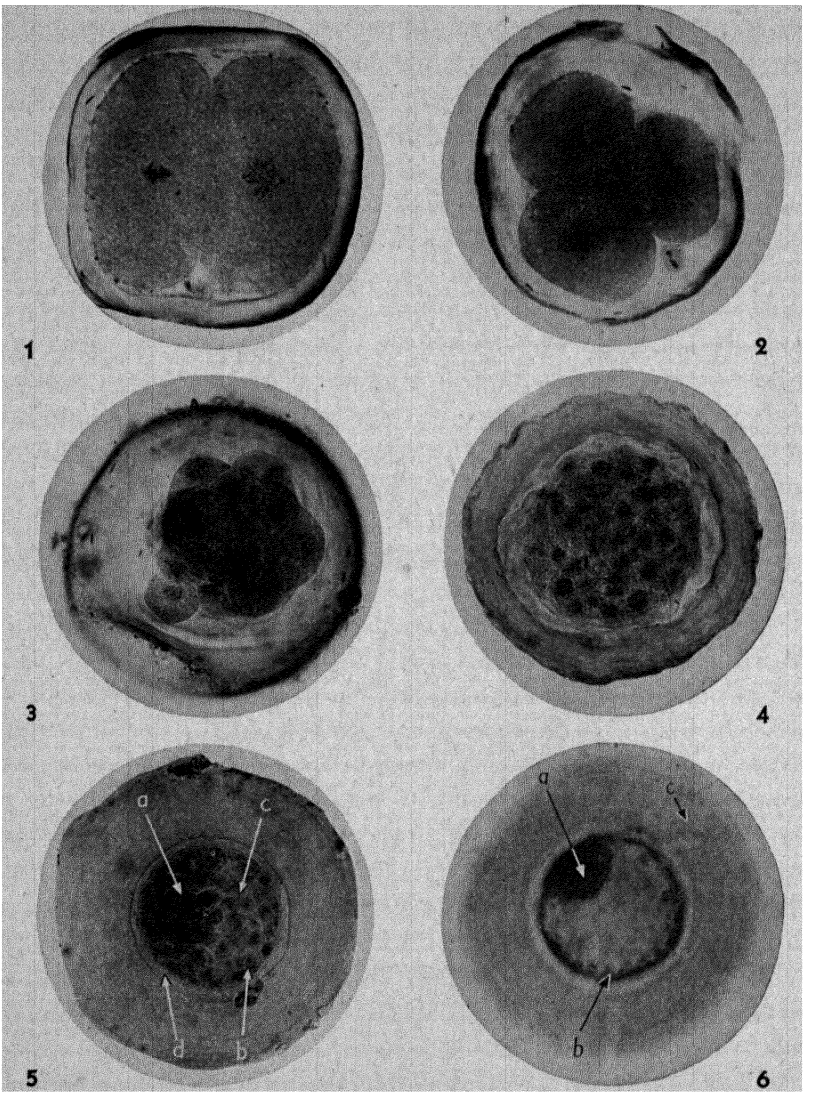


The events of vertebrate embryonic development as illustrated in the development of the frog: A, fertilized egg; B, embryo after second cleavage division; C, embryo after third cleavage division; D, late blastula; E, embryo at the beginning of gastrulation, the arrows showing the direction of movement of cells toward the dorsal rim of the blastopore; F, transverse section of early gastrula showing cavity (h); G, embryo at later stage of gastrulation showing blastopore (b); H, transverse section of late gastrula showing primitive gut (g), ectoderm (d), and endoderm (e); I, embryo at early stage of induction of neural folds (f); J, transverse section of embryo at early stage of induction of neural folds, also showing the notochord (n), mesoderm (m), and the direction of folding (arrows); K, embryo at early neural fold stage showing forward-hinder (A---P) and upper-lower (D---V) body axes; L, longitudinal section of embryo with neural tube completed showing neural tube (n.t.), brain regions (br), notochord, heart (c), and primitive gut with mouth (o), anus (a), and liver outpocketing (p).

Reference to the drawings illustrating the development of the frog will aid in understanding both the embryonic processes which have already been discussed and those which are about to be described. Comparison with the drawings illustrating the development of the embryo sand dollar serves to bring out the fact that the principal differences between these two embryonic types during cleavage and gastrulation are caused by the presence of a greater amount of yolk material in the egg of the frog and by the tendency of this heavier material to accumulate in the bottom half of the egg. As a result of this unequal distribution of inert food materials in the protoplasm of the frog's egg, cleavage is very unequal and leads to the production of a blastula in which the cells are graded in size and number from top to bottom. They are smallest and most numerous at the uppermost pole and fewest and largest at the lowermost. The dense accumulation of coarse yolk granules in the bottom hemisphere tends both to retard cleavage and to distort gastrulation.

Repeated divisions of the cells in the upper regions produce crowding and pressure so that the cells on the sides must go somewhere else. This eventually results in overgrowth of the lower hemisphere. Moreover, certain cells in the mid-line region of the hinder ectoderm sink inward at a point which becomes the dorsal lip of the blastopore. With continued overgrowth, the rim of the blastopore extends downward on the sides until eventually a circular opening is formed. Meanwhile, the rapidly dividing cells of the top and sides are forced toward the rim of this opening and pass over it into the inside. The cells which pass over the rim of the blastopore continue to move upward and forward on the inside, gradually forming the roof of the primitive gut.

That those cells which move inward over the upper lip of the blastopore have undergone some reorganization is shown by the simple fact that they proceed to specialize, forming a peculiar rod-like axial structure known as the "notochord." This primitive backbone initially develops on the roof of the primitive gut and is composed of endodermal cells. Eventually, however, it is inched off from the wall of the gut and forms a core about which he vertebral column is laid down. Our own vertebral columns riginate in this way in the early embryo. Search for the chemical



A photographic record of the early embryonic development of the rabbit. (1) Shortly after the fertilization the egg divides into two smaller cells, that is, it cleaves. (2) "The two cleavage products soon divide to give four." (3) By the fourth cleavage, sixteen cells are formed. (4) The cleavage process continues until many small cells are formed. (5) In mammalian embryonic development the stage corresponding to the blastula of lower forms is called a "blastocyst." (a, inner cell mass, from which embryo develops; b, trophoblast, which erodes away the mucous membrane of the uterus; c, segmentation cavity; d, egg membrane). (6) The mammalian embryo develops from a restricted portion of the blastocyst (a) known as the "inner cell mass" (b, trophoblast; c, follicle membrane). (General Biological Supply House photographs.)

that emanates from the cells of the upper lip of the blastopore to stimulate those just ahead of them to form a notochord is one of the most important researches going on in many biochemical laboratories all over the world. If the chemical nature of the "organizer" can be found, it will be a scientific event of the first importance. At present, workers in Cambridge University in England think it may be a very complex fatty substance, related in molecular structure to the vitamins and sex hormones.

The upper lip of the blastopore gives rise to the tail bud from which the tail of the frog tadpole develops. The point of most forward extension of the notochord marks the division between the future forebrain and midbrain in the head of the embryo. Moreover, the primitive gut marks the lower side. Thus, with the completion of gastrulation, the principal axes of the body have been established, and, for the first time, the terms forward and rear, upper and lower, and right and left may be applied.

Building Body Systems

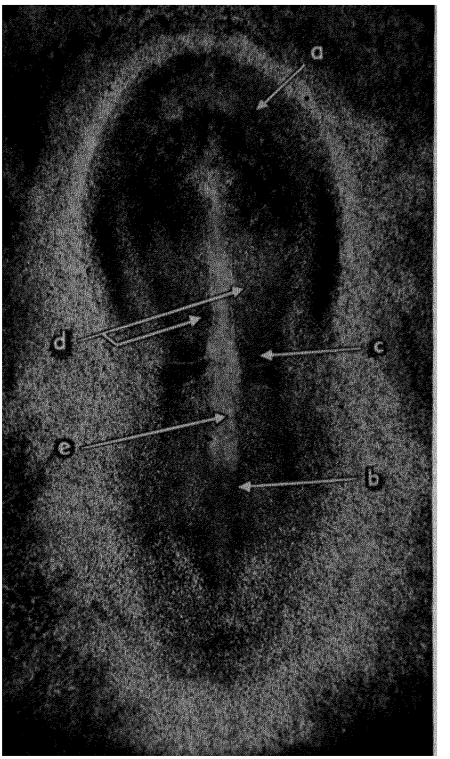
As soon as the principal axis of the body has been established, another master force comes into action to direct the ensuing stages of development. This is the process of induction, by which is meant the organization of the definitive body organs under the stimulus of interaction between the elementary organs and tissues. The latter are distinct parts of the early embryo, which are uniform in themselves. Each of these elementary organs and tissues is the result of one distinct act of form building. Examples are the notochord, the primitive gut, and the primary germ layers. They are typical of elementary organs and tissues with regard to position, histological properties, form, and, to a certain extent, size. Their size is partly controlled by the duration of the form-building processes which bring them into existence. The duration of each process, in turn, is subject to variation with the temperature and other physicochemical factors. The form, size, and histological structure of the elementary organs and tissues are governed in part, also, by considerations of present or future function. They at least prepare for this function by a specific metabolism which begins at a very early stage in their development.

The first, or primary, induction in the embryo is that which the cells of the notochord exert upon the overlying layer of ectoderm to form the beginnings of the nervous system. In short, the brain and spinal cord are "induced" to develop, presumably by the action of some chemical compound produced by the notochord cells. This substance apparently diffuses into the overlying ectoderm, because direct contact between the notochord and ectoderm is always necessary before the nervous system can develop.

Our own brains, and likewise those of all other vertebrates, appear first as a flat layer of ectoderm cells, known as the "neural plate." This is in the early gastrula stage. Soon, a change takes place on the outside. First, a groove appears directly above the notochord and, almost immediately, two folds or ridges bulge up on the sides of this groove. These are shown in different views in the drawings. The two ridges or folds join each other around the front end, forming a sort of hairpin-shaped loop. A process of rolling up now begins. While the groove sinks in deeper, the folds slowly come together, arch up, and meet above the groove. Thus they form a hollow tube, the neural tube, which soon becomes closed at both ends.

The front part of this tube swells into a sort of bulb, similar to that on a medicine dropper. The bulb is the rudiment of the brain. Its walls thicken here and there and by various bulges and constrictions form the different parts of the brain. Meanwhile, the rest of the neural tube becomes the spinal cord. Since all nerve fibers grow out from neural tube cells, it can be seen that our whole nervous system is derived by induced differentiation exclusively from the ectoderm layer.

Formation of the neural folds was called the primary induction. Now let us turn to the formation of other organs and systems in the rest of the body. Analysis shows that in nearly every case as, for example, the eyes, ears, legs, heart, and so on, differentiation of the organ is similarly caused by inductions from underlying or adjacent cells. Such inductions are spoken of as secondary, to distinguish them from the main one of the nervous system. It thus appears that the pattern of development unfolds by a whole series of inductions, each depending on



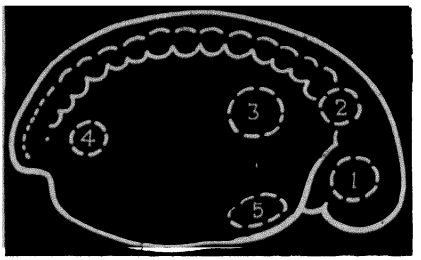
The germinal disc of the rabbit, showing an early stage in the formation of the main body systems. a, head region; b, tail region; c, myotome, or muscle mass; d, neural folds; e, primitive streak, or region of the notochord. (General Biological Supply House photograph.)

fectly understood, it is becoming clearer that each induction depends on the chemical action of some sort of "organizer" near by. In the primary induction, the notochord acts as an organizer which induces the formation of the neural tube from the ectoderm. How the organizers first appear is another question which is still unsolved. All we know is that they are somehow precisely controlled by the genes.

Patterning Life

The organizers for the different body systems are not scattered about haphazardly but are progressively localized in groups of cells arranged in definite patterns, like the designs in

rugs. Such localized groups of cells are called "embryonic fields"; some of these are represented in the accompanying drawing of the embryo salamander. There are fields for the eye, ear, limb, heart, and many other organs in the body. The rolling inside of some cells during gastrulation and the rolling up of others into the neural tube result in the sliding of the layers over one another and distortions of the original patterns of embryonic fields by stretching. By these so-called migrations of cells, the embryonic fields are pushed or pulled into final position. We may now define an embryonic field as a group of cells which contains a specific chemical organizer but which has not yet begun to take shape as an organ.



"Embryonic fields" in the embryo salamander: 1, eye field; 2, ear field; 3, forelimb field; 4, hindlimb field, 5, heart field.

Until recent years there was no way to test or prove the existence of embryonic fields. Then, some thirty years ago, Dr. Harrison at Yale University and Dr. Spemann in Freiburg, Germany, developed techniques for cutting out small squares or disks of cells and transplanting them elsewhere in the same embryo, or even to another one, to find out what would happen. When a definite field, such as the eye field, has been transplanted to a neutral or less important area, as, for example, the body wall, only an eye can develop at this spot. It does so in the new location just as it would in its normal position, the cells undergoing structural changes for their special jobs. By means of experiments employing these techniques, some of the more important embryonic fields have been mapped out.

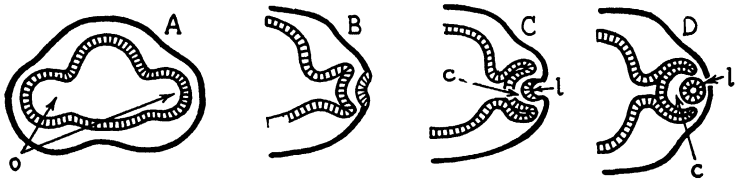
The next act of the moving-picture drama of embryonic development has to do with the changes by which unspecialized cells are transformed to become embryonic fields and finally true organs and systems. This next act is referred to as "differentiation," or specialization of cells for definite jobs. The early ectoderm and endoderm cells merely look like irregular little bricks in a pavement or tiles in a mosaic. The mesoderm cells are even less definitely shaped, appearing like small amoebae

crawling around. In differentiation the cells change both shape and function. Such changes have a twofold chemical origin: first, in an outside stimulus from contact with an organizer; second, from an internal stimulus depending on the genes comprising the chromosomes of each cell nucleus. Both sets of forces are always necessary, but their relative importance varies. Let us note briefly how the specialization of cells works out in a few instances. How does the leg form? How does the heart form? How does the eye form? The answers to these questions are now rather well known.

An understanding of how the leg forms may be gained by considering the foreleg or arm of the embryo frog. The embryonic field starts as a small thickening of mesodermal cells in the forward parts of the body, as shown in the drawing. This, of course, causes the overlying ectoderm to bulge out. Soon the bulge grows out like a finger in a glove. It is now called the limb bud. This limb bud grows to a length of about a millimeter, then the tip begins to branch. At first two digits appear. These are followed immediately by two smaller branches which form the third and fourth digits of the four-fingered animal. At the same time, the inside mesodermal cells have largely abandoned their nomad existence. Some of them settle down in groups and produce cartilage. These are the arm, wrist, and finger cartilages. Other mesodermal cells grow more spindle-shaped and link up in orderly rows. They become muscles. Still others connect these two sets together, making tendons. These transformations of wandering mesoderm cells into cartilage cells, muscle cells, and tendon cells are typical differentiation. Later, bone cells are differentiated which invade the cartilage, replacing it with bone.

The heart originates in two separate lateral regions of mesodermal tissue. These two regions move together and meet in the midlower line of the embryo, where the wandering cells rearrange themselves to form tubes. By the process of mitosis more cells appear, and the tubes grow longer in both forward and backward directions. In the region from which the heart forms, the tubes unite to produce a single structure. Then the cells in the walls link together and differentiate into heart muscle. Simultaneously, the tubes grow out from the forward part of the heart to become arteries. Branches from these arteries gradually

penetrate into every nook and crevice of the growing embryo as blood capillaries. The veins form in somewhat similar fashion.



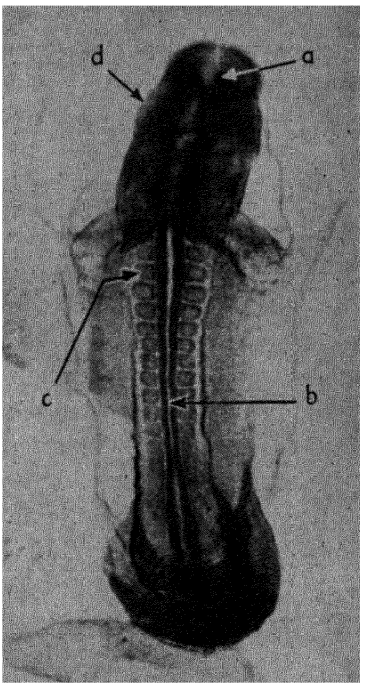
The formation of the vertebrate eye involves differentiation and a secondary induction: A, brain wall swelling out to produce optic vesicles (o); B, optic vesicle sinking in and inducing a thickening and insinking of the adjacent ectoderm; C, optic cup (c) forming from optic vesicle, lens vesicle (l) pinching off from ectoderm; D, lens forming in opening of the optic cup.

Now a unique thing begins to happen. The differentiated muscle cells in the walls of the heart start to contract rhythmically. Alternate relaxations and contractions cause waves of constriction to pass forward along the tube. The heart has begun to beat, even before any blood is present, as may be noticed by looking at such an embryo under a microscope. Soon, however, certain mesoderm cells in the lower body region cast off from their moorings and launch into the fluid serum that bathes all the interior of the embryo. These round up to become literally streamlined. We recognize them as differentiated blood corpuscles.

One further example claims our attention. It is the formation of the eye. This really involves a double induction and differentiation. We must first go back to the primary step, in which a neural tube was induced by the notochord. We should recall that one end of this hollow tube had formed a bulge, the beginning of the brain. The rudimentary brain further divides into five smaller bulges. Now, from the second bulge a large swelling appears on each side. What then happens is shown in cross section in the accompanying drawing. The brain bulge, or optic vesicle, pushes out to the ectoderm. Here a secondary induction takes place. The outer skin is induced to form a sac-like depression at this point. The optic vesicle itself then cups in. Meanwhile, the new ectodermal sac pinches off, forming a little hollow sphere that differentiates as the crystalline lens to focus light rays on the inside of the optic cup. The sensory layer of the

inside of this optic cup becomes the retina. Here the cells further differentiate into light receptors called rods and cones.

From this brief account it is seen that the sensory part of the eye is formed from an outgrowth of the brain, while the accessory structures are produced from an induced ingrowth of the skin to meet the brain extension. The conclusion is obvious, that embryonic differentiation depends on precise sequences of events, as the succession of inductions. Nowhere else is timing more important or more perfect. The undeniable fact that such events are ultimately controlled by the protein molecules which make up the genes is still too complicated to be comprehended entirely.



A later rabbit embryo. At this stage the main organ systems of the body have been laid down in outline. a, brain; b, spinal cord; c, myotome, or muscle mass; d, eye rudiment. (General Biological Supply House photograph.)

Coordination of Activities

It might be thought that the climax of this moving picture of embryonic development is reached when the main organs and systems of the body have been formed. In some respects this is true. The great construction work has been accomplished and the parts arranged in proper order. However, it must be kept in mind that the living embryo is a thriving, going concern. The parts must work together and they must be coordinated and regulated in their growth. There are two more acts, then, before the drama is completed.

The first one of these is interaction, or the exchange of effects of one system on another. Up to this point we have seen that, once an embryonic field has been organized, it is capable of self-differentiation; that is to say, once a forelimb area has been

organized or determined, those cells now have no other choice than to make a foreleg. However, if this were all, an embryo would develop only to some part-way stage. For complete development something more is needed. This fresh impetus to further development comes from the interaction of the parts.

Two examples should make this clear. A rudimentary leg even with toes, bones, and muscles can form, but alone it cannot function; in addition, nerve connections from the neural tube system must arrive, and a blood supply is essential. Although the leg muscles are formed, they soon degenerate and disappear unless nerve fibers penetrate into the limb bud. Connections of the motor nerves to a few muscle cells soon cause limb motions. These in turn aid the penetration of capillary rootlets which are destined to bring a blood supply laden with food and oxygen for the leg cells to grow on. The limb bud, the nervous system, and the circulatory system must intereact with each other for normal development to proceed.

A second example of the importance of interaction is somewhat the converse of the one above. For the normal development of brain and spinal cord, it is absolutely necessary for the first outgrowing nerve fibers to make connections with leg muscles, or heart, or ear, or tail, as the case may be. Once such connections have been made, then impulses travel up the fibers into the cord and back to the brain, where localized cell division is greatly stimulated. Thus the corresponding brain areas are forced in their turn to grow larger in order to care for the additional load of body control. Interaction, therefore, often works both ways.

We now come to the last important act of embryonic development. This is coordination and regulation of growth as the embryo gets larger and the number of cells increases into astronomical figures. By the seven acts already reviewed, the main patterns of development are completed. Thus, in a human embryo, the brain, the skeleton, the alimentary canal, the circulatory system, etc., are all established by the end of the twenty-first day. Such an embryo is approximately four millimeters long. The remainder of embryological development is mostly a matter of growth. No new systems are added. Only relatively minor changes take place, except for increase in size. The relative

growth of parts is controlled by the four factors of blood supply, hormones, mechanical forces, and, especially, factors inherent in the genes of the chromosomes.

Experiments have shown that decreased blood supply to any growing organ system limits or stunts its growth, although not all organs are equally affected. It seems certain that there is actual competition between all the developing parts of an embryo for the available food in the blood stream. Some hormones, as, for example, those from the pituitary gland, are able to control the rate of food uptake of an organ. But just how genes operating through chemical hormones cause a giraffe's neck to grow long and a gorilla's to grow short is still a major biological mystery.

The regulation of proportions in size is likewise but slightly understood. For instance, when an eye from a giant species of salamander is grafted into the head of a small species, the eye causes the host's skull to enlarge appreciably to accomodate it. Eventually, however, the foreign tissues shrink partially, remaining about a third again as large as the normal eye on the other side. Further experiments in size regulation are needed to complete our knowledge in this respect.

In Retrospect

If this story of development as presented here seems complex and difficult, it must be remembered that in the past hundred years, since Karl von Baer discovered the human egg, embryologists themselves have made but slow progress in the study of early growth of a new individual. This is so because of the great complexities of the subject. To get even a general understanding of the knowledge man now possesses regarding so complex a phenomenon is not easy, regardless of how interesting the subject may be. These few pages, while attempting to give a brief survey of the processes involved, have scarcely raised the curtain on the drama of human development.

In this chapter and the preceding one an attempt has been made to present the essential characteristics of living creatures as distinguished from inanimate materials and to point out how cells reproduce their kind by cell division and how a new individual develops during embryonic growth. It should be empha-

sized that the processes discussed are those that are essential to life on the earth and also those that have served to make this life continuous since it first appeared. Let us consider briefly in the next few chapters the development of life on the earth throughout the past geologic ages and note to some extent how it has specialized into different forms so as to produce the great variety of living creatures now existing or that have existed in the past.

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6: DOWN TO THE SEA

Where Early Life Existed during the First Geologic Ages

IN THE year A.D. 79 the people of the flourishing city of Pompeii were going about their luxurious and leisurely daily life. Then in August the quiet and majestic volcano that towered above the city began a violent quaking. Within a short time a cloud of lava ash was pouring forth. Soon Pompeii and 2,000 of its inhabitants were buried from the light of man. The people and their complex civilization were soon forgotten, since the memory of man is short. Their story became little more than a legend as time passed and they lay buried within their lava-covered city.

The city remained beneath this blanket of death for 1,700 years, and vineyards grew above its ruins. Then a peasant dis-

covered traces of its walls below his soil. During the eighteenth and nineteenth centuries the ancient city was dug out. Many of its houses and treasures have since been restored, and the dead have been excavated. From these ruins a vivid picture of the life and buildings of this ancient city is now reconstructed.

The records unearthed at Pompeii tell the story of a small but prodigal group of the earth's population that inhabited this favored spot for a few generations of human life. Other excavations over large stretches of the earth have revealed a widespread and extensive existence of once-living creatures. The span of time involved in this buried past is not a few generations, as was the case at Pompeii, but hundreds of millions of years. The story of this past life is written in the fossils left in the rocks, and these fossil rocks constitute the only documentary evidence of life on the earth before man learned to write a few thousand years ago. Their study gives an insight into the origin and development of the different species of life as well as some understanding of modern creatures, including man himself.

Slow Unfolding of a Mystery Story

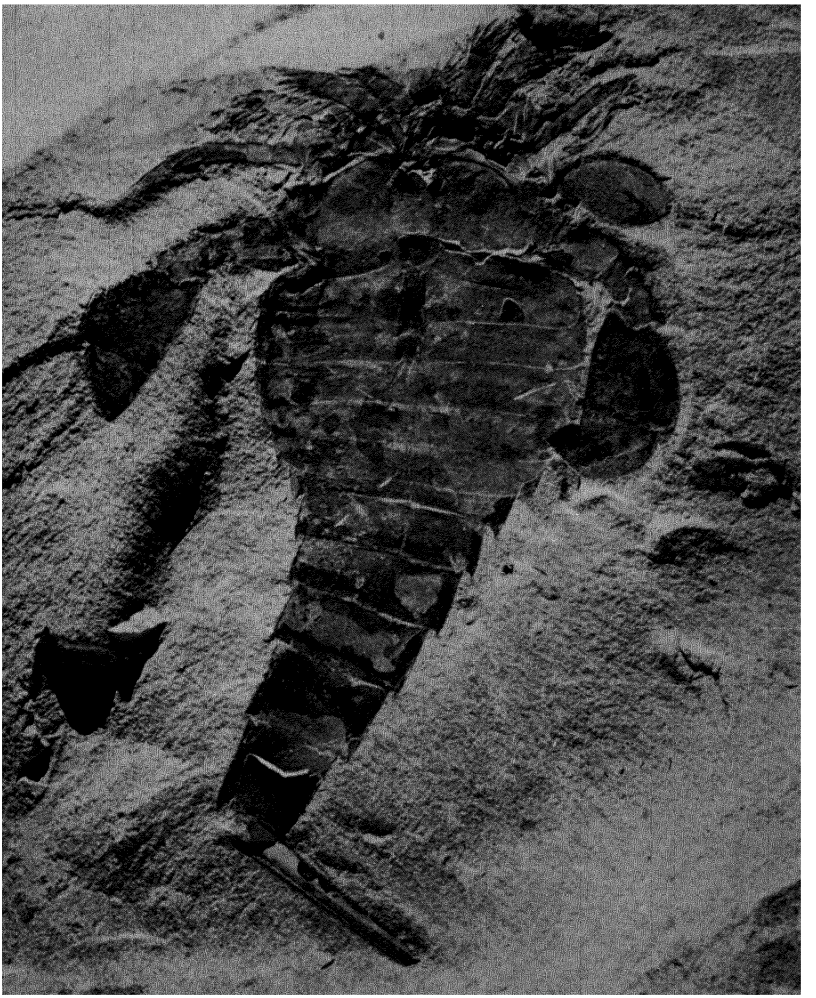
The unraveling of the story of early life on earth has been a slow and much-varied process. What we now know of this past is nothing more than the discoveries of our ancestors and the modern scientists, along with the explanations and deductions that have been made from such findings. This understanding of the earth's past is not some supernatural decree or some abstract dogma. It is one of man's accomplishments, one of the fruits of his labors. The different views that have been held of these past conditions have changed many times. Until the rise of the early Babylonian and Egyptian civilizations, mankind had little insight into the meaning of life and the relationships existing between living creatures. Following these times, for many centuries, only meager and usually fantastical speculations prevailed. As observations of resemblances of living things and particularly discoveries of imprints in rocks were made, they were accounted for in some unusual manner or their existence was entirely ignored.

From the earliest times, those who examined the strata of the earth's rocks were surprised to find markings and remains of

plants and animals in them. Some regarded them as works of an occult influence in nature to convey some hidden meaning or lesson. Others believed them to have been produced by the forces of evil to mislead and terrify mankind. Later is was held that such figures were formed by vapors generated in the rocks from fermentation. Even the pottery and urns sometimes found in deep deposits were explained as having been produced by the circular movements of these vapors as they escaped from lower deposits.

Another explanation of these rock figures that was widely accepted up to about A.D. 1750 was that they "grew" in the rocks from "seeds" that were lifted from the sea (or sky) and transplanted to distant lands by a supreme power. Such a "seminal root" was thought a sufficient cause of these figures. The final overthrow of this kind of belief was heralded by probably the greatest hoax in geologic literature. A German scientist by the name of Johann Beringer taught geology at the University of Würzburg about 1730 and collected fossils in the chalk beds near by. Some of his students prepared a number of artificial "fossils" of various living and imaginary things, including some Hebrew characters, and deposited them in the chalk beds. These, were found of course, by the unsuspecting Beringer, who described them extensively and reverently in a number of publications. The distressing climax was reached when one day he found a fragment bearing his own name. Having finally discovered his mistakes, Beringer attempted to recall and suppress his writings on the subject, but the cruel and silly joke had reached proportions beyond his control. Not only the professor but much of the whole belief he represented was made ridiculous.

Gradually the true explanation of the origin of fossils became established; namely, they are the actual remains of once-living creatures. These creatures had been caught and preserved in the sediments as the rocks were being formed either beneath the sea or on land, depending upon whether the fossil was of water or dry-land organisms. Of course, this implied that much of the country now dry had in long ages past been beneath the ocean or inland seas, a well-established fact at present. Such ideas were first materially advanced by Leonardo da Vinci in A.D. 1508; however, they were championed by only a few others



Fossils are the remains in rocks of once living creatures. A fossil of an eurypterid, **Eusarcus scorpionis, found near Buffalo, New York. American Museum of Natural History photograph.)**

through the centuries until about 1800. At about this time such able scientists as Baron Georges Cuvier and Jean Baptiste de Lamarck in France and William Smith in England established geology on a firm research and scientific basis. Since then many great geologists in both America and Europe have added much to our knowledge of the geologic past and life during those ages.

Geologic Eras and Periods

Geologic history covers a long period of time. A kaleidoscopic view of it adds only confusion. Fortunately, it may be divided into eras and periods for study. In this respect it is comparable to the division of human history into eras, such as ancient history, medieval history, modern history. These eras in geologic times may be arranged chronologically, as is done in recording human affairs. As such they help to classify our knowledge and facilitate its study.

Here, then, are some divisions of time that may be new to you. However, their names and approximate dates are worth knowing in any consideration of life's ancient past. The Azoic, Archeozoic, Proterozoic, Paleozoic, Mesozoic, and Cenozoic eras are the great divisions of geologic time. Let us pause to study these names. We shall meet them many times as we proceed. They are chronologically arranged, the first being the earliest. All the names have the same endings, "zoic." It is derived from the Greek language and means life. The remainder resolves itself into knowing the meanings and order of the prefixes. A, the firts one, means "no"; therefore, Azoic is no life. Archeo is "ancient" or "most ancient." Protero signifies "former." Paleo refers to "old." Meso means "middle," and Ceno, "recent." We have them in order then: no life, ancient life, former life, old life, middle life, and recent life.

Their dates are given in the accompanying chart. These dates are based upon ages of certain rocks as determined by nature's well-regulated time clock, that is, radioactive minerals found in those rocks. Even though these dates are only approximate, their order of magnitude is correct. The length of geologic time here indicated is nearly two billion years. This is a figure that staggers the imagination, even in these days when many billions of dollars are the figures that represent the national debt. However, this long history of the earth is attested to by all contemporary geologists who have made studies of this age-old question.

The oldest rocks so far examined are some found in Russia. They have an age of 1,850,000,000 years, and they are younger rocks than those of the original earth's surface. Radioactive mineral-bearing rocks belonging to each of the geologic eras have

CHART OF AGES

Millions of Years	Eras	Epochs	Ages of Life
	RECENT		
	CENOZOIC	PLEISTOCENE	MAN
		PLIOCENE MIOCENE OLIGOCENE EOCENE PALEOCENE	MAMMALS
60			
	MESOZOIC	CRETACEOUS JURASSIC TRIASSIC	REPTILES
200			
	PALEOZOIC	PERMIAN	AMPHIBIANS
		CARBONIFEROUS	COAL
		DEVONIAN SILURIAN	FISH
		ORDOVICIAN	CEPHALAPODS
		CAMBRIAN	TRILOBITES
500			
	PROTEROZOIC	KEWEENAWAN HURONIAN	PRIMATIVE MARINE LIFE
1100			
	ARCHEOZOIC	GRENVILLE DEPOSITS	OLDEST KNOWN LIFE
1600			
	AZOIC		FORMATION OF EARTH'S CRUST
2000?			

Chart of geologic time, showing divisions into eras and epochs. The ages of these divisions have been determined by means of radioactive minerals in the rocks.

been discovered and dated. Thus, the time order of the different eras is well established.

The divisions between eras are clear and distinct in most cases. These divisions were determined by times of great movements of the earth's crust, when mountains were being elevated and inland seas were being obliterated. They were marked by definite changes in living forms from one era to another, at least during the latter eras; that is, the forms that were numerous and widespread in one era diminish or disappear and gave way to new forms that multiplied and flourished in the following era.

Let us consider briefly how a geologic era came to an end, and a new one was ushered in, since the geographic and climatic changes thus brought about affected life on the earth profoundly.

In the St. Lawrence area of North America there is an extensive series of sedimentary rocks called the Grenville Series. In some places they constitute masses of limestone that are estimated to be as much as 50,000 feet thick, a thickness of limestone that is unequaled anywhere else in the world, so far as is known. Beneath the scattered remains of the Grenville strata is an extensive complex of gneiss rocks known as the Laurentian Gneiss which seems to form the basement for the entire region. The age and structure of the Grenville and Laurentian formations show that toward the end of the Archeozoic era the Laurentian formations were produced by an intrusion of liquid magma which cooled beneath the overlying Grenville strata, at that time evidently forming the bottom of an inland sea. This flow of magma probably exceeded in magnitude any other flow the earth has ever experienced. As a result, a great system of mountains, the Laurentian Mountains, was elevated from the sea. These mountains were rapidly eroded in the succeeding ages until now they are almost completely obliterated.

This same process of extensive mountain building and subsequent rapid erosion is noticeable as having occurred in many other parts of the earth at approximately the same geologic time. The end of the Archeozoic era is considered as having been brought about by an age of widespread mountain building, usually referred to as the Laurentian revolution, followed by a time of very active erosion. This period of extensive earth-crust movements separates the Archeozoic from the Proterozoic era.

The end of the Proterozoic era was heralded by another time of major earth-crust movements. In the United States these are represented by the elevation of many sections, one of which was a mountain range, known as the Killarney Mountains, that extended east and west through the Great Lakes region for perhaps a thousand miles and with a width of at least a hundred miles. This time of mountain building was followed by an interval of perhaps millions of years, when extensive erosion leveled the high places. The Killarney revolution and the subsequent period of erosion represent the break between the Proterozoic and Paleozoic eras.

Toward the end of the Paleozoic the earth witnessed another long age of extensive mountain building. During this period the great land area paralleling the present Atlantic Coast was thrust westward and folded the strata of the Appalachian geosyncline to the west into a majestic range of mountains, the Appalachians, which extended from Nova Scotia to Alabama. The geosyncline as well as much of the area west to the Mississippi River had been beneath an inland sea at intervals during the Paleozoic, and the Appalachian elevation raised this country permanently above the sea. Elevations in other parts of the earth, too detailed to be included here, occurred during the same period. This extensive mountain building, known as the Appalachian revolution, did not occur suddenly and probably not violently, except perhaps in small local areas. Rather it extended over tens of millions of years. Simultaneous with the mountain building rapid erosion was taking place. Much of the great height of the original Appalachian Mountains was worn down. Eventually the pronounced movements subsided in degree and the Mesozoic era began.

The closing stages of the Mesozoic produced a series of extensive crustal movements over the earth that were, without doubt, the most pronounced in western United States. The great geosyncline extending from the Gulf of Mexico to Alaska was folded and upthrusted on a wide scale to produce the Rocky Mountains by a regional compression from the west. It is also probable that volcanic activity was common throughout the entire western part of the United States. This extensive crustal movement is known as the Laramide revolution, sometimes popularly referred

to as the Rocky Mountain revolution. The climax of the Laramide revolution determined the end of the Mesozoic and the beginning of the Cenozoic eras. These earth disturbances continued with decreasing vigor, however, long into the Cenozoic.

The Cenozoic was an era of exceptional crustal movements. The Rocky Mountains were extensively eroded and again elevated to their present heights. The highest mountains now in the United States, the Sierra Nevada, were formed. The Colorado Plateau was slowly elevated, and the Colorado River cut the Grand Canyon. The Himalaya and Alps were pushed up from the sea bottoms. The era was brought to a close by the Cascade revolution, which produced the Coastal Range Mountains along the Pacific Coast, and the subsequent period of about a million years, during which time four great glaciers covered much of North America and Europe. Hence, the Cenozoic era may be thought of as bounded by two great revolutions, the Laramide, which started it, and the Cascade, which brought it to a close.

Such broad and pronounced changes in the earth's crust had an enormous effect upon living creatures. Old habitats were obliterated or so completely changed that creatures specifically adapted to them could not endure. They had to give way to less specialized forms that found the new environments suitable. Such forms may have been insignificant in both size and number under the previous conditions, but in the changed environment these forms increased in number and in complexity of body structure until they became the most important in the new geologic era. These emergent forms in turn gave way when the curtain rang down at the end of the era of conditions to which they had become adapted. Many specialized types of creatures have arisen in the past to flourish for long intervals of time and have now become entirely extinct. In general, these changes occurred with the change of geologic eras.

Changes within Geologic Eras

In addition to the widespread and pronounced changes of the earth's surface toward the end of a geologic era, other less extensive changes have occurred within the geologic eras. These less extensive changes have had decided but usually not extreme effects upon living creatures. It is possible, therefore, to divide

the geologic eras into shorter divisions on the basis of the less extensive changes. These shorter units are called epochs. For example, the Paleozoic era is divided into the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian epochs. The Mesozoic era is divided into the Triassic, Jurassic, and Cretaceous epochs. The Cenozoic era consists of the Paleocene, Eocene, Oligocene, Miocene, Pliocene, and Pleistocene epochs. During the different epochs one form of life gradually developed new forms in a rather continuous process. However, there was no great decay or disappearance of the earlier existing forms, as in the case of change from one era to the next.

The above list of geologic epochs constitutes quite an array of names. There are a few of them that should be learned by the reader who wishes to obtain even a general picture of developing life on the earth. Without doubt one of these is the Cambrian. It is the first epoch of the Paleozoic era, and began about 600 million years ago. It is one of the great mileposts in geologic history. Other epochs worth knowing, along with their place in the order of this scheme of classification, are the Ordovician, Devonian, Triassic, Jurassic, Miocene, Pliocene, and Pleistocene.

One illustration will serve to show how these epochs were determined and how they tended to influence life on the earth. Notice, for example, the Mesozoic era. It consisted of the Triassic, Jurassic, and Cretaceous epochs. The rocks that immediately overlie the great coal measures of Great Britain, which were formed during the latter part of the Paleozoic era, are thick beds of red sandstones. This same layer of red sandstones can be traced into the European continent where, in Germany, it becomes divided by a layer of limestone. Thus, three layers are recognized, an upper and lower layer of red sandstone and a middle layer of limestone. Because of this threefold character, the name Trias was applied to the series, and the word Triassic eventually came to designate the epoch when these formations were laid down.

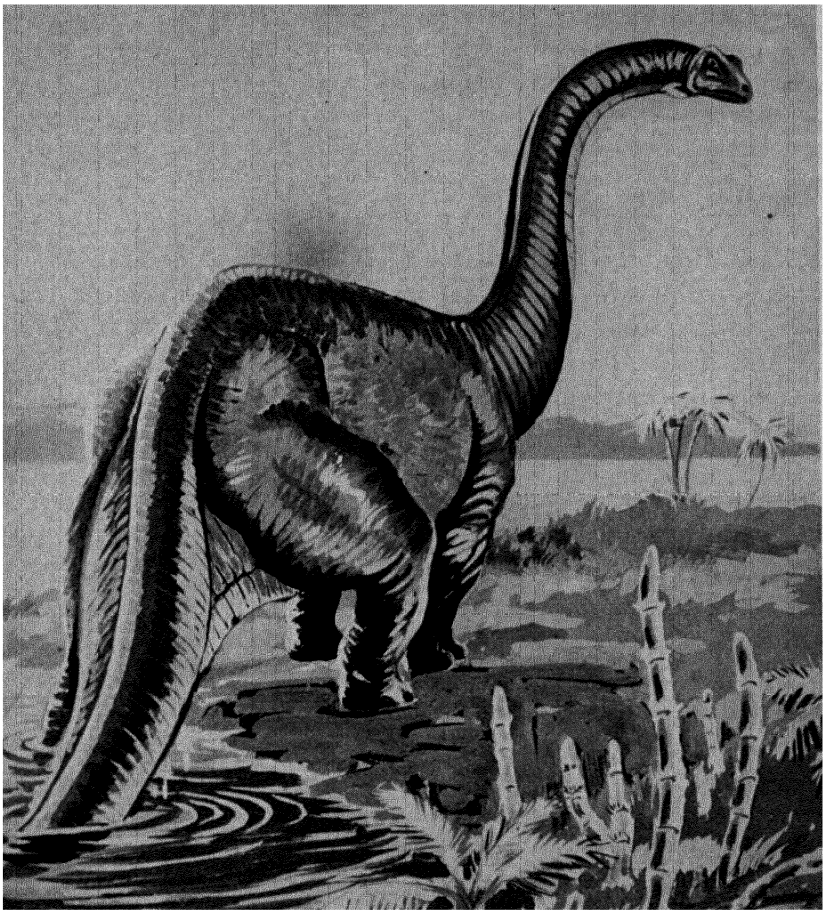
In Southwestern United States the Triassic rocks are found widely distributed. Here the red sandstones predominate. However, they are often found with thinner layers of shales and gypsum intermingled, producing now some of our most colorful

landscapes, such as the Painted Desert in Arizona. The physical features of these rocks show that they were laid down, for the most part, in a warm and arid climate. The sand was deposited when the land was above water, while the shales and gypsum were deposited in fluctuating areas of fresh-water swamps or marine lagoons. In Eastern United States the rocks of the Triassic epoch are more complex. They show in general, however, that most of the area was above water and that considerable sections were lowlands that repeatedly dried between infrequent rains.

It is reasonable to assume that during the Triassic the climate was relatively warm and arid or semiarid over great parts of the land. Much of the United States was above the sea, but some areas were lowlands or even swamps. Such conditions of mild climate and extensive land areas facilitated the development of land animals of the cold-blooded type. This epoch saw the rapid rise of the reptiles. The previous disappearance of the shallow seas of the Paleozoic era brought about the decline or obliteration of some of the older marine forms, and once the reptiles had become established on land in the Triassic they began to invade the shallower seas also.

Following these times great inland seas began gradually to spread over Europe and large areas of Western North America. This marked the beginning of the Jurassic epoch. For most of North America it was a time of general degredation of land areas with an evident continuance of mild climates. Inland seas from Alaska pushed in over what had been arid regions of Utah, Wyoming, Montana, and the Dakotas, forming what is known as the Sundance Sea. About the middle of the Jurassic epoch this sea began to recede and formed great plains or swamps in this area. It became the scene of luxuriant plant growth and extensive animal habitation. Sluggish streams must have flowed across the area, and their deposits buried the remains of the largest of all American dinosaurs.

These formations as well as many others, in different parts of the earth, belonging to the Jurassic epoch indicate that the climate generally was warm and humid. Evidences show that subtropical climates existed over much of the United States and over Europe. This condition favored wide multiplication and



"Thundersauran", a thirty-ton dinosaur that inhabited the swamp lands of Southwestern United States during the Jurassic epoch. (Science Service photograph of drawing by George F. Mason, American Museum of Natural History.)

distribution of cold-blooded animals, particularly the dinosaurs. They ranged over the plains as far north as Montana, and in Asia their remains have been found over most of Mongolia.

The end of the Jurassic epoch was marked by local mountain building in some areas and by a broad increase of inland seas in Western North America. There was an upflow of basic lava along the west coast of Canada and also along the eastern part of California, where the Sierra Mountains now exist. Following this a great stretch of land, which now constitutes the Rocky

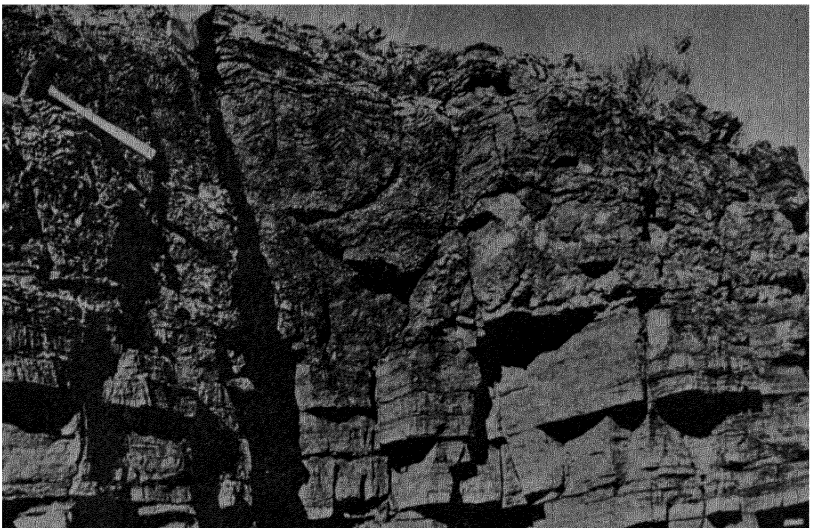
Mountains, began to sink, forming there a great geosyncline. A broad inland sea overflowed the geosyncline. It eventually extended from the Gulf of Mexico to Alaska and completely divided the North American continent into two land areas. The Cretaceous epoch, the last one in the Mesozoic era, had begun.

This sea evidently overflowed the land very gradually rather than by any sudden movement of the earth's crust. Then it began gradually to recede, forming first shallow, connected seas, then swamp areas, and finally low-lying plains. In many of the shallower seas great deposits of chalk beds were laid down. These are often rich in fossils of great marine reptiles, diving birds, and flying reptiles, which were in abundance at that time. These beds repeat themselves in many places in the United States and in Europe and other continents. Dinosaurs continued to inhabit the lowland areas, as indicated by their fossils. The climate was mild and humid, perhaps a little less so, however, than during the preceding Jurassic epoch. Tropical and temperate-zone plants grew as far north as Alaska, and many of the coal beds of Western North America were formed by luxuriant plant growth in the lowlands during this epoch.

The Cretaceous epoch came to an end with the great disturbances which elevated the Rocky Mountains from the inland seas, as well as similar crustal movements in other parts of the earth. Most of the inland seas of North America were obliterated and the continent took on much the boundary it has at present. This was, of course, also the end of the Mesozoic era. The climates of the earth became much colder, glaciers appeared in many areas. With such changes in climate and alterations of land and sea environments, the great dinosaurs were obliterated and many other forms of life profoundly affected.

Pre-Cambrian Life

The play "Victoria Regina" had a long and successful run in New York City theaters in recent years. The remarkable thing about this play was the excellent portrayal by the play's leading actress of the entire life of England's great queen. Each period in the queen's long and eventful life, from the time of the slim girl's coronation to her last days as a plump old empress, was

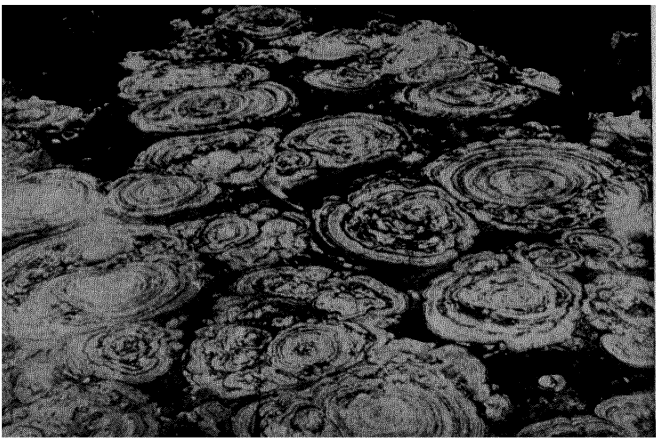


A layer of limestone of the Proterozoic era in the Grand Canyon showing presence of colonies of fossil algae. (Science Service photograph.)

vividly and artistically revealed by this noted actress. This is unusual, for in most plays or novels embodying a long stretch of time, great gaps are only vaguely hinted at or left entirely to the imagination. This latter procedure is forced upon us in considering life's early events upon the earth. It is mainly because there were no great actors to play the leading roles.

Over half of the long span of life on the earth had passed before the beginning of the Cambrian epoch. The Archeozoic and Proterozoic eras, not to mention the Eozoic, we see only in dim outlines. Thus nearly a billion years had elapsed before the beginning of Cambrian time. This stretch of geologic time is designated Pre-Cambrian, in somewhat the same manner as the historian uses the expression "before Christ." The history of life on the earth since the Cambrian epoch can be pieced together in such detail as to give a rather continuous picture. Before this time this is not possible. Therefore, the beginning of the Cambrian epoch is an important geologic date.

The search for evidences of life during Pre-Cambrian times must necessarily be made in the rocks formed in those far-off ages. Such rocks that have come down to us in unaltered condition are found at the bottom of the Grand Canyon and in other



Cryptozoön fossil formations in limestone, showing one of the earliest forms of life. (American Museum of Natural History photograph.)

parts of the earth. The Colorado River has cut its way through the overlying formations and, some 6,000 feet beneath the surface, has eroded the present gorge into the Pre-Cambrian sediments. In these sedimentary rocks are found abundant deposits of algae. These were lowly, microscopic plants that grew in colonies, over which they deposited calcium carbonate. They built up, therefore, masses of limestone deposits, somewhat hemispherical in shape, which consisted of one layer upon another. There are in the seas today certain varieties of algae which secrete limestone and build up similar "cabbage-head" masses of this deposit. It is reasonable to assume that the Grand Canyon deposits were formed by such microscopic plants. Similar rocks of Pre-Cambrian origin have been found in Montana, Michigan, and the Hudson Bay regions. These microscopic plants were evidently widespread in the early seas.

Some of the Pre-Cambrian deposits of France have yielded radiolaria. These are a form of one-celled animal that secrete delicate mineral layers around their bodies, and there are many varieties that may be seen in present-day waters: Several different forms of sponges have been found in the Grand Canyon and other Pre-Cambrian deposits. These were microscopic animals that lived in colonies, perhaps somewhat as sponges do today.

Some of the Pre-Cambrian formations contain graphite between layers of sedimentary rocks. This is a pure form of carbon, familiar to most people as "lead" in pencils. These streaks of carbon are now known to have been organic in origin and were deposited from the bodies of once-living microscopic plants and animals. The only explanation of this graphite is that such creatures must have been swarming in the Pre-Cambrian seas. As their bodies disintegrated the carbon, which is an essential component of all living tissue, was deposited in these layers.

Pre-Cambrian rocks of Montana have yielded evidence that wormlike creatures existed in the seas of those times. This consists of trails and burrows found in the Pre-Cambrian shales and sandstones. These burrows were most likely made on the sea bottom by some kind of worms crawling through the mud or sand much the same as sand worms do today, as may be observed at the seashore or in a sea-water aquarium. The soft bodies of these creatures left no fossils, but their burrows in quiet sediments left holes as the sediments eventually formed rocks. This lowly creature represents the highest form of Pre-Cambrian life known at present.

It may be said, then, that there existed a somewhat varied and extensive sea life near the end of the Proterozoic era. However, this life was simple in form and consisted of microscopic plants and animals, and sea worms. This is very much in contrast to conditions existing at the very beginning of the Cambrian epoch. Then there appeared a great abundance of sea animals with shells, some of them quite complex in their physical organization. Why there should be such a scarcity of more highly developed forms in Pre-Cambrian times and such a profusion of them in the following epoch has been one of the great questions of historical geology.

One of the explanations offered is that Pre-Cambrian rocks have been metamorphosed since they were laid down and all fossils in them destroyed by the intense heat. However, not all Pre-Cambrian rocks have been thus heated. Still no shell fossils are found. Another explanation is that relatively complex forms of aquatic life had developed during Pre-Cambrian times, but that none of them had shells and hence left no remains. It is beyond the scope of this discussion to consider the possible

causes for sea invertebrate animals not growing shells at that time as they did during the Cambrian Period and have at all times since. However, when all things are considered it seems likely that all Pre-Cambrian animals were motile creatures and without any skeletal parts of limestone composition. Few fossils are likely, therefore, to have been formed. It seems probable that our understanding of Pre-Cambrian life forms will always be rather meager.

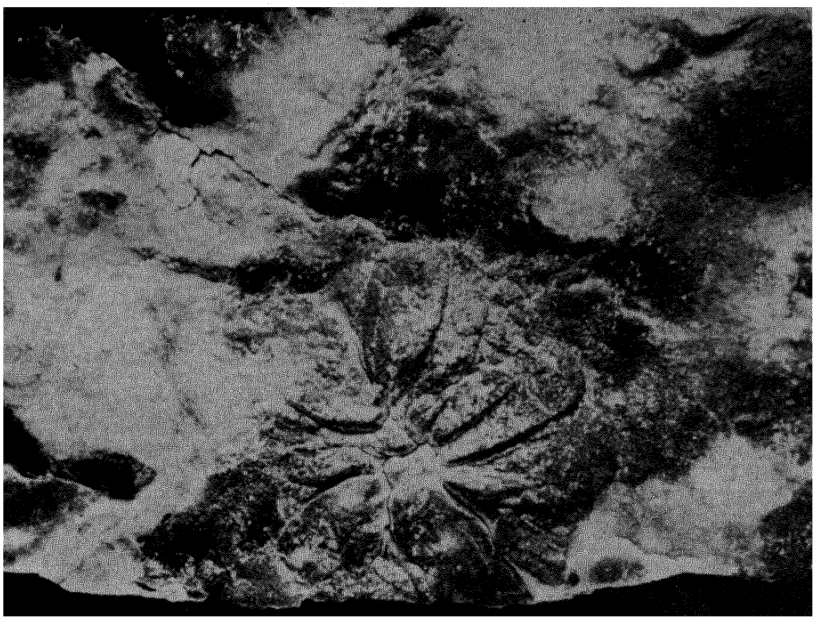
Invertebrate Surge

During the Cambrian epoch occurred the first great development and diversification of invertebrate life in the sea. These backboneless creatures bearing shells have left a profusion of fossils widely scattered in the rocks formed in the Paleozoic era. Something like 1,200 different species of fossil invertebrates that existed in North American seas in Cambrian times are now known to paleontologists. Including fossils from the rest of the Paleozoic era, we increase the number of known fossil species by many thousands.

The surge of invertebrate creatures that began in this early geologic age has rapidly increased until the present time. Now there are some 600,000 recorded living species, a great majority of which are the insects. In addition to these, there are some 60,000 extinct fossil species now known to man. Of the known living species about 40,000 now live in the sea, whereas all the early creatures existed there.

Many of the fundamental kinds of invertebrates found in the sea today started in the far-off Paleozoic era. It is true that these Paleozoic creatures were primitive kinds of ancestors to modern species; however, the similarities of the main groups of modern invertebrates to these early forms can be noticed. Today the seas swarm with many thousands of invertebrate animals. Some of them seem very strange to persons not familiar with sea life. The remarkable thing is that they not only exist at present, but that their ancestry can be traced back hundreds of millions of years.

One group of creatures whose fossils are found in Paleozoic rocks are the coelenterates. Modern forms of the coelenterates include the corals, jellyfish, the hydra, and sea anemones. They

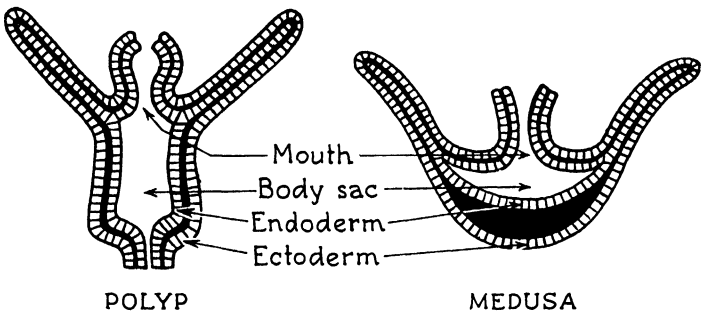


Imprint of a jellyfish left during the Cambrian epoch in beach sand which later hardened into a slab of rock, in the Grand Canyon, Arizona. (Science Service photograph.)

are to be found widely scattered in the seas or fresh waters today. A well-preserved imprint of a jellyfish, one of the most fragile of animals, has been found in the early Cambrian rocks exposed in the Grand Canyon. This record thus establishes the long lineage of the jellyfish, even though it is a record that would hardly be expected to be left. The group of animals to which the hydra belong are first represented as fossils from the early Paleozoic. These are imprints of extinct forms, known as graptolites, on black shale rocks which have been found in many parts of the earth, and they must have been world-wide in their distribution. Sea anemones, having no hard parts in their bodies, have left no recognizable fossils, but their nearest of kin, the corals, provide an abundance of records. Fossils of free-swimming corals date back to the early Paleozoic era. True corals began to build reefs from their limestone deposits during the Devonian epoch. This process has continued to the present time.

A distinguishing feature of the coelenterates is that the body is composed of two layers of tissue, an outer ectoderm and an

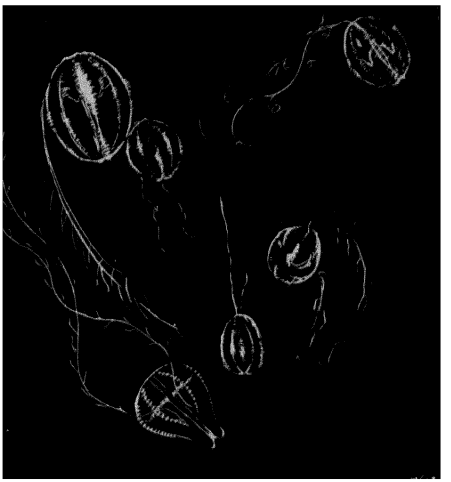
inner lining, the endoderm. The body is usually in the form of a simple sac with a single opening at one end, forming the mouth as



The polyp and medusa have similar body patterns. (Redrawn from Buchsbaum "Animals Without Backbones.")

well as exit for waste materials. Most of the coelenterates are armed with stinging cells and oval capsules filled with a poisonous fluid and containing a long hollow thread, the outer end of which contains a bristle-like spine. When the animal is disturbed the poison cell contracts, causing the thread to be shot out with considerable force so as to pierce whatever comes in contact with it. The poisonous fluid then flows down the hollow thread into the body of the captive. This may paralyze or kill some creatures. The animal feeds on its victims by drawing them down into its body sac, with tentacles in the case of the sea anemone, or by wrapping its body sac around the food as in the case of the jellyfish.

Two main body types are found among these simple and primitive animals. One is the free-swimming or medusa type typified by the jellyfish and one stage in the life cycle of many hydra. The other type has the body sac drawn out to a stem, the lower end of which is attached to some anchor. This is typical of the polyps, a common variety being the hydra that may be easily seen with a magnifying glass in most fresh-water streams and ponds. The sea anemone, or marine "flower animal," belongs to the polyps. These animals have a basal disk or foot, with which they attach themselves to some rock or solid object. They have a stout, muscular body and many tenacles surrounding the mouth. Different species have a variety of bright colors, and they constitute an attractive part of the marine fauna.



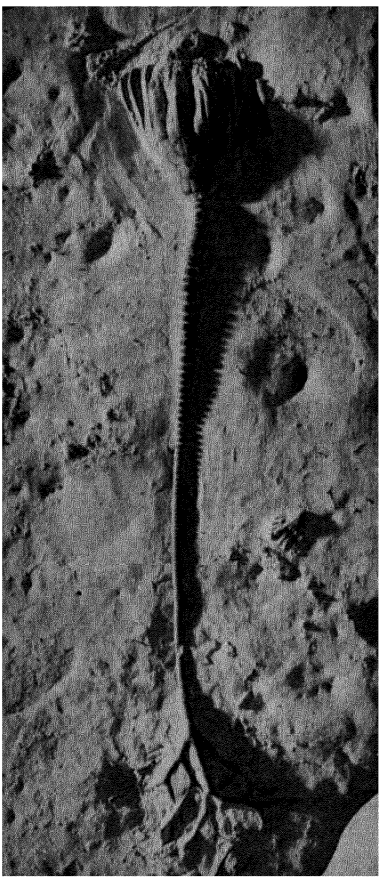
Comb jellies are transparent echinoderms that occur in the surface waters of the sea, mostly near the shore. They are noted for the beauty of their daytime iridescence which is produced by the tiny rows of combs along the sides of the body refracting light.

The coral polyps are specialized types which have the ability to secrete lime around and throughout their delicate bodies. When the animal dies this lime formation remains behind attached to its original base. This ability of these minute animals to secrete lime has added thousands of square miles to the land surface of the earth throughout the geologic past. Southern Florida and many of the low islands of the Pacific, for example, were originally coral reefs that resulted from such activity.

Another group of animals that originated during the Paleozoic era were the echinoderms. Their descendants are also common in the seas today, in such forms as starfish, sea urchins, sand dollars, cucumbers, comb jellies and crinoids. They are animals which are radially symmetrical. They usually have a set of tubes which radiate from a large body cavity and which carry water. This circulating water serves for breathing and to operate the tube feet that are frequently used for locomotion. Their skin is strengthened by a deposit of calcium carbonate, usually in the form of rods and plates.

Since these animals have deposits of limestone in their bodies, they have left an extensive fossil record. The earliest fossils are those of ancestral crinoids, which date back to the very begin-

ning of the Paleozoic era. Later in the era the true crinoids appeared, and varieties of them have lived in the sea to the present.



Fossil crinoid or sea lily. (American Museum of Natural History photograph.)

Fossils of Paleozoic crinoids show them to have been plated and spiny-skinned animals with many arms radiating from the larger body cavity somewhat like the petals of a flower. The lower part of the body secreted a limestone stalk that attached the animal to rocks on the sea bottom. These feather stars, as they are called, could produce a wave-like motion by a slight bending of the stem, and they secured their food from the water that came in contact with their bodies. They are sometimes called sea lilies, so much do they resemble in general outline this delicate and glorified flower.

The starfish is another animal with a long family history as well as widespread modern progeny. Early Paleozoic rocks show fossils of starfish, their fossils are numerous in later marine formations, and, as is generally known, starfish are to be found in most seas today. The earlier forms are now extinct; however, these fossils bear such likeness to modern species that the lines of development are clear. Starfishes usually have five arms that radiate symmetrically from the body. These arms are supplied on the underneath side with muscular tubes that end in suckers. These tubes are filled with water from a water-vascular system. By a sort of pumping of the water through the system the animal is able to use these tubular feet for locomotion. The starfish has the power of regenerating lost parts; that is, it may

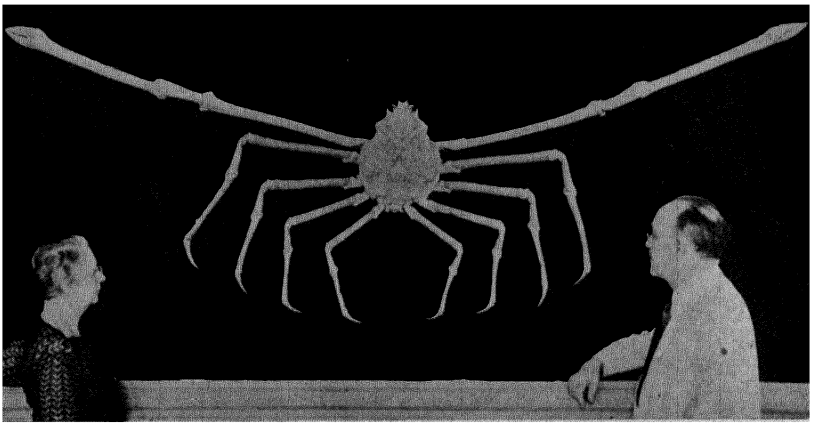


The starfish is a radially symmetrical animal, usually having five arms. The underneath side of the arms are supplied with muscular tubes that end with suckers.

grow new arms, new tube feet, or even a new stomach, if any or all of these are lost by its method of feeding or by being chopped off by man.

The Paleozoic era saw the development of another group of invertebrates that were destined to become in modern times the most numerous multicelled animals on earth. These are the arthropods, which include the modern forms of insects, spiders, scorpions, centipedes, shrimp, lobsters, and crabs. In the Cambrian rocks are found fossils of segmented animals known as eurypterids or "sea scorpions." They apparently lived in the sea and flourished for several hundred millions of years. At their zenith they grew to a length of ten feet. However, they declined toward the middle Paleozoic and became extinct before the end of the era. Before disappearing it is believed that they gave rise to the true scorpions and spiders, land animals that have continued to the present.

Insects appeared on the land during the latter part of the Paleozoic era. Some of them developed rapidly into remarkable size. In the coal measures of Belgium has been found a fossil of a dragon fly with a wing spread of twenty-nine inches. It is the largest insect known to have lived on the earth. It is fortunate for man and the other vertebrates that later insects did not develop into large forms. If so, this might have been an invertebrate



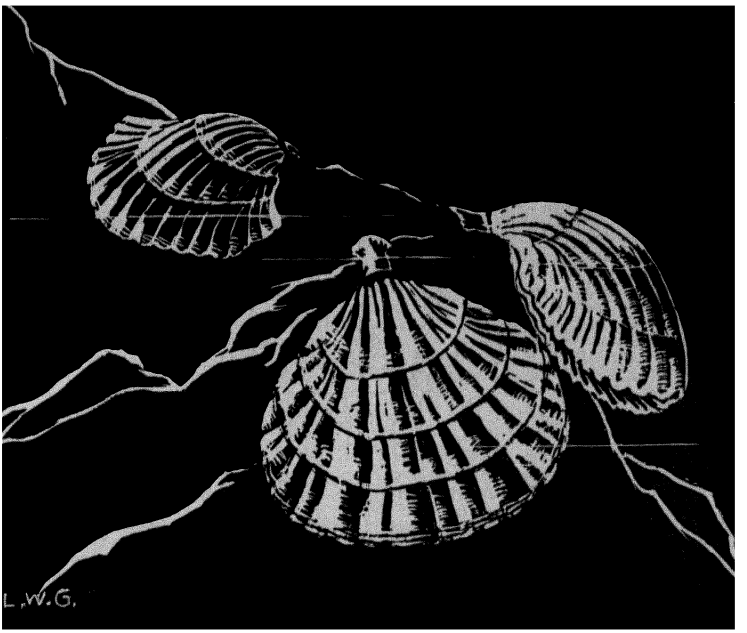
The giant crab of Japan, shown above on permanent exhibit at the Buffalo Museum of Science, reaches eleven feet between its claws. (Science Service photograph.)

world. Cockroaches very much like modern ones were exceedingly numerous during the late Paleozoic. Some of them were three and four inches long, although most of them were smaller. During the Mesozoic era insects became widespread on the land. Since then they have continued to increase in both species and numbers until today there are over a half million living species on the earth.

The shrimps, crabs, and lobsters first made their appearance during the Mesozoic era. Their fossils have been found in rocks as early as the Jurassic epoch, and these animals are extensive in the seas and fresh water at present.

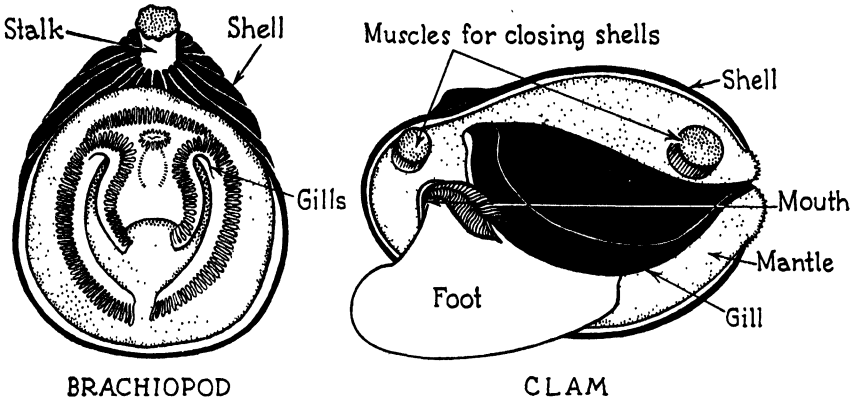
Animals Bearing Shells

A group of animals which exist in relatively small numbers in the sea today but which have had a long and prominent history during past geologic ages are the brachiopods. They made their first appearance in the Cambrian seas, and before the epoch was ended they constituted about one-third of the Cambrian faunas. They reached their climax of development during the Devonian epoch and for hundreds of millions of years they were an extensive form of life in the sea. Their fossils are so extensive and their forms so characteristic of different geologic epochs that they have long been the favorites of geologists in correlating and determining the age of the rocks of sedimentary formations.



Brachiopods made their first appearance in Cambrian seas and still persist in the sea today. The Terebratella, pictured above, is found off the coast of Japan.

The brachiopod is an animal which is enclosed in a bivalved shell. The two units of the shell are quite different, however, from those of the clam or oyster. The upper shell is somewhat smaller than the lower part, and the two are hinged together at one end rather than on the side, as is the case with the clamshell. At the rear end of the lower shell there is a sort of upturned opening through which a fleshy "foot" or stalk projects. The animal attaches itself to rocks or other objects in the sea by means of this stalk. The two halves of the shell may be opened quite widely at the front. Anatomically, the brachiopod consists of a skin which lines the shell, digestive and circulatory systems, and two spirally coiled ridges or "arms," in addition to the body stalk which protrudes through the shell. The spiraled ridges are really a pair of gills which have on them rows of hair-like tentacles. The waving of these tentacles sweeps minute organisms toward the mouth, which is located between the arms. Thus the two "arms" serve for breathing and entrapping microscopic plants and organisms for food rather than as an aid in locomotion, as

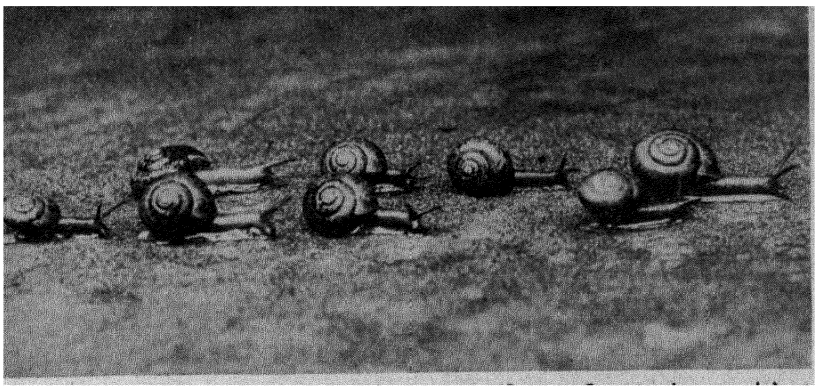


BRACHIOPOD CLAM

was suspected by the first person to describe and name the animals.

One remarkable brachiopod is the lingula. In this creature the shells are held together only by muscles; there is no hinge. The stalk is usually long and passes out between the shells. Its fossils are found in rocks as old as the early Paleozoic era. Such fossils show that the lingula of those days were almost identical in form to the lingula that still lives in the seas at present. For 600 million years they lived in the sea with their ways and characteristics pretty much unchanged. They exist at the bottom of the sea in deep water and live permanently attached to the sea bottom. The long unchanging persistence of the lingula suggests that living forms may exist without any evolution taking place and that such forms may long endure after more highly developed forms have passed away. There are many examples of this in addition to the lingula. In general, they are forms that live in an environment that is least subject to change as geologic time goes on.

One other group of invertebrates that became exceedingly numerous in the Paleozoic seas were the mollusks. These are animals with soft muscular bodies, most of which have solid, limy, external shells. Modern forms include the clams, oysters, snails, periwinkles, squids, cuttlefish, and octopuses. The oldest members of the mollusk group are represented by fossils which appear in the early Cambrian rocks. Such fossils are the shells of small snails. They had a shell that was spiraled into a small cone. These animals increased in number and variety as geologic time

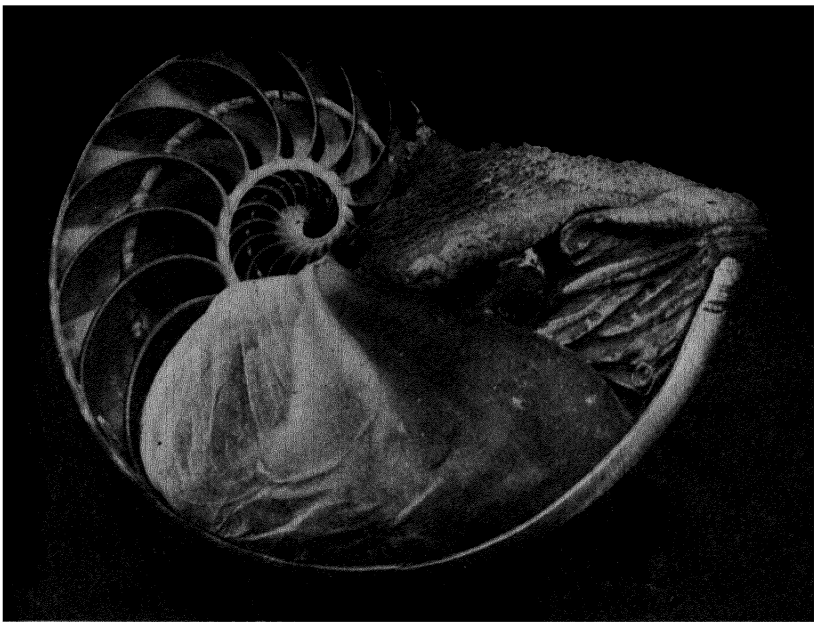


Land snails, showing their method of locomotion. (Science Service photograph.)

went on. Not only are they found today in the sea, but other species are found in fresh water and in damp land areas.

Fossils of other mollusks that are almost as old as the snails are those of the cephalopods. The cephalopods are a group of animals that have had a remarkable geologic history and that justify some acquaintance on the part of anyone interested in the earth's present varied life forms. The cephalopods not only were among the first of the mollusks to appear in the Cambrian seas, but also were for millions of years the most aggressive of all invertebrate creatures. Today they include the largest of invertebrate animals. The most numerous of modern cephalopods are the squids and octopuses, mollusks which no longer grow shells. However, there are a few species in the sea today which have shells and are known as nautilids. It was these shell-bearing types that have made cephalopod history, as well as having inspired Oliver Wendell Holmes to write one of our literary classics, "The Chambered Nautilus."

The shells of the cephalopods are cone-shaped and are divided into chambers. The animal built a new chamber at the end of the cone as it grew larger. After the group became established they increased not only in number but also in size. Fossil shells have been found in middle Paleozoic rocks that are fifteen feet long, a length never reached again by any shelled invertebrate. Later the shells began to be coiled, much as is found in modern nautilids. These coiled cephalopods reached their greatest development in the ammonites. These were large animals that

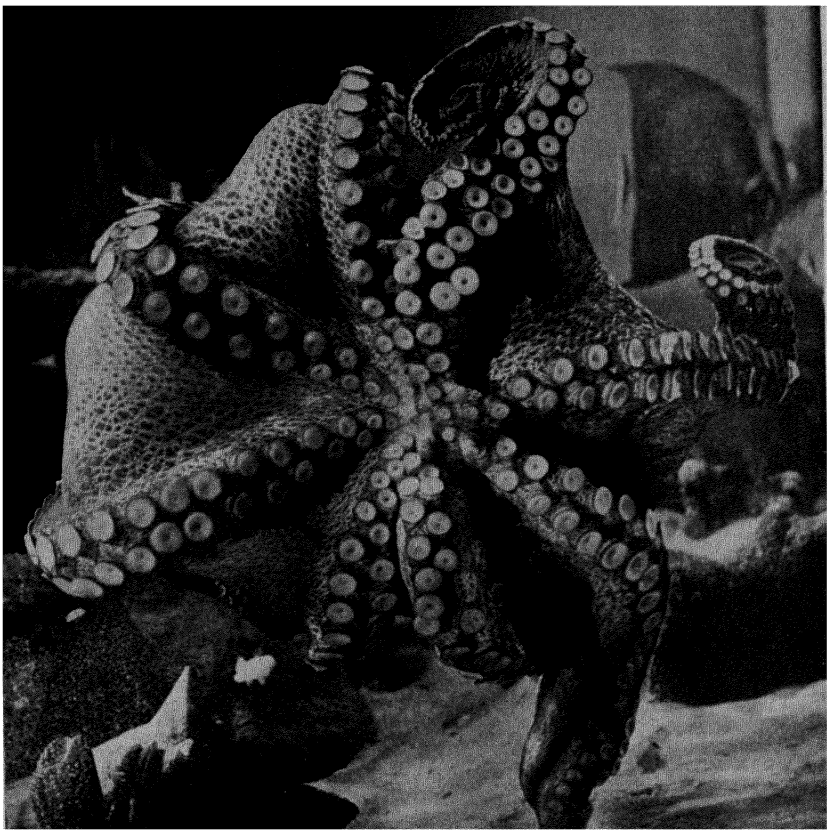


Chambered Nautilus, sectioned to show shell structure and animal living in outer chamber. (American Museum of Natural History photograph.)

developed during the middle Paleozoic and which lived on in large numbers far into the Mesozoic era. During this time they must have been the ruling creatures of invertebrate life in the sea for a hundred million years.

The highest degree of development of the present cephalopods is represented by the squid and octopus. Both of these animals are characterized by an almost complete absence of the original shell so typical of other mollusks. Instead they have developed a strong muscular body entirely devoid of skeletal parts and usually covered with a tough skin. These animals are usually vigorous and aggressive. In the matter of size they include not only the largest mollusks but also the largest living invertebrate animals. While a great many of the species are relatively small, a few attain enormous sizes.

One of the largest squids is the giant squid that lives in the North Atlantic. Sometimes it grows to a total length of over forty feet. One such specimen was recently stranded on the coast of Yorkshire, England. The largest octopus is the giant octopus



Octopus, showing tubular "suckers" along arms, also muscular coiling of arms. (Photograph by Karger, Pix Publishing Company.)

of the Pacific. It grows to a total arm span of about thirty feet. However, the type found in American oceans rarely exceeds a ten-foot span. These animals are popularly thought to be ferocious, and current stories include their attacks on man. Such attacks are usually limited to their onslaughts on fishing boats when they have been netted or otherwise disturbed. Their usual method of resistance to man or large sea animals is flight behind a murky ink cloud, which they secrete from ink sacs, rather than a vicious killing attack.

Dominant Groups

In the Paleozoic era there occurs for the first time a phenomenon that was to continue in some form or other throughout

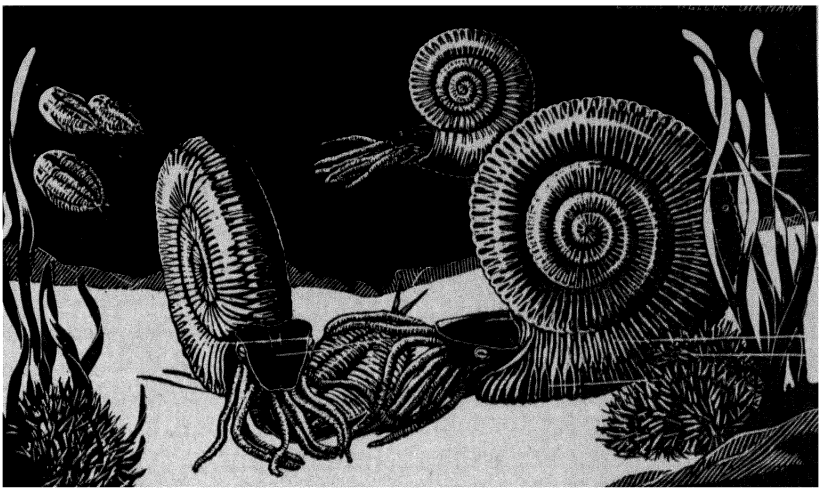
remaining geologic history; that is, a group of animals came into a position of dominance over the rest of living creatures. This may have resulted from certain animals being more highly developed than others or by their existing in much greater numbers.

The first group of creatures to occupy this position were the trilobites. They swarmed in the oceans in great numbers during the Cambrian epoch. They were, as might be said, masters of the seas, at least of the remainder of life in the sea. They have left their shells widely scattered over surfaces that were beneath the sea in Cambrian times. Wherever man has access to such rocks he finds their fossils. The Cambrian epoch is thus referred to as the Age of Trilobites.

The trilobites were curious-looking, segmented animals with their bodies divided into three longitudinal lobes and flattened. The head was covered by a large shield. There was a set of compound eyes, the lenses of which sometimes reached the great number of 30,000 in the two great eyes of the head. The rest of the body had an upper shell, which was segmented, the last few segments often being cemented together to form a tail shield.

These segmented creatures were the most primitive type of jointed animals. Their dominance lasted for a period of about one hundred million years, which is quite an impressive record. They declined after the close of the Cambrian, and became entirely extinct before the end of the Paleozoic era. While it is believed that they gave rise to no other group of animals, they were most like certain arthropods that appeared much later, such as the shrimps, crabs, and lobsters. These are animals with segmented bodies and an outer, segmented skeleton which is shed periodically as the animal grows larger, characteristics that were common to the trilobites.

The Ordovician epoch which followed the Cambrian witnessed the development of another group of creatures that exceeded the trilobites and became the dominant form of invertebrate life. These were the cephalopods. The earlier types developed into the ammonites; these grew large coiled shells, many fossils of which are three feet or more in diameter. The ammonites must have been ferocious-looking creatures. They had a mouth surrounded by many tentacles and two large



The ammonite lived in the end of its coiled shell. These ancient nautilids probably fed on the trilobites, as well as other invertebrates of the Paleozoic and Mesozoic seas.

compound eyes. While we would not ordinarily think of them as building mansions, they did grow compartment shells. The ammonite lived in the end of its shell, building a larger compartment as its body size increased and leaving the outgrown part attached behind. It could probably sink or float by forcing water in or out of these unoccupied compartments on much the same principle as is now used in our submarines.

The earlier cephalopods and later ammonites probably fed upon the trilobites, as they were no doubt aggressive, carnivorous animals. This would explain in part why the dominance of the trilobites vanished. A more highly developed creature had evolved. The struggle for existence in the ancient seas was quickened. Those creatures best fitted to survive increased in numbers and size while the less fortunate ones were reduced to a position of unimportance or became extinct. Such is the way of life.

Since the time of the trilobites and ammonites many different forms of life have developed to dominate the earth for a time. These have in turn given way to higher forms in later geologic periods. Today that position is occupied by the highest form of life ever to develop on the earth. That species is called *Homo sapiens*, wise man.

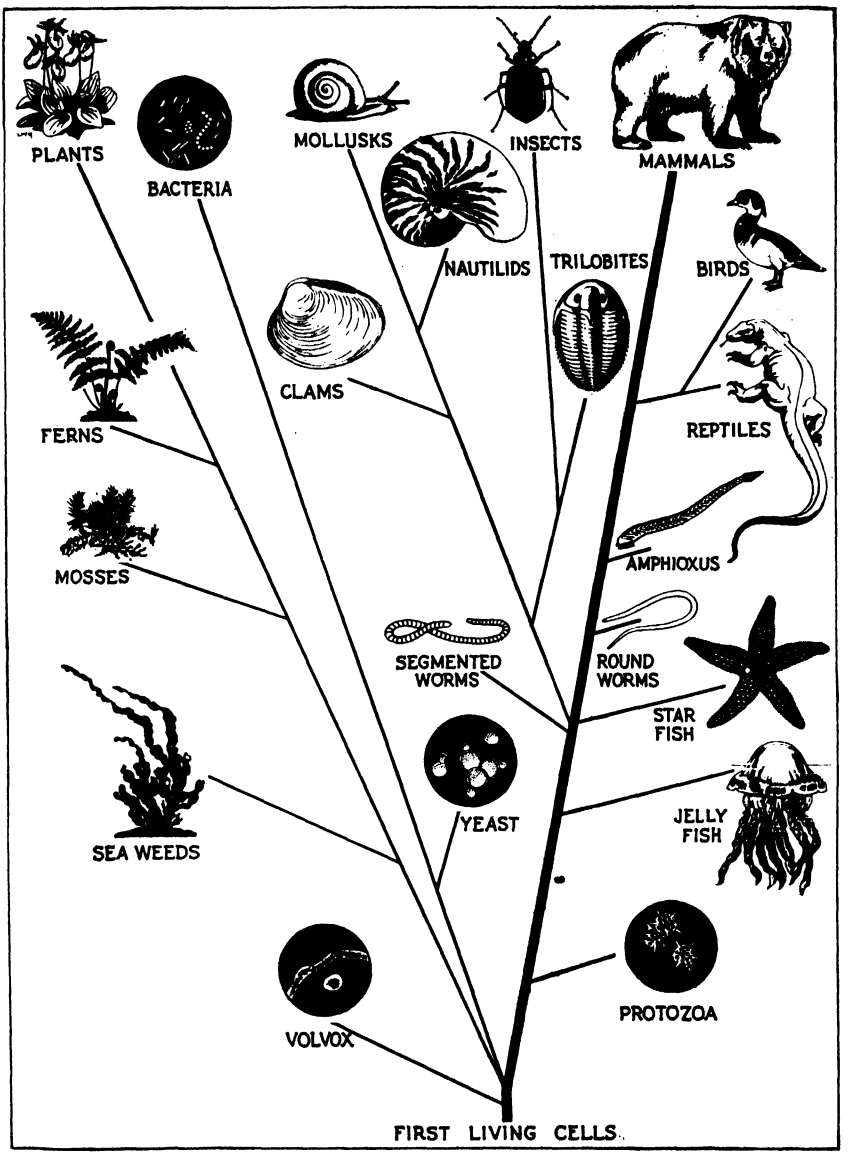
Divergence

The variety of living forms was becoming much more extensive in the seas of the middle and latter epochs of the Paleozoic era. Fossils numbering hundreds of thousand have been found. These show a great number of different kinds of creatures. Also, they show that some of them were more alike than others. There were different kinds of mollusks, different kinds of corals, different kinds of fish. Thus relationships and kinships may be traced. Life was diverging into different species, families, and classes.

When there are a large number of different forms to be considered, it is necessary to classify them into groups for purposes of study. In biological classification the creatures that are most alike in minute details belong to the same species. Thus the domesticated cat is one species of the group of cats. The species that are most nearly alike are placed together in larger groups, called genera; that is, the domesticated cats, the tigers, the lions, and the leopards belong to the same genus. Similar genera make up a family, and all living cats, including lions, lynx, etc., belong to the cat family. Likewise, families that are most similar are arranged in classes. Thus the cat family and all other families of animals that nurse their young from mammary glands belong to the mammal class. Classes which have relatively close resemblances are grouped into phyla. All mammals, birds, and reptiles belong to the vertebrate phylum. Similar phyla constitute kingdoms; that is, all animal life belongs to the animal kingdom.

As an example to show how this works out in naming an animal according to such a classification, consider the domestic cat. The species is *domestica*, and the genus is *Felis*. Therefore, it is classified *Felis domestica*. On the other hand, the Rocky Mountain lion, belonging to the same genus but of different species, is *Felis oregonensis*.

This divergence and classification may be represented by a branching chart which illustrates the relationship of all living plants and animals. In some cases the relationship is close; in other cases it is remote, the same as shown by the small branches or the large limbs on such a diagram.



A branching chart showing the important divisions and relationships of living creatures.

For example, the first great divergence of life led to the plant and animal kingdoms. Since that time almost all living creatures on earth have the characteristics of either plants or animals. In the animal kingdom a later divergence produced the vertebrates

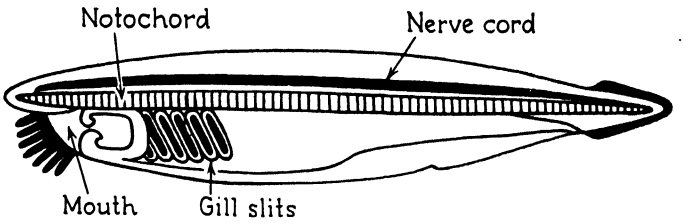
as separated from the invertebrate animals. Within the vertebrates, divergence and change have produced the reptiles, birds, and mammals. Likewise, within the mammal class there are such divergent creatures as mice, pigs, deer, apes, and men.

Early Vertebrate Life

During the Ordovician epoch, or possibly somewhat earlier, there occurred an event of vast importance to life, at least to man. This was the development of backboned creatures, or animals with an internal jointed skeleton. This internal jointed skeleton distinguishes all the animals called "vertebrates" from all the others, called "invertebrates." It is to the vertebrate group that man and all the other higher animals belong. Of all the forms of body structure which have been developed since life began, the vertebrate is the type which is representative of the most complex physical and mental organization.

There is still some uncertainty about just how the backbone was first developed. Fossils of the earliest vertebrates are so scarce that they fail to give any definite clue as to how they originated. The best connecting link between the vertebrates and invertebrates is provided by a few primitive animals living today, classified as the "chordates." These include the acorn worm, tunicates, and amphioxus. They possess certain vertebrate characteristics that are found nowhere else in invertebrate animals. Particularly is this true of the amphioxus.

The amphioxus is a little animal about three inches long that lives in shallow marine waters in all parts of the world. The most distinctive vertebrate characteristic it has is a cartilage-like rod, called the notochord, which runs the length of the body. This, of course, is not a backbone, but it is a stout, flexible axis to which muscles are attached to give support and strength to the body. The notochord is always present in the embryos of true vertebrates, including man. In vertebrate embryos a notochord develops first, then is gradually displaced by the jointed backbone that grows around it. However, in amphioxus and other lower chordates, development stops with the notochord. Another distinctive characteristic of the amphioxus is a tubular nerve cord running the length of the body above the notochord. This is the type and position of the nerve cord found in the



The amphioxus has a notochord running the length of its body and a nerve cord above the notochord.

embryos of all vertebrates. Furthermore, the amphioxus possesses gills that are similar to the aquatic vertebrates, and it has the rudiments of a vertebrate skin.

The amphioxus must not be considered the direct ancestor to the vertebrates. It is a specialized ancient type that has lived on to the present. However, in descending the ladder of the modern vertebrates as far as possible, it is found that the above-mentioned vertebrate characteristics find their rudimentary expressions in these animals. They probably are somewhat similar to the first creatures developing a backbone. Unfortunately, fossil records available at present do not show the actual first steps in the development of backboned creatures.

The first vertebrate fossils are found in rocks dating back to the Ordovician epoch. They were bizarre types which show only a prophecy of modern fishes. The skin was covered with large bony scales, and armor plates covered the head. These oldest known vertebrates were entirely devoid of jaws, the mouth consisting of round openings or a crosswise slit. These "shell-skinned" creatures lived in the seas for about sixty million years but finally became extinct about the middle of the Paleozoic era. However, it is possible that they gave rise to a group of fishes that have endured to the present. These are the jawless fish, which resemble in many respects this ancient armored type. Perhaps the best known of modern jawless fishes is the lamprey eel.

The prophecy of true vertebrates was fulfilled in the Devonian epoch, when the "bony fishes" appeared in great numbers, establishing the ancestors not only to modern fish but also to all land vertebrates. These fishes with the fundamental pattern of vertebrate skeletons quickly divided into the so-called ray-finned type, which comprise most fishes of today, and into a

lobe-finned (or fleshy-finned) type, which gave rise to later land vertebrates and modern lung fish. The waters of the rivers, lakes, and seas were swarming with fish of many different kinds during the latter part of the Devonian epoch, as evidenced by the profusion of fossils they have left. This is so much the case that this epoch is referred to as the Age of Fishes.

Vertebrate Migration to the Land

"As helpless as a fish out of water" is a homely saying that unconciously reveals the difficult but momentous move that vertebrate life made in first coming out of water onto land. Back in Devonian times many kinds of fish developed a sort of primitive lung or air sac in the throat and upper chest region. Thus, they became the first lung fish. This sac was apparently supplied with blood vessels, which could absorb some of the oxygen when the sac was filled with air. The climate of this age must have been such that there was an alternation of wet and dry seasons, much as is found in certain tropical regions today. As the pools and streams became dry or sluggish and refilled again with each succeeding rain, such air sacs were a necessary adjunct for survival. By being able to gulp air, these fishes could exist for a time in stagnant water that was devoid of oxygen.

With the return of more stable climates in the millenniums following the Devonian epoch this rudimentary lung in the ray-finned fishes reverted into a sort of vestige which modern fishes use as a swim bladder. However, the Devonian lobe-finned fishes seemed to have fared better in the use of air-sac lungs. Those sacs developed into true lung tissue, which became divided into two lobes situated toward the upper side of the chest. Thus, air breathing became more efficient. Also, the lobe fins developed a bony structure which shows a remarkable similarity to the leg and arm pattern of land vertebrates. This enabled these creatures to hobble over the mud soil in search of food and more lasting and better water holes. These old air breathers had about declined to extinction by the close of the Paleozoic era, but before disappearing entirely they produced a long line of descendants that have persisted to the present.

Even as archaic as was this first attempt to cross the narrow dividing line between water and land, it was a red-letter period



Diplovertebron was one of the earliest types of amphibians that inhabited the swamps during the Carboniferous epoch.

for the vertebrates. A new habitat for vertebrate life was discovered, and a new vista for backboned creatures was opened.

A Further Venture—Amphibians

Those Devonian lobe-finned creatures that developed the best lungs and legs ventured farther onto the land and became less dependent upon the water for existence. They gave rise to a group of animals known as the amphibians. The first true four-legged land vertebrates were the ancient amphibians. Once the amphibians were established they became common before the close of the Paleozoic era. However, the primitive amphibians were very different from modern forms. They were clad in the armor of their fish ancestors. In many cases the scales of the amphibians were larger and stronger than those of the fish. Their brain cases were in many species covered with thick bones originating in the skin, producing a sort of "armor-headed" creature. These ancient amphibians ranged in size from about two inches to six or eight feet long. The majority of them, however, were small, comparable in size to modern mud puppies and salamanders.

Perhaps the most famous of the early amphibians are the armor-headed type, scientifically called "stegocephalian." The term itself means "mailed head" and refers to the fact that the upper surface of the actual skull was roofed over by thick dermal bones. Their fossils are found widely scattered in the coal measures of the latter Paleozoic era, indicating that they lived extensively in the swamps where the great ferns that later produced our coal beds grew. About ninety different species have been found in North America alone.

The early amphibians retained one fundamental characteristic of the fish; that is, the eggs were laid in the water and the young lived there for a time. Even modern amphibians have never outgrown this characteristic. The amphibian egg is such that it cannot hatch on dry land. In this egg, food and air for the growing embryo are absorbed directly from the water, and carbon dioxide and waste products are thrown out directly into the water. Further, the egg has no protective shell around it to prevent it from drying up or being easily crushed on land. Of course, the embryo in such an egg cannot grow on dry land.

Although very abundant during the late Paleozoic era, the amphibians have now shrunken into insignificance, being represented only by such modern forms as toads, salamanders, newts, mud puppies, and the like. The life cycle of the toad illustrates most of the modern amphibian characteristics. Its eggs are laid and fertilized in the water and develop there without further care from the parents. This is much like the fishes and very unlike the higher vertebrates. The eggs hatch in the water into little animals called "tadpoles" or "polliwogs." They have a round head and a long tail which they wriggle in swimming, as do the fishes. The tadpoles have gills that extend from the sides of the head for water breathing.

In about eight weeks they grow an inside air sack or rudiments of lung similar to the lung fish. Then they undergo a rather complete metamorphosis. Hind legs are grown first, followed by a pair of front legs. The long tail shortens by internal absorption and finally disappears completely. The gills are absorbed or dropped off, and the rudimentary lungs develop into true lungs. Soon the small toad takes to the land, where it lives its adult life. Thus, in a few months at most there is a recapitulation of Paleozoic history that required millions of selections before the early vertebrates crossed the dividing line between water and land.

Hence the amphibians represent the vertebrate animals that made the first great step in moving out onto the land. However, as we have seen, their method of reproduction kept them forever chained to the water. Before the broad reaches of the land could be populated by the vertebrates a new method of egg production had to be developed, or a new method of growing



Modern amphibians; bullfrog and leopard frog. (Photograph by Lynwood M. Chace.)

the young embryo inside the body of the mother had to be evolved. A land type of egg is now laid by reptiles and birds, while growing the embryo inside the body of the mother is the method of mammalian reproduction. The land type of egg historically preceded mammalian reproduction.

The group of vertebrates that first solved the problem of an egg that would hatch on the land was the reptiles. They constitute the animals that finally conquered the land for the vertebrates. After doing so, they were the ruling creatures for millions of years. Their story constitutes a part of the following chapter.

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Bulletin of New York Zoological Society, published by the New York Zoological Society, New York.

This is a bimonthly publication which contains articles on natural history and relating to work carried on at the Zoological Park and the Aquarium. The articles are usually of popular interest and are extensively illustrated.

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A technical journal published monthly. It contains short papers dealing with problems of general interest to biologists in all fields of science.



7: SIZE AND CUNNING

In the Development of Vertebrate Land Life during the Later Geologic Ages

THE largest cannon ever built was a superbombard constructed by the skilled Hungarian gunmaker, Urban, for the Turkish Sultan, Mohammed II, in 1453. It was made of hooped iron and threw a ball weighing 800 pounds. Sixty oxen and two hundred men were required to move it to the walls of Constantinople, which the Sultan had beseiged. The cannon was fired only a few times, as it soon blew to pieces, killing all the attendants. However, the few shots fired so damaged the towers of the Gate of St. Romanus that the gate fell to pieces. A short time later the Turks entered and conquered the walled city.

The largest animals ever to inhabit the earth were the reptiles. These creatures were the first to conquer the land for the vertebrates. Many different species were evolved after the

main stem became firmly established. Some of these species were the mighty dinosaurs. They became in many instances highly specialized, and one specialization was size. This great specialization and large size no doubt contributed somewhat to their undoing, as the dinosaurs have all long since disappeared from the earth. Their majestic rise and dramatic decline was not sudden or within a few years, as was the case of the cannon episode mentioned above, but occupied a period of about a hundred million years during the Mesozoic era.

The mighty reptiles were followed by the mammals. These were a type of vertebrate animal more completely developed physically for rigid land life, and they possessed a larger and better brain. This larger brain enabled them to adapt themselves better to their environment and to live under a great diversity of conditions. They were able to outwit their enemies with a higher degree of cunning and to survive where other creatures perished. With the decline of the dinosaurs the mammals multiplied and developed rapidly. During the Cenozoic era, they became the dominant form of land life and they have held this position to the present day, a period of approximately sixty million years of geologic time.

What Are Reptiles?

There is plenty of confusion when it comes to any accurate determination of the distinction between "Aryans" and "non-Aryans" of the human races. However, the distinction between the reptiles and their nearest of kind, the amphibians on one side and the mammals on the other, is clear and marked; that is, reptiles have certain characteristics that serve to set them apart from other creatures most like them. Their distinctions from the amphibians are significant, as these characteristics finally enabled them to become successful vertebrate land animals where the amphibians failed.

For one thing the reptiles developed a type of egg that could be laid on land. It is not necessary, therefore, for any part of the life span to be spent in the water. One other respect in which the reptiles differed from the amphibians was in the placement of legs for locomotion. Particularly was this true of the larger reptiles that came into prominence during the Mesozoic era.

The amphibian's legs in most cases were widely spread out on the sides of the body. While there was a great diversity in the locomotor adaptation worked out by Mesozoic reptiles as well as by modern forms, one rather efficient type of leg structure was more or less typical of the ancient ruling reptiles. The legs were brought more toward the underneath of the body, and there was an extensive development of the bones and muscles of the hind legs. Speedy locomotion was obtained by running not on all fours but on the hind limbs; that is, most of the great reptiles were bipeds. Furthermore, the reptiles have scales growing from the skin and covering the body, lungs for air breathing, and cold blood.

Growth of a Ruling Class

The ancestry of the reptiles has been traced back to the latter part of the Paleozoic era. In fact, the family tree of the reptiles dates back almost as far as that of the amphibians. One of the most primitive types left its fossils widely scattered in the deposits of the great coal swamps of the Carboniferous epoch, where it must have lived beside the early amphibians of those times. It has been called *Seymouria* after a town in Texas where its remains were first found. Its broad mouth and short sprawling legs are very similar to those of the primitive amphibians, to which it was no doubt closely related.

From such archaic stem types thousands of different kinds of reptiles developed during the Mesozoic era. The reptiles that were the most successful and grew to the largest sizes were the dinosaurs. The earliest dinosaurs made their appearance in the early part of the Mesozoic era, and by the time of the Jurassic epoch they had come into a position of complete dominance of the remainder of land life. They were apparently widespread over much of the earth, as evidenced by their fossils and footprints. At the present time their fossils usually constitute the most impressive display in any museum of natural history. Most of these great dinosaur fossils have come from a single formation of deposits that extends from Montana to New Mexico and from Kansas to Utah. This is the area, it may be recalled, that was covered by shallow inland seas or great low plains and swamps during the warm and humid Jurassic and Cretaceous epochs.



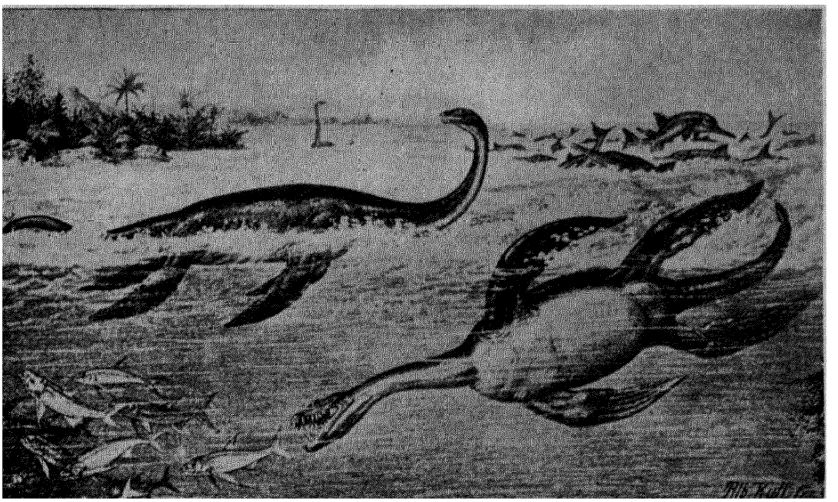
Seymouria was one of the most primitive of known reptiles. (Drawn from restoration by L. I. Price.)

The dinosaurs may be divided roughly into two main groups, based upon the size and shape of the pelvic bone. In the first group the pelvis is shaped like that found in crocodiles and lizards today. In the other group the pelvis is bird-like in character. Reptiles of the first group were almost all carnivorous, or flesh-eating, with the exception of the giant *Brontosaurus* ("thunder saurian"); while those of the second group were all herbivorous, or plant-eating.

One of the first general type of the flesh eaters was the "near lizard." It was a primitive dinosaur with a light body, long neck, and long tail. From this type probably developed later all the great carnivorous dinosaurs, most of which were bipeds with strong hind limbs.

One of these bipeds, common in Montana, Utah, and Wyoming during the Cretaceous epoch, was the king-tyrant reptile, called Tyrannosaurus. It had a height of about twenty feet, and its weight exceeded that of an elephant. It ran on two powerful hind legs. The front ones were small, usually short, and were probably used for grasping prey. The tyrant reptile had a large head on a powerful neck. The jaws reached four feet long and were equipped with numerous saber-like teeth. No other animal has ever had a fiercer biting head. The Tyrannosaurus had a length of about fifty feet. In speed, ferocity, and size it has been referred to as the "most destructive life engine ever evolved."

Some of the carnivorous reptiles tended to take to a water-dwelling life, much as do the crocodiles of today. They, of course, abandoned their bipedal habits and developed limbs suitable for water locomotion. Such were the ancient crocodiles and plesiosaurs. They were common inhabitants of shallow seas during the



Restoration of plesiosaurus as they probably inhabited the shallow seas of Kansas during the Cretaceous epoch. In the background is seen an ichthyosaur, a marine reptile, leaping above the water. (American Museum of Natural History photograph of painting by Kull.)

Jurassic epoch, and their fossils are world wide in their distribution.

The plesiosaur must have been a weird-looking monster, growing to a maximum length of forty feet in many instances. It had an exceedingly long neck and small head. The body proper was short, broad, and box-shaped and to it were attached four powerfully developed short limbs. The fingers and toes were entirely covered with a tough skin, which gave them a somewhat paddle or rudder-like appearance. The long necks of the plesiosaurs probably served them well in swiftly darting the head through the water to catch the fish on which they fed. The plesiosaurs along with the ichthyosaurs, another water-dwelling reptile, probably made troublesome times for the fish in these ancient seas. These reptiles, of course, had lungs instead of gills and had to keep their heads above the water when breathing.

Another variation of the flesh-eating reptiles were the flying dragons of the air, known as "pterodactyls." They were biped reptiles in which the front legs or arms took on a special adaptation; that is, one of the fingers grew exceedingly long and stout. It was covered with a broad flap of leather-like skin that extended along the arm and back to the thigh region. This flap of

skin constituted the wing. The skin was practically naked and contained no feathers. Such a wing was probably a fairly efficient flying mechanism, similar to that possessed by bats of today.

These highly carnivorous flying reptiles were somewhat bird-like in appearance. However, they are not to be confused with the birds. Their bodies were covered with reptilian scales, and there was an absence of feathers. The largest ones had a wing spread of about twenty-five feet. Many of them had a long beak armed with sharp teeth. Judging from their skeletons, their bodies must have been of small and light construction, a sort of an appendage to support the long beak and the two large wings. These aerial reptiles must have fed mostly on small fish, which they probably caught by diving as marine birds do today. The hind legs and feet were poorly developed, and it is likely that walking or standing was a slow and cumbersome task for them. No doubt they spent most of their time soaring over the shallow seas or near-by lands. Their fossils are numerous, and they apparently were a common form of reptilian life during the Jurassic epoch.

The flying reptiles might be called the organic airplanes of the Mesozoic era. It is said that Langley, from a study of their fossils as well as modern soaring birds such as the albatross, obtained ideas for his invention of the first flying machine.

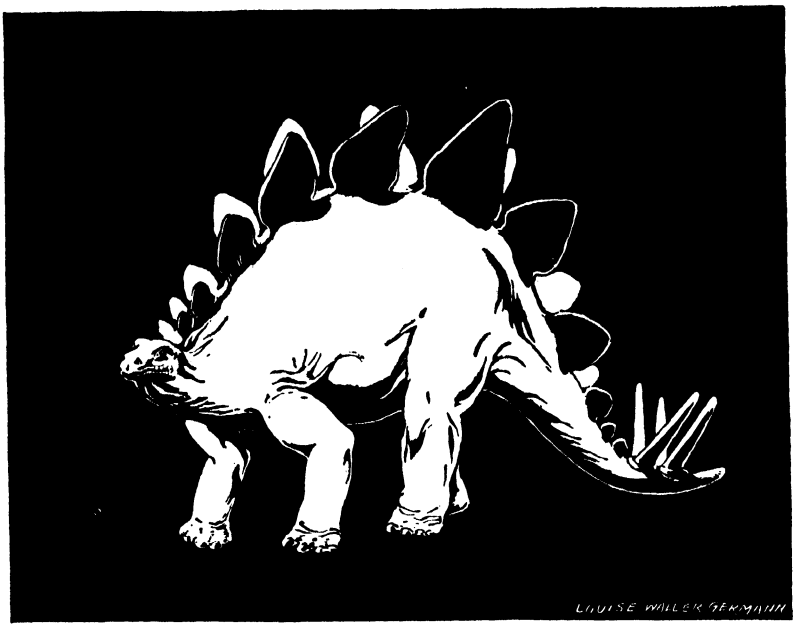
One dinosaur that varied considerably from the flesh-eating biped type yet retained the same kind of hip bones was the Brontosaurus. These are the dinosaurs commonly pictured in modern advertisements. Their teeth show that they changed to a plant diet, and their bodies became considerably bulkier. With a lessened need for speed, they slumped back into a four-foot method of walking. They reached the peak of their development during the Jurassic epoch. The greatest of these were the largest animals ever to live on the earth. They grew to a length of about 80 feet and weighed something like 40 tons. These huge creatures had massive hind legs very much like large weight-bearing columns. The backbone was constructed in a great arch to support the animal's bulk. The neck was long and terminated in a small head. The tail usually measured about one-third the total body length.

The head seems absurdly small when compared to the rest of the body. The jaws were weak and short, and the animals probably fed on the soft water plants of the swamps in which they lived. The nostrils were at the top of the skull, indicating that these giant reptiles spent most of their time in the water. They could breathe and see with only the top of the head exposed above the surface, and the water helped support their great weight. The brain was excessively small in proportion to the body size. However, there was an enlargement of the spinal cord between the hips that constituted a sort of hindbrain that was about twenty times larger than the one in the head. This hindbrain probably controlled most of the body functions and the animal's motions. Someone has said that they had more sense in their hips than in their heads. But without doubt these ponderous creatures had little intelligence either in the brain in the head or in the one above the hips.

These giant reptiles attained a world-wide distribution. They are well known from fossils that have been found in as widely separated areas as the United States, East Africa, western Argentina, and Germany.

The Great Vegetarians

The other large group of Mesozoic reptiles were those which possessed the bird-like pelvis and all of which were plant eaters. Some of them were bipeds while others walked on all four feet. One was a bizarre type of heavy-limbed four-footed dinosaur. These creatures fed on leaves and twigs. They were the plated and armored types, known as the armored Stegosaurus. They appear to have lived completely away from the water on the uplands. They specialized in the production of an elaborate bony structure as an outgrowth of the skin, which could be used for protection or as a weapon against their enemies. A double row of bony plates extended down the back from the head to the tail. Over the hips these plates were some two feet high, two and a half feet wide, and about four inches thick at the base. The tail was covered with sharp spines that grew to a length of about two feet. These sharp spines must have been their chief weapons of

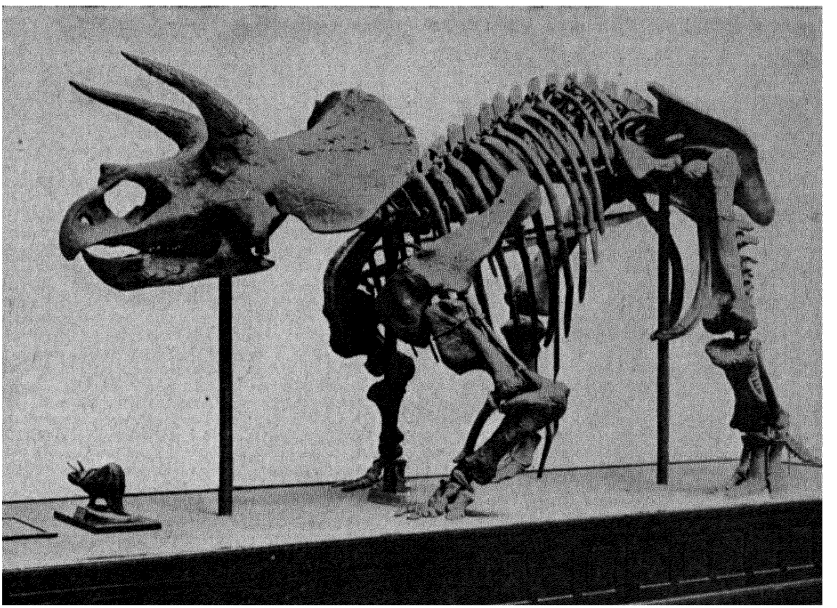


The armored Stegosaurus had a double row of bony plates down the back and sharp spines on the tail.

offense. With a slashing motion of the tail, they became a sort of multiheaded spear. The small head attached to the ponderous 20-foot body added to its unusual appearance but probably not much to its intelligence.

There was the weird-looking horned type of plant-eating dinosaur known as Triceratops. It had three prominent horns about four feet in length, the cores of bone being covered with a sheath of horn. From the back of the skull there extended a broad frill of bone that formed an armored plate over the neck and shoulders, in some cases exceeding eight feet in length. The total head was large, being about one-third the entire body. However, this large size was made up mostly of bony armor rather than brain cavity. The brain weighed less than two pounds out of the total body weight of ten tons.

The horned Triceratops must have been great fighters in their time, as judged by the dints of deep wounds found on many of the fossil skeletons. The animals probably charged as does a rhinoceros, head on, and, with a sweeping uplift of the powerful



A horned Triceratops skeleton and miniature reconstructed model on exhibit at the United States National Museum. (Science Service photograph.)

head, he forced the great horns against or through the impaled enemy, not unlike the legendary exploits of King Arthur's armored knights.

Thus the reptiles reached an extensive and varied stage of development. As we have seen, the climatic and physical conditions of the earth were favorable to reptilian development during the Mesozoic era. They became exceedingly numerous in species as well as in numbers. For a period of approximately one hundred million years they were the mighty rulers of the land and lords of the air and to some extent masters of life in the inland seas as well. This era has appropriately been called the Age of Reptiles. However, when the Rocky Mountain revolution began at the end of the Mesozoic era their death knell was sounded. The rising mountains obliterated the inland seas and the great swamps, and there was a marked reduction in temperature that followed the rising mountains. Even local glaciers began to appear. These changes foretold the end of a great era. No cold-blooded creatures of the size and habits of the dinosaurs could withstand cold winters. Their ranks were thinned rapidly,

geologically speaking. By the end of the Mesozoic era they had all disappeared from the earth.

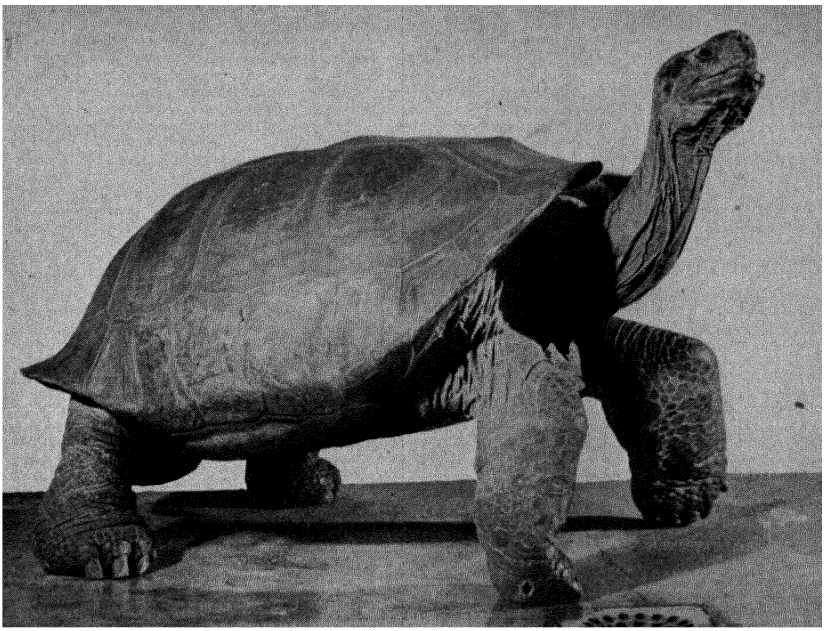
Descendants of a Dynasty

Some reptilian groups have had less spectacular careers than the ruling reptiles. However, they have been successful in surviving to the present time, and their descendants still hold on in the struggle for existence. They were the less specialized types that culminated in modern reptiles. These living forms include generally the lizards, snakes, turtles, and crocodiles.

The lizards are the most abundant of living reptiles. They are found in the tropical and warmer temperate regions of all lands. They have generally retained the primitive sprawling type of walking. The limbs, however, are usually light, and some lizards are able to run swiftly. Some species, when rapid motion is necessary, rise on their hind legs and, balancing the body with the tail, run with great rapidity. The body is covered with scales. Most lizards are small; however, in the East Indies and Australia there are monitor lizards that grow to a length of about twelve feet.

The snakes are a development from the original lizard stock. They probably are the most evolved and progressive of modern reptiles. Snakes have lost their legs entirely and depend upon a sinuous twisting of the body for locomotion. The scales are so placed on the snake as to prevent any backward slip as it twists its body, but they offer no hindrance to a forward motion. One remarkable characteristic of the snakes is the structure of the skull. It has been greatly modified from that of the ancient reptiles. The two jaw halves are loosely connected so that they may be stretched far apart. The snake is, therefore, able to swallow larger animals. A snake a few feet long can swallow a rabbit and digest it at its leisure. The python and some other tropical snakes are able to swallow a good-sized pig or even an animal as large as a man.

Snakes and lizards have proved themselves very useful to man. They generally feed upon insects and small mammals, such as mice and rats, which often prove very destructive to man's cultivated food plants and stored grain. The natural food and prey of the lizards and snakes are, then, man's troublesome



Giant tortoise is a land turtle that grows a shell about four feet long, and weighs about six hundred pounds. (Photograph by Ewing Galloway.)

enemies. Most snakes as well as lizards are quite harmless, and to spare them rather than to destroy them is to add to our own general welfare.

The turtles are structurally the most remarkable of the living reptiles. Their most obvious characteristic is the shell. It has had a profound effect upon the architecture of the body and served to keep all the turtles pretty much alike. The shell consists of two halves, an upper one and a lower one, firmly united at the sides but widely separated at the front and behind to accommodate the head, tail, and legs. The ribs as well as part of the vertebral column are attached to the upper plate. The ribs are, therefore, immovable, and the great back muscles characteristic of other vertebrates have been lost. The nonflexible ribs have necessitated the development of a different method of breathing from that of most other vertebrates. This is accomplished by a system of bones, the hyoid apparatus, which compresses and dilates the throat and roof of the mouth and thus forces air into and out of the lungs.

Each half of the bony shell is overlaid with horny plates, which have the same general arrangement as the bones but do not correspond with them. These plates are not shed periodically, as are most reptilian scales, but they grow larger as the animal grows older to correspond to the increase in size. These plates increase in size by adding a sort of outer ring each year. By counting the rings on the plates, it is sometimes possible to get a rough measure of the turtle's age.

The largest of all modern turtles are the luths or leathery turtles. The oldest ones reach a total length of eight feet and weigh nearly a ton. Another large species is the giant tortoise, which was once common around the Galápagos Islands, but now has been about destroyed by man. Some grow a shell about four feet long and weigh about six hundred pounds. However, most turtles seen away from the seashore and larger rivers are small creatures. They usually feed on animal life such as snails, insects, or small fish and are quite harmless to man.

Crocodiles, too, have quite an ancient lineage. Their fossil ancestors can be traced back to the dinosaurs. All of them are semiaquatic, feeding and passing most of their time in the water. However, they frequently come ashore to eat, and they are capable of making long journeys overland in search of water holes in time of drought. They, of course, lay their eggs on land, usually in sand or soft clay, to be hatched by the sun's heat.

Adaptation to a water habitat has brought about a peculiar and special structure of the breathing apparatus. The nostrils open through a sort of dome on top of the snout. Separate tubes lead from these nostrils along the roof of the mouth down to the base of the throat. In this way a continuous passage is formed from the nostrils to the windpipe, an arrangement which enables the crocodile to drown its prey while still able to breathe itself. The eyes are on top of the head, and the animal can lie in the water with only its eyes and nostrils exposed.

Crocodiles have within their ranks the largest living reptiles. The largest species is the salt-water crocodile. Some of them probably grow twenty feet long. The average length of most other species, however, is from four to ten feet long. Most crocodiles and alligators usually lie quietly in the water, with only the eyes and nostrils and perhaps a part of the back show-

ing, and look like floating logs. They usually feed on fish, but any unwary bird or beast approaching within range of the powerful jaws may be seized, dragged under water, and eaten. They undoubtedly will attack man, but as a rule they recognize him as an archenemy and in his presence become cautious and difficult to approach.

Early Birds

The group of animals living on the earth at present in largest numbers that are most like the great reptiles of the past are the birds. They have been called by an early writer "glorified reptiles." Furthermore, it has been often stated that almost every feature of their body structure, other than feathers and warm blood, can be matched in some dinosaur type. It is generally agreed that the birds, while exceedingly unlike the dinosaurs in appearance, are descended directly from the types of animals that produced the ruling Mesozoic reptiles. The modifications which they worked out proved effective for existence through the Cenozoic era and to the present.

The pelvis in the bird skeleton is the kind found in the great herbivorous dinosaurs. The three toes common to most birds were also characteristic of many of these dinosaurs; the ankle bones are similar and are quite different from those of mammals. The type of egg developed by the dinosaurs has not only been retained by modern reptiles but by birds as well. The wings of modern birds possess no claws, but these have been lost by a fusion of some of the finger bones to form better wing supports. The breastbone is well developed in the birds in contrast to smaller ones in the dinosaurs. This seems to be a modification that was made as flight developed, since the breastbone serves as an attachment for the strong wing muscles in modern flying birds.

The earliest fossil bird known is one called by the imposing name of Archaeopteryx. Incidentally this term is derived from the Greek language and means "ancient wing." It was found in limestone deposits of Germany belonging to the Jurassic epoch. The features are so well preserved that it seems as if the creature had come flying out of the Mesozoic past into the present. Had not the imprints of feathers been so clearly preserved, it might

have been easily judged a small dinosaur. It had a long tail, three toes on each foot, claws on the arms, and teeth in the jaws. The breastbone was small, indicating weak flying muscles. However, there were long feathers on the sides of the tail and the arms and shorter ones over parts of the body. Feathers in modern birds are known to be a modification of reptilian scales. It is likely that the feathers developed by this ancient bird provided it with some measure of flight and retained for the creature some of its body warmth.

The next glimpse we get of developing bird life is from fossils found in Kansas belonging to the late Mesozoic. These are for the most part remains of large reptilian water birds, known as the "regal western bird." Some of these skeletons measured six feet in length and about five feet tall. The wings indicate that these birds had lost the power of flight and apparently spent most of their time in the water. Also found there are some fossils of smaller birds, much like those of modern gulls, with powerful wings. In both types teeth were present in long jaws that took on the appearance of beaks. The tails had become much shorter than that of the archaeopteryx, and the feathers grew much as in modern birds.

By the beginning of the Cenozoic era teeth had been lost, and a horny beak is common to most well-preserved fossils. Many of the present families of birds had become established, and it is not unlikely that bird life generally presented much the same picture as it does today.

Warm Blood for Cold

Such then is the story, briefly told, of an important group of vertebrates that once extensively inhabited the earth and their modern descendants. Now the ruling reptiles have gone, leaving in their place the mammals as earth's dominant form of land life. The warm-blooded mammals have a higher and more complex form of bodily development than the cold-blooded reptiles. They were able to endure and progress where the great reptiles perished.

One species of mammals is modern man, whose majestic development has far exceeded that of any other form of life ever to exist upon the earth. It is a long story in both time and

development from the earliest mammals to man. However, it is a story that is becoming increasingly better known. Its unfolding reveals a slow and ever-changing evolution throughout a history of many millions of years and accounts for many of the forms of mammal life we know today as well as an exceedingly large number of extinct ones the remains of which are buried in the fossils of rocks.

Special Characteristics of Mammals

It is not uncommon to see a squirrel or cottontail or many other kinds of wild mammals during even the severest of our winters. At such times a snake or turtle is rarely encountered. Instead, they are inactively secluded in some protected spot. These activities are indicative of one fundamental difference between mammals and reptiles. Mammals have warm blood; that is, a high body temperature is maintained regardless of the temperature of the surrounding air. This is not true of the reptiles, as they have no mechanisms to regulate the temperature of their bodies. Accordingly, mammals can remain active in cold weather and inhabit polar as well as milder climates; reptiles cannot. A covering of hair on the skin of most mammals aids in conserving the body heat, while the functioning of sweat glands serves to cool the body during periods when the surrounding air is hot.

The name of the group, mammals, signifies one of their characteristics; that is, mammals nurse their young. The mammary glands are a well-developed mechanism for supplying nourishment to the young during postnatal care. Such features have never existed in the reptilian body, and reptiles rarely manifest any care of their young. Furthermore, in mammals the fertilized egg and growing embryo are retained and nourished inside the body of the mother. This constitutes a more complex body structure and a more efficient form of reproduction than any other group of animals has ever developed.

The brain of mammals, even the most stupid of them, is enlarged enormously over that of reptiles. However, the enlargement has occurred mainly in one particular part of the brain, the cerebrum. The cerebral hemispheres are the seat of the higher mental processes while the other parts of the brain serve

as the automatic control of bodily functions. Within the cerebral hemispheres are the centers of learning that have placed the mammals as a group far above any other vertebrate stock in their degree of mental functions.

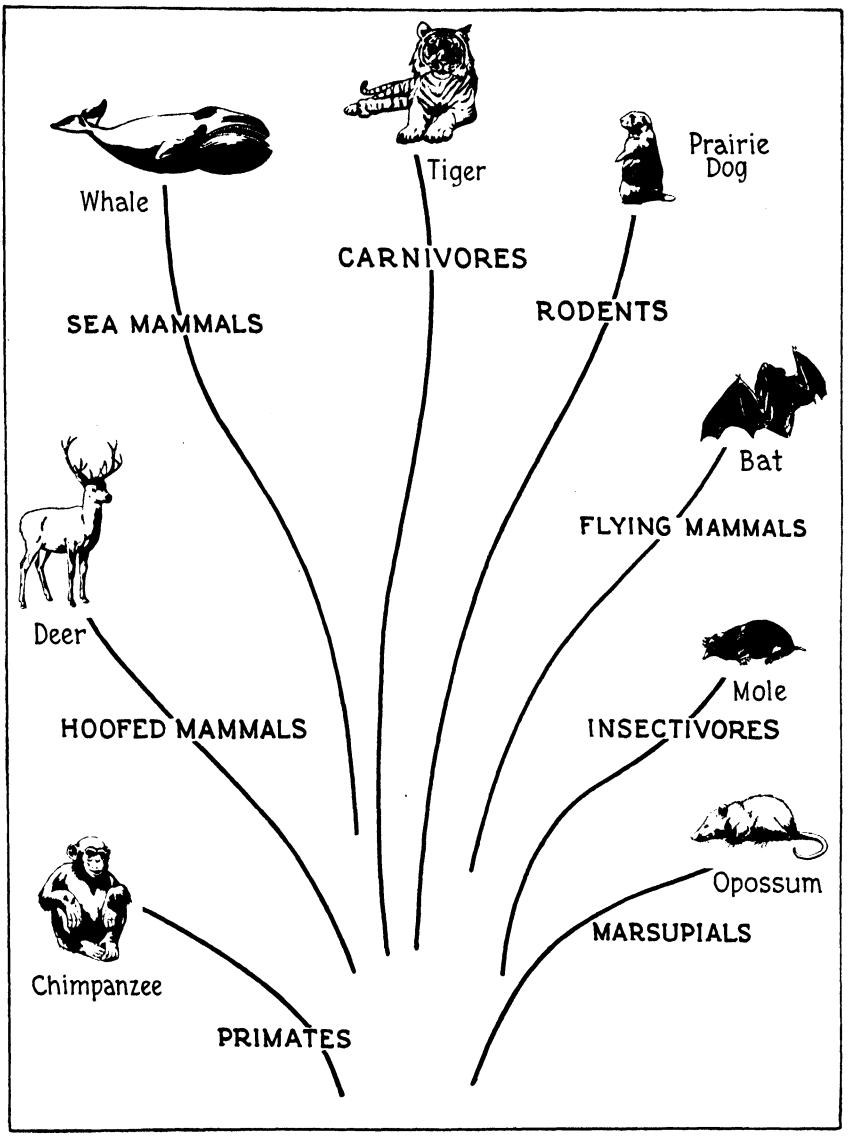
The method of walking employed by most mammals has given them ease in movement and made them fleet of foot. The four legs in most cases have been retained. However, they have been brought around directly beneath the body, the knees bend forward, and the elbows swung backward, thus permitting a more rapid and a more perfect gait.

Geologic Development of Mammals

It is a mistake to imagine that the mammals evolved from the highly developed dinosaurs. The stem from which mammals sprang was one of the first to diverge from the primitive reptile stock. The first mammals appeared almost as early as the first reptiles.

Fossils of creatures that are mostly reptile but have some mammalian characteristics are found in rocks dating back to the very beginning of Mesozoic time. These are the dog-toothed reptiles, known as "cynodonts." Their fossils have been found mainly in South Africa; however, a few scattered remains have been found in Triassic coal beds of North Carolina. Many authorities are of the opinion that they were either the ancestors of the mammals or were close to the original mammalian stock. They possessed the specialized dentition of mammals, having the teeth divided into incisors, canines, and molars rather than the unspecialized teeth of reptiles. The skull was intermediate between that of reptiles and mammals. In the roof of the mouth a secondary plate had developed, just as mammals have. Other skeletal features are midway between mammals and reptiles. It is difficult to classify this creature as either reptile or mammal. It shows that the original ancestors of these two great groups of vertebrates were very similar.

Even while the great dinosaurs were dominant there is evidence that there were in existence some small, more active, somewhat warm-blooded creatures about the size of rats or cats, possibly descendants of the earlier cynodonts. Fossils of the



Simplified chart showing important groups of modern mammals.

Jurassic epoch from Germany, Mongolia, South Africa, and North America show that these mammals had sharp teeth; however, they were too small to attack the dinosaurs. Their brains were larger than the reptiles in proportion to their body size. They had some features which indicate a tree-dwelling life. They

most likely were nocturnal in habit, in order to escape the carnivorous dinosaurs during the day.

The threat of death from the great carnivorous reptiles lay constantly over the early small mammals. This probably had much to do in determining the survival of these creatures, which had developed a higher degree of cunning, a greater ability to move more rapidly, and the adaptability to move around in cold weather, when the reptiles were inactive. As a result, after the close of the Mesozoic era, when the reptiles declined, the mammals developed rapidly and during the Cenozoic era they took the leading place in the drama of evolution.

The fossil records show that as mammals progressed, they branched out into all sorts of habitats and developed many specialized features of body structure. As a result there arose such diversified creatures as the carnivores and the herbivores and such opposites as mammals with hoofs and mammals with claws, mammals with swimming limbs and those with flying limbs, mammals both large and small.

Golden Age of Mammals

The Cenozoic is known as the Age of Mammals. This geologic age began about sixty million years ago and extended down through the last great glaciers about twenty thousand years ago. The mammals of the early Cenozoic were archaic in form and differed greatly in appearance from modern creatures. However, with the beginning of the Miocene epoch, itself sometimes called the Golden Age of Mammals, thousands of forms much like present-day creatures began to appear. There are present on the earth now over twenty thousand different species of mammals. The remains of more than this number of extinct forms have been discovered in the fossil rocks.

It is obvious that only a thumbnail sketch of the more important groups can be presented here. For this general consideration let us take brief note of the hoofed mammals, the carnivores, and the primates. For those interested in more detail some of the other orders of mammals are represented in the accompanying chart.

Mammals with Hoofs—the Ungulates

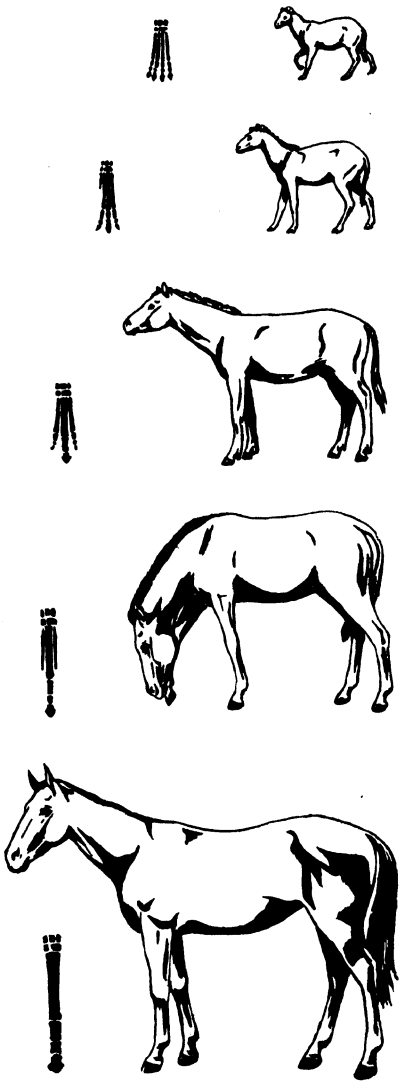
Of the hoofed mammals one of the early exceedingly specialized forms to develop were the giant creatures known as "titanotheres." They first appeared as small animals about the size of dogs in the early Cenozoic. Before the middle of the era they had attained the size of elephants and were widely distributed in North America. They were heavy in body, with four columnar legs and feet supported on thick pads. In the earlier ones the heads were long and narrow and devoid of horns. However, as the animal later developed into greater size, knobs grew over the eyes. As time went on the knobs shifted forward and grew into enormous proportions. They were situated on the nose, the head becoming broad and massive in proportion. The horns must have been used as powerful weapons. However, the brain was comparatively small. This indicates that the great beasts were stupid but large, probably even surpassing the modern rhinoceros in this respect. They rather suddenly disappeared from the earth—another illustration of the failure of great body size.

In contrast with the titanotheres, the evolution of the horse has shown a steady and progressive development. Their ancestry has been traced back to the very beginning of the Cenozoic, and their descendants are common on the earth today. Their family tree is one of the best known of all animal creatures, and it constitutes an unbroken lineage of over fifty million years.

The first record in North America is of a small four-toed "dawn horse," *Eohippus*, that was a graceful little creature no larger than a dog. These horses swarmed in the forests and lower plains. In the Miocene epoch they had increased some in size, lost one toe, so that they walked on three toes, and were rapidly becoming roaming grazers on the uplands. Toward the latter part of the Cenozoic, the horses had progressed to a larger and swifter animal, running on one toe that had become greatly developed as the others shrunk to insignificant appendages. They belonged to the genus *Equus*, which is the one including all modern horses.

The fossil remains of horses are found widely scattered over the continents of the Americas, Europe, Asia, and Africa. They

have migrated into all climates and adapted themselves to a wide variety of environments. In this respect they have had but two equals, elephants and man. The brain of the modern horse is large and convoluted, and its evolutionary development kept pace with other body changes. The intelligence of the modern horse is notable, as well as is its emotional disposition. This emotional instability is probably an inherited characteristic growing from a long history of rapid flight as a method of protection or escape from danger.



The development of the horse from the small, four-toed Eohippus to the modern one-toed Equus constitutes a well-known lineage of over fifty million years.

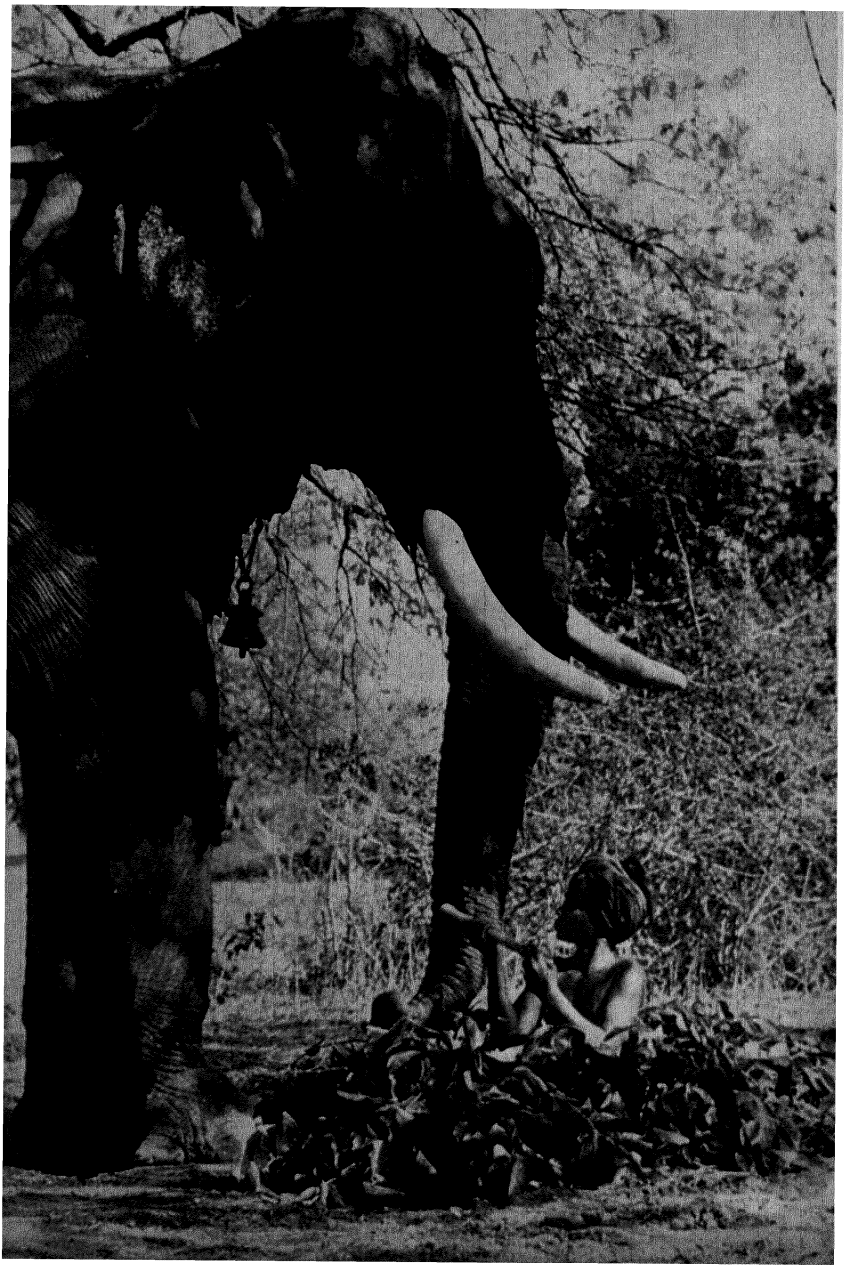
The elephants belong to a group of the ungulates that have developed a proboscis; that is, they are mammals with a trunk. During the middle and latter Cenozoic they were among the most widespread of the mammals. However, they are distinctly on the wane today. The first ancestors to a long and distinguished line made their appearance in the early Cenozoic. Their fossils were left in the delta deposits of the Nile, an area where the proboscidians are believed to have originated. The earliest ones possessed no tusks. Also, they were no larger than a good-size dog or pig. From such creatures the true elephant-like or mastodon stock developed, and they migrated rapidly into Europe and Asia. At a later time they invaded North America,



A remarkable picture of a full-grown African male elephant made in his native haunts in the Belgian Congo. (Globe photograph taken in Africa by Dorein Leigh.)

probably by way of Siberia and Alaska. They became exceedingly numerous here until within ten to twenty thousand years of modern times.

Many kinds of elephants or mastodon have lived on the earth. One was the "woolly mammoth" that lived at or near the ice fronts during glacial times. Some specimens have recently been found frozen in the ice sheets of Siberia. No doubt the unlucky animals fell into great crevices of the ice some twenty to thirty thousand years ago. They were, of course, quickly frozen, and in such condition their bodies have been preserved to the present time. This is a record for long-time refrigeration. These specimens not only show the skeletal parts, but skin, hair, tissue structure, and undigested food contents of the stomach as well.



Photograph of "Iravatha", said to be the largest male elephant in Southern India, and a twelve year old Indian lad. This picture was made in India during the filming of the motion picture "Elephant Boy". (Life Magazine photograph.)

One such specimen has been carefully removed to the Leningrad Museum in Russia, where it is now on exhibition.

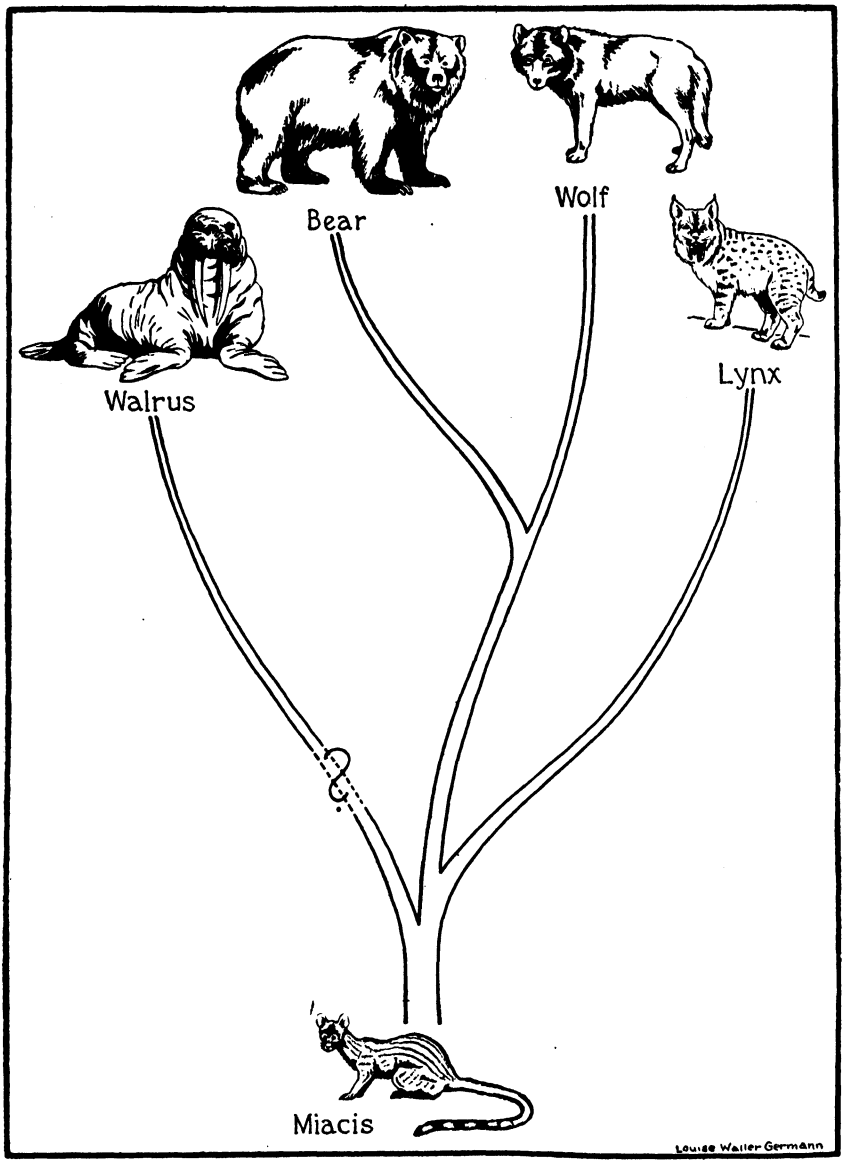
The "imperial mammoth" roamed the plains of the Western and Southwestern United States. It grew to large size, measuring some fifteen feet in height. Fossil remains of this great elephant together with its smaller relatives have been found scattered from Florida to Alaska, from Connecticut to California, as well as in South America, Europe, Asia, and Africa. The proboscidians have, therefore, been world travelers, equaled only by the horses and exceeded only by man.

Only two species of elephants remain on the earth at present. These are the Indian elephant and the African elephant. The Indian elephants usually stand about eight to nine feet tall, have tusks about three to six feet long, and have ears somewhat smaller than the African elephant. The African elephant, like its earliest ancestor, is exclusively an inhabitant of that continent. It grows to a height of about ten feet, with tusks eight to twelve feet long, and the males have exceedingly large ears.

The Carnivores

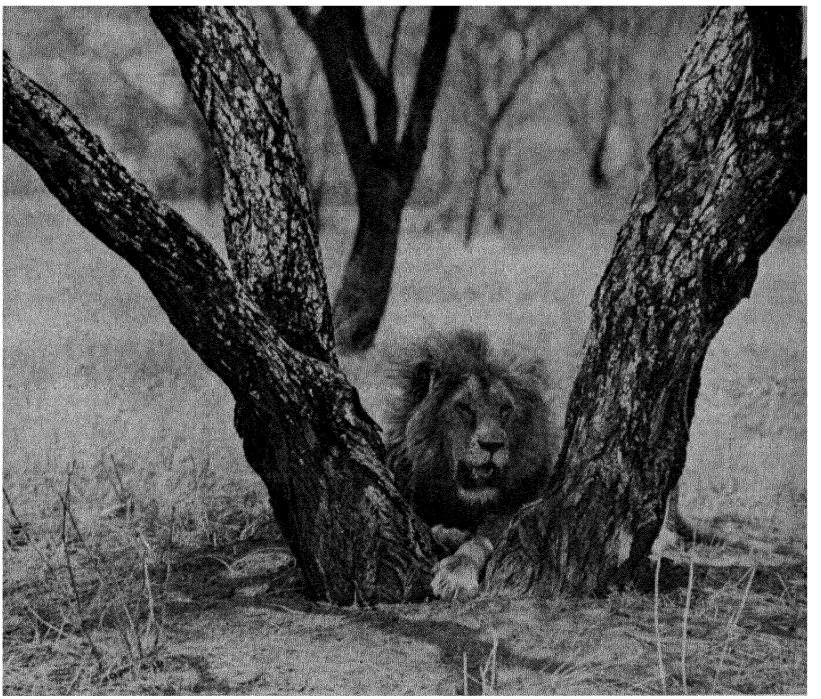
Of the carnivorous or flesh-eating mammals, there is a great variety of different forms. Their development and modern progeny can be traced here only in brief outline. They arose from the small creatures that were in existence during the reign of the great reptiles and probably fed on insects, grubs, and berries. As the dinosaurs declined and disappeared, they increased rapidly, feeding upon plant-eating mammals that developed along with them. A still later diversification of the archaic "insect eaters" led in one direction toward the hunters and strictly flesh eaters, and in another direction toward the arboreal dwellers that fed on a mixed diet. These latter ones gave rise eventually to the primates, the group to which man belongs.

The various strictly flesh-eating mammals of the early Cenozoic are usually referred to as "creodonts." They had feet on which the appendages grew claws rather than hoofs, and the teeth were more highly specialized. The front teeth, the incisors, became sharp and even for cutting and tearing, while the canines, or "dog teeth," were long and pointed, making them effective in stabbing their prey once it was in the mouth. The



Simplified chart representing development and relationship of modern carnivores.

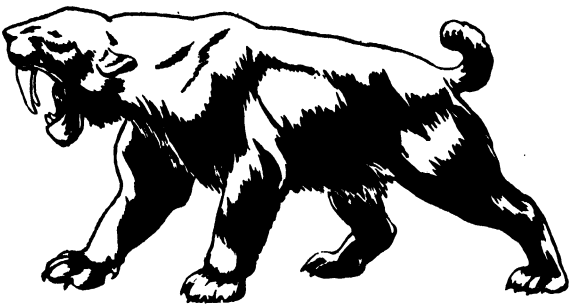
earliest such creodont was an animal known as Miacis, which was a small but likely a progressive cat-like creature. Some of the later types are comparable in size and general appearance to modern weasels, some to wolves, and some to tigers or lions.



An intimate and artistic photograph of a wild African lion taken unawares at a time of repose under a shade tree in his native habitat in Tanganyika Territory, Africa. (Photograph by Dr. W. D. Campbell in 1939 while on the William D. Campbell African Expedition for the American Museum of Natural History.)

Near the middle of the Cenozoic there appeared fossils of what are called "dog weasels," which were creatures believed by many to be the early ancestors to modern dogs, wolves, and foxes. The body was long, legs were relatively short, and the brain was rather well developed. These ancient creatures thus had some characteristics of the modern wolves or dogs as well as of the modern weasels, two groups that are rather closely related. They were probably rather close to the original stem of these two modern types of hunters and killers, if not their actual ancestors.

Ancestry of the felids or cats goes back to middle Cenozoic. Such fossil remains show that they had sharp incisors, pointed canines, and no molar teeth, these being characteristics of modern forms. The claws were highly developed, and the body was slim and light, probably agile and suitable for stalking their



The now extinct saber-toothed tigers were once widespread over the earth.

prey and capturing it by a sudden lunge or jump. The modern descendants of these early cat-like mammals are the lions, leopards, tigers, wildcats, lynx, and household pussies. More distantly related descendants are such forms as the mongoose, hyena, and civit cat.

One other strict flesh eater that is worthy of mention is the saber-toothed tiger. Although now entirely extinct the saber-toothed tigers once were widespread over the earth; and they must have stricken fear into all other large mammals of their time. They grew to the size of the largest tigers. However, they differed from the other felines in one important respect, that is, in the killing mechanism of their jaws. The upper canine teeth were exceedingly long, and they were curved somewhat like sabers. Furthermore, the lower jaw could be dropped down to more than a right angle. The large muscles of the neck and head seem to have fitted these old cats well to use the great saber teeth for effectively spearing and slicing. They, no doubt, fed chiefly on the large mastodons of their times.

No discussion of the carnivores would be complete without some mention of the marine forms, these being the various seals, walruses, and whales. They differ from all other mammals in that limbs have been converted into swimming paddles, and they are distinguished by including in their number the largest animals on earth at present.

The walrus is a huge animal native to North Atlantic and Arctic waters. It feeds mostly on mollusks at the bottom of the sea. Its most pronounced specialized features are the large tusks and the absence of outer ears. The herd instinct is strongly developed, and it often shows remarkable cooperation in defense

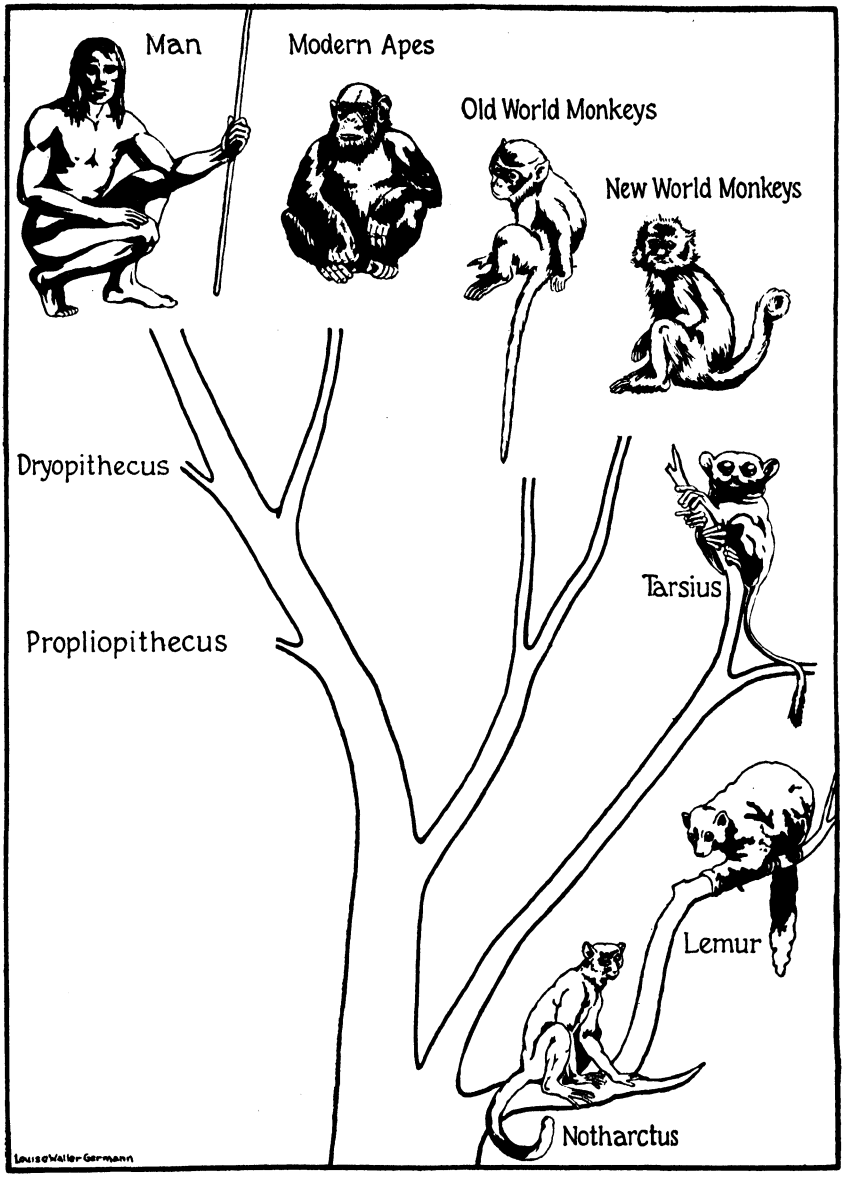
when attacked. However, the walrus has been so persistently slaughtered by man that it is now relatively scarce and is to be found only in the Arctic Ocean.

A great many species of seals inhabit the oceans. One variety, the northern fur seal, is a most prized animal to man because of its valuable fur. It was formerly common in the Pacific. Man's extensive hunting of these animals has reduced their number, until now their breeding places are strictly protected in order to prevent complete extinction. They come ashore for breeding purposes. The males are the first to occupy a coast line or island and contest among themselves for a space to accommodate the females. These arrive a few weeks later, and each male secures as many as he can entice to his chosen area. The young pups are born soon afterward, and the pairing season for the following year's families begins. The seals inhabit these chosen areas for two to three months, during which time the young have learned to swim. Then about November they take to the sea and follow the fish southward for the winter. The following May or June they return to northern islands again.

The whales are other mammals that live in the sea; in fact, they have become so modified to sea life that people generally confuse them with the fishes. All external traces of hind limbs have disappeared, and the flipper tail is provided with a horizontal fin. There is also a fin on the back. Whales live exclusively in the water and come to the surface only for breathing or feeding. One, known as the blue whale, has been found to grow to about one hundred feet long and to weigh over a hundred tons. The whales most hunted by man are the great sperm- and whalebone-bearing animals. These have been so extensively destroyed that their number is rapidly decreasing. They are only one of a large number of great and interesting animals that man has completely or materially eliminated from the earth.

Arboreal Mammals—the Primates

The other great divergence of the earliest "insect eaters" led toward specialization in another direction. Such specialization was in tree-dwelling habits and a mixed diet of fruits, berries and small animals. These arboreal insectivores gave rise to the primates, the order of mammals including the lemurs, monkeys



The primates are the order of mammals that include the lemurs, tarsiers, monkeys, great apes and man, as well as a number of extinct forms.

great apes, and man himself. The fossil record of the primates is much less complete than that of the other great mammal groups. Therefore, the pedigrees of man and his nearest of kin are much less documented than those of horses, elephants, and cats. Their habitats probably account for such scarcity of fossil remains. Being tree dwellers, their remains were left in the forests, and fossil remains of vertebrates are normally not generally formed in forested areas. Particularly is this true in tropical climates, where the early primates most certainly must have lived.

The earliest tree-living insect eaters were probably not unlike certain tree shrews now existing. These animals are usually smaller than squirrels and have long bushy tails. They are found in large numbers in Borneo, South China, and the Malay Peninsula. Fossil remains of animals similar to these and belonging to the early Cenozoic have been unearthed. These creatures are called Northarctus. The head was about two inches long and in the fine characteristics of its bones it was partly similar to tree shrews and partly similar to the Old World monkeys. No doubt, then, it was very close to the stem leading to modern primates.

The most primitive of the primates are the lemurs, found today mainly on the tropical island, Madagascar. The lemur is a small animal with busy hair; it is nocturnal in habits and lives in trees. Fossils of lemurs not unlike the modern ones of Madagascar have been found in Europe and North America in rocks dating back to the early Cenozoic. This primitive stock has been able to endure in Madagascar to the present, apparently because the island has long been separated from the mainland of Africa. In consequence, few flesh eaters have been able to enter this region and dispute the territory with the lemurs. However, no fossil remains in their former continental homes have been found that are later than the early Cenozoic. It is likely that these early primates were all killed in such localities or developed into more advanced forms.

Next up the ladder of modern primates is a curious little animal found in the East Indies, known as Tarsius. It has a few specialized features such as a long rat-like tail, long hind legs, and exceptionally large eyes turned completely to the front of the face. However, the rest of the body structure is remarkably intermediate between lemurs and monkeys. The brain is large,



Capuchin howler monkeys photographed in their native wild haunts of Barro Colorado Island, Panama Canal Zone, expressing contempt for some captive monkeys nearby. (Photograph by Dr. Frank M. Chapman, American Museum of Natural History.)

the head round, and the face an archaic prototype of that of the monkeys. While the modern Tarsius is a specialized type, the early fossil Tarsius remains which date back to early Cenozoic appear to be close to the stem leading to monkeys and apes.

Above the Tarsius in primate development are the monkeys. Modern forms are found in both the Old World and the New World. They, too, have large eyes that look to the front, as is true of the Tarsius. However, in the case of the Tarsius the creature has two fields of vision, one in each eye, as the nerves

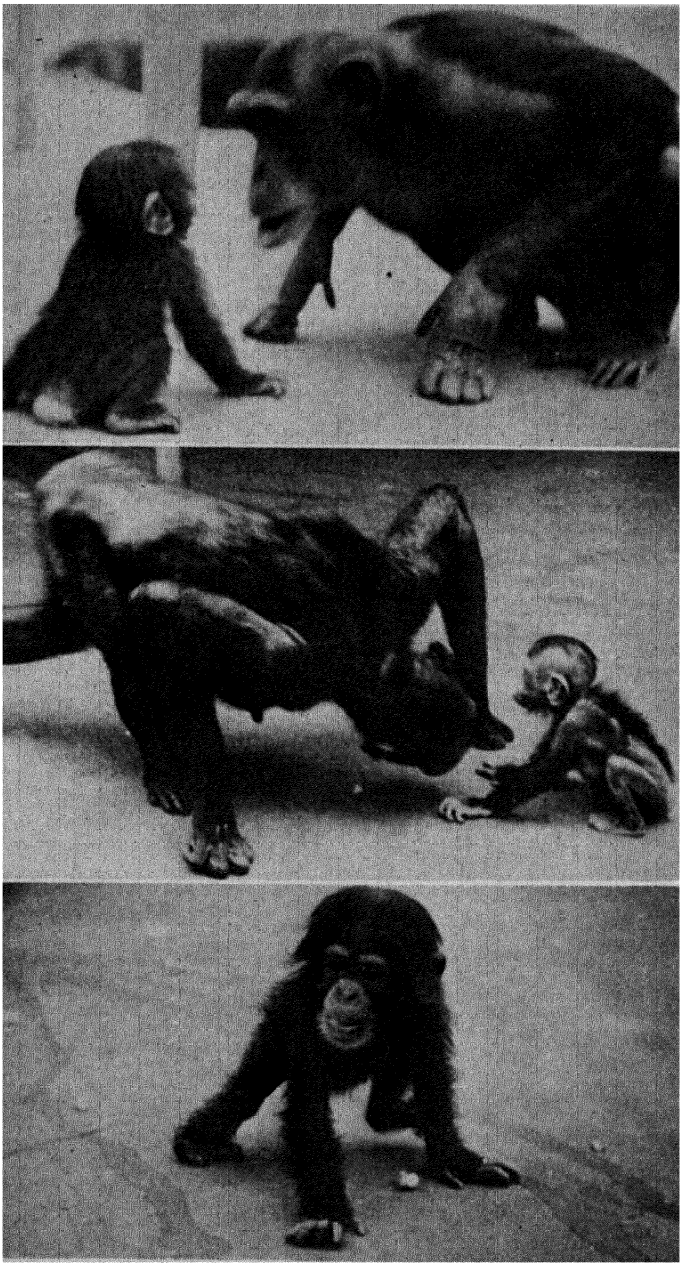
leading from each eye do not cross or mix in the brain. Therefore, it cannot blend the picture into a single image, but rather must see two images of the same scene. The monkeys have a crossing of the optic nerves before entering the brain, which permits a blending of the images. This gives them true stereoscopic vision, such as man possesses.

Another line of development led to the higher primates, inincluding the anthropoid apes and man. This divergence apparently took place before the Miocene epoch, for in the same bed in Egypt that was referred to above have been found the remains of a small ancestral ape which is known by the imposing name of Propliopithecus. The jaw is about two and a half inches long and has the beginnings of characteristics found in modern apes.

Fossils of apes are exceedingly scarce; however, those that have been found seem to show that these anthropoids were the last to separate from the primate stem that eventually led to man. In the Miocene and more recent rocks of India have been found fragmentary remains of large ape-like primates, known as Dryopithecus. These bones possess features found today in the chimpanzee and gorilla. Another highly significant fossil is one that was found in South Africa; it has been assigned the long name of Australopithecus. Considerable difficulty has been encountered and weighty controversies have ensued in the classification of this fossil. It has some characteristics that are typical of modern apes and some that are distinctly human. This uncertainty of classification is indication of the relatively recent divergence of the ape and human stems from some common ancestry.

Anthropoids of Our Times

There are at present on the earth four species of the anthropoid apes. These are the gibbon, orangutan, chimpanzee, and gorilla. In size they range from the light-bodied gibbon, about three feet high, to the heavy-bodied gorilla, which stands about five and one-half feet high. They have broad chests in contrast with the narrow chests of monkeys and all other mammals except man. The hands are quite similar to man's, except that the fingers are long in comparison to the thumb. In many other respects, the skeletons are close to the human type. The main



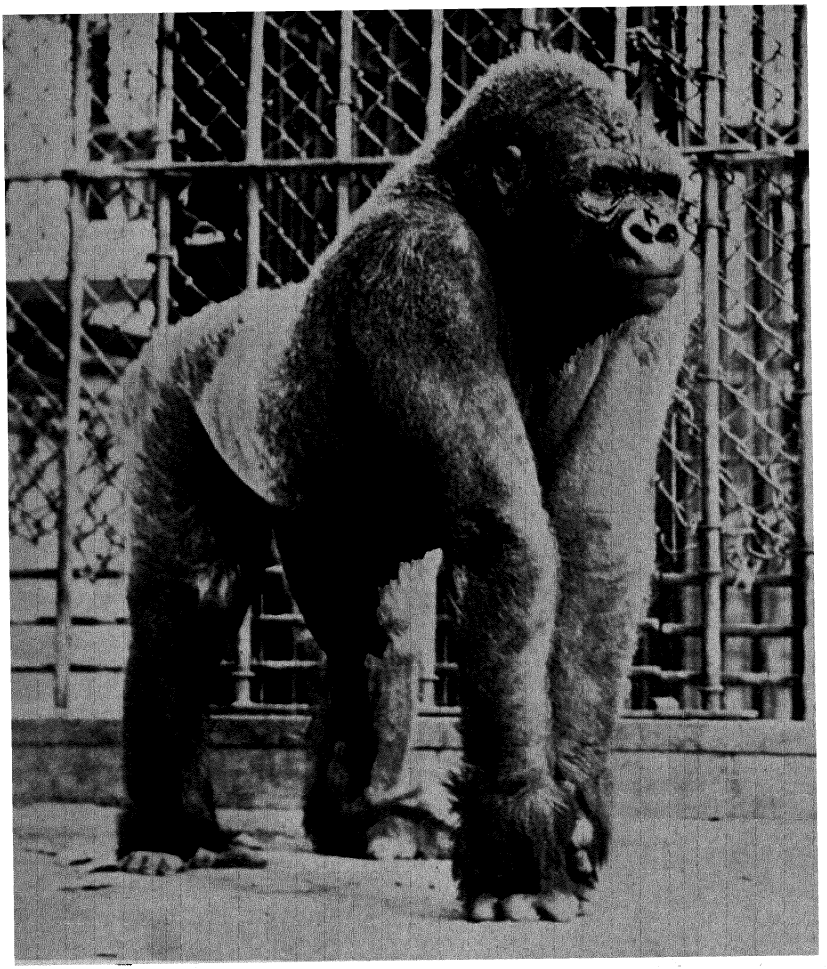
Chimpanzee mother teaching baby to walk. Upper picture, mother calls baby to come to her arms. Middle picture, teaching baby to step. Lower picture, proud moment when baby walks alone in fifth month. (Science Service photograph.)

differences are in the shape of the skull, the short legs, and the long grasping type of large toe.

The gibbons, found chiefly in the Malay region, are the most primitive of the anthropoid apes. They have extremely long arms and usually walk erect, with the hands reaching the ground, and live chiefly in wooded slopes of hills and valleys. Being arboreal in habit, they move through the trees with great agility. They swing themselves from the limbs of trees with their hands and arms, being able to clear spaces of fifteen to thirty feet with the greatest ease and finest precision. They are, therefore, the great acrobats of the anthropoids. The gibbon is the most specialized ape in the length of its arms and other adaptations to arboreal life. Its brain cavity is small as compared to other apes. However, the top of the skull is smooth, and the forehead lacks the prominent ridges above the eyes. Its profile, therefore, closely resembles that of man.

The orang is confined mostly to the swampy forests of Sumatra and Borneo. This red-haired creature grows to about four feet in height, and its body is bulky. It has long arms, which reach to its ankles. It is a good arboreal type and remains in trees most of the day, being able to swing from one treetop to another. It builds a sort of platform or nest in a convenient crotch in the tree, on which it reposes much of the time. Usually these nests are about twenty-five feet above the ground. The orang is a highly intelligent ape, but sluggish in its disposition and habits. It runs laboriously on all fours. It never stands erect. It is a highly specialized type and represents one distinct branch of ape development.

The chimpanzee is a native of Equatorial Africa. This ape is essentially a tree dweller, but is much more at home on the ground than the gibbons or orangs. It grows to about five feet in height and is not so bulky as the orang. It sometimes stands or walks on the hind limbs, but it runs on all fours. It responds readily to human association, and it is the interesting little ape that is seen so frequently in the captivity of man. The chimpanzee has a comparatively well-developed brain and seems to adapt itself easily to its environment. Much experimentation by psychologists has recently been done in testing the intelligence of these animals. They show the rudiments of human intelli-



"Bamboo", adult male gorilla raised at the Philadelphia Zoo. (Science Service photograph.)

gence; for example, they have a good memory, and they show some reasoning powers of the human type.

The gorilla is found only in Central Africa. It is by far the more impressive of the man-like apes, and, it is the most like man in body structure and in mental development. It has a brain capacity equal to nearly half that of man. It is not easily captured, and adults rarely live long in captivity. A few baby gorillas have been captured. They prove to be both affectionate and intelligent. The male gorilla grows to about five and one-half

feet in height, and it has an arm spread of about eight feet. It has departed from the slender-bodied, long-limbed type which is adaptable for arboreal life. It exhibits a transitional stage leading to ground-dwelling habits, such as those most highly developed in man. The body is powerful and the legs are strong. The hands are human in form and shape. Gorillas rarely walk erect, their bodies being too heavy to be easily supported by the legs.

Quite contrary to general belief, the gorilla is not an aggressive, ferocious animal. According to Carl Akeley, noted African explorer, the gorilla shows no indication of marked aggressiveness, or that he will fight if there is any means of escape. Rather he is a perfectly amiable, good-natured creature when not harassed or attacked by man or other animals. The gorilla has developed the rudiments of family life. Gorillas are usually seen in their natural habitats in family groups consisting of the father, mother, and one child or more. Also, the family may adopt some particular spot of territory that is considered as "home."

REFERENCES FOR MORE EXTENDED READING

GREGORY, W. K., and H. C. RAVEN: "In Quest of Gorillas," The Darwin Press, New Bedford, Mass., 1937.

Here is told a lively and interesting story of a scientific exploration into the mountains and jungles of equatorial Africa. Aside from the personal experiences of the expedition, the authors have included an extensive account of the gorilla's characteristics and life habits.

AKELEY, DELIA J., "J. T., Jr.": The Macmillan Company, New York, 1937.

The author subtitles this book, "The Biography of an African Monkey." It is an account of Mrs. Akeley's exploration in East Africa for the Field Museum of Natural History of Chicago and the experiences of a small African monkey which accompanied the expedition and finally was brought to New York. The records of the daily life of "J. T., Jr.," prove to be an interesting story and one that has scientific value in the study of the habits and characteristics of monkeys.

ELY, A., H. E. ANTHONY, and R. M. CARPENTER: "North American Big Game," Charles Scribner's Sons, New York, 1938.

This book is a unique combination of a scientific description and distribution of the large mammals of North America and a fascinating story of their habits and characteristics as observed by many experts who have hunted them. In addition, it makes a subtle recommendation for the conservation of these wild animals. Illustrated with photographs, maps, and drawings.

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This book is an excellent general account of the most important present-day reptiles of the world. It is written in popular style but is in general accord with the scientific study of modern reptiles.

CURRAN, C. H., and CARL KAUFFELD: "Snakes and Their Ways," Harper & Brothers, New York, 1937.

This publication is a general and thorough treatment of snakes, dealing with their habits, habitats, appearances, and relationships to each other. It is written in highly interesting style, yet adheres to the scientific facts regarding the species discussed.

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CRONEIS, CAREY, and W. C. KRUMBEIN: "Down to Earth," University of Chicago Press, Chicago, 1936, Chaps. XLIII, XLIV, XLVIII.

The chapters referred to are a lively discussion of the ruling reptiles and the warm-blooded mammals of the Mesozoic and Cenozoic eras. The unique drawings add interest and understanding to the text.

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In the chapters referred to are to be found an excellent nontechnical account of the origin of reptiles and mammals and the most important modern types of these animals.

SCHUCHERT, CHARLES, and C. O. DUNBAR: "Historical Geology," 3d ed., John Wiley & Sons, Inc., New York, 1933, Chaps. XV–XX.

These chapters include a wealth of well-written material regarding the rock formations and life of the Mesozoic and Cenozoic eras.

Natural History, published by the American Museum of Natural History, New York.

Natural History is a monthly magazine published for members of the museum, which contains articles on a great variety of natural-history subjects. These articles are interestingly written and usually illustrated with remarkable photographs.

Journal of Mammology, published by the American Society of Mammologists, Baltimore.

This is a professional journal published quarterly for the members of the society. It contains nontechnical articles on various types of mammals as well as articles dealing with original investigations in this field. An extended list of recent literature and a review of current books relating to mammal life are included in each issue.



8: THE LAST MILLION YEARS

Or Human Development from Early Man to Modern Races

IN 1891 Dr. Eugene Dubois, a medical officer of the Dutch army, discovered at Trinil in Java the fossil remains of what is known as the Java ape man. The discoverer at once claimed that the fossil represented an intermediate state between apes and men, and it was widely labeled "the missing link." The real status of this ancient fossil has been the subject of great debate for five decades. Many experts have strongly argued that the fossil is human in character, while others formerly maintained that it was an oversized ape. Likewise, its age has been widely placed at from a half million to nearly one million years old. However, in light of more detailed studies of this fossil and the recent discovery of other human fossils in Java which resemble it, present-day paleontologists are generally agreed that Java ape man is quite definitely to be considered human and that he lived during the early part of the Pleistocene epoch.

This primitive fossil and the controversies that have centered around it indicate that human origins are definitely connected with the primate stem. While it is no longer maintained that Java ape man is the direct ancestor to modern peoples, it is known to represent one branch of human development. Even in this case it gives some indication of the steps man has gone through in his long ascent to the foremost place in the world of life.

It has been said that man seems so different from all other animal nature that he stands isolated and alone. However, if the fabled man from Mars, first chronicled by H. G. Wells thirty years ago and recently made real in a dramatization, should actually visit the earth, he probably would not recognize such isolation in man. No doubt man would be described as a biped mammal, of specialized development and of large brain capacity. Upon examination of his life processes and his body structure, comparing the body organ by organ with that of other animals, he would be found to be related to other vertebrates and most like the great apes. The fossil records, even now available, would show a probable origin from the primate stem and many stages of development from those primitive types to modern peoples. Fortunately, it is not necessary to await the arrival of the hypothetical Martians for this enlightenment. Man himself has discovered much information of this type.

Distinguishing Man from the Apes

When one makes a casual comparison of man with the great apes, it seems that their differences are so enormous that they have little likeness in common. The chimpanzee's short legs and feet adapted to arboreal life, its protruding jaw, and hairy skin appear to bear little resemblances to man's long legs and feet specialized for erect walking, his reduced jaws, and the relative absence of hair on his body. However, a careful analysis of the physical structure of the bodies of apes and man shows them to be fundamentally more alike than different.

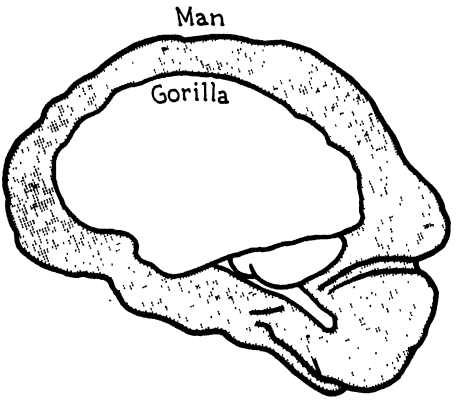
We would think that the apes are more nearly like monkeys than man as regards their coat of hair. Careful counts of the number of hairs on unit areas of skin on the back and chest have shown that the number of hairs on the skin of the apes is much

less than that on the skin of monkeys. Likewise, the number of hairs on the skin of man is less than on the skin of apes. However, the difference between apes and the monkeys is greater than the difference between man and the apes; so much so, that the apes may be considered to have a relatively hairless skin. The seeming absence of hair on the body of man is more apparent than real. His entire skin, with the exception of the palms of the hands, soles of the feet, and a few specialized areas, such as the lips, contain hair follicles. The rudiments of a hair grow in each follicle, a condition that may be seen under microscopic examination. In most cases these rudimentary hairs do not develop on the skin of man to be as noticeable as the hair on the apes.

The long arms and hands of the apes show marked contrast to those of man. This is an adaptation to the habit of hanging from branches and to the use of the hands in walking. The apes progress over the ground by means of "hand walking."

The feet of the apes have not become adapted to bipedal walking as have the feet of man. In this respect, however, they are more like man than they are like the feet of monkeys, which are strictly arboreal. The feet of the gorilla, in particular, seem to be about midway between adaptation to arboreal and to bipedal ground habits. The great toe is opposite the other toes, a condition that makes the foot a grasping organ. In adult man the great toe is in line with the others so that the foot rests flat on the ground. In human infants, on the other hand, the great toe is somewhat opposable, but rapidly develops into the human type as walking is learned. The mountain gorilla of the Eastern Belgian Congo has feet that are most like man of any of the great apes. In all apes, however, the bones of the hands and feet match those in man. The main distinctions between them are slight differences in size and length and in the muscles which are attached to them.

The bones of the head of man are also distinctive when compared to those of the apes. This distinction is one of size and shape rather than number or type. The bones of the cranium have been greatly enlarged to accomodate the expanded brain. The jaws and teeth are reduced in size. The human canine teeth are much smaller than those teeth in the apes. Despite the



The human brain is more than twice the volume of the gorilla's brain.

conspicuous difference in size between the teeth of apes and of man, the teeth of both are of the same basic pattern. The large cranium of man is balanced on top of the vertebral column, rather than being thrust forward as in the apes.

Biochemically and physiologically the apes and man are very similar. Only the most accurate and delicate tests show any difference between the blood of man and of the apes. Apes are susceptible to practically all human diseases. The normal life span of the apes is believed to be about that of man. Chimpanzees have been captured that are said to be about sixty years old. The placenta of the developing ape embryo is much more nearly like that of man than it is like that of the monkeys. Full-time pregnancy in the chimpanzee is about eight months and in the gorilla is thought to be slightly longer.

The most outstanding characteristic of man is the human brain. In this respect he stands greatly superior to the other anthropoids. This superiority is due to the size and complexity of organization of the brain rather than to new parts. It is a difference in degree only. The convolution pattern in the brains of apes is very similar to that in men. Even the microscopic structure of nerve cells within the brain stem of the apes is almost identical with that found in man. In man the cerebrum, which is the seat of higher mental facilities, is greatly enlarged over that of the apes. The human brain ranges in volume from about 1,000 cubic centimeters to about 2,000 cubic centimeters; however, for most people the volume ranges between 1,200 cubic

centimeters and 1,500 cubic centimeters. The volume of the gorilla's brain is about 600 cubic centimeters, while that of the chimpanzee is somewhat smaller.

The apes are entirely lacking in the capacity for speech, which is one of the chief criteria of human mentality. Lack of speech on the part of the apes is not due to the absence of vocal cords and other apparatus for making sounds. Speech requires an elaborate association mechanism in the mind to coordinate sound symbols into intelligent language. In man this involves several different parts of the brain. No such association mechanism seems to exist in the brains of apes. This deficiency will probably prevent modern apes from ever attaining any cultural inheritance.

These bodily differences between man and the apes did not arise in one swift change. They were slow in their development and have extended over most of the last great epoch in geologic history, that is, the Pleistocene epoch.

Period of Great Climatic Changes

So far as we know, practically all human development has occurred since the beginning of Pleistocene times. It is only during this period that any fossils of man are found, and those belonging to the earlier part of the Pleistocene have exceedingly primitive characteristics. This indicates that at the beginning of this time man had just emerged from the primate stem. The Pleistocene was a period of great climatic changes. It was one of the critical times in the world's history. It is in order, therefore, to review the climatic conditions existing during this period, since these changes apparently had a great effect upon mammal life of those times.

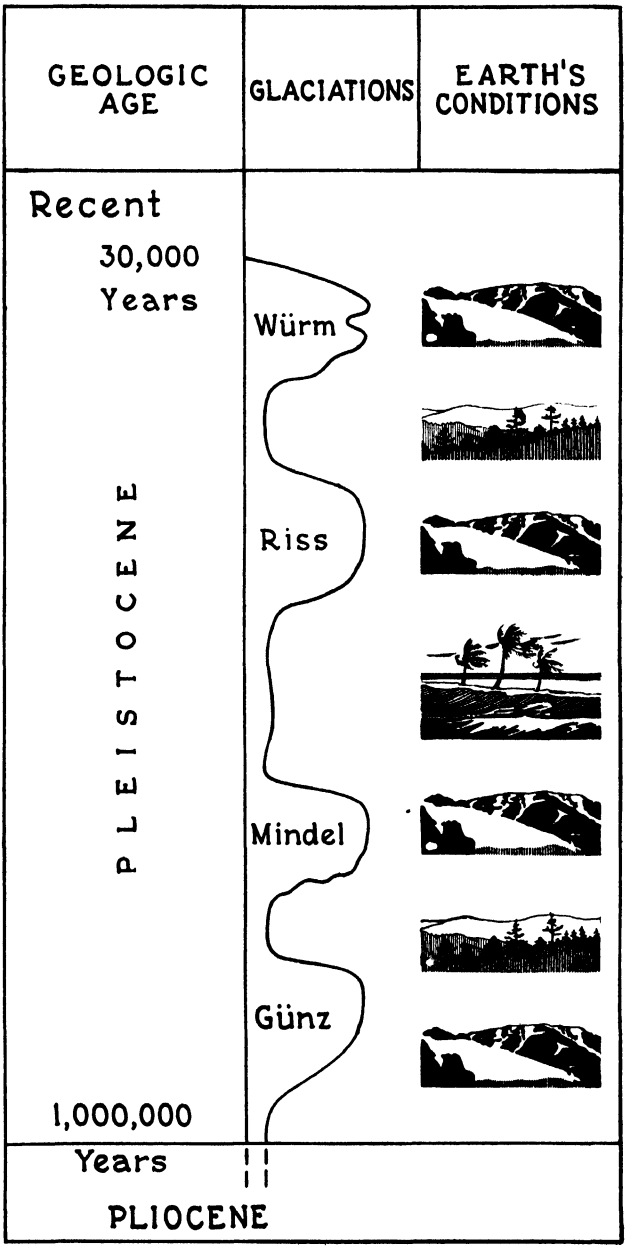
The Pleistocene epoch began about a million years ago, and ended about twenty-five thousand years ago with the receding of the last great glaciers. It is often referred to as the "Great Ice Age." In fact, during this time at least four great continental glaciers covered many millions of square miles of the northern parts of America and Europe. The ice sheets extended, at the greatest, as far south as New York City, the Ohio and Missouri rivers, and the head of Puget Sound in North America. In Europe they covered most of Great Britain, present Germany,

European Russia, and all countries to the north of them. Glaciers were practically absent from all of Asia, probably because of lack of precipitation to form snow and ice. It is not known exactly how thick these continental ice sheets were; however, they were very great. They must have been at least 4,000 feet thick, and some authorities more than double this figure.

In America, studies have shown distinctly that there were four successive periods of glacial maxima. Between each of these times of the ice sheets there were long periods of time, tens or even hundreds of thousands of years, in which the glaciers melted as far to the north as they are today, or perhaps farther. During these times the climate was temperate or tropical in Northern United States and Southern Canada. Also, in Europe, there were four glacial periods separated by periods of mild climate, about the same as those occurring in North America. The exact time of the glacial periods has by no means been determined. However, for Europe, it is probable that the first two, Günz and Mindel, occurred relatively close together near the first part of the Pleistocene, and that the latter two, Riss and Würm, were somewhat associated near the end of this epoch. The first of these four glaciers began to creep down over the continents probably about a million years ago. The Würm glaciation, the last, receded about twenty-five thousand years ago.

These glacial periods are indicated on the accompanying chart. The names given above refer to the glaciers in Europe. For those who might be interested, it is worth noting that corresponding glaciers in America have been named the Wisconsin, Illinoian, Kansan, and Nebraskan.

The glaciers reduced greatly the habitable land in Europe and North America. Man as well as the rest of life had to make adjustments to these changed conditions. However, the advance of the glaciers made great areas to the south of them desirable habitats which are now desert wastes. North Africa and the Sahara received much greater rainfall than at present and apparently had mild climates. All of Asia as far north as The Gobi and North China had abundant rainfall and moderate climates, so that the whole vast deserts from Southwestern Asia to Mongolia became habitable areas. It is within some of these areas that all the great early historic civilizations sprang up



The Pleistocene period was a time of great climatic changes in which four glaciers extended over much of Europe and North America. These ice ages were separated from each other by long intervals of time when temperate or tropical conditions prevailed over the greater part of these continents.

and not at the foot of the glaciers. It is likely, therefore, that Southern or Central Asia was the home of much earlier human development.

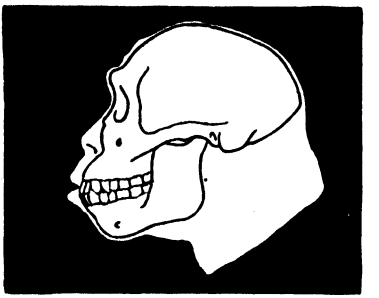
Thus during the Pleistocene epoch, Europe and North American experienced periods of great glaciers and icy blasts coming down from the north, interspersed with warmer times when tropical conditions prevailed far into our present temperate zones. It seems evident that during much of this time Africa had temperate and semitropic climates. Probably these conditions existing over such great areas during the Pleistocene had much to do with the geologically rapid development of man and the other primates. The Pleistocene epoch is to be considered the "Age of Man."

Peoples of Bygone Ages

The fossil record of man gives some insight into the development and characteristics of peoples in times long since past. This record is painfully incomplete, and great gaps still exist in man's ancestral lineage. However, the number of present known human fossils that predate recorded history is far greater than most people realize. Over three hundred complete or fragmentary human fossils of earlier vintage than modern man have been unearthed from their elusive burials. In addition, thousands of artifacts, or human tools, have been discovered which add their bit to the picture of human development. The main outline of this development we see in clear relief; however, the details are often obscure.

One of the earliest known of the man-like fossils is the Java ape man, referred to in the opening paragraphs of this chapter. The remains in the original discovery consisted of the top of a skull, a left thighbone and two upper molar teeth. Somewhat later a third tooth, a premolar, was found in the same deposits, and it has been added to the original collection. The fossil was found in a layer of volcanic debris which exists some sixty feet below the present level of the land in the Solo River bed near the village of Trinil. River erosion has cut through the overlying strata and exposed the volcanic eruptions which are believed to have occurred in the tropical forests of Java during the second glacial period in Europe. This establishes the fossil as belonging

to about the middle of the Pleistocene epoch. Thus, Java ape man lived at a time not later than about a half million years ago.



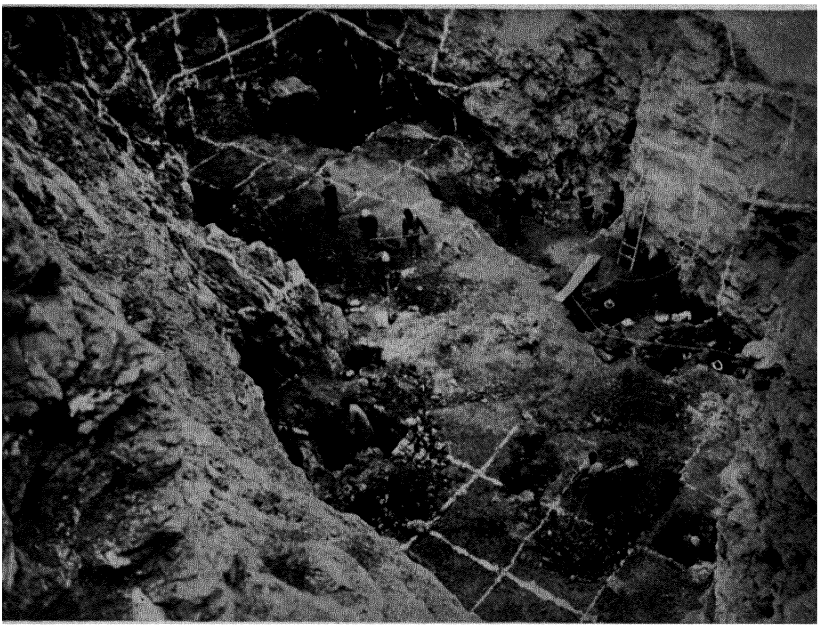
Java ape man.

The name given to this creature by the discoverer is *Pithecanthropus erectus*. This means "erect ape man." The leg bone is definitely human and shows that he walked erect. The bone indicates a height of about five feet six inches, which is near the average of modern man. The skull cap shows from very careful measurements completed by Dr. J. H. McCregor of Columbia University that Pithecanthropus had a brain capacity of slightly less than 900 cubic centimeters. This puts it near the minimum range of some modern human skulls. The shape of the brain as reconstructed from the configuration of the skull cap resembles more that of man than it does the apes. Motor and auditory areas were developed to the extent that it may be inferred that Java man had a rudimentary language.

The skull as a whole is primitive and ape-like in character. The cranial vault is low and receding. The forehead was narrow, and there was a very heavy brow ridge over the eyes. These features must have given an ape-like appearance. However, the median ridge over the skull is quite reduced, and the area of attachment of the temporal muscles indicates that the jaws were much smaller than those of the apes.

The first two teeth found are large and resemble closely those of an ape. It has recently been substantiated that these two teeth do not belong to the skull, but rather are those of an extinct ape living in Java at that time. The third tooth, the premolar, is decidedly human. If it belongs to the skull, as generally agreed, it would also indicate that the jaws were more nearly human than ape in size and shape.

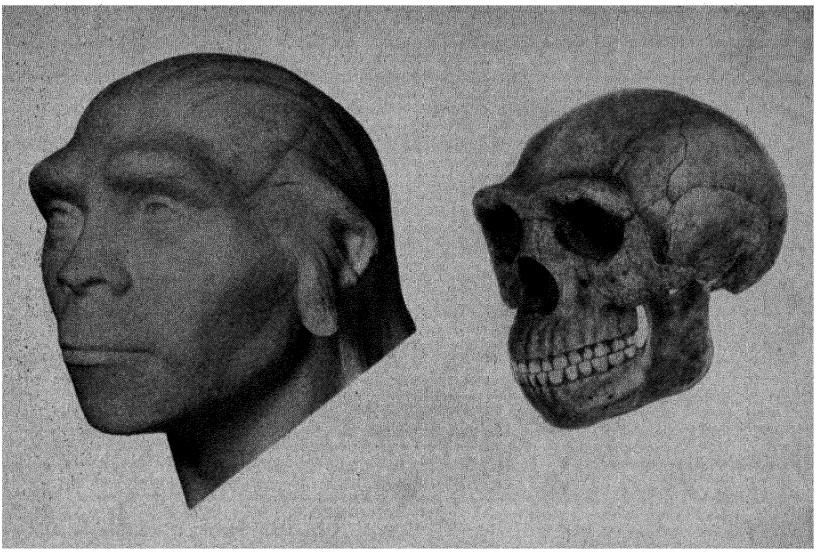
What, then, is the relationship of the Java man to later human types? There is no general agreement among the authorities on this subject. It seems unlikely that Pithecanthropus was the direct ancestor to either modern man or to the Neanderthal people, a specialized type which lived in Europe in large numbers



General location and excavation of some of the Sinanthropus skulls near Peking, China. Careful records of exact location of all fossils in the formations were made by designating each point in areas marked off with the white lines. (Photograph by Dr. Franz Weidenreich.)

at a much later date and which has now become extinct. However, its importance is not diminished by this unknown relationship. It is at least one early type of human development.

A series of discoveries of major proportions in the study of prehistoric man have been made near Peking, China, within the last few years. They are fossils of a primitive human type which has been called *Sinanthropus pekinensis*, meaning "Chinese man of Peking." The first remains were found in 1926, and they consisted of three human teeth. These teeth were discovered in filled-in fissures at the base of limestone hills. During Pleistocene times these fissures were open caves in the limestone which were used by both man and beasts. In the course of the succeeding ages the caves became gradually filled with red clay and bones. These were cemented together by limestone from the caves. Today these filled-in caves remain as great pillars and columns of hard sedimentary rock within the hills of purer limestone. A careful study of the extinct animal bones found in these deposits



Reconstruction of head and skull of a Sinanthropus woman by Dr. Franz Weidenreich and Mrs. Lucile Swan. (Photograph by Dr. Franz Weidenreich.)

shows that the deposits were laid down not later than the middle of the Pleistocene, or approximately one half million years ago. They may be much older.

In 1927 a systematic evacuation of the sites was organized under the joint auspices of the Peking Union Medical College and the Geological Survey of China. Despite the task of removing sizable portions of the limestone hills and the drawbacks resulting from a war in the area and its occupation by a foreign army, the work has continued to the present. Parts of twenty-six human fossils had been excavated by 1939. Of these, six are fairly complete skulls. The others are fragments of skulls, jaws, and teeth.

The shapes of all the skulls are quite similar, although they vary considerably in size. The vault of the skull was low, the forehead was narrow and retreating, and the brow ridge over the eyes was prominent. In these respects Peking man resembled closely Java man, with whom he is now believed to have been contemporaneous. In other features Sinanthropus was more like the later Neanderthals and even modern man. The brain capacity of one of the skulls is about 900 cubic centimeters, which is

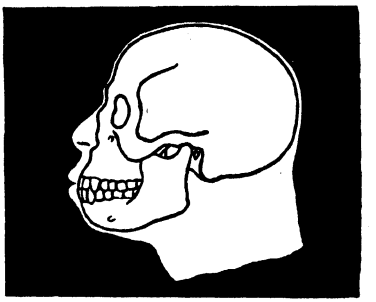
about the same as Pithecanthropus. The others are larger, with cranial capacities ranging from 1,050 cubic centimeters to about 1,200 cubic centimeters. These come within the brain sizes of Neanderthal, as well as exceed the minimum size for modern man. The cheekbones, where found, are prominent and do not slope obliquely backward. This is quite unlike Neanderthal and resembles more the Mongoloids of modern peoples. The teeth exceed in size somewhat those of Neanderthal and modern man; but in shape they are characteristic of Neanderthal, and remarkably enough, of modern yellow-race peoples.

It is difficult at present to determine Peking man's relationship to later human types. The sizes and shapes of the skulls bear some close resemblances to Neanderthal man. The dentition as well as certain features of the jaws indicate that Peking man was not far removed from the stems which led to Neanderthal or to modern man. Recent discoveries of human stone tools in Mongolia that are intermediate in their chipping between those of Peking man and the later ones of Neanderthal strengthen the claim that Peking man was the ancestor to the Neanderthals. On the other hand, it has been claimed by some authorities that Peking man is the remote ancestor to modern Mongoloids. However, such a claim is probably immature on the basis of our understanding of the history of modern races and the immediate successors to Peking man.

About two thousand pieces of crudely fashioned stone and bone implements were found in the deposits. Many of these stones were foreign to the region and must have been carried in from great distances. There were also found pothole fireplaces, charcoal, and the charred remains of animals. The charred remains of animal bones indicate that these people knew how to use fire and how to cook their foods. In discovering the use of fire and how to make tools, Peking man had developed the beginnings of human culture.

Another human fossil of ancient lineage and very unusual characteristics is the Piltdown man. It is scientifically called *Eoanthropus dawsoni.* The first part of this imposing name means "dawn man" and the second part is designated in honor of its discoverer, Charles Dawson. It was found near Piltdown, England, in deposits that have been dated as belonging to the

middle Pleistocene epoch. Had the skull alone been discovered, it probably would have been identified as a modern human skull and forgotten. However, near it was found a part of a lower jaw that contained two teeth. This jaw was remarkably like the jaw of a chimpanzee, but no fossils of chimpanzees were known in England. The fact that the jaw and skull were found close together in the same deposits and have the same degree of fossilization has led the foremost anthropologists of England to assert that they belong to the same individual. The teeth are primarily ape-like but have crowns that approach those of man, thus strengthening somewhat the idea that the skull and jaw belong together.



Piltdown man.

When the head is reconstructed the cranium is distinctly human. The forehead is relatively vertical, and there is a complete absence of a brow ridge above the eyes. The head is large and has the general contour of modern man. The skull bones are exceedingly thick, however, and the brain capacity is about 1,240 cubic centimeters. The jaw is distinctly ape-like in the chin region, and the teeth are large. Thus the fossil is a peculiar blend of anthropoid and human characteristics. Even with this perplexity, many anthropologists hold that the Piltdown man was very close to the stem which led to modern man.

The modern human genus, *Homo*, is first represented by Heidelberg man, *Homo heidelbergensis*. It is a fossil type which belongs near the middle Pleistocene epoch and possibly to the second interglacial time. This makes the fossil at least 150,000 years old and probably twice that age. This fossil was found near Heidelberg, Germany, in 1907, in a sand quarry at a depth of seventy-nine feet below the present surface. It was in a layer of ancient sand and gravel deposited by a river overflowing into an old lake bed. Only the lower jaw with the teeth well preserved was found. It apparently had drifted down with the old river sands. The rest of the skull and skeleton was evidently washed elsewhere and probably lost forever. Careful search for many

years since the time of this original discovery has failed to locate any additional fossils of Heidelberg man.

The jawbone is massive and broad; however, it has certain features in common with the later Neanderthal race. The chin is distinctly receding. In this respect it resembles the jaw of an ape, but the teeth are definitely human. The canines do not project beyond the line of the other teeth, as do those of the apes as well as of some prehistoric human fossils. It is probable, therefore, that Heidelberg was a Neanderthal man in the making, or very near the direct line of ancestry which led to this race of later European inhabitants.

Homo neanderthalensis

Neanderthal man represents an extinct people who would merit a description occupying the entire space allocated to this chapter because of their large numbers, the long period of time they inhabited Europe and Asia, and the wealth of information that has been secured regarding them. The discovery which first led to the recognition of Neanderthal as a definite human type was made in 1856, when portions of a skeleton were found in a cave in the Neanderthal valley near Düsseldorf, Germany. Because these remains showed many distinctive features, they were made the type specimen of the species, *Homo neanderthalensis.* Since then many of their fossils have been found in other parts of Germany, in Belgium, France, Spain, at Gibraltar, in the islands of the English Channel, in Italy, and in various parts of the Balkans. In 1932 a remarkable series of skeletons were discovered in Palestine, some of which have many Neanderthal characteristics. Thus the Neanderthal or proto-Neanderthal peoples are definitely known to have inhabited Southwestern Asia, as well as Europe.

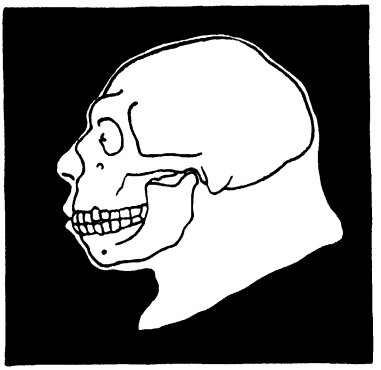
In addition to these skeletons, many thousands of artifacts in the form of stone tools and implements of bone that were fashioned by Neanderthal have been found in more widely scattered areas of Europe and Asia and Northern Africa. As recently as 1939 Dr. Alex Hrdlicka of the Smithsonian Institution discovered unquestionable Neanderthal artifacts in Mongolia, and it has been reported that similar artifacts have been found in Northwestern China.

Many of the Neanderthal remains have been rather accurately dated. The fossils found in Palestine, usually referred to as the Mount Carmel skeletons, were deposited during the early part of the Third Interglacial period, which was the warm interval between the Riss and Würm glaciers. This would conservatively place them as about 75,000 years old. It is believed that some of these fossils represent people of the Neanderthal type who migrated into Europe from Asia, where it is not unlikely the Neanderthals originated. Likewise, some of the European Neanderthal fossils definitely belong to the Third Interglacial. Others have been found in deposits as recent as about 25,000 years ago. Thus, Neanderthal lived in Europe for a period of approximately 50,000 years, a time that is twice as long as that from the date of their extinction until the present. Apparently they were in Asia for a longer period.

There is some variation in the physical features of Neanderthal man, even as there are variations among modern racial groups; however, the type can be rather accurately described. A few details here are sufficient to give a general picture. Neanderthal man was of short stature, averaging about five feet to five feet four inches. The limb bones were particularly robust. The forearm and shin were short in comparison to the upper bones of the arm and leg. The thighbone was curved forward. The tibia, one of the bones of the lower leg, indicates that the knee was flexed somewhat in the standing and walking positions. These conditions of curved thigh and flexed knees warrant the statement from some anthropologists that Neanderthal probably walked in a semierect position. However, this is denied by others who explain these peculiar characteristics as probably resulting from a squatting habit, rather than portraying a nonerect walking position. The ribs were heavy, with large muscle attachments, and indicate a large chest. The vertebral column was short and massive, but otherwise was probably similar in shape to modern man.

The most characteristic features of Neanderthal are to be found in the skull and jaw. The forehead sloped rapidly backward from large ridges above the eyes. The eyes were deep-set below the overhanging brow. The face was exceedingly long and narrow as compared to modern man. The nose was of great

width, also long and large, not flat. The cheekbones were not at all prominent. The head was somewhat imperfectly balanced forward on the neck. The jaw had no chin prominence, and the teeth were large in all their dimensions.



Neanderthal man.

The Neanderthal features were distinctly human in most cases, even if in some instances they are more ape-like than are those found in modern man. The brain capacity ranged from about 1,100 cubic centimeters to approximately 1,600 cubic centimeters, limits that do not compare unfavorably with modern peoples. Neanderthal was much more human-like in appearance than ape-like, even though popular representations of him have frequently been the opposite. Judged by today's standards of human features, however, he was probably a stodgy and unattractive creature. Neanderthal seems to have been a successor to Heidelberg man and possibly descended from earlier types in Asia. He is known to have lived in Europe until the receding of the last glacier, when other peoples began to migrate there in large numbers. After this he disappeared from the European scene as a pure type, either by complete extinction or by inbreeding with other types.

Homo sapiens Appears

As we have just noted, the Neanderthal people lived in Europe, apparently in large numbers, for thousands of years. They were the first example of man's occupying a continent in somewhat the widespread manner in which man occupies the earth today, at least so far as we know. However, with the receding of the last glacier another group of people appeared in Europe and became the dominant type there. Their conquest of the Neanderthals was not so rapid as was the conquest of the North American Indians by the white man, but it seemed to have been about as effective. Not only did this new group introduce into Europe a new and improved culture, but they were a new race

of mankind. These people were definitely of the modern type and belonged to our own species, *Homo sapiens.* They are generally referred to as Cro-Magnon man.

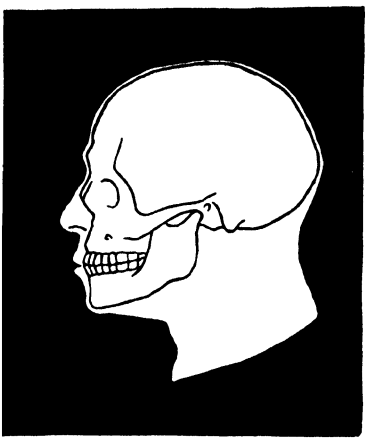
Just where these people came from is not known. It has been held by the eminent authority, Dr. Hrdlicka, that they developed from Neanderthal man. However, he says there is not sufficient evidence as yet available to prove this theory. The fossil remains and cultural material now known make this claim seem unlikely. There are few, if any, human fossils from Europe that show any definite intermediate stages between the physical features of Neanderthal and Cro-Magnon. Further, Cro-Magnon cultural remains are found in deposits immediately above those of Neanderthal and sometimes in contemporaneous deposits. This indicates that the change of culture was sudden, not a gradual development.

It is likely that Cro-Magnon man originated elsewhere, probably Asia or Africa, and migrated into Europe as the climate changed to mildness following the receding of the last glacier, approximately 25,000 years ago. One substantial bit of evidence which indicates Cro-Magnon migrated from Asia into Europe is found in the Mount Carmel skeletons. These skeletons, it may be recalled, were found in Palestine and predate by thousands of years Cro-Magnon's appearance in Europe. Certain features of some of the Mount Carmel skeletons resemble greatly Cro-Magnon, although the characteristics were somewhat more primitive. It may be reasoned from these skeletons that Cro-Magnon man developed in Southwestern Asia and later migrated into Europe.

The type specimens from which Cro-Magnon man was first described were five skeletons found in the Cro-Magnon cave in central France in 1868. Since then other skeletons of similar type have been found in such widely separated areas as Italy, Spain, present Germany, and many other localities in France.

The men of the Cro-Magnon peoples are usually described as tall, averaging six feet or over in height, and of large frame. This is true of the type specimens and many others that have been found. However, some Cro-Magnon male skeletons are much shorter. It is likely that there was considerable variation in height, just as is found in present peoples; but as a race the

Cro-Magnon men were evidently a tall people. The women were considerably shorter than the men, averaging about five feet five inches.



Cro-Magnon man.

Cro-Magnon had an extraordinarily large cranial capacity. The forehead was vertical and high-vaulted, and the brain capacity averaged about 1,700 cubic centimeters. The skull was decidedly long-headed, but the face was short and broad with prominent cheek-bones. This probably gave the face somewhat of a disharmonic shape. The nose was narrow. The lower jaw was strong and the chin prominent and relatively narrow.

The chief type of change which was ushered in with the Cro-Magnons was a superior brain power and with it a modern forehead and forebrain. This race was evidently an extremely able people, judged not only from their physical development but also from their cultural achievements, a subject which will be considered later. These people existed in Europe for a few thousand years. As a true type they have now disappeared. It is unlikely that they became entirely extinct, but rather intermixed with other peoples who came into Europe later, so that their descendants live today in France, Spain, and other parts of Western Europe.

Races of Modern Man

There are now alive on the earth four distinct human races, all belonging to the same species, Homo sapiens. These are the white, yellow, Negro, and Australian races. Of the first three there are many subraces. The story of these races is one with which increasing knowledge brings absorbing interest. This story involves the place, time, and manner of their origin, how they spread over the earth, and their characteristics, cultures, and habits. It gives a better understanding of the relationships of all peoples and the struggle which man has had in order to reach his present stage of civilization. Obviously such a broad considera-

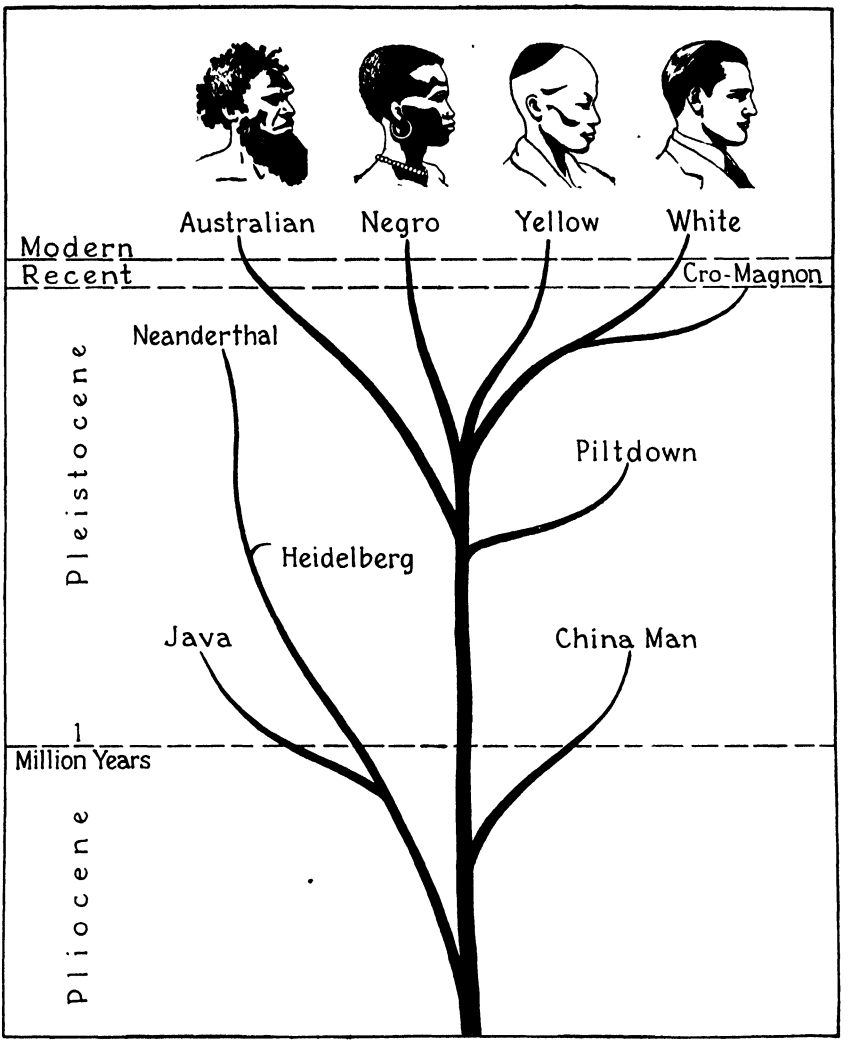


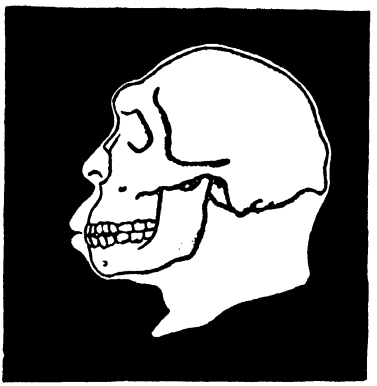
Chart representing prehistoric and modern man.

tion cannot be undertaken here. However, a few points regarding the probable origin of modern races and their physical characteristics may serve to give a general insight into this interesting question.

Origin of Modern Races

It is impossible as yet to say where man originated. It may have taken place in Central or Southwestern Asia. The physical

and climatic conditions of the earth there during the late Cenozoic era and particularly the Pleistocene epoch were such as to have encouraged this development. The most ancient known human fossils have been discovered in Asia. The Java man was living in Java at a time when this island was most certainly connected with Southern Asia. Peking man to the north was contemporaneous with the Java man or perhaps somewhat earlier. However, it is a long step from these two ancient types to modern man, and there is no known link directly connecting them. The first known definitely modern man to appear in Europe was Cro-Magnon. As previously pointed out, his exact origin is unknown. This means that at present we know very little about the origin of our own species. Likewise, the steps man went through from Cro-Magnon to modern races are still in the realm of speculation and argument. Further studies of the Mount Carmel skeletons and additional discoveries in Southwestern Asia may shed more light on the first modern Europeans.



Rhodesian man.

A fossil that it was thought for a time might shed some light on the origin of the modern species is that of Rhodesian man, found in Northern Rhodesia in 1921. The skeleton is an odd mixture of some very primitive characteristics and some which are like Homo sapiens. The most obvious features seem to resemble Neanderthal, while some others are like Cro-Magnon. This was the basis for reasoning that it might represent a step in the development of the modern species from Neanderthal. More detailed studies have revealed that the primitive features are not those of Neanderthal, and it now seems do not show any relationship between Neanderthal and Cro-Magnon. The skeleton has not been accurately dated, and there is reason to believe it is much too recent to be ancestral to Cro-Magnon. It is now believed by some that it is an abnormal example of Homo sapiens of relatively recent date.

Many other human skeletons of considerable antiquity have been found in Africa. Some of these have been identified as early examples of present stocks of the Negro race. They seem to indicate that there were several Negro types before the end of the Pleistocene epoch, and that the Negro race developed its distinctive characteristics in Africa. One of these skeletons, in particular, is the ancestor to the modern Bushmen and yet resembles Cro-Magnon man to such an extent that it is considered by some to represent African Cro-Magnons who migrated from Europe and finally reached Central and Southern Africa.

Australia, too, has yielded some early human fossils. Two of these closely resembling modern Australians are dated as belonging to the late Pleistocene and give evidence that the ancestors to those modern people were on that continent during Pleistocene times. Even more important in establishing the ancient lineage of the Australians is a series of fossils found in Java in 1936, known as the Solo man. They have been dated as belonging to the Third Interglacial Period. They are remarkably similar to modern Australians in some respects and help to establish the idea that the ancestors to the Australians migrated there from Southern Asia at times during the Pleistocene when Australia was connected to Asia by a land bridge.

The brief discussion of these few examples has been given to point out that modern races have probably developed separately by a slow and gradual process after migrating to different continents. Since all modern man is of the same species, it is not unlikely that the different races developed from some common ancestry. What the relationship of the original Homo sapiens was to the very early fossil types of man is not known.

Distinguishing Modern Races

Should anyone stand on a busy street corner of almost any American city and observe the people passing by, he would recognize that they have certain marked differences. The differences lead him to know in a general way that different ones belong to the white, black, or yellow races. However, when more precise designations are asked for, difficulty is encountered. Not

so many can distinguish between people from Mongolia, China, or Korea; or between people from Arabia and India.

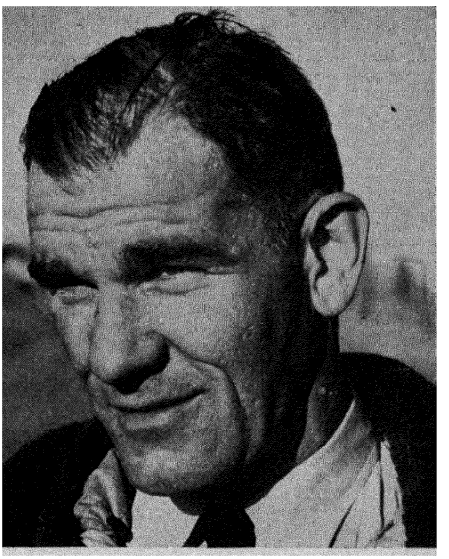
Differentiating between all the modern human races is a difficult and often complex process. Racial divisions depend upon fine distinctions, and only a general outline can be attempted here. A complete classification of races is based upon their physical, functional, chemical, mental, and pathologic differences. When all these things are taken into account, it is found that a great many subdivisions of peoples live in different parts of the earth today.

There is opportunity here for consideration of only some of the physical differences in the larger divisions or main races of modern man. Some of the most important of these physical distinctions are skin color, eye color, hair color, hair texture, hairiness of the body, size of the bones, body shape, and head shape or cephalic index. The anthropologists have devised methods whereby these physical features may be very accurately measured. With such exact measurements available, they are able to apply them to living individuals and give us a description of different peoples.

If people generally were relatively pure racial types, it would be simpler to analyze and describe them. However, there has been such intermingling and inbreeding of peoples of all races that there are few today who show pure racial characteristics. Most people represent complex admixtures, at least of subracial strains. It is always true, however, that certain dominant traits will be so evident that there is little doubt as to any individual's main racial classification.

The Whites

The most definite physical feature we generally associate with the white or Caucasoid race is white skin. However, our interpretation of the term "white" is exceedingly broad in many instances. This liberal interpretation is an indication that there are also other features which we recognize as just as descriptive of the white race as is white skin. When individuals or groups possess these other features, even though their skin is exceedingly brown or dark, they are included within the white race. Skin color is the most variable characteristic, as a matter of fact.



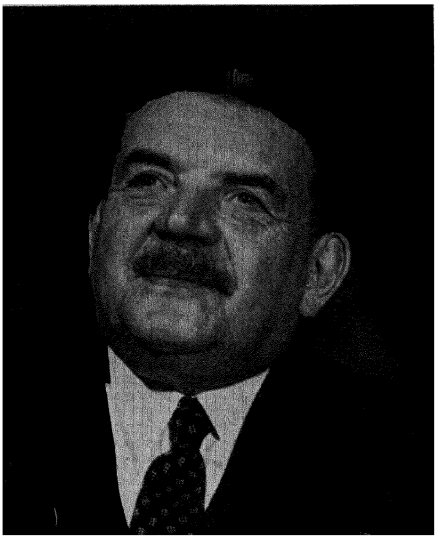
The Nordic type is represented by flying officer G. L. Ingram of the Canadian air forces. (Life Magazine photograph.)

It ranges from a delicate pink white to an exceedingly dark brown.

What then are these main features of the white race? Almost universally there is a high development of the frontal region of the skull, or a high forehead. The nose is long, relatively narrow, and high. The lips are relatively thin. Usually there is an abundance of hair on the face and body of the males.

Within the subraces are more definite and specific resemblances. At least three subraces are recognized in the whites of today. They are the Nordic, Alpine, and Mediterranean. In addition, many anthropologists would form another division to include the Hindu. Still others would increase the number of subraces so as to have a separate group for the Cermenians and even other groups. It all depends upon how fine are the distinctions to be made. However, these last-mentioned groups usually have at least one feature of one of the three main subraces rather prominently developed. In any simple consideration of the subject, such as this, they may be considered as some modification of the Nordic, Alpine, or Mediterranean.

The Nordic has a blond to light complexion, blue or gray eyes, and light hair of fine texture. The whiskers grow long, and

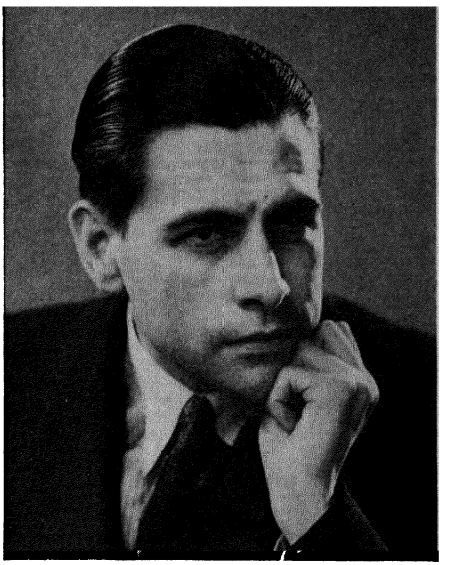


Edouard Herriot, former President of the French Chamber of Deputies, possesses many Alpine characteristics. (Life Magazine photograph.)

there may be a considerable hairiness of the body. The head is long, narrow, and high. Usually the face is also relatively long. The Nordic has big bones and is of tall stature. The shoulders are broad and the chest is thin to medium in thickness. These people dominate in large measure the regions bordering the North and Baltic seas. They are best typified by the people in Sweden, Norway, and Denmark, Northern Germany, and parts of England.

The Alpines are shorter and stockier than the Nordics. They have a ruddy to reddish complexion, which tans only moderately. The eyes and hair are, in general, brown. The hair is somewhat coarser than that of the Nordics and is usually wavy. The beard is ample and there is much hair on the body. One of the most distinguishing features is the possession of a high, short, and broad head. The face, too, is usually broad. This subrace, more or less mixed, forms the predominating element in the population of Central Europe, the Balkans, most of European Russia, and the steppes of West Turkestan. They are best typified by the round-headed, stocky-built German and the Polish Slav.

The Mediterranean race is also shorter than the Nordic. The stature averages about five feet five inches, and the body shape

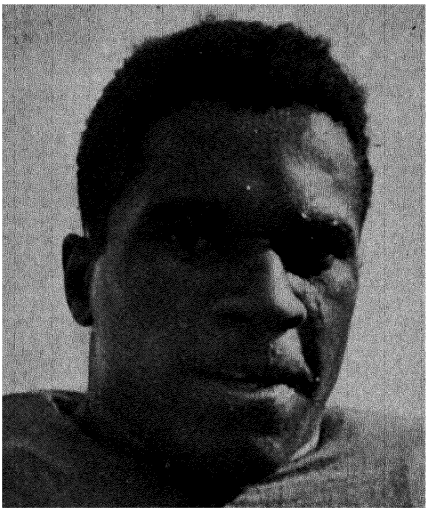


Mediterraneans usually have straight black hair, dark eyes, long head and face. (Globe photograph.)

is slender. The bones are small. The head form is similar to the Nordics, however. The head and face are long, and the nose is straight and thin. The skin is olive to very dark brown in shade. It may become ivory white when not exposed to intense sunlight, but it tans easily. The hair varies from brown to black and is usually straight. There is little hairiness of the body. The eyes are dark, varying from brown to black. The Mediterranean is the type found generally in Southern Europe, Southwestern Asia, India, Northern and Eastern Africa, and parts of the British Isles. These racial peoples have long been prominent in these native areas. The great ancient civilizations of Sumeria, Babylonia, Egypt, and Greece were all developed by the Mediterraneans.

The Negroes

The Negroes or Negroid race are a group of people who, likewise, have certain characteristics that set them apart from other peoples. They have spread widely over Africa and the islands of the Pacific as far as New Guinea. They are, however, by no means uniform over this wide area. They range from tall



"Ebony Statue" Bell of University of Minnesota football fame in 1938. (Life Magazine photograph.)

to short in stature, and from yellow to black in skin color. This, of course, makes for many subracial groups in any detailed study of them. But, as is true with the whites, all these groups possess certain features in common.

The eyes are without exception black. The hair on the head is black, short, and exceedingly curly or kinky. Usually there is very little hair on the body. The skin is always dark but varies considerably in intensity of shade from a brownish yellow to heavy black. The Negroid head tends to be long, narrow, and relatively low. Usually the lips are thick and the nose low and broad.

The native peoples of a large part of Southern Africa are of relatively short stature and have yellowish brown to olive skin. The head shape varies from long and narrow to medium broadness. They usually have a small chin and a flat, broad nose; the cheekbones are relatively wide and prominent. These people are the Bushmen and Hottentot subraces of the Negroes.

The pygmies constitute another large group of the Negro race. They are found in Central Africa as well as scattered in the Malay Peninsula, Andaman Islands, and New Guinea. They are short in stature, usually slightly less than five feet tall. The head

shape is short and broad. The body is usually sturdy, with the trunk long in comparison to the length of the legs. Skin color ranges from yellowish to dark brown or black.

Within the Sudan region of Africa there is a subrace of the Negroes that is characterized by tall stature. They average nearly six feet tall. The head is long and narrow, frequently with a high forehead. The face is long, and the nose may be relatively long but is always broad. The skin is very dark.

This very brief mention of some of the different subraces of the Negroes is probably sufficient to illustrate that there are well-recognized variations within the Negro race. In some respects these variations are greater in kind and degree than are those found in the white race.

Yellow Peoples

The yellow or Mongoloid race constitutes the other large division of modern peoples. They inhabit the eastern half of Asia, many of the near-by islands, and the Malay Peninsula. They once occupied the greater parts of the North and South American continents.

There is more uniformity in physical features among people of this race than among either the white or black races. The hair is black, coarse, and straight, almost without exception. There is little or no hair on the body proper. The eyes are black or dark brown. There is usually a fold of the skin of the upper eyelid over the inner angle of the eye, known as the Mongolian fold. This gives the eye opening a decided slant toward the nose. In general the head is short, broad, and high. The face is broad, this broadness being accentuated by prominent, wide cheekbones. The greatest variation is found in skin color and body size. The skin varies from light color with a yellowish undertone to dark brown and red. Body shape is slightly robust to slim, and somewhat shorter in height than the white race.

The yellow race is probably best exemplified by the Chinese and the inhabitants of Mongolia. The oceanic Mongoloids, including natives of Japan, British Malaya, Dutch East Indies, and parts of French Indo-China, have certain characteristics in common and may be grouped as one or more subdivisions of the



Madame Rosa Feng of Peking, China, exemplifies many of the fine physical characteristics of the yellow race. (Photograph by Ewing Galloway.)

yellow peoples. The American Indian, the Eskimo, and the Siberians are other subraces of the Mongoloids.

The long existence of the Indian under climatic conditions of the American continents produced a number of variations in their racial features, in addition to a deep-tone red skin. These other features are, however, far from being uniform. The North American Indians ranged from medium to tall stature. They were of sturdy build and a vigorous people. The head shape varied from broad and high to long, narrow, and high; however, prominent cheekbones were almost universal. Even among the scattered tribes still living within the United States there are to be found almost as many subracial variations as are found in the conglomerate of white races living here today.

Native Australians

The native Australians are sufficiently different from other subraces of modern man to warrant brief mention here. They have black skin, but they do not belong to the Negro race. The Australians have a long and narrow head, but the vault of the skull is exceedingly low and sloping. There are heavy brow ridges

across the base of the forehead. The chin is moderately receding, and the nose is wide. They have a heavy growth of whiskers and hair over the body. The hair varies from relatively straight to very curly. While always black, it is not kinky, as is true of the Negro race. The mouth is relatively large with thick lips. In stature the Australians range from short to medium.

What remains of this race is found mostly in Northwestern Australia. They represent a small, retarded group of people who are rapidly decreasing in number and will probably soon become extinct.

Race Betterment

The conditions that have served to bring about the formation and perpetuation of races have also had other effects upon homogeneous peoples. They develop somewhat common social and religious practices, and may even build up strong national ties. Then when diverse racial groups come into close contact with each other, each attempts to maintain its own mores and customs and even to enforce them upon the other. Thus, racial differences lead to enslavement, discrimination, and wars. It is, however, not uncommon that under such conditions there is finally considerable mixing of the two races; thereby, new racial strains come into existence.

It is usually true that each race possesses some quality of superiority that is valuable in advancing human culture. In fact, there are no fundamental and important criteria by which either of the three major races can be judged superior in all respects to the others. The same thing is true (within limitations) of the various subraces. It would be to the advantage of mankind for each of the racial groups to attempt to understand and value the peculiar characteristics of the others. Probably much that is valuable to the advancement of human culture could be promoted rather than destroyed, as has so often been the case in the interracial conflicts.

The development of racial purity or the retaining of such purity is primarily a matter of isolation of the group and uniform habits within. It is not unusual for such attempts to be made. They are rarely successful. Race mixture goes on. However, the maintaining of racial purity by isolation has in the past usually

resulted in a static condition within the group. The native Australians and Tasmanians are emphatic examples of such lack of progress. In contrast to this, it is often true that the greatest progress made by a group of people has been fostered by racial admixtures. During the "dark ages" of European history the Arabs held the torch of learning in Europe and Northern Africa. For many centuries previously the land of the Arabs had been the scene of the great migrations, wars, and racial intermixing of many peoples.

These conditions may prove of great advantage to the United States. Here there is the greatest mixing of racial groups that the earth has ever witnessed. Some twelve million Negroes are now scattered throughout most of the states, being no longer isolated in one section of the country. There are large elements of all three subraces of the whites that make up a big percentage of our population. In addition, considerable traces of Asiatic yellow peoples are to be found here. In most cases little assimilation and blending of these diverse racial groups has taken place. Only those elements of different racial groups that migrated here before the end of the nineteenth century seem to have been effectively assimilated. Many other racial elements came here in such great numbers within so short a time around the turn of the last century that they have tended to retain their foreign racial, social, and nationalistic characteristics.

However, it is inevitable that assimilation will eventually occur. Whether the results are beneficial or harmful will most likely depend upon the type of racial heritage we pass through within the next century or so. Should the stronger strains of the different racial groups be perpetuated and cultivated, it is quite likely that a better racial admixture than now exists will result. However, should the less desirable and weaker elements be multiplied and fostered with special care, it is just as likely that racial deterioration will be the outcome. These conditions emphasize the need of wise study and the guidance of our national racial composition and inheritance. They would involve a close coordination of genetics and social conditions, serious consideration of any prolonged relief practices, and rigid adherence to a policy of refusing admission to large groups of foreign elements within the immediate future.

REFERENCES FOR MORE EXTENDED READING

SCHUCHERT, CHARLES, and CLARA M. LEVENE: "The Earth and Its Rhythms," D. Appleton-Century Company, Inc., New York, 1927, Chaps. XXV, XXXI.

In these chapters is found a short and easily read account of the climates and geographical features of the earth during the Pleistocene epoch, together with a discussion of the physical development of early man and his relationship to the other primates.

MACCURDY, GEORGE GRANT: "Human Origins," D. Appleton-Century Company, Inc., New York, 1924, Vol. I, Chap. VIII.

This chapter includes a comprehensive discussion of fossil man in Europe before the beginnings of historical times, as well as some account of the distribution and general relationships of the primates.

MACCURDY, GEORGE GRANT: "Early Man," J. B. Lippincott Company, Philadelphia, 1937.

This is an edited group of papers that were presented at the International Symposium on Early Man, held in Philadelphia in 1937. It recounts the researches of many of the world's authorities and students of prehistory, and it is an extensive summary of the recent discoveries in this field. The topics discussed include work that has been done in recent years in Java, the Near East, China, India, Africa, Australia, Norway, and many parts of North America.

BOAZ, FRANZ, and OTHERS: "General Anthropology," D. C. Heath & Company, Boston, 1938, Chaps. II, III.

The chapters referred to are a well-written and comprehensive account of early man and modern races by two of the foremost authorities in these fields.

BEAN, ROBERT BENNETT: "The Races of Man," The University Society, New York, 1932.

The formation and movements of races of man are concisely discussed in their relation to geographic and economic factors. There is some brief account given of prehistoric man and a review of the modern races and their chief physical characteristics.

COON, C. S.: "The Races of Europe," The Macmillan Company, New York, 1939.

The author traces the racial history of the white race from its Pleistocene beginnings to the present. There are also chapters on racial identification and classification of living white peoples which are extensively illustrated with photographs of peoples of different racial types.

Asia, published by Editorial Publications, 10 Ferry Street, Concord, N.H.

This monthly journal is concerned primarily with articles that relate to the present peoples of Asia and their national and political life. In addition, there are usually

articles regarding the cultural and racial characteristics of modern as well as early historic peoples of that continent which may be of interest to the scientifically minded reader.

American Anthropologist, published by The American Anthropological Association, Menasha, Wis.

This is a quarterly magazine which includes a wide range topics regarding modern as well as ancient peoples and their characteristics, customs, and mores.



9: COMPARATIVE FEATURES

Human Anatomy in Relation to That of Lower Vertebrates

THE long story of life on earth has been briefly traced in the preceding accounts of the geologic and immediate past. It has revealed to us an ever-changing picture—one of slow progress and development from simpler forms to more complex types of living creatures. Man was one of the latest higher forms to appear on the earth. Even the early human creatures were quite different from man today. His struggle upward along the long, hard road of physical development has just been noted. Man stands today as the product of the ages. This is no less true of his cultural heritage than of the structure of his body.

Human anatomy has been studied in minute detail, as a thorough knowledge of it is indispensable to the medical practitioner. On the other hand, it is of immediate interest to everyone

because in the structure and well-being of the body reside the comfort and joys of living. It has been stated poetically that the body "is the temple of the soul."

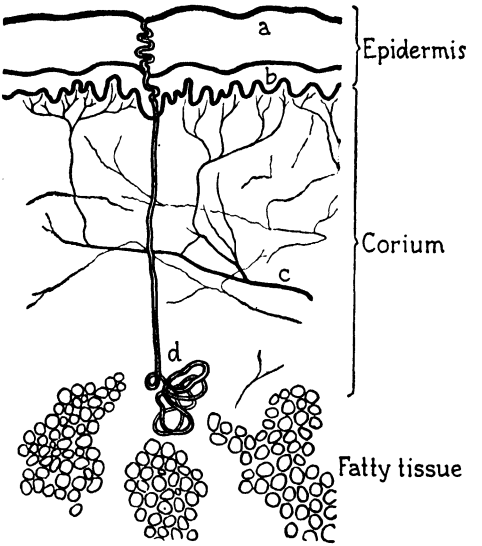
One of the strangest fruits of the extensive study of human anatomy has been the discovery that many of the problems which arise in connection with it find their solution in a study of lower forms of animals. It has been proved that frequently more may be learned of human development and structure by the intelligent examination of some lower vertebrate than by the study of the human body itself. This is due not only to the greater availability of such animals for dissection and experimentation, but also to the fact that parts of lower animals show simpler stages through which the human body has passed in arriving at its present condition.

All the parts of the human body are represented by similar parts in lower animals. These parts in lower forms are frequently much less complex in their development than in man. A comparative study of these similar parts shows in many cases the origin and development of human body structures. Often it accounts for the particular nature and function of some human organ or system. In getting an understanding of human anatomy, nothing about the structure and activities of any animal, however familiar or strange, becomes trivial or insignificant. The study of even a few points in comparative anatomy will serve to give some understanding of the development of the human body and probably a greater appreciation of this remarkable mechanism.

The Skin and Its Derivatives

In making this brief study it is well to begin with the skin, or outer covering of the body. This is appropriate, not only because it is the first part to be encountered in the examination of any animal, but also because in man and many animals it is a very versatile organ serving a great variety of purposes. It forms a pliable covering for the body, protects it from foreign materials, helps to regulate body temperature, and prevents the excessive evaporation of body moisture. From the ectoderm of the embryo are developed the nervous system and sense organs, and from the skin itself, the special coverings and appendages. The outside

of the body, including even the exposed surfaces of the eyeballs, is entirely clothed with the skin or its derivatives. At the



The skin of vertebrates is made up of two principal layers, the epidermis and the corium or dermis. The epidermis is composed of a layer of closely packed and dead cells (a), and a layer of growing, dividing cells (b). The corium contains coiled glands (d) and numerous capillaries (c) and nerve fibers.

nose, mouth, and genital openings it passes over into a related tissue, the mucous membrane, which lines these passages.

The skin is made up of two general layers: an outer stratification known as the "epidermis" and an inner layer called the "corium" or "dermis." In the young embryo these two parts are seen to be derived from two separate germ layers. The epidermis arises from the ectoderm, while the corium is formed from the mesoderm. The epidermis usually consists of several layers of cells, of which the innermost or germinal layer is constantly producing new cells, while the outermost layers tend to become horny. The protoplasm of these horny cells dies, and they are constantly being worn away by friction and being replaced by new cells from the germinal layer. From the epidermis are formed a number of accessory structures, such as epidermal scales, hair, horn, nails, claws, feathers, and the enamel of teeth. Also, it may contain sensory cells.

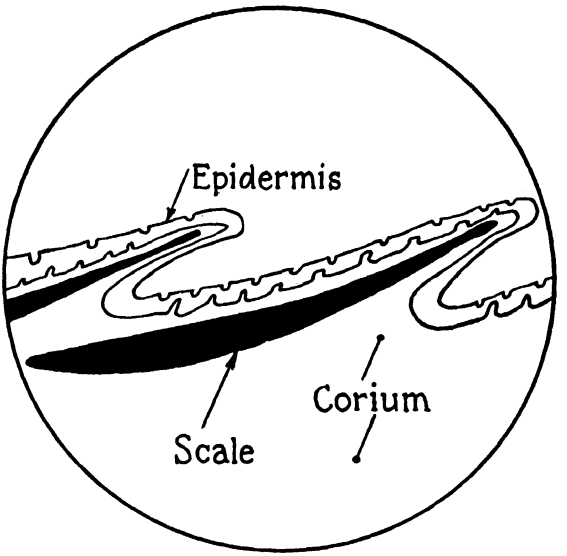
The corium is sometimes called the true skin. It is quite different from the epidermis, having a distinctive composite

structure. It is usually thick and is the part of the skin which forms the leather of commerce. In addition to smooth muscle, it contains fibrous and elastic tissues, which give it strength. It is richly supplied with blood vessels and with numerous types of sensory cells. These sensory cells are strictly specific in function and have nerve endings which form a sort of network in various parts of the corium. Most of the pigment cells which are responsible for the color of animals are located in the corium.

Bone is commonly developed in the corium, or dermis, primarily by the formation of scales of the bony type. These bony formations are often used in skeleton building, this being true in man as well as in many lower animals. There are many dermal bones in the skull, and they are now known to be modifications of scales which have grown together. In many lower animals these scales remain as such throughout life, but in man and other higher animals they develop further to form bones after the embryonic stage is passed. The development of many parts of the human skull may be traced from such simple beginnings. The dentine of teeth also is derived from the corium.

Development of the Skin of Vertebrates

It is not known at present exactly how the vertebrate skin originated. The best indication is secured by studying certain modern simple forms. In descending as far as possible down the ladder of animals with a backbone, a little creature known as "amphioxus" is eventually reached. Amphioxus is the simplest of the chordates. It possesses a notochord, like the embryos of all vertebrates, but does not have a vertebral column. The skin structure of this animal, while characteristic of the vertebrates, is reduced to its simplest expression. The epidermis consists of a single layer of cells which in adult life produce a sort of noncellular layer typical of the single-layered skin of all invertebrates. This is indicative of the primitiveness of amphioxus and its nearness to the invertebrate stem. The skin of the amphioxus also possesses a corium consisting of a thin layer of gelatinous connective tissue. However, only vertebrate animals possess a dermal layer of the skin. Thus, amphioxus assumes the dignity of a vertebrate. It is probable that the many layered vertebrate



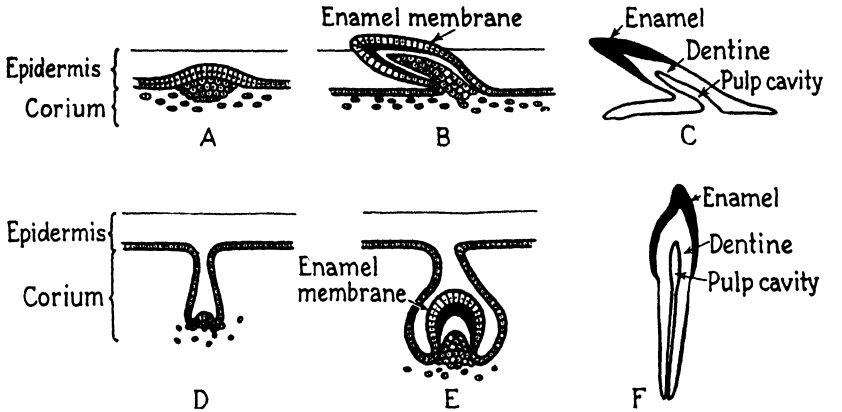
"The scales of fishes usually develop from the corium alone. . . . "

skin began in some fashion similar to the condition seen in this little animal.

The amphibians, such as toads and salamanders, possess a typical but a simplified vertebrate skin. It has a rather thin corium of fibrous structure and is scaleless. The epidermis consists of several layers and contains many glands for keeping the skin moist as an aid to respiration. In those forms which remain mostly out of water, the epidermis has a dead outer layer which may be shed all at once, as is also true of the epidermis in reptiles.

In many kinds of vertebrates, scales form a conspicuous modification of the skin. This is particularly true of fish and reptiles. The scales of fishes usually develop from the corium alone, as illustrated in the accompanying drawing. The scale is a bone-like material which grows from and is nourished by the corium. It represents the beginning of dermal bone, which is found extensively in the bodies of many vertebrates. Frequently the corium as well as the scales in lower vertebrate forms is pigmented in different colors, which decorate the body with an endless variety of patterns and shades. The epidermis of fish is usually a thin, superficial structure, extending over the scales, which serves to anoint the body with mucus.

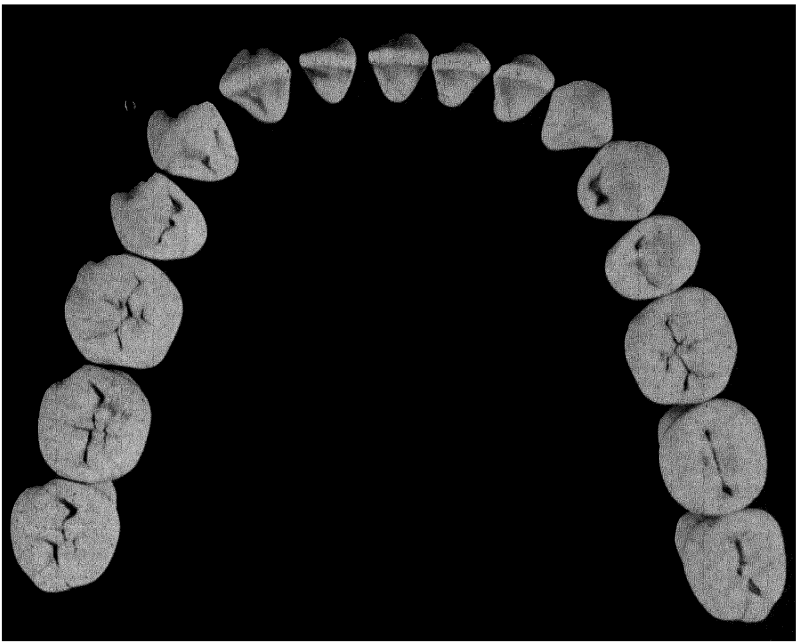
The scales of the shark are of interest and significance because they show conclusively the origin of teeth. The shark scale



The scales of sharks are of special interest and significance because they indicate clearly the origin of teeth. A, B, C, diagrams showing the formation of a shark scale; D, E, F, similar diagrams for a tooth.

consists of a flat base, buried deep in the corium, from which a naked cusp projects to the outside of the skin. The base consists of dentine, and the cusp is covered with enamel. The scale originates from two sources, the dentine from the corium and the enamel from the epidermis. Each scale has a permanent cavity filled with pulp, by which blood vessels and nerves are brought to the scale. The shark tooth appears to be a scale drawn into the mouth. In many sharks there is a perfect intergrading of the regular scales of the body into the teeth. The origin of teeth, even in higher vertebrates, where it is not so evident, is thus made clear.

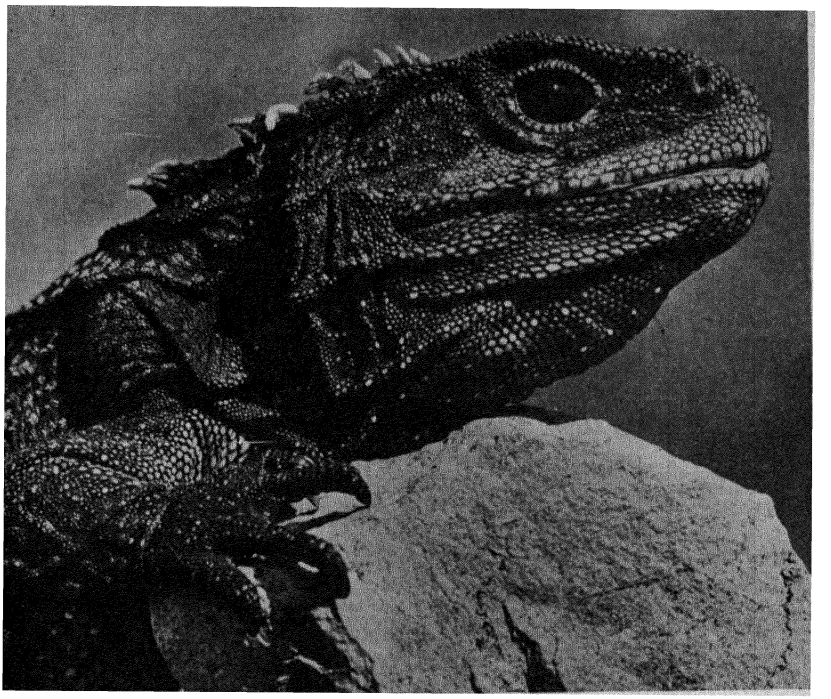
The development of scales reaches a high degree of perfection in the reptiles. These animals are also the first vertebrates to evolve a skin well suited to land life. In contrast to the fishes, reptiles have a thick layer of dead epidermis which comes in contact directly with the air. This layer is entirely impervious to moisture, and there is no loss of water through it. Thus reptiles can live out of water without any serious evaporation of the body fluids. Such evaporation would soon prove fatal to most water vertebrates, even if they had lungs for air breathing. The scales of reptiles arise from the epidermis alone. They are



A well-formed set of human teeth. (Life Magazine photograph.)

horny structures formed from dead epidermal cells. Along with the highly cornual outer layer of the skin, the epidermal scales are periodically shed and replaced from the germinal layer. Many of the large reptiles of the past grew, in addition to the horny scales, enormous bony plates from the corium, some of them over two feet long. These dermal scales were not shed but were carried around for life.

The skin of birds is thin, with only a rudimentary epidermis. As we know, the typical covering of birds is the feather. This is a kind of modified scale. It grows from the corium, and its development is similar to that of the fish scale. It appears first as a small papilla, formed from the corium, having a thin epidermal covering. This papilla sinks into the corium and forms a feather follicle, from which the growing feather gradually protrudes. The bill of birds, on the other hand, is not a true scale. Rather it is a horny sheath produced from the epidermis. True epidermal scales are found on the legs and feet of birds.



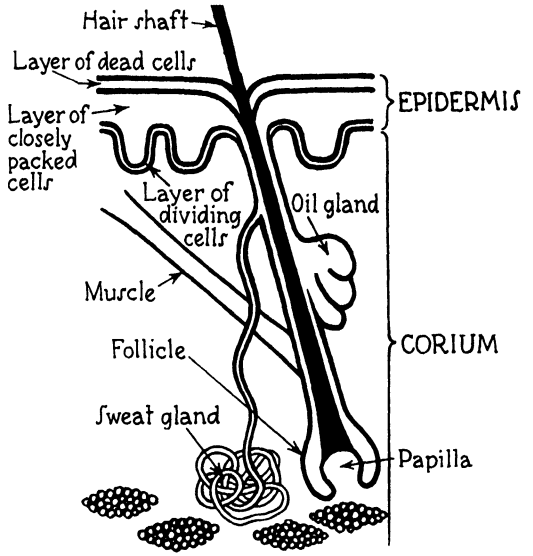
Scales form a conspicuous modification of the skin of many vertebrates, as is shown in this close study of the lizard-like Tuatara. Tuatara inhabits New Zealand and is the oldest living species of reptile known to man. (Life Magazine photograph.)

The Specialized Skin of Mammals

Mammals have a typical land skin, consisting, of course, of a corium and an epidermis. There is a layer of dead epidermal cells on the outside, so that no living cells are exposed to the air. The greatest specialization of both layers of the skin is reached in mammals. Such specialization is attained by modifications of the characteristics of lower vertebrates rather than by the development of new parts. For example, one of the greatest specializations of the skin of mammals is the development of numerous skin glands of various kinds. In other vertebrates, except the amphibians, the glands are relatively few and unspecialized. In mammals they are extensive and specialized as sweat, oil, and mammary glands.

The covering of mammalian skin generally consists of hairs instead of feathers or scales. The development of the individual

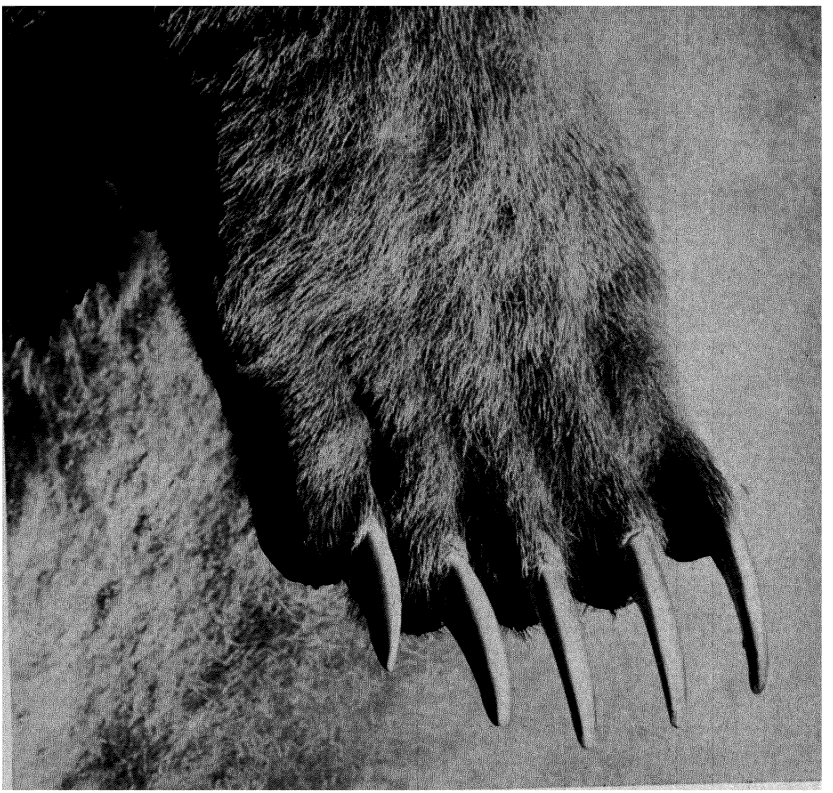
hair parallels that of the feather and scale. It starts with a thickening of the epidermis to produce a papilla, which then dips



The covering of mammalian skin consists of hairs, which develop from epidermal cells nourished by the corium. The skin of mammals is characterized also by the presence of sweat and oil glands.

down into the corium. From the resulting pit or follicle a solid horny shaft is pushed out by rapid growth of the epidermal cells, which get their nourishment from the corium. Before birth a mammalian embryo, including the human embryo, develops a coat of hair which is shed immediately before or after birth. The hair pattern is quite regular, suggesting that hair began originally by developing around scales, which have long since been lost by most mammals. However, there are a few mammals, such as the armadillo, which still retain some scales surrounded by hairs. The tails of such mammals as rats, muskrats, and beavers have scales covering them, interspersed with hairs. The porcupine has a covering of spines, which are a particular type of scale, surrounded by hairs. Embryo bears have a complete covering of spines which are lost after birth.

Particular derivatives of the epidermis of mammals which have become highly specialized and useful are claws, hoofs, and nails. Claws are horny caps which fit over the terminal bones of the feet. They not only serve as a protection in walking but,

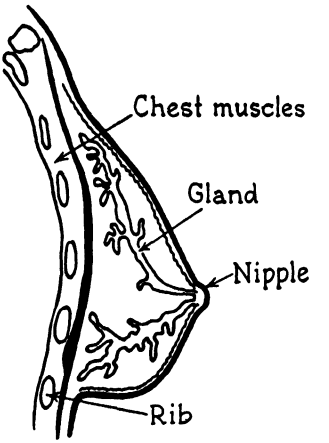


Claw of Kodiak bear. (Photograph by Ewing Galloway.)

when they become specialized, have a number of useful purposes. Thus, badgers and moles have broad, strong claws for digging. The cats have developed sharp, curved claws that are very useful in holding and killing prey. The hoofs of cattle, horses, sheep, and goats are a special type of claw, associated with spongy pads, which aid in running over hard ground or climbing on rocky surfaces. The nail in man and other primates is a highly specialized claw which, being flat and merely forming a plate over the finger tip instead of being a cap, may be used in handling very small objects. In fact the nails are one of the most distinctive features of the human hands, permitting man to perform many delicate movements impossible for other animals.

Among the specialized skin glands of mammals are the sweat glands. They are the most common and generally distributed of

the coiled glands, there being over two and a half million of them in the skin of man. In some mammals that are abundantly clothed with hair the sweat glands become crowded out and highly localized. In cats and dogs, for example, they are localized on the soles of the feet and on the muzzle; these are the only parts of the skin of these animals which ever feel moist.



The mammary glands are tubular skin glands which serve to distinguish the mammals from all other vertebrates.

The sweat glands are tubular glands which reside in the corium and have openings through the epidermis. They have their early counterpart in the mucous glands of fishes and amphibians. The character of the secretion of the sweat glands varies greatly in different mammals. In man it is a watery and colorless fluid; in the hippopotamus and kangaroo it is red; in the African antelope it is blue. In each case, however, the secretion is derived from the blood and contains waste products from the body cells, along with a considerable amount of water.

Most striking of all skin glands are the mammary glands, by which the mammals are distinguished from all other creatures as a separate class of the higher vertebrates. These milk-producing glands are tubular structures. They develop in connection with certain areas, known as the milk ridges, on the underside of the females and are similar in this respect to the ridges which develop in birds on the underside of the body while they are incubating eggs.

The fluid from these glands is believed to have poured out over the surface of the skin of the early mammals, as it still does in the case of the duck-billed platypus and other monotremes, which do not have teats. The system is more specialized in the kangaroo and oppossum, where nipples are present. It reaches its highest development in the placental mammals, where the glands are closely associated with the bearing of the young and their feeding during infancy. The mammary glands dry up when milk is no longer needed.

The development of the mammary apparatus starts in the embryo, beginning at about the fourth or fifth fetal week in the human embryo. A milk line occurs down each side of the belly of the mammalian fetus. It is simply a thickening of the epidermis. It breaks up into small remnants, or beads, which sink into the corium, forming pits. The mammary glands arise from the sides and bottom of these pits, or milk pockets. In some mammals as many as twelve pairs of glands are formed; in others, some of these fail to develop. In man, ordinarily only one pair develops, the fourth from the forward end. Occasionally, however, extra nipples are found in man, the number reaching as high as three or four pairs. This occurs as often in males as in females. Also, there are cases of women who have two and even three pairs of breasts. Such extra nipples and breasts arrange themselves along the vanished embryonic milk lines.

Origin and Development of the Skeleton

The problem of support and protection was encountered by animals at an early date. The first animals were probably small marine forms which either depended upon the currents in the sea for transporting them from place to place or moved about by sluggish efforts of their own. They might have been attached to objects. In such creatures, buoyed up as they were by the water, there was little necessity for supporting structures, and their tissues were soft and unspecialized. Such hard parts as these animals possessed were in the nature of shells or other protective coverings. With increase in size and with the development of vigorous movement, there was an immediate need for greater support and for structures which provided leverage for the body. This need was met independently by the two great groups of animals. Among the invertebrates, the problem was solved by the development of a hardened outer covering and paired jointed appendages. The vertebrates, on the other hand, developed an internal jointed skeleton in connection with paired appendages. Three types of skeletal materials were produced by the vertebrates, namely, notochord, cartilage, and bone.

The notochord seems to have been the first internal skeletal structure to appear. At least it is present in the simplest types of chordates, as is well illustrated in amphioxus, where it is the



The two front teeth in the upper and lower jaws of the beaver are especially adapted to enable the animal to cut wood with ease and rapidity. (Photograph by Ewing Galloway.)

only stiffening and supporting part of the body. It is a tough, flexible rod running the length of the body along the back and below the nerve cord. It gives rigidity to the body and provides for the attachment of the muscles of the trunk.

Cartilage is a translucent material which is firm and elastic and capable of rapid growth. It is a derivative of simpler connective tissue. It is a common supporting material in lower vertebrates. In lampreys and sharks it is the only skeletal material other than the notochord. In land forms its importance has waned, but the ends of the ribs are composed of cartilage and there are layers of it between the joints of the backbone.

In man and other higher vertebrates bone is the skeletal material which predominates. It is made up of a great network of tiny interlacing fibers and irregularly branching cells. Between the meshes of this network is deposited a matrix of inorganic salts, chiefly calcium phosphate and calcium carbonate, which make up about two-thirds of the bone substance. The bones, however, are not solid structures. Most of the large bones are essentially hollow. They are solid at the surface, with bony bars interlaced within for reinforcement of the walls, not unlike the steel framework of modern skyscrapers. The inner cavities of the bones are filled with the marrow, composed mainly of living



"Shell-skinned" animals.

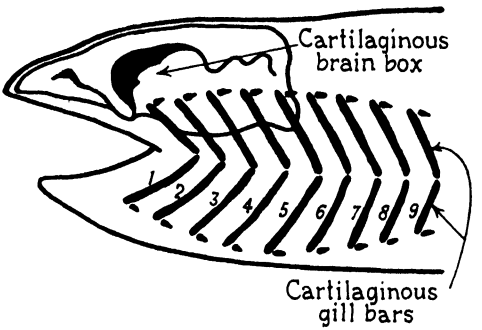
cells around which blood circulates and in which red blood cell are manufactured.

Bone is developed in the vertebrates in two separate and distinct ways. The greater part of the skeleton is formed first as cartilage and is later transformed into ossified bone material. Such bones may be thought of as replacing or cartilage bones. Some bones, on the other hand, chiefly those forming parts of the skull and pectoral girdle, do not go through a cartilage stage at all. They are laid down directly as bony plates, or special scales, in the dermis of the skin. They become closely joined in adult life, particularly in man and the higher vertebrates, and their origin can be seen only in the developing embryo. These bones may be thought of as investing or dermal bones. Cartilage bones and dermal bones do not differ in structure in any way. They cannot be distinguished from each other by microscopic examination; the difference between them lies entirely in their mode of origin.

Head Structures

In man the skeletal part of the head consists of the skull, movable lower jaw, the cartilages of the larynx and trachea, and a few bony structures in the tongue and middle ear. The skull is an exceedingly complex structure. Obviously, no detailed account of it can be given here. However, some idea of the reasons

for its complexity may be gained by a brief review of its comparative features in simpler and more primitive animals.

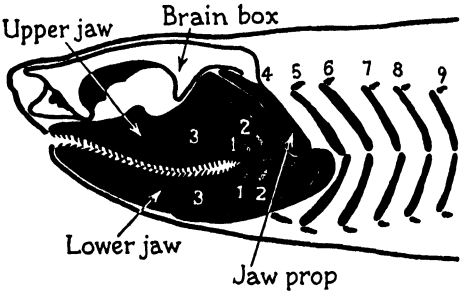


The head skeleton of the ostracoderms probably consisted of a simple cartilaginous brain-box and gill bars of the same material.

The earliest vertebrates of which there is any fossil record were jawless and limbless creatures probably not unlike some forms living today, such as the lampreys and hagfishes. These most ancient of all vertebrates were covered with thick bony plates, forming a solid armor over the head region, and a coat of mail made up of scales over the trunk and tail. With reference to this armored condition, the primitive vertebrates have been called ostracoderms, or "shell-skinned" animals. The skeletal structures of the head, like those of the modern lamprey and hagfish, probably consisted of a simple cartilaginous brain box and gill bars of the same material. A typical example of the head skeleton in such an animal is shown in the drawing. There was no skull in the proper sense, nor any jaws, either upper or lower. The gill bars gave support to the gills, which were the respiratory organs of the ostracoderms. Each gill bar was composed of two parts, upper and lower, as shown in the drawing. Together, the elements of the gill bars formed the gill arches, seven to nine pairs of them, numbering from the pair nearest the mouth.

The ostracoderms were small, sluggish creatures, rarely over a foot in length and often presenting bizarre shapes. They probably fed upon decaying organic material on the bottom of the ancient streams in which they lived. Eventually, some of them, or some creatures closely related to them, migrated into the salt waters of the ancient seas, abandoning their bottom feeding

habits to prey upon other living things. Among them were the ancestors of the modern lamprey and hagfish, whose jawless



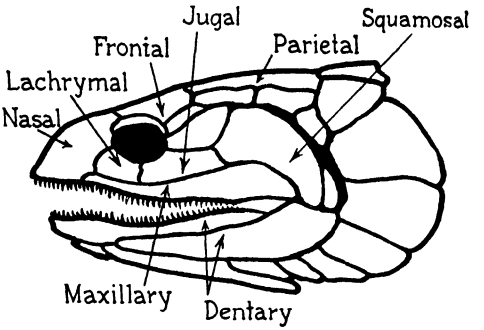
That the jaws of vertebrates are derived from gill bars is clearly indicated by the structural relations of these parts in a primitive shark-like fish.

round mouth forms a sucking disk for attachment to the higher fishes on which they feed by the rasping action of a horny tongue-like structure. Among them, also, were certain forms which developed jaws in order to tear apart the flesh of the creatures upon which they fed. Correlated with the adoption of predacious habits was the assumption of a streamlined body shape and the development of paired appendages to aid in the rapid locomotion necessary to capture their prey. From such beginnings the ancestors of the modern sharks evolved.

The development of jaws was the first important step in the evolution of the typical vertebrate skull. That the jaws were derived from gill bars is clearly indicated by the structural relations of these parts in modern sharks (especially in the ancestors of the modern sharks), and by their mode of origin from primary gill arches in the embryonic development of these and all higher forms. In the change from scavengers to predatory creatures, the mouths of the ancestral vertebrates which gave rise to the earliest shark-like fishes underwent considerable enlargement. It appears that one or two of the foremost pairs of gill bars interfered with this process. These became reduced in size and ultimately disappeared. They are represented in modern sharks by pairs of cartilaginous nodules in the angles of the jaws.

One pair of gill bars, however, increased in size and became associated with tooth-like structures in the skin. The free ends of the paired cartilages comprising this gill arch apparently rotated forward. The upper pair became attached to the brain case by

means of ligaments and formed the upper jaw. The lower pair, through enlargement and modification of their shape, produced



Skull of primitive bony fish.

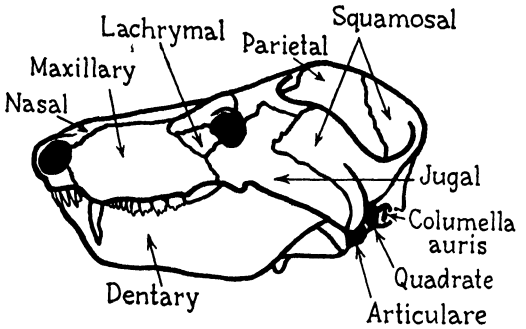
the lower jaw. The point of contact between the upper and lower paired elements of the gill arches became the hinge joint of the jaws. The upper paired cartilages of the next gill arch were utilized in propping the jaw joint against the brain case.

The condition attained through the developments just described is illustrated in the drawing of the skull, jaws, and the skeleton of the gill apparatus of a primitive shark-like fish which lived in the Devonian seas. The brain case, jaws, and gill arches were cartilaginous structures, as in modern sharks, but the teeth were bony modifications of scales with an outer covering of enamel.

Additional significant developments in the formation of the skull occurred in the evolution of the higher fishes. The cartilaginous elements of the brain case, jaws, and gill arches were replaced by true bone. Moreover, bony plates laid down in the dermal layer of the skin covering the head region became associated with the original cartilage bones of the jaws and brain case. These investing bones covered the top and sides of the head completely, fusing with each other and with the brain case and upper jaw to form a true skull. They even invaded the mouth cavity, which is lined with skin, producing a bony palate or roof of the mouth. The skull thus became a solid structure, pierced only by openings for blood vessels and nerves and by the orbits of the eyes and openings of the nostrils.

The cartilage bones of the lower jaw likewise became covered with dermal bones, which, in fishes, extend over the throat on the

underside and over the gill region to the shoulder girdle. The lines of fusion of the dermal bones are clearly visible in the skulls



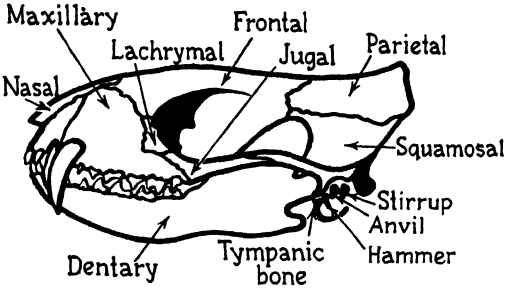
Skull of a primitive mammal-like reptile.

of primitive bony fishes, as shown in a typical instance in the drawing, and even to a certain extent in those of modern bony fishes. Many of these bones, identified by their proper anatomical names in the accompanying drawings, can be traced down through the ages in the evolution of the skulls of higher vertebrates, even to that of man.

When the vertebrates emerged from the sea to live on land, gill breathing gave way to lung breathing. The retention of gill bars was therefore unnecessary, and they have been relegated to a sort of anatomical scrap heap or used in constructing new bones more suitable to the skulls of land animals. This is true to a certain extent in the skulls of amphibians, but more so in those of reptiles and mammals. The dermal bones covering the gill and throat regions disappeared, becoming restricted to the skull and jaws and to isolated elements of the shoulder girdle.

In passing from the fish type of skull and jaws to the condition of these structures in mammals, the most important changes took place in the articulation of the jaws. In fishes, the jaw joint is between two cartilage bones, the quadrate and articular, derived from the upper and lower elements of the gill arch which went into the formation of the jaws. The upper elements gave rise to a quadrate bone on each side of the skull at the rear end of the upper jaw. The upper ends of the lower elements gave rise to the articular bone of each half of the lower jaw. The upper elements of the next gill arch produced the hyomandibular bones,

which prop the jaw joint against the sides of the skull. In amphibians, reptiles, and birds the articulation of the jaws is essentially



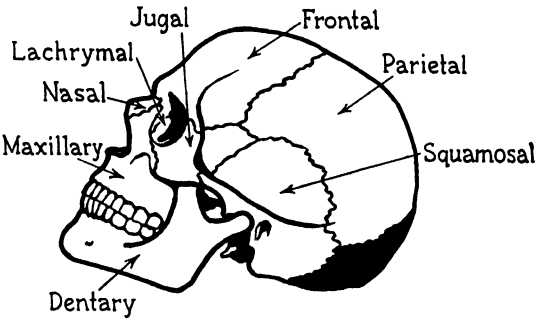
The skull of a primitive mammal serves to illustrate the new type of jaw-joint necessitated in this class of vertebrates.

the same as in fishes, except that the quadrate and articular are much smaller. In these higher vertebrates, moreover, the jaw prop is no longer present. Instead, the hyomandibular is very greatly reduced in size, forming a small bone in the middle ear.

The middle ear is an entirely new structure which appeared first in the most primitive amphibians. It is derived from a rudiment of the first gill slit in fishes. It is a chamber formed by closing off the external opening of the gill slit with a thin membrane, the eardrum. The greatly reduced hyomandibular is attached to the center of the eardrum and serves to transmit vibrations of the membrane to the inner ear.

In mammals, there is a brand-new type of jaw articulation, necessitated by further development of the middle-ear apparatus. The hyomandibular of amphibians, reptiles, and birds has undergone further reduction in size and change of shape. It is now represented by a tiny bone, commonly called the stirrup because it resembles that object in shape. The broad base of the stirrup bone fits into an opening in the bony casing of the inner ear. Associated with the stirrup bone in the middle ear are two tiny new bones. One of these is roughly anvil-shaped and is therefore popularly called the anvil. The other is shaped roughly like a hammer and takes its name from its resemblance to that object. These two new auditory structures are derived from the bones which formed the jaw articulation in lower vertebrates. The anvil bone is formed from the quadrate and the hammer is the remnant of the articular. The handle of the hammer is

attached to the center of the eardrum. The anvil bone lies between the free ends of the hammer and the stirrup bone, com-



Human skull with dermal bones shown in white, cartilage bones in black.

pleting the jointed bridge by means of which sound vibrations striking the eardrum are transmitted to the inner ear.

The result of the migration of the quadrate and articular into the middle ear was that a new type of jaw joint had to be formed in the mammals. As indicated in the series of drawings representing the structure of the skull in the principal vertebrate types, there is considerable reduction in the number of dermal bones in the mammalian skull as compared with that of a fish or reptile. In the lower jaw the dentary bone is the only remaining dermal element. It has expanded to cover and replace the entire original cartilage of the lower jaw. The jaw now articulates with the squamosal, a dermal bone of the skull.

In man the dermal bones of the upper skull have become much enlarged in order to make room for man's expanded brain. At the same time the bones of the upper and lower jaw have become reduced. These changes in the proportions of the head bones have greatly changed the contour of the human face from that of the faces of lower animals. The dermal bones are shown in black and the cartilage bones are represented in white in the drawing of the human skull. A few of the more important bones from a comparative standpoint are labeled to indicate the fusion that has taken place, as well as the change in size and shape, in producing the architectural features of the human skull. Only a few of the original gill arches are present in the human neck, forming the cartilages of the trachea and larynx, or "Adam's apple."

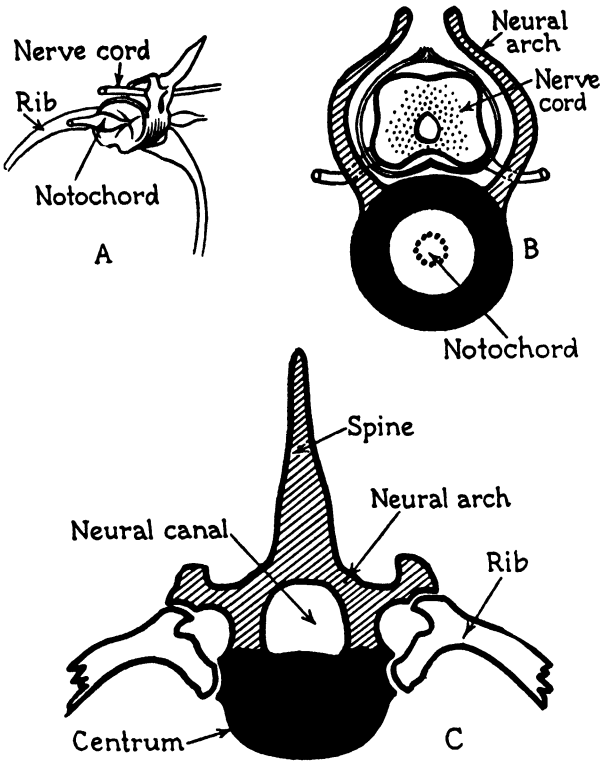
The Vertebral Column

The head bones of vertebrates serve primarily as a protective covering for the brain and a number of special sense organs and nerves. The vertebral column is the part of the skeleton which gives support to the abdomen and some protection to the central nervous system. As is generally known, the vertebral column is made up of separate vertebrae, some of them having long rib extensions. The vertebrae are the end product of a long series of developments which began with the appearance of the notochord. A notochord is present in the embryos of all vertebrates, including man, as has previously been noted. It is the only skeletal structure present in amphioxus and other lower chordates, but in the vertebrates an axial skeleton composed of the vertebral column, ribs, and sternum is attained.

The lowest forms possessing structures comparable to vertebrae are the hagfishes and lampreys. In these primitive creatures there are little paired cartilaginous struts or pegs rising up from the notochord on each side of the nerve cord. There are usually two pairs in relation to each muscle segment along the mid-line of the body. The notochord is continuous and unconstricted. In the embryos of all higher vertebrates the vertebrae first appear in this manner, as paired upper and lower cartilages corresponding to each muscle segment.

Inserted between each of these primary pairs there may be additional secondary paired cartilages. In the formation of each vertebra, the paired upper and lower primary cartilages of one segment fuse with each other and with the secondary paired cartilages inserted between them and the primary cartilages of the next segment behind. The resulting vertebra is therefore intersegmental, permitting attachment of two segmental muscle masses to it. The paired upper primary cartilages of the vertebrae form an arch over the spinal cord, while the paired secondary cartilages and the central portions of the paired upper and lower primary cartilages completely enclosed the notochord. In the tail region the lower pair of primary cartilages form an inverted arch around the main artery of the body.

The sharks are the lowest forms possessing a true vertebral column. In these and certain higher fishes the vertebral column



The vertebral column is made up of a series of separate bones called vertebrae; these being the end product of a succession of developments which began with the appearance of the notochord. A, vertebra of a fish; B, vertebra of a young eel; C, human vertebra.

is cartilaginous, and the remains of the notochord may be seen in the center of the vertebrae, as shown in the drawing. In the bony fishes and in all higher vertebrates, including man, the notochord becomes completely replaced with bone. In some forms, as shown in the drawing of the vertebra of a young eel, the arch over the nerve cord does not quite cover this structure. The drawing of the human vertebra illustrates the typical structure found in higher vertebrates, with the complete neural arch forming a continuous canal in which the nerve cord lies.

In a primitive vertebrate, ribs may be found on every joint in the backbone. This is true even in some reptiles. However, in mammals, including ourselves, many ribs have become much reduced in size and are fused to the separate vertebrae. This gives the impression that the ribs are not present. However, if a

careful examination of the vertebrae is made, these rudimentary fused ribs are clearly visible. In man, for example, there are seven vertebrae of the neck which have only miniature ribs fused to them. The following twelve vertebrae have long curving ribs, the first ten pairs of which extend around to the front of the body. There they are joined to a cartilaginous and bony structure, called the breastbone or sternum, forming a sort of basket for the breathing apparatus. The next five vertebrae have the ribs greatly reduced and fused to them so as to make them heavier and stouter. The succeeding five vertebrae are more or less fused to each other, and have strong projections on each side to form the sacrum, in the hip region, to which the pelvis is attached.

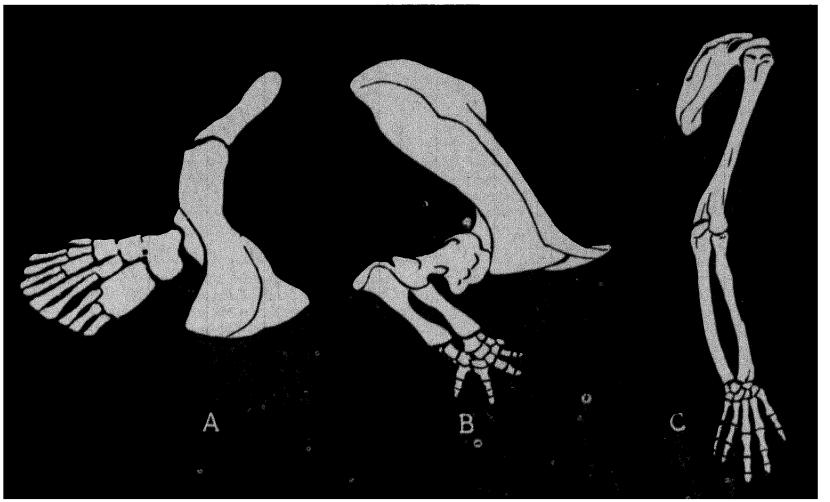
Legs and Arms

As soon as vertebrates emerged from water to land, legs became necessary for locomotion. At first these were small, awkward appendages, as in the case of the amphibians today. In the higher vertebrates they increase in size until they not only form a large part of the skeleton of man but also provide him with ease and delicacy of motion. Therefore, the legs and arms of man represent one end product of a long series of developments in vertebrates, many stages of which are quite clear to us now. Some of these stages are represented in the developing human embryo. In other cases, similarities between the bones of the legs and arms of man and those of other vertebrates show the steps in this long evolutionary process.

The first step in the evolution of appendages in the early vertebrates probably consisted in the development of a pair of lateral skin folds extending along the sides of the body from the head to the tail. These folds were strengthened by supporting tissue, which grew out of the mesoderm and gave them a fin-like structure. It is likely that two regions in each fold, a forward region and a hinder region, became separated and capable of independent movement by means of special muscular development. These two paired regions became more pronounced by continued growth, and at the same time the fold between them decreased in size. A similar condition is observed in some present-day primitive fishes. The muscular folds were reinforced by cartilaginous rays or spines, some of which developed into bones.



This famous X-ray photograph of a young woman made on a film as large as the human body shows the entire human skeleton. The bones are more opaque to X rays than are the other tissues of the body, and therefore cast a shadow which makes them visible. (Photograph by Eastman Kodak Company.)



Forelimbs of three vertebrates: A. Australian "walking" fish; B, primitive amphibian; C, human.

Other bones of dermal origin entered the upper region of the forward paired appendages. Thus, the paired fins of fishes represent the simplest true appendages. No fishes have more than two sets of paired fins, corresponding in number and position to the "legs" and "arms" of terrestrial or land-dwelling vertebrates.

The paired appendages of all land vertebrates are built on the same plan. They consist of the same sequence of bones. These are, essentially, (1) a trio of bones forming a "girdle," which is anchored to the backbone; (2) a single shaft-like bone, called the "femur" in the leg and "humerus" in the arm; and (3) two long bones side by side, known as the "radius" and "ulna" in the arms and "tibia" and "fibia" in the legs. In addition, there are a number of small bones making up the wrist or ankle and, at the tip of these, five sets of four small bones each arranged end to end to form the fingers or toes.

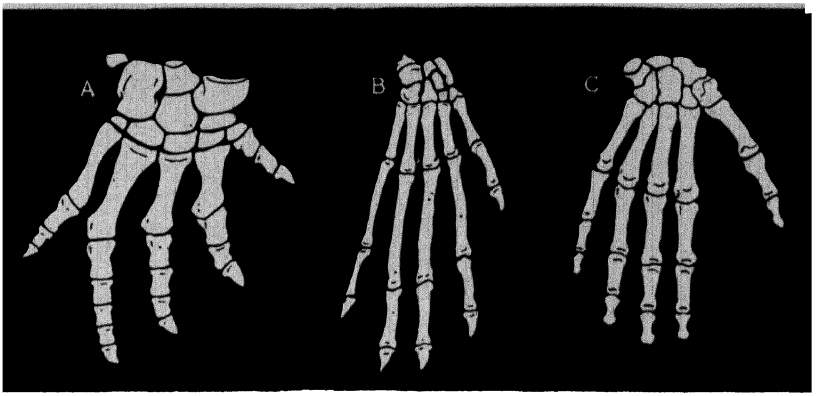
The great diversity of the appendages in vertebrates is brought about primarily by a variation in the shape, size, and length of these bones and to a certain extent by an increase or decrease in the number of bones present. For example, considerable modification of the bones in the fins of fishes takes place when the base is constricted to allow more motion. One type of



A remarkable study of a pigeon at the beginning of flight made by high-speed photography with a motion picture camera employing 2,000 exposures per second. The adaptation of the forward pair of appendages for flight is shown in interesting detail. (Photograph by Edgerton, Germeshausen and Grier, Massachusetts Institute of Technology.)

"walking" fish has only one long bone of the fin (corresponding to the femur) attached to the backbone, the girdle being missing. Two bones constitute the next segment, thus giving the basic pattern of all land animals. The bone structures of the limbs of three types of vertebrates are shown in the drawing on the preceding page. One is the fin of a fish; another, the leg of an amphibian; and the third is the arm of man.

The development of the hand is again a case of slight variations in size and length of the bones and in their arrangement with respect to each other. Illustrations of the bones of the hands of a few vertebrates are shown in the drawings. The hand, although structurally most unspecialized, attains a high degree of coordinated movement in man. It may be said that the human hand takes its place along with the human brain in placing man triumphant at the head of the animal kingdom. It is first of all a grasping organ, capable of holding a tool, a small delicate instru-



A, hand of primitive four-footed animal; B, monkey's hand; C, human hand.

ment, or a weapon. Without its aid the arts and sciences, which are the flower and expression of human civilization, would not have been possible.

This brief comparative study of the skin and skeleton could be continued for every structure of the bodies of animals. Space and other considerations do not permit of such extended treatment here, however. The account which has been given may serve to show in a general way the reasons for the great complexity of the human body, and, in some degree, the manner in which its various anatomical features have been developed.

REFERENCES FOR MORE EXTENDED READING

GREGORY, WILLIAM K.: "Our Face from Fish to Man," G. P. Putnam's Sons, New York, 1929.

While not strictly a "popular" book, this volume is written in such an interesting style and is so well illustrated that it may be read with understanding by the layman.

ROMER, ALFRED S.: "Man and the Vertebrates," University of Chicago Press, Chicago, 1933, Chaps. XIII, XV.

The chapters to which the student is referred contain a brief, but comprehensive account of certain features of the structure of the human body, and the relationship of the conditions found in man to those of other vertebrate animals.

BROOM, R.: "The Origin of the Human Skeleton," H. F. and G. Witherby London, 1930.

This small volume presents a very readable account of the history of the vertebrate skeleton written by one of the foremost authorities on the subject.

KINGSLEY, J. S.: "Outlines of Comparative Anatomy of Vertebrates," 3d rev. ed., P. Blakiston's Son & Company, Inc., Philadelphia, pp. 29–131.

A detailed descriptive account of the anatomy and phylogeny of the vertebrate skin and skeleton. The book is a standard, almost a classic text.

ROMER, ALFRED S.: "Vertebrate Paleontology," University of Chicago Press, Chicago, 1933.

Recommended for the student who wishes to gain a better understanding of the evolution of vertebrate animals.

SNIDER, LUTHER: "Earth History," D. Appleton-Century Company, Inc., New York, 1932.

An excellent reference volume for the student who is especially interested in paleontology.

The American Naturalist, published by The Science Press, Lancaster, Pa.

The American Naturalist is a bimonthly journal containing a variety of articles regarding evolutionary changes in living creatures. These articles range from reports of experimental research to popularized discourses on many fundamental subjects of biology.

Journal of Morphology, published by the Wistar Institute of Anatomy and Biology, Philadelphia.

This is a bimonthly magazine which includes articles on original research in animal physiology and morphology, featuring such fields as cytology, anatomy, and embryology.



10: THE HUMAN ORGANISM

A Study of Its Digestive and Respiratory Systems

IN THE Museum of Science and Industry in New York City there is a complete model of a woman, all parts of which are made of glass. The glass figure forms the main exhibit in the large rotunda just inside the entrance to the museum, and thousands of persons view it annually with absorbing interest. This transparent figure has exposed to view the essential structure and organization of the human body to many people. Were it possible to produce life and movement in all the intricate parts of the model, and then photograph it in a colored, sound motion picture, the story of the human body would be better told than is possible in these pages.

Such a picture would show that the human body is a complex structure made up of an almost countless number of tiny cells

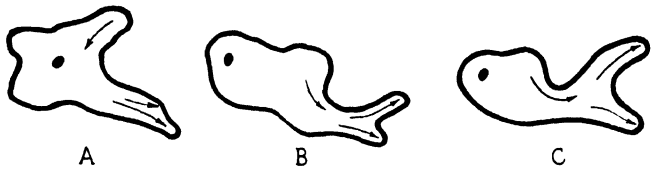
organized into various organs and systems. All of these are delicately adjusted to each other and function with a degree of perfection and coordination unrivaled in the most intricate machine ever designed and built by man. The details of this picture would present the fruits of man's ceaseless inquiry into the structure and functioning of his physical being, a search which has been going on for centuries and which has revealed many remarkable things, not only about the make-up of the human body, but also about the processes of life that surge within it.

From Cells to Systems

It is about a hundred years since the German scientists, Schleiden and Schwann, first announced the cell doctrine (1839) that the structural and functional unit of living matter is the cell. The years that have elapsed have served to strengthen this viewpoint and to reveal its fundamental character. It is impossible to overestimate the importance of Schleiden's and Schwann's contribution to our knowledge of living things. It forms the very foundation upon which rests the whole structure of modern biology and medical practice. Indeed, it is quite possible that in a thorough understanding of the cell is to be found the answer to the question of what life itself is.

There is a large group of animals whose entire bodies consist of a single cell. These are the protozoa. Probably the most familiar protozoa are the amoeba and paramecium. In such creatures, all the intricate processes necessary to life are carried on within a single cell. An amoeba is able to digest food and convert it into the living substance of its body quite as well as does man himself. Digestion is accomplished by the secretion of substances which react with foods, breaking them down or changing them into simpler chemical compounds. These are then absorbed into the cell body; there they take part in chemical reactions which result in the synthesis of exceedingly complex proteins and other substances that make up the living cells or which yield energy for performing the work of the cell. The tiny one-celled animal is able to receive stimuli and respond to them by movement. Stimulation involves chemical and electrical changes in the body of the cell when energy is received at the

cell membrane. The amoeba moves by extending a finger-like projection from its body in a given direction and then causing



The amoeba moves by extending a protrusion of its protoplasm in a given direction, forming a sort of arm, and then causing the remainder of the protoplasm to flow into it.

the rest of its protoplasm to flow into it. Moreover, the amoeba is able to reproduce itself. This occurs by division of the cell, involving intricate processes which are only too little understood today.

All these activities take place within an animal form so small that without the aid of a microscope it escapes the eye entirely. In other similar one-celled organisms the same processes are carried on with structural modifications in various parts of the cell. The bodies of all higher forms of life, including man, however, consist of a large number of cells. With this increase in the number of cells different parts of the body behave differently. Some tissues have functions that are quite different from those of other tissues. One organ, for example, the stomach, is able to digest food. This it can do much more effectively than can the amoeba, but to the exclusion of some other life processes. The stomach is not sensitive to the variety of stimuli to which the amoeba is able to respond, neither are the stomach cells capable of the general movements which amoeba can perform. Another organ, the brain, is able to receive and transmit stimuli. This, too, it can do much more effectively than the amoeba, but at the sacrifice of other functions. Nerve cells cannot digest food nor produce any motion within themselves.

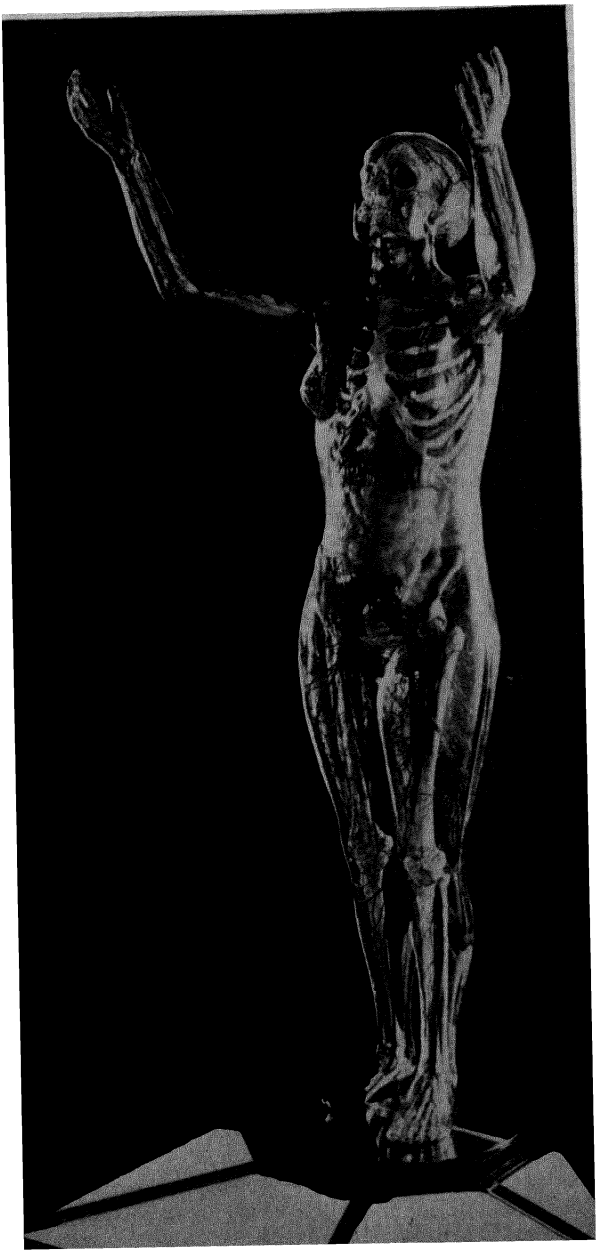
The reason that one organ of the body can perform one function well while another is efficient at some other function is that the cells of which each organ is made are different. There are four main types of cells which make up the bodies of larger animals. These are epithelial, muscular, nerve, and connective-tissue cells. Epithelial cells serve the purpose of protection; also, in some instances they manufacture and secrete various juices. They cover the surface of the body and line the mouth, lung

membranes, stomach, and intestines. Usually they are somewhat flat and oblong in shape, but great variation is manifested. Muscle cells are long and slender and have the special ability to shorten, or contract, when stimulated. They are usually grouped together in bundles and bound with connective tissue to constitute the muscles of arms, legs, and other parts of the body.

Nerve cells have a nerve cell body proper, from which extend two types of fine filaments. One of these filaments may be very long. It is the special adaptation of having protruding filaments which enables the nerve cells to serve their function of transmitting impulses from one part of the body to another. Connective-tissue cells serve to bind together into various units and organs all other cells and tissues. They also act as filler tissue to close up spaces in various parts of the body. In addition, bone cells are modified connective cells.

All the highly specialized cells of the body are forms of or are derived from these four types of cells. In this high degree of specialization, the cells of the body are somewhat comparable to the people living in a big city. Each person in such a community follows some particular line of activity. One is a baker, another a lawyer, a bus driver, a clergyman, and so on. Each does his own task, but to the exclusion of the other's. Together, their activities make up the life of the city as a whole, just as the activities of all the specialized cells of the body make up the life of the complex individual.

In the human body, as well as in the bodies of all other multicellular forms, the specialized cells function together. Usually they are grouped, forming the tissues of the body. Thus, the cells whose special duty it is to filter certain waste materials from the blood make up the functional tissue of the kidneys. The cells that receive, focus, and respond to light energy constitute the essential tissues of the eyes. The cells capable of transferring oxygen to the blood and removing carbon dioxide and water vapor from it form the active tissue of the lungs. These groups of specialized cells are more closely knit and function together more perfectly than does a carpenters' or a barbers' union, to continue the analogy with the economic organization of human societies.



The transparent woman on display at the Museum of Science and Industry is a life-size anatomical model, showing veins, arteries, nerves, skeleton and every organ of the human body. A unique lighting system illuminates each organ in turn until the whole body stands forth in natural color. (Science Service photograph.)

Just as the architect, contractor, building supervisors, and tradesmen must cooperate in the construction of a modern skyscraper, so the various tissues of the body must work together, mutually assisting each other in the welfare of the organism. The association is closer in the case of the body tissues, which are grouped together physically to form organs. In many cases the organs of the body are combined to form systems, comparable to the railroad system or the telephone system of a great nation. The telephone system may be said to consist of the executive officers, research scientists, switchboard operators, linemen, repairmen, bookkeepers, and all the materials and equipment that they use. So, also, in the human body, the brain, spinal cord, ganglia, and nerves, together with their connective tissue, constitute the nervous system. The heart, blood, and blood vessels form the circulatory system.

It is well known that a painters' strike in an automobile plant may upset the whole production schedule or that a truck drivers' strike may discommode an entire city, so specialized and closely interwoven has our economic life become. To an even greater extent is the life of the human organism dependent upon the proper functioning of each of the various organ systems of which it is made up.

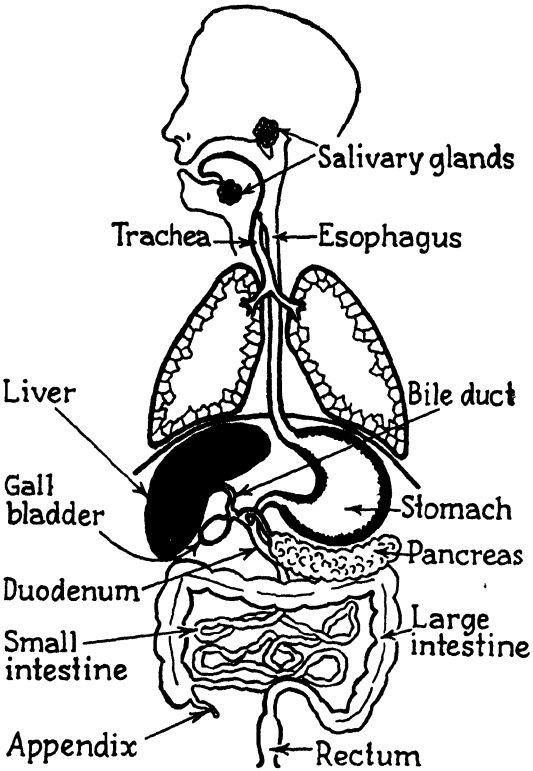
Supplying Foods for a Great Community

In the performance of its particular services to the body community, each of the many billions of cells in a complex animal, such as man, depends on the same vital processes which are necessary for the continued existence of the body as a whole. The energy utilized by the cells in carrying on their specific functions ultimately comes from the oxidation of foodstuffs, with the production of waste products which would seriously impair the operation of the cell, or destroy it altogether, if allowed to accumulate. By far the greater part of these cells are so situated in the body that they cannot secure food and oxygen directly nor rid themselves of toxic wastes in some such simple manner as does the amoeba. Moreover, even if the specialized body cells could obtain raw food materials directly, they are incapable of breaking these substances down into forms suitable for their own use.

One of the important systems of the body of a complex animal, then, is the digestive system. It supplies the body with foodstuffs in a form suitable for use by the specialized cells in growth and repair and in obtaining the energy for carrying on these and other more particular functions. It might be likened to the commissary system of the army or to the agencies which supply food and fuel to a great city.

The lowest animals possessing a digestive system are the coelenterates, such as the fresh-water hydra and the sea anemone. The bodies of these simple creatures are built around a cavity known as the gastro-vascular cavity, since it combines some of the functions of the digestive and circulatory systems in higher animals. Food is taken into this cavity through a single opening at the top. Certain of the cells lining the cavity secrete chemical substances which act upon the ingested food masses and help to break them down into small particles. These particles are engulfed by other cells lining the cavity, which behave very much like amoebae in this respect. The food particles undergo the final stages of digestion within the protoplasm of these cells. Digested foodstuffs then pass from cell to cell in the body wall by diffusion, while undigested masses of food pass out of the cavity through the same opening by which they entered.

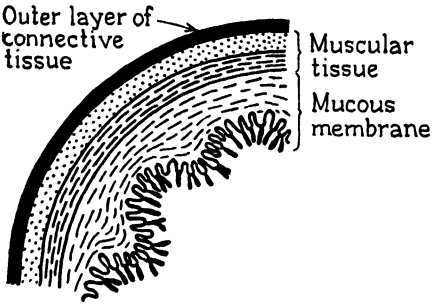
In higher animals, digestion is essentially the same process of rendering food chemically suitable for absorption by the individual cells. The apparatus for accomplishing this is much more extensive, however, because of the magnitude of the task to be performed. There are no amoeboid cells in the digestive system of man for the purpose of engulfing food particles and digesting them inside the cell. All the digestive process must be accomplished outside the cells. The human digestive system consists of the alimentary canal and associated glands and connective tissues. The alimentary canal is a tube, some twenty-five to thirty feet long, which passes through the body. Its contents are not inside the body, but only in contact with a part of its surface. It consists of the mouth, pharynx, esophagus, stomach, intestines, and rectum. Its work involves receiving such food as is offered to it, tearing and grinding this into bits, treating it chemically so that it may be absorbed into the blood stream, and then getting rid of unused materials.



The digestive system in man consists of a much-coiled tube about thirty feet long and a number of accessory glands for supplying digestive enzymes.

The walls of the alimentary canal, except in the region of the mouth, are composed essentially of three kinds of tissues, arranged roughly in layers. The innermost of these is a delicate lining of epithelium, a single layer of epithelial cells usually referred to as the mucous membrane. Certain of the cells of this layer secrete a slimy film of mucus, which is chiefly protective in function. The mucous membrane is the primary functional tissue of the digestive system. Its cells are specialized for the purposes of secreting digestive chemicals or absorbing water and digested food materials. Surrounding this inner lining and composing the main body of the walls are layers of smooth muscle tissue. These smooth muscle fibers give the walls of the alimentary canal considerable elasticity and, by their contraction and relaxation, serve to mix the food with the digestive chemicals and

to push it along through the tract. The muscular and epithelial layers are bound together by loose connective tissue containing



Part of a cross section of the small intestine showing the three essential layers that compose most of the digestive tract. (Redrawn from Carlson and Johnson, "The Machinery of the Body.")

numerous blood vessels and nerve fibers. The stomach and intestines are suspended from the upper wall of the abdomen, or main body cavity, by a thin sheet of connective tissue, which lines the inner surface of the cavity and surrounds the alimentary canal in this region.

The intestines comprise a narrow tube about twenty-two feet long. In the interests of conservation of space, this tube is coiled in a complex manner so as to fit into the abdominal cavity. On first consideration, the system may seem to be needlessly complicated, since a shorter, broader tube would obviously require less coiling. However, one of the primary functions of the intestines is to provide for the absorption of digested foodstuffs. This is a surface phenomenon. Its rate is governed by the amount of surface provided, and a long, narrow tube presents a greater surface than a shorter, broader one.

The alimentary canal is an extensive chemical plant where many chemical reactions take place. The substances which take part in these reactions are the food, water, and certain digestive chemicals manufactured by special cells and organs connected with the digestive tract. Most important of such organs are the salivary glands, pancreas, and liver. In addition to these special organs or chemical plants for the manufacture of digestive fluids, there are countless microscopic glands with tiny ducts opening into the alimentary canal. These are the minute glands found in the inner lining of the stomach and small intes-

tine. They, too, supply special digestive fluids. The digestive fluids contain organic catalysts, or enzymes, which hasten the decomposition of different kinds of foods into substances which can be used by the body cells.

Digestion

As the food enters the mouth it is usually broken up through mastication, or chewing, and is thoroughly mixed with saliva. The saliva is secreted by three pairs of salivary glands. These glands are located in three different regions of the mouth cavity, as if to insure against any one injury destroying entirely the salivary function. One pair is located in the corners of the jaws, just beneath the ears; another is under the jawbone; and the third pair is located on each side of the floor of the mouth. Small tubes or ducts lead from them to the mouth cavity, those from the first pair opening in the cheeks opposite the upper molar teeth and the others just beneath the tongue.

The slow secretion of the salivary glands most of the time serves to keep the mouth moist. When food is taken into the mouth, salivary secretion is greatly increased. The saliva dissolves certain constituents of the food and in so doing initiates the sense of taste, which can be aroused only by substances in solution. Its chief function is to lubricate the food masses, aiding in their mastication and in their passage down the esophagus. The particular material present in the saliva which aids in digestion is an enzyme known as "ptyalin." It brings about the breakdown of cooked starches into sugar substances. The reaction is rather rapid; however, much of it occurs after the food and saliva have been carried down to the stomach. The sugars formed by the decomposition of starches under the influence of ptyalin are the type called "double sugars." An example is ordinary table sugar or cane sugar. Double sugars cannot be used by the body cells as foods unless they are split into simple sugars. Remarkably enough, ptyalin does not effect this splitting. The further breakdown of the double sugars is delayed until the food reaches the stomach or the small intestine, where other enzymes act upon them.

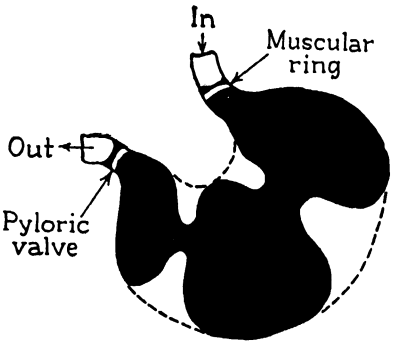
After mastication and mixing with saliva, the food is forced into the throat by an upward motion of the tongue. The muscles



Illustration of how the food is digested, as shown at the New York World's Fair, 1939. (American Museum of Health photograph.)

of the throat contract so as to close the entrance into the larynx, or passage leading to the lungs, and to open the entrance into the esophagus, at the same time forcing food into this passage. Thus we have the process of swallowing. The muscular walls of the esophagus contract behind the food in such manner as to produce ring-like constrictions forming a peristaltic wave that moves along toward the stomach. In this manner, the food is pushed down the esophagus to the point where it enters the stomach. This entrance ordinarily is closed by a thick ring of tightly contracted muscle. When food comes in contact with it, the muscular ring relaxes, allowing the food to pass. Immediately thereafte

the ring contracts again, closing the opening and preventing the food from returning up the esophagus and into the mouth.



Peristaltic waves in the stomach mix the food and move it toward the pyloric valve. (Redrawn from Carlson and Johnson, "The Machinery of the Body.")

The stomach is an elongated sac located near the center of the abdominal cavity. The upper and larger portion, called the fundus, is a rounded compartment, connected with the esophagus and extending down the left side of the abdomen. It tapers into a narrower portion, known as the pylorus, which curves to the right side of the body and connects with the upper end of the small intestine through the pyloric valve. The pyloric valve is, again, a muscular ring which serves to hold materials in the stomach until they have been thoroughly mixed with its digestive juices.

The muscular walls of the stomach exhibit two types of activity. The fundus serves as a storage compartment or reservoir. The muscles of its walls undergo powerful and prolonged contractions, exerting a steady pressure on the food mass and causing it to be pushed gradually toward the pylorus. The muscular walls of the latter undergo ring-like constrictions in peristaltic waves. This action slowly moves the food toward the pyloric outlet but does not force it through. Owing to pressure effects, some material escapes back toward the upper end of the pylorus so that the net result of stomach peristalsis is a sort of churning of the food, serving to mix it thoroughly with the gastric juice.

The digestive juice of the stomach is a mixture of substances secreted by tiny glands located in the mucous lining. The chief components of this mixture are hydrochloric acid and "pepsin," an enzyme that causes the hydrolysis of proteins. By hydrolysis is meant a chemical reaction in which a complex molecule is broken down into simpler parts by the addition of water. The large protein molecules of foods are broken down in the stomach into substances called "peptones." These are materials that are similar in structure to proteins but of lower molecular weight.

They are soluble derivatives of proteins. The hydrochloric acid gives to the stomach contents the acid character so noticeable when, through an upset condition, they are regurgitated into the throat and mouth. The hydrochloric acid does not affect digestion of proteins directly, but it insures the acid environment necessary for efficient action of pepsin. Peptic digestion takes place only slowly if at all in an alkaline medium. The saliva is slightly alkaline, so that the stomach contents must be acidified before peptic digestion can take place to any appreciable extent.

Two other substances are also secreted by the tiny glands of the stomach lining. One of these is an enzyme known as "rennin." Its chief function is to hasten the coagulation or curdling of protein substances in milk. The curdled milk is then subject to an initial breakdown by pepsin. The other substance is an enzyme which brings about the hydrolysis of finely divided fatty material into glycerin and fatty acids. Its action is inhibited by acids and hence it takes place only in small amounts, chiefly at the beginning of gastric digestion, before the stomach contents have become too acidic.

While many people consider the stomach as the most important organ in the process of digestion, it actually plays little part in the final preparation of foods for use in the body. The proteins are only partly broken down, and ordinarily no extensive digestion of fats takes place. Even the ptyalin of the saliva from the mouth does not ordinarily convert starches and double sugars into the simple sugars required by the body cells. The primary function of the stomach is to serve as a storage reservoir in which the food material is thoroughly mixed and converted to the condition of colloidal suspension, after which it is fed into the small intestine. This movement of food into the intestine begins approximately ten minutes after eating and continues slowly for three or four hours before the stomach is empty.

The mixing of the food in the stomach by the peristaltic waves flowing along the muscular walls of the pylorus and the slow passage of the food into the intestine may be strikingly viewed by means of X rays. If a meal is eaten that contains food mixed with a little barium sulphate, the salt renders the food in the digestive tract opaque to X rays; yet it is innocuous to the person digesting the meal. The barium-impregnated food will

cause the X rays to cast a dark shadow wherever it appears. Thus its movement through the digestive tract may be followed by making an X-ray motion picture. Dark shadows of the organs containing this food stand out in clear relief in contrast to the surrounding tissues, through which the X rays readily pass. Contractions of the stomach walls or forward peristaltic movements of the intestinal walls may be plainly observed in this manner.

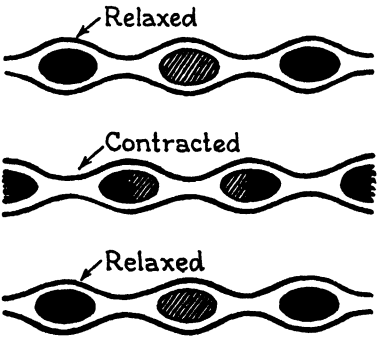
Within the Intestines

On the basis of its diameter, the intestine is roughly divided into two regions, the small and large intestine. As the name implies, the first is the narrower portion. It is also the longer, consisting of some eighteen to twenty feet of the intestine. It extends from the pyloric valve of the stomach to the beginning of the colon. At its upper end it connects with the pyloric valve through a portion known as the duodenum. A large compound duct known as the "common bile duct" empties into the duodenum. One branch of this duct comes from the pancreas, while the other comes from the gall bladder. The duct pours into the intestine the digestive fluids from these organs.

The pancreas is a thin gland, about five inches long, situated just behind and below the stomach. Its head is encircled by the duodenum. The gall bladder is a contractile sac located in a hollow on the underside of the liver. It serves as a storage reservoir for the bile that is secreted by the liver. The liver itself is the largest organ of the human body and the secretion of bile only one of its several functions. It is located in the upper part of the abdominal cavity just beneath the diaphragm and slightly above and to the right of the stomach. Its chief function is to act as a storage place for sugars, after acting upon them to convert them into a complex substance, and to discharge them into the blood stream as needed.

The food is moved along the small intestine by one kind of contraction of its muscular walls. This consists of peristaltic waves similar to those of the stomach and esophagus. The waves occur only slowly and move the food along for but a few inches, when they seem to die out. Another type of contraction of the intestine consists of a rhythmic squeezing and relaxing of the

intestinal wall. This serves to keep the food in a constant sort of churning process and thereby effects a complete mixing with the bile and intestinal digestive juices. It seems that in any particular section of the intestine these churning movements will continue for a time; then a peristaltic wave will move the contents along a short distance to the adjoining section, where the process is repeated.



Rhythmic squeezings and relaxations of the small intestinal wall serve to keep the food in a churning process. (Redrawn from Carlson and Johnson, "The Machinery of the Body.")

The mucous lining of the intestine is not smooth, as it is in the mouth and esophagus. Rather it is deeply folded into ridges, which run around it. The surface area of the intestinal lining is thereby increased so as to permit a greater contact with the food materials. Even more important in this respect is the fact that these folds are completely covered with tiny hair-like projections called "villi." The villi give the intestinal lining a velvety appearance and admirably provide for an increased surface to effect one of the functions of the small intestine, namely, the absorption of digested materials.

Digestion is carried on in the intestine through the action of the pancreatic juice, aided by the bile and certain fluids secreted by one-celled, tubular glands located in the intestinal lining. The pancreatic juice contains digestive enzymes, which are effective, either directly or indirectly, in breaking down each of the three major substances—proteins, carbohydrates, and fats. The products of protein digestion in the stomach, the peptones, are further split up by hydrolysis in the intestine under the influence of one of the enzymes of the pancreatic juice, namely, "trypsin." The action of trypsin on the peptones is usually to produce compounds of several amino acids, called "polypeptides." These are substances which must be further digested before they can be used by the body cells. Thus, the original proteins of foods require still further reaction, and this is accomplished by digestive enzymes from the small intestine, as

will be noted presently. Still another pancreatic enzyme brings about the hydrolysis of starches and double sugars to simple sugars. This is merely a continuation of the process begun in the mouth and stomach through the action of salivary ptyalin and the hydrochloric acid of the stomach.

Perhaps the most important of the pancreatic enzymes is "steapsin," which brings about the hydrolysis of fats to yield fatty acids and glycerol, substances which can be absorbed and utilized by the body. The pancreas is the only gland which secretes a fat-splitting enzyme in significant amounts, and the only appreciable digestion of fat in the body is brought about through the action of this enzyme. If the pancreas is removed, or if its functioning is impaired through disease or accident, one of the most important consequences is that fats pass through the alimentary canal almost unchanged and, therefore, are lost to the body. This result can also be brought about by a failure of bile secretion, since the efficiency of pancreatic enzymes is more than trebled by the complementary action of the bile. Actually the bile is a mixture of certain salts called "bile salts," and products of the decomposition of hemoglobin in the blood. The bile salts aid the action of steapsin by causing the large particles of fat to be broken down into fine droplets that are suspended in the intestinal contents in the form of an emulsion. The surface presented for action of the enzyme is thus greatly increased, considerably hastening the digestive process. The bile salts also aid in making the contents of the intestine alkaline, a condition necessary for the proper activity of the pancreatic enzymes. The pancreatic juice itself is alkaline, owing to the presence in it of sodium bicarbonate, which serves to neutralize the acidity of the stomach contents as they are poured into the intestine.

There remains still another important part of the digestive process. This is accomplished through the action of enzymes in the juices secreted by the tiny glands in the mucous lining of the small intestine. One of these enzymes completes the hydrolysis of polypeptides to amino acids. These are protein products which can be used by the body cells. Thus although this enzyme would be without effect upon whole proteins, it is responsible for the completion of the digestive process begun on them in the stomach and continued by the trypsin of the pancreatic juice. Other

enzymes of the intestinal juices bring about the hydrolysis of double sugars such as milk sugar, cane sugar, and malt sugar. It will be recalled that these double sugars are the products of salivary and pancreatic digestion of starch; also they may constitute a part of the original foods that are eaten. Their conversion into simple sugars, such as glucose and fruit sugar, is accomplished to a certain extent by the hydrochloric acid of the stomach and by the action of a pancreatic enzyme but chiefly through the action of specific enzymes of the intestinal juice.

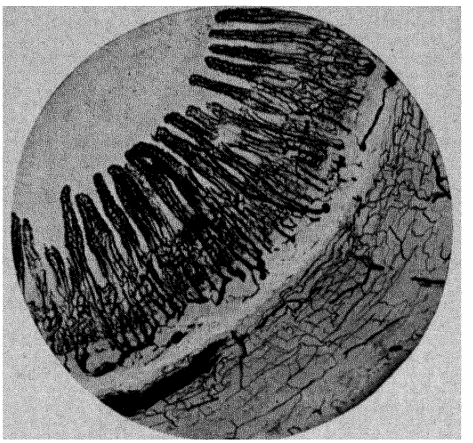
Let us summarize the main steps of digestion of the three major food constituents. We have seen that the first action on starches is by salivary ptyalin. This begins in the mouth and converts these materials into double sugars. The next action on these double sugars, as well as on other double sugars found in foods, is brought about in the small intestine by an enzyme of the pancreatic juice. Here some of the sugars are converted into the simple sugars. Additional specific enzymes in the juices from the tiny digestive glands of the small intestine hydrolize the remainder of the double sugars to simple sugars, such as glucose and fruit sugar. These are products which can be used by the body cells.

The first action on fatty substances occurs in the stomach, where small amounts of these materials are converted into glycerin and fatty acids by the action of one of the gastric enzymes. However, most of the digestion of fats is accomplished in the small intestine by the action of the pancreatic enzyme steapsin with the assistance of certain salts in the bile. The result of this digestion is fatty acids and glycerol, materials that can be used by the body.

We have seen that proteins are first hydrolized by pepsin in the presence of hydrochloric acid to form peptones. This occurs in the stomach. These are further digested in the small intestine by pancreatic trypsin to form polypeptides. The digestion of proteins is completed by the action of specific enzymes secreted by minute glands lining the small intestine, which hydrolize the polypeptides to amino acids.

Absorption

We have seen how in the process of digestion foods are converted into dissolved material chemically suitable for use by the

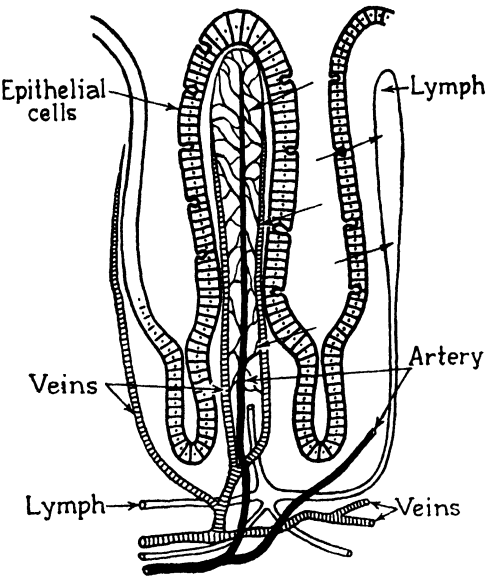


By an effective method of injection, the minute and extensive network of blood capillaries in the villi lining the small intestine of the cat are clearly shown. (Photomicrograph by Roy Allen.)

cells of the body. However, in the strictest sense, these materials in the alimentary canal are still outside the body proper. They must be absorbed into the circulating fluids before they become a part of the internal environment and thus actually available for the tissue cells. This absorption takes place mostly in the lower part of the small intestine, although it occurs to a certain extent throughout the length of the intestinal tract. Very little is absorbed from the stomach. A notable exception is alcohol, and this fact accounts for the rapidity with which the effects of excessive imbibition become noticeable. Practically the only absorption that occurs in the large intestine, or colon, is of water.

The absorption of foodstuffs from the intestine is a complex phenomenon involving specific cellular action modified by the purely physical factors of diffusion and osmosis. The villi of the intestinal lining are covered with a thin membrane beneath which is a rich supply of blood capillaries and a network of lymph vessels. The food materials are passed through the epithelial cells of the villi into either the blood capillaries or the lymph vessels.

The simple sugars, which are the products of digestion of carbohydrates, and the amino acids, which result from the action of the digestive juices on proteins, pass directly into the blood stream by way of the capillaries of the intestinal villi. They are carried by these capillaries into the portal vein and through



Within the villi are found an extensive network of capillaries that connect the arteries and veins, also an ending of the lymph vessels.

it to the liver. Here the simple sugars are stored in the form of a complex sugar, which is a product of synthetic activity of the liver cells. Some of the amino acids pass right through the liver and finally reach the body cells, where they are converted into proteins of the living cell protoplasm. Each different type of cell forms its own specific kinds of proteins. Usually more protein is eaten than is required to furnish the necessary amino acids for this purpose. By far the greater part of the amino acids are acted upon by the liver in such fashion as to remove their nitrogen, producing fatty acids and ammonia. The fatty acids may be utilized in the synthesis of fats for use in the body as fuel or stored energy, or they may be converted into carbohydrate to be put to the same uses. The ammonia is almost immediately combined with carbon dioxide in the liver and converted to urea, which is excreted in the urine.

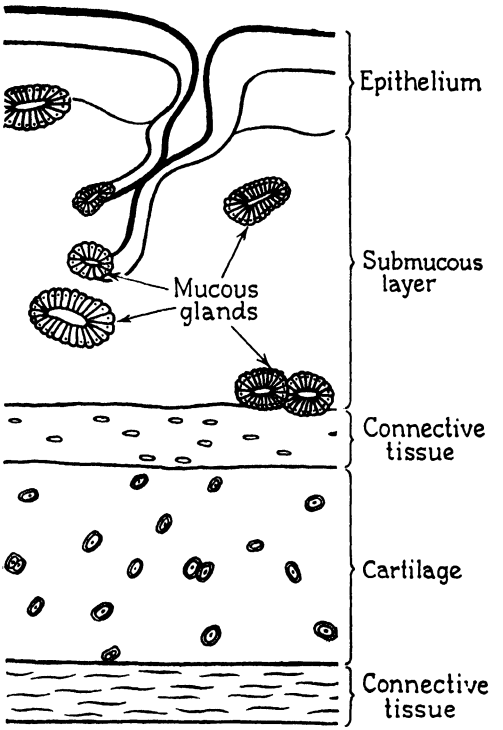
The other great group of food materials, the fats, are absorbed in a somewhat different manner. It will be recalled that in digestion such foods are broken down into fatty acids and glycerol. In the process of absorption the chemical reaction is reversed. Even in passing through the absorbing cells of the

epithelial membrane covering the villi, at least a part of the fatty acids and glycerol are reconverted into fats again. However, the fats now formed are of the human type rather than of the different types formed by other animals. The composition of fats varies considerably, even though the substance glycerol is common to them all, and each species of animal has its own particular kind of fat.

The tiny droplets of fat formed in the epithelial cells enter the lymph vessels of the intestinal villi rather than the blood capillaries. The lymphatics of the villi connect with an extensive system of vessels, which carry the lymph all over the body. Eventually, however, these vessels empty into a large vein in the left shoulder region. By this indirect route, the fats eventually reach the blood stream. After reaching the body cells the fats are used as fuels; their oxidation or burning releases energy and produces a part of the body heat. The consumption of fatty foods in excessive amounts results in the storage of fat in certain connective tissues of the body, notably around the heart, kidneys, intestines, and just beneath the skin.

By the time the food has run the gauntlet of the countless villi in the long length of the small intestine, most of it has been absorbed. At least, most of that part which was properly digested has been absorbed. What remains when the colon is reached, therefore, is primarily undigested and indigestible substances and water. Little digestion of food occurs in the colon except that which is carried on by bacterial action; even less absorption, except of water, takes place from the colon. The absorption of water tends to form the feces or give them their more solid consistency.

The intestine, especially at its lower end, and the colon contain an abundant bacterial flora. The function of these bacteria is largely unknown, although in animals which feed exclusively on plants they play an important part in digesting cellulose and rendering this material useful to their hosts. The bacteria are acquired shortly after birth and are present throughout life. They are harmless as long as they remain in the intestine, but when they invade the blood stream, through a break in the intestinal wall caused by accident or disease, they produce serious disorders which often result in death. A similar result



Transverse section of trachea showing important layers.

occurs if they escape into the body cavity, where they produce inflammation of the peritoneal lining, or peritonitis.

The bacteria are particularly abundant in the vermiform appendix. This is a small extension of the lower part of the small intestine, at its junction with the colon. Inflammation of the appendix produces the condition known as appendicitis, in which there is infection and more or less destruction of the walls. Should the inflammation become acute, the walls may swell and burst unless the organ is removed. Rupture of the appendix permits the contents of the alimentary canal, including numerous bacteria, to pour into the peritoneal cavity surrounding the intestines, resulting in peritonitis and usually death.

Such is the delicate and complicated mechanism which supplies the body with all its food. An understanding and better appreciation of the structure and function of the digestive system should influence one to exercise more care in its treatment.

The Breath of Life

All the energy that man utilizes in his bodily activities, or radiates in the form of heat, in the last analysis comes from the chemical process of oxidation. As ordinarily understood, this has reference to the combination of oxygen with other atoms or molecules. In a stricter sense, however, the term "oxidation" refers to any chemical reaction involving the loss of electrons by an atom. It is always accompanied, therefore, by reduction, in which an atom gains electrons. In a biological sense, the popular interpretation of the oxidative process is permissible only because the substance ultimately reduced in the living cell is oxygen and the final products of the reaction are oxides of carbon and hydrogen, namely, carbon dioxide and water.

It is evident that a constant supply of oxygen is required for the continued liberation of energy in the body and that this element is one of the raw materials essential to life. It is readily available in the atmosphere about us, comprising about one-fifth of it. The problem of obtaining this oxygen is simple enough in minute, single-celled animals, such as an amoeba, whose entire body is in direct contact with water containing dissolved oxygen. In an animal as large, complex, and bulky as man, however, a complicated organ system is required to extract the oxygen from the air, and another is needed to provide for its distribution to the various cells of the body. The latter is one of the functions of the circulatory system.

The function of obtaining oxygen from the air is assigned to the respiratory system. Here the oxygen is brought in contact with a moist membrane of epithelial tissue. It is transferred



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These six pictures of super-fast photography made at the rate of 4000 per second show the movement of the vocal cords during one cycle of a high-frequency note being

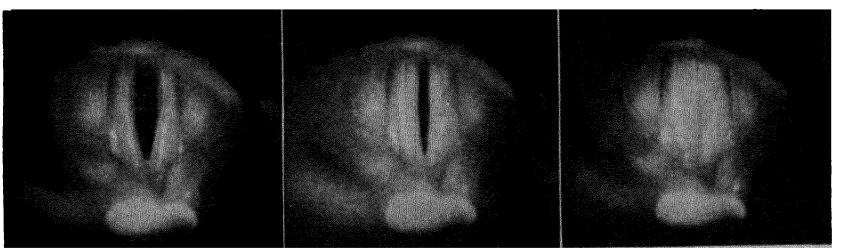
through the cells of this membrane into the blood stream by way of numerous tiny capillaries. The moist membrane also provides for the transfer, from the blood to the air, of the chief products of biological oxidation, namely carbon dioxide and water.

The respiratory system is composed of the lungs and the air passages connecting them with the exterior. The latter are relatively large tubes and include the nasal passages, throat, larynx, trachea, and bronchial tubes. All parts of the respiratory system are lined with a delicate membrane of epithelial cells. Most of the lung structure and the air passages have an outer layer of connective tissue, providing considerable elasticity. In the larger passages, such as the larynx, trachea, and bronchial tubes, a third layer grows between these two. It consists of some muscular tissue and some cartilage or gristle. The cartilage is arranged in rings which encircle the tubes and give them rigidity. These rings are most pronounced in the region of the larynx, or "Adam's apple," where they may easily be felt. They serve to keep the tubes always open so as to allow free passage of air through them.

The inner layer of epithelial cells secretes a moist substance, called "mucus," which tends to lubricate the passages and moisten the air before it reaches the finer structure of the lungs. Some of these cells are ciliated; that is, they have tiny hair-like projections on them. The cilia beat with a continuous forward wave motion which tends to dislodge dust particles and germs from the surface and sweep them upward to the throat.

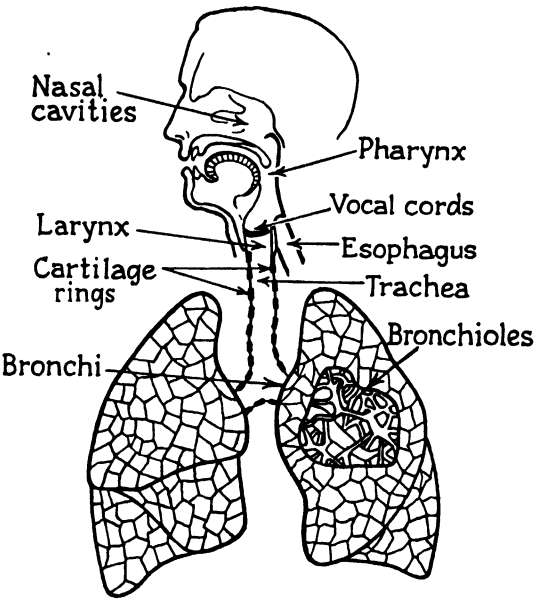
The Breathing Process

The process in which air is taken into the lungs and then expelled from them is known as breathing. The air we breathe



4 5 6

sung by the subject. (Photographs by Dr. J. C. Steinberg, Bell Telephone Laboratories.)



The respiratory system. (Redrawn from Strausbaugh and Weimer, "General Biology.")

is taken into the nose, or should be, where it is freed somewhat of dust and germs by the fine hairs growing at the nasal openings. In the nasal passages the air is warmed to body temperature, saturated with water vapor, and freed of still finer impurities by the whip-like motion of the cilia of the mucous membrane. After this "air-conditioning" process, it enters the cavity of the throat, from which the larynx channel, or windpipe, leads off to the front, while the esophagus going to the stomach leads off from the back. The windpipe is normally open and the esophagus closed. Only during swallowing does the windpipe close and the esophagus open for the passage of food. If one attempts to swallow and to breathe at the same time, both passages are open, and it is likely that the food will enter the windpipe, with a likely "explosive" result, or strangulation.

From the throat cavity the air passes into the larynx, where is located a set of muscular bands called the "vocal cords." They may be tightened or loosened, opened or closed; and by such movements the air passing through them may be set into sound vibrations. Just beneath the larynx, the air enters the trachea. About halfway down the chest the trachea divides into

two branches, called the bronchial tubes. One of the bronchial tubes leads to the left lung, the other to the right lung.

Within the lungs there are finer and finer divisions and ramifications of the tubes connecting with the bronchi. Soon the air has reached very tiny passages known as bronchioles. These are the last of the air passages. Each bronchiole opens into about six or eight small pockets, called "air sacs." Some three to six minute, sac-like nodules, the alveoli, are found on each air sac, so that the final structure is not unlike bunches of grapes in general arrangement. The alveoli average about four-thousandths of an inch in diameter, and their number in the two lungs has been estimated at seven hundred and fifty millions.

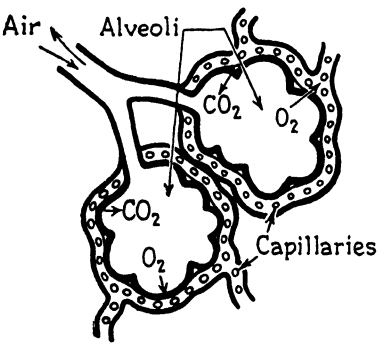
Exchange of Gases in the Lungs

By the time the alveoli have been reached, the epithelial lining of the lungs has become exceedingly thin and the connective-tissue layer has disappeared entirely. Just beneath the layer of epithelial cells there is a thick network of blood capillaries. The actual exchange of oxygen, carbon dioxide, and water vapor takes place across the thin walls of the alveoli and these capillaries. It might seem that some unique process is necessary for the oxygen to filter through the alveoli and capillary walls in one direction and the carbon dioxide and water vapor to pass in the opposite direction. However, this exchange is accomplished by the straightforward and well-known physical process of diffusion.

For a simple illustration consider a gas jet. If the jet is turned on in the kitchen and left unlighted, it will not be long until the odor of gas may be noticed over the entire house. The gas molecules move from the place of their higher concentration, that is, the jet, to areas of lower concentration. If the jet is then turned off, but no ventilation provided, the gas will eventually become as concentrated in one part of the house as in any other part. In other words, the gas molecules continue to diffuse until their concentration is equalized in all parts of the house. This diffusion always takes place in the direction of decreasing concentration.

The air one inhales contains about twenty per cent oxygen and four one-hundredths per cent carbon dioxide. These are the concentrations of respiratory gases reaching the thin walls of

the alveoli. On the other hand, the blood flowing through the capillaries of the alveolar walls, having just returned from the body circulation, is short in oxygen. At the same time it is heavily laden with carbon dioxide. The air exhaled from the lungs contains about sixteen per cent of oxygen and four per cent of carbon dioxide. This difference in composition of the expired from that of the inspired air tells us there has been an exchange of gases in the lungs. Since the concentration of oxygen within the alveoli is greater than that in the blood just across the thin membrane in the capillaries, oxygen diffuses through this membrane and dissolves in the blood. Similarly, the concentration of carbon dioxide in the blood of the capillaries is greater than it is in the air within the alveoli. Consequently, there is diffusion of this gas from the capillaries to the air sacs.



The alveoli are surrounded by capillaries, and an exchange of gases takes place through the thin walls separating them.

The amount of oxygen that may be carried by the blood is greatly increased by a loose chemical union that takes place between the oxygen and the pigment of the red blood corpuscles. As oxygen diffuses through the alveolar and capillary membranes, it is dissolved in the blood much the same as sugar dissolves in water. However, the amount of oxygen which will dissolve in the blood represents only about one per cent of that actually carried in the blood leaving the lungs. Obviously some other mechanism than simple solution must be sought to account for the transportation of oxygen by the blood. Briefly, this mechanism is as follows. As the oxygen goes into solution in the blood, it is immediately removed by forming an unstable compound with hemoglobin, the red pigment present in the blood corpuscles. The capacity of the blood to hold oxygen is thus increased a hundredfold. The formation of the compound between hemoglobin and oxygen is accompanied by a change in color of the pigment from a purplish to a bright red hue. This gives us the marked distinction between venous and arterial blood.

The chemical reaction of oxygen and hemoglobin must occur very rapidly, since the blood in passing through the capillaries remains in contact with the small alveoli only for a second or two. Speed in this case is facilitated by exposing large surface areas of hemoglobin to the oxygen in solution. The red blood corpuscles are exceedingly small. Furthermore they are disk-shaped, with somewhat concave sides, and this shape gives them the greatest amount of surface area possible in proportion to their volume. Their small size makes it possible for an enormous number to exist in the blood, so that the total surface area exposed to the dissolved oxygen is very large. In frogs and other amphibians that do not require so much oxygen as man, the red blood cells are much larger, with a corresponding decrease in surface area. They may easily be observed with a low-power microscope. In man, however, their exceedingly minute size prevents them from being seen except with high powers of magnification.

In the tissues of the body, the chemical reaction between hemoglobin and oxygen is reversed. Here the concentration of oxygen is much lower in the protoplasm of the tissue cells than in the blood. The unstable compound of hemoglobin and oxygen tends to break down, and the oxygen diffuses into the tissues. This process is considerably hastened by the rapidity with which the oxygen is used by the tissue cells.

Just as little oxygen is carried by the blood in simple solution, so also little carbon dioxide is transported in this form. The dissolved carbon dioxide reacts with the water to form carbonic acid. This is a moderately weak acid, which reacts with certain protein salts of the blood to form sodium bicarbonate and potassium acid carbonate. In addition, some carbon dioxide apparently combines directly with hemoglobin, forming a loose union similar to that of oxygen with hemoglobin. This fraction of the total carbon dioxide carried in the blood is very small, however, in comparison with the part transported as bicarbonate.

The formation of bicarbonates and the compound of hemoglobin and carbon dioxide takes place in the capillaries pervading the tissues of the body. In the alveolar capillaries of the lungs the reactions are reversed, since the concentration of carbon dioxide in the alveolar air spaces is considerably less than in the blood. Thus, in the lungs carbon dioxide is released from the blood into



Metal cast of air spaces and passages of the lungs of a dog. Where the metal filled the alveoli well, it formed an almost solid mass; at other places the branching air tubes can be seen. The inset shows a cast of clusters of alveoli at the ends of tiny air tubes. (Photograph by Dr. Victor Johnson, University of Chicago.)

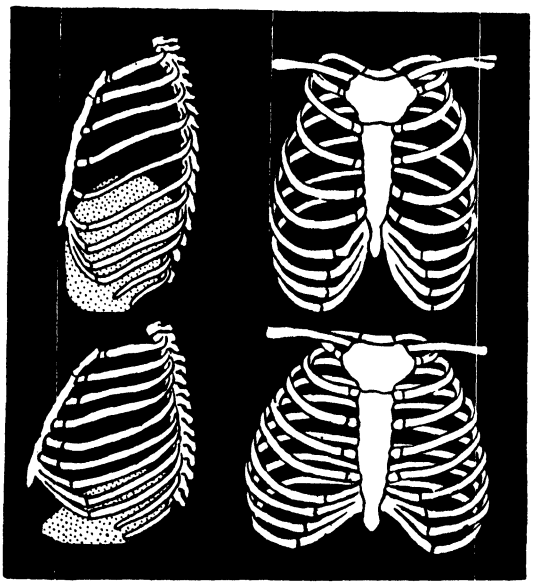
the air, whereas in the tissues dissolved carbon dioxide and carbonic acid diffuse from the tissue cells into the blood.

Quite apart from their significance in the transportation of carbon dioxide from the tissues to the lungs, the bicarbonates have an important role in the regulation of the acid-base balance of the body. The tissue cells are very sensitive to changes in acidity of the fluids surrounding them. In fact they can live only within a very narrow range of concentrations slightly on the alkaline side of neutrality. The accumulation of acids in the system is prevented by neutralization with the bases of the blood to form salts and water which are excreted in the urine. The carbonic acid released in this process of neutralization breaks down in the lungs into water and carbon dioxide, which are excreted.

Mechanics of Breathing

The mechanical phases of the breathing process consist of getting fresh air into the lungs and exhaling the used air. Here well-known physical principles are beautifully applied by the body. The lungs lie completely enclosed in two airtight compartments of the chest, one on the right side and one on the left side. Each lung itself is an airtight sac, opening to the outside only through the bronchial tubes. The arrangement is one in which a bag with a single opening to the outside is placed inside a chamber that is entirely closed. The walls of the inner sac or lung are quite elastic and capable of considerable stretching.

The chamber, or chest cavity, is bounded by the body wall and ribs on the top and sides and by the diaphragm at the bottom. Its volume may be regulated by two mechanisms. One of these involves contraction of the muscular diaphragm; the other, movements of the ribs. The diaphragm is the muscular membrane separating the chest from the abdomen below. It extends up into the chest cavity in somewhat the shape of a dome. When the muscles of the diaphragm contract, the convexity of the upward arching is greatly reduced, pulling the diaphragm down so that the size of the chest cavity above is increased. At the same time, enlargement of the cavity in other diameters is effected by raising the ribs. Each pair of the ribs, which are attached to the vertebral column behind, forms a ring extending



Mechanics of breathing. During exhalation the ribs are lowered as shown in upper drawings, and the diaphragm extends up into abdominal cavity. During inhalation the ribs and breast bone are raised as shown in lower drawings. At the same time the diaphragm is flattened, giving larger volume to the chest cavity.

around to the front to join the sternum, or "breastbone." These rings slope downward and to the front. With each inhalation the front of the ribs is raised by a contraction of certain muscles. The raising of the oblique rings pulls them outward and increases the volume of the chest cavity.

When the chest cavity enlarges, the pressure on the outside of the lungs is decreased. As a result of this unbalanced pressure, air is forced in through the nose by the outside air pressure, and rushes down the air passages into the lungs. This causes the lungs to expand in size until the pressure is equalized on both sides, that is, both inside the lungs and in the chest cavity. The elasticity of the lung tissues permits their expansion in much the same manner as a rubber balloon will stretch because of the elasticity of the rubber when air is forced into it.

Diminution of the volume of the chest cavity is brought about by a relaxation of the diaphragm, which permits it to take its normal shape, and by a relaxation of the rib muscles, which permits the ribs to resume their natural position. Dropping of the

ribs and relaxation of the diaphragm take place simultaneously. When this occurs, the lungs are squeezed into a smaller volume, thus forcing the air out of them.

How Much Air Do We Breathe?

The lungs contain about three liters (three quarts) of air under conditions of normal, quiet breathing. Approximately 600 cubic centimeters (about a pint) of air is inhaled and exhaled with each normal breath while resting. This is called tidal air. However, not all this air reaches the alveoli to supply oxygen to the blood and remove carbon dioxide. About 150 cubic centimeters remain in the larger air passages. Thus in each normal breath about 450 cubic centimeters of air are used for rejuvenation of the blood stream. Under conditions of strenuous exercise or forced breathing about two liters, or 2,000 cubic centimeters, may be inhaled and exhaled at each breath.

But even with forced breathing all the air cannot be exhaled from the lungs. The amount left, of which the lungs can never be deprived, is not less than about one liter. It is generally referred to as the "residual air" and represents the minimum amount of air that is present in the lungs of every person from birth until death. A small part of this residual air cannot be removed even though the lung be dissected out from the chest and completely collapsed. Under no conditions can it be squeezed out of the alveoli. This small amount of so-called "minimal" air is present in the lungs of infants who have taken even one breath after birth and, of course, in all persons of greater age. This property of the lungs is important in certain cases of fatalities in newly born infants. If the infant is born dead, there will be no minimal air in the lung. If, however, a single breath has been drawn, a test will substantiate without any error whatsoever that death by foul or natural cause occurred after birth.

Thus the body possesses an intricate and nearly perfect system for providing the circulating medium with fresh, pure air and for keeping an ample residual supply always in contact with the capillaries just beneath the alveolar membranes. Only when the organs become diseased or damaged by foreign organisms or misuse do they fail in their functions and cause trouble.

REFERENCES FOR MORE EXTENDED READING

BOGERT, L. J.: "Diet and Personality," The Macmillan Company, New York, 1936.

In this interesting and nontechnical little book a well-trained student of nutrition has presented facts and explanations which may be of help to laymen in adapting and regulating their diet intelligently to their special physical type and to modern living conditions. Practical and sound suggestions regarding the relationship of diet to body size, age, health, infections, indigestion, undernourishment, and overfatigue are some of the subjects included.

HILL, A. V.: "Living Machinery," Harcourt, Brace & Company, Inc., New York, 1927, Lecture IV.

This book consists of six Christmas lectures delivered by the author at the Royal Institute in London in 1926. Lecture IV contains much information on how the lungs supply the blood with oxygen and how this oxygen is distributed to the body. The excellent manner in which the author describes how these things are demonstrated and proven is one of the features of the book.

ROMER, A. S.: "Man and the Vertebrates," University of Chicago Press, Chicago, 1933, Chap. XIV.

A part of this chapter treats concisely and clearly of the digestive and respiratory organs and respiratory processes in man.

STILES, P. G.: "Human Physiology," rev. by G. C. Ring, W. B. Saunders Company, Philadelphia, 1939, Chaps. XIII, XIV, XV, XX, XXI, XXII, XXV, XXVI.

The authors have written in these chapters an exceedingly clear and complete elementary discussion of the organs and processes of digestion and respiration. In Chap. XXII is an explanation of the "transformation of matter" after it has been absorbed by the body cells. Nutrition and hygiene are discussed in the last chapters to which reference is made.

BEST, C. H., and N. B. TAYLOR: "The Human Body and Its Functions," Henry Holt & Company, Inc., New York, 1932, Secs. IV, V.

These sections are an explanation of the mechanisms and processes of respiration and digestion. The authors have included a considerable amount of detail of the body structure and functions. Descriptions and discussions are often by analogy, and the chapters are clearly illustrated, the illustrations tending to make the book readily understandable.

CRANDALL, LATHAN A.: "An Introduction to Human Physiology," W. B. Saunders Company, Philadelphia, Chaps. VIII–XIII.

In these chapters is found a description of the respiratory and digestive organs, including some detailed account of how respiration and digestion is accomplished.

EULENBURG-WIENER, VON RENÉE: "Fearfully and Wonderfully Made," The Macmillan Company, New York, 1938, Chaps. III, IV, V, VI, VII, XII.

This is a rather comprehensive survey of the digestion of foods written in style that is quite understandable to the general reader. Chapter XII includes a discussion of the respiratory system and the processes by which gases are exchanged in the blood flowing through the lungs.

CARLSON, A. J., and V. JOHNSON: "The Machinery of the Body," University of Chicago Press, Chicago, 1937, Chaps. VI, VII, VIII.

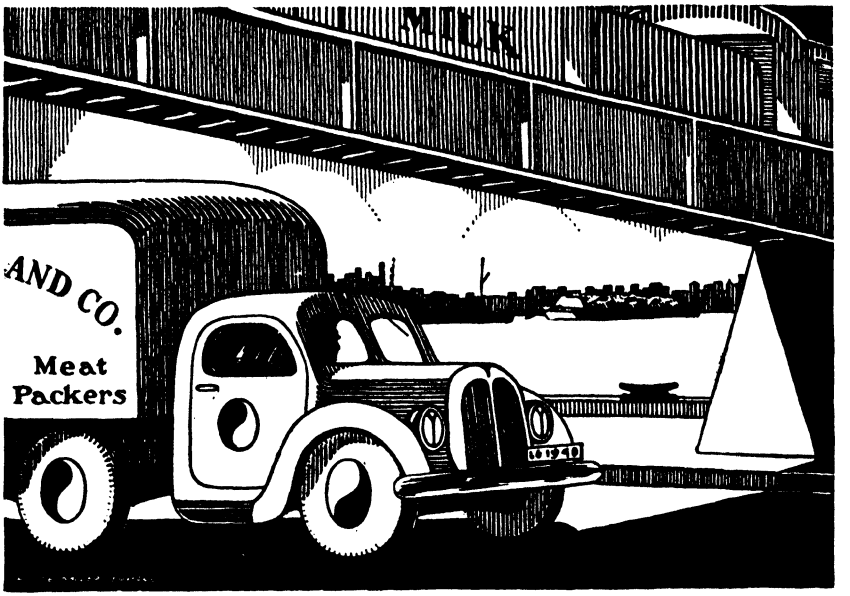
Chapter VI is a well-written and clearly illustrated discussion of respiration, and Chapter VII treats similarly of digestion. Chapter VIII deals with the uses of food elements by the body, metabolism, and the excretion of wastes.

Human Biology, published by Johns Hopkins Press, Baltimore.

This quarterly journal contains only articles that are records of research. The subjects discussed include a wide range of studies in human biology, and many are subjects that will be of interest to the intelligent layman. An elementary understanding of the statistical methods of presenting data is necessary for a thorough reading of the text.

The Anatomical Record, published by The Wistar Institute of Anatomy and Biology, Philadelphia.

The Anatomical Record is a monthly professional journal which publishes original researches on vertebrate anatomy. The articles are usually accounts of highly specialized investigation and cover a wide range of subjects in the field of vertebrate anatomy.



11: MOVEMENTS OF MATERIALS

A Study of the Human Circulatory System and Excretory Organs

PEOPLE who live in a large city are aware of the necessity for an adequate system of transportation. This is especially true when some circumstance produces a partial or complete paralysis of the regular facilities. People and supplies cannot reach their destinations. Wastes accumulate, imperiling the health of the community. Inconveniences or severe hardships result for everyone. In villages the problem is less acute or does not exist at all. The grocery, the drugstore, the church, and individual homes are in close proximity. Intermingling of the people and the exchange of goods and services are correspondingly easy and simple.

These varying degrees of economic dependency find their counterpart in organic nature. In the simplest one-celled creatures no circulating or transporting mechanism is required. The organism is in direct contact with a medium containing both

food and oxygen and obtains these directly by ingestion and absorption. Higher forms show the beginnings of a system for the distribution of materials within their bodies. As the latter get larger and more complicated, this system increases in complexity. The human body is as intricate and elaborate an organic structure as any found in nature. It contains the most complex and delicately balanced of transportation facilities.

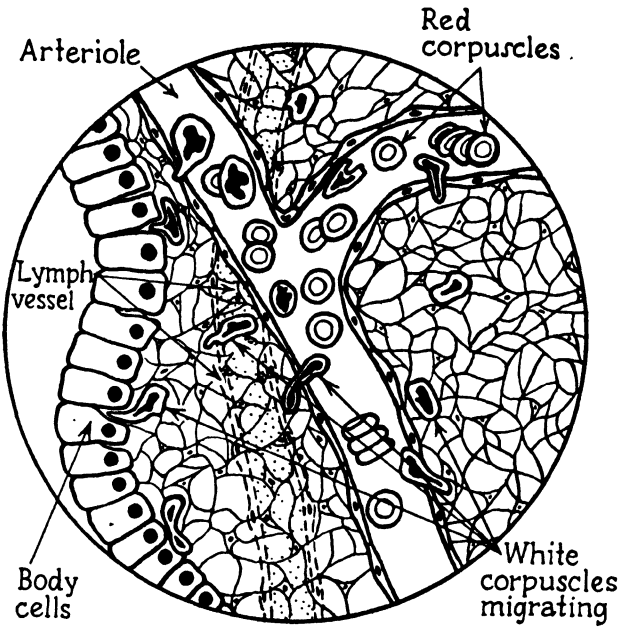
Providing a Suitable Cell Environment

In the preceding chapter two great systems were discussed which supply the body with materials from the outside world necessary for life. Another system was mentioned which transports these materials to the individual cells and carries away their waste products. Most of the cells of the body are far removed from any outside food or oxygen supply. They cannot get life necessities unless these are brought to them. Likewise, the waste products formed by the individual cells would soon accumulate in and around them unless removed. Without such removal all soon would become poisoned and would die.

It may accurately be said that much of the work of the body is concerned with maintaining a special environment around the individual cells in order that they may live and carry out their specific functions. This special environment is a watery salt solution derived from the blood. In many respects it is not unlike the sea water surrounding marine animals. It is known as the tissue fluid. In many places in the human body, where the cells are closely packed, this fluid is only a thin film between them; nevertheless, it is always there.

Dissolved in the tissue fluid are digested foodstuffs and oxygen, which are taken up and used by the cells, and waste products, which are continually being produced within the cells by their metabolism. The oxygen and food supplies must constantly be replenished and the wastes removed in order for the cells to function normally. This turnover in composition of the tissue fluid is brought about at an exceedingly rapid rate, and it is the function of the blood circulating in every part of the body to maintain a stable condition of this internal environment.

The blood does not actually mingle with the tissue fluid. Rather it flows in a closed system of vessels which reach all



A network of arterioles and lymph vessels permeate the entire body, maintaining a proper condition in the tissue fluid surrounding the body cells.

parts of the body. The finest branches of this system, called "capillaries," form a network around and between the tissue cells. The digested foodstuffs carried in the blood stream pass through the thin walls of the capillaries into the tissue fluid. This is accomplished by diffusion of the molecules of such foodstuffs from the center of their higher concentration to one of lower concentration, since the amount of food materials in a unit volume of the blood is greater than it is in a corresponding volume of the tissue fluid just on the other side of the thin capillary membrane. Oxygen likewise diffuses into the tissue fluid for the same reason. However, the larger molecules of the blood, such as those of the blood proteins, cannot readily get through the meshes of the capillary membranes. The same thing is true of the red corpuscles. Therefore, they tend to remain in the blood. A selective diffusion results, in which only the materials useful to the body cells pass into the tissue fluid to any great extent.

Certain waste products produced by the tissue cells diffuse in the opposite direction. The tissue fluids tend to be richer in

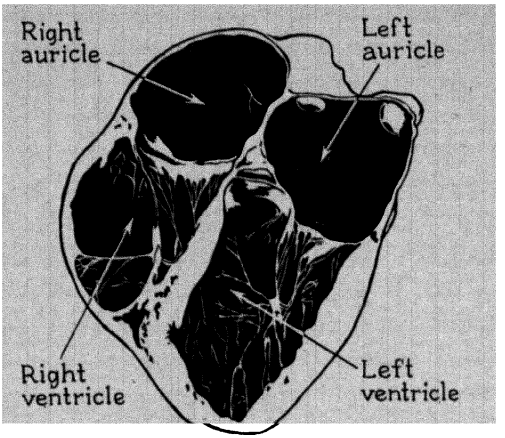
carbon dioxide than the capillary blood. Therefore, this substance will move from the tissue fluids into the capillaries, to be carried away and thus prevented from accumulating around the cells. Also taken away in this manner are various salts and other substances having relatively small molecules. Other waste products are removed from the tissue fluids in an entirely different manner. This is especially true of certain materials composed of relatively large molecules, fragments of dead cells, and bacteria which generally will not go through the capillary walls. Such materials pass into a second set of capillary tubes which also permeate the entire body. These vessels have very thin membranous walls, even thinner than those of the blood capillaries. The capillary tubes join larger ducts so as to form a continuous system. This second set of capillaries are the lymph capillaries, and the larger passages constitute the lymph vessels. The lymph vessels eventually empty into the blood stream in the shoulder region. Thus, all the waste products of the cells finally are delivered into the circulating blood.

We have seen that very definite and delicately balanced conditions are maintained around each cell of the entire body. In order to accomplish this materials must often be transported great distances within the body at definite, though changing, rates. The mechanism for facilitating this transportation we call the circulatory system. It consists of the heart, blood vessels, and blood, supplemented by the lymphatic system.

Heart Action

It is not necessary to tell anyone that the heart is an important part of the circulatory system. Everyone knows this to be true. It is also generally known that the continued and regular beating of the heart is necessary to life. When the heart stops beating a person soon dies. There are few other natural causes of death that act more suddenly or with greater dispatch than does heart failure. However, beyond these general concepts, most people are confused in their knowledge of the precise structure and action of this important and vital organ. Usually they are ignorant of a few general precautions that should be observed in order that the heart may function satisfactorily until mature old age.

The heart is a thick-walled, muscular organ which acts as a great pump to force the blood to all parts of the body. The heart



The human heart consists of two separate parts, a right heart and a left heart. Each of these parts has two chambers, an auricle and a ventricle, which are connected by valves.

of an adult human really consists of two separate organs, a right heart and a left heart. As a result of their evolutionary origin and embryonic development, these two hearts are adjacent to each other and give the appearance of one organ. The right heart receives blood from the body circulation and passes it on to the lungs. The left heart receives the blood coming from the lungs and pumps it to the rest of the body. While both hearts work in unison, the blood from one does not mix directly with that of the other.

Each of the separate hearts consists of two chambers, an auricle and a ventricle. The auricles receive blood into the hearts; the ventricles force it out of them. Blood coming into the right heart from the vessels of the body flows into the upper chamber, the right auricle. This is a relatively thin-walled cavity which connects below with the right ventricle. The blood is forced into the ventricle from the auricle mainly by a feeble contraction of the latter's walls. The passage which connects the auricle and ventricle is guarded by a structure consisting of three thin flaps directed downward, known as the tricuspid valve. No obstruction is offered by this valve to movement of the blood in the direction of the ventricle. However, when the blood attempts to flow back into the auricle, the tricuspid valve closes immediately,

preventing such movement. The valve is supported from beneath by strong fibers so that the flaps cannot be turned upward too far, thus permitting leakage of blood into the auricle.

The right ventricle is a somewhat triangularly shaped chamber with relatively thick, muscular walls. When the walls of the ventricle contract, the pressure of the blood closes the tricuspid valve and the blood itself is forced into the vessels leading to the lungs. In leaving the ventricle, the blood must pass a set of three pocket-like valves guarding the entrance into the pulmonary artery. These valves allow the blood to flow only in the direction of the lungs. They provide a sort of safety stopgap to prevent the blood from flowing back into the ventricle and piling up during the latter's period of relaxation.

The left auricle, which is situated at the top of the heart, receives blood from the vessels coming from the lungs. It, too, possesses relatively thin contractile walls. Below, it connects with the left ventricle through an opening surrounded by two flaps pointing downward, known as the bicuspid valve. This valve functions in a manner similar to the tricuspid valve, permitting the blood to flow only one way, that is, from auricle into ventricle.

The left ventricle is a triangularly shaped chamber, like the right ventricle but with very much thicker muscular walls. Contraction of the left ventricle forces the blood out through the great aorta to all parts of the body. The greater thickness of its walls in comparison with those of the right ventricle gives it a more powerful pumping stroke. This is indeed necessary, since the left ventricle must pump the blood over a much greater distance. Just at the beginning of the aorta are a set of three pocket-like valves which prevent the blood from flowing back into the ventricle during the period when it is relaxed. These valves, and the similar ones at the beginning of the pulmonary artery, serve as exit gates from the heart. They permit outgo but never entrance of blood to the ventricles. They are the only valves in the entire arterial system.

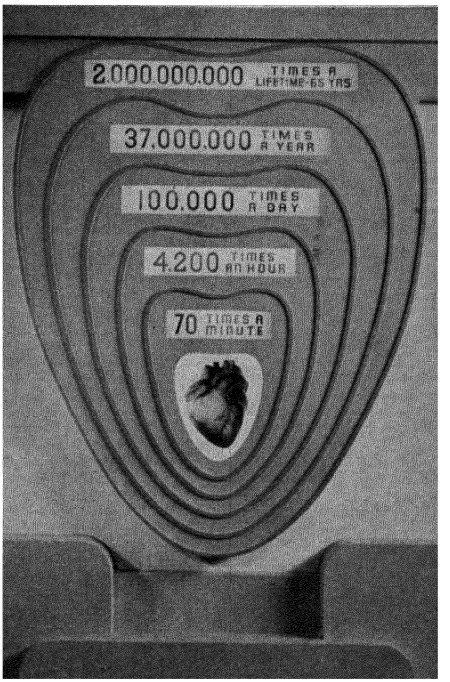
The cycle of operations in the heart begins with the contraction of the walls of the two auricles, the right auricle slightly preceding the left. Blood is forced thereby into the right and left ventricles through the tricuspid and bicuspid valves,

respectively. There is a slight pause, then simultaneous contraction of the ventricles takes place, the tricuspid and bicuspid valves close, and the blood is forced from the heart. This is followed by relaxation of the muscular walls of the auricles and ventricles in the same order. Blood again flows into the auricles from the veins, and the cycle is repeated.

The total time consumed in a single cycle of contraction and relaxation of the heart is about 0.8 seconds. This interval is so brief that the original discoverer of the circulation of the blood, the English scientist William Harvey, was forced to remark three hundred years ago that "the motion of the heart is to be comprehended only by God." However, since Harvey's day instruments of greater precision have been devised which permit not only of observing the motions of the heart but of timing them as well. The time required for the auricular contractions is about 0.05 second; that for the ventricular contractions is 0.30 second; and the total time for relaxation is about 0.45 second.

The events of heart action produce certain sounds that accompany the contractions and the closing of valves. The manner in which the heart is functioning can be judged very accurately by the exact nature of these sounds. Each normal beat produces two sounds. The first is rather low-pitched and prolonged. It is produced from two actions, one the closing of the tricuspid and bicuspid valves, and the other the contraction of the thick walls of the ventricles. This sound is definitely altered when the valves do not close properly. The other sound of the heartbeat is high-pitched and of short duration. It is produced by the rapid closing of the valves leading into the great aorta and the pulmonary artery at the instant when ventricular contraction is finished. If these arterial valves become damaged or begin to leak, this second sound is greatly altered or disappears.

In addition to the above normal sounds, heart murmurs are sometimes heard. They usually result from some irregular flow of blood through the heart or great aorta. For example, when the tricuspid or bicuspid valves do not close properly, there is a backward flow of blood through them during the contraction of the ventricles. This backward flow will produce a gurgling sound, or murmur. When there is leakage through the valves at the entrance to the aorta, blood will flow back into the left



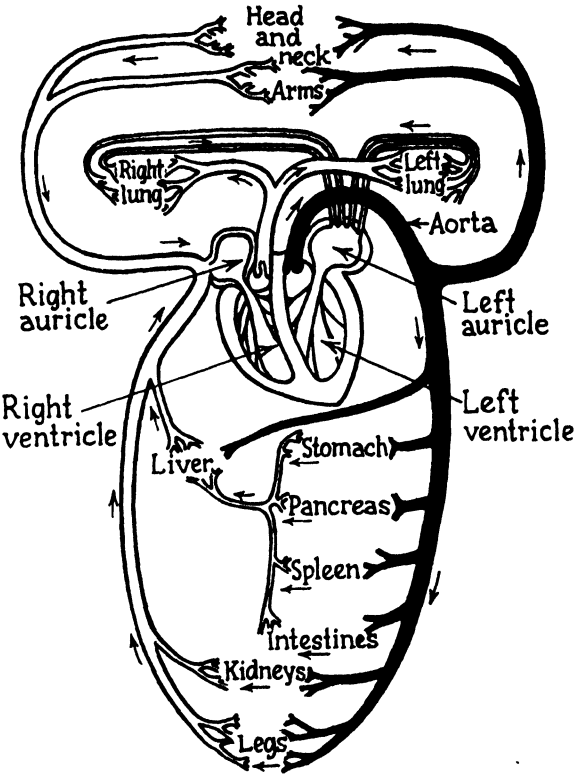
A striking exhibit at the Golden Gate International Exposition in 1939 to illustrate the number of times the heart beats within a lifetime of 65 years. (Ciba Pharmaceutical Products photograph.)

ventricle during its interval of relaxation, again producing a murmur as well as seriously interfering with the normal heart action.

Any such irregularities as are revealed by peculiar heart sounds can easily be detected by a competent physician. The same is true of certain infections or chronic conditions that may later produce serious effects upon heart action. A periodic, complete medical examination oftentimes would reveal to the individual minor disorders that could be effectively treated before they became serious. Such periodic examinations are important for discovering the condition not only of the heart but also of the entire body.

Canals for Circulation

The blood vessels constitute another integral part of the circulatory system. The vessels carrying blood in a direction



The circulatory organs are the heart, arteries, capillaries and veins which form a closed system of tubes that extend throughout the entire body. (Redrawn from Young "The Human Organism and the World of Life.")

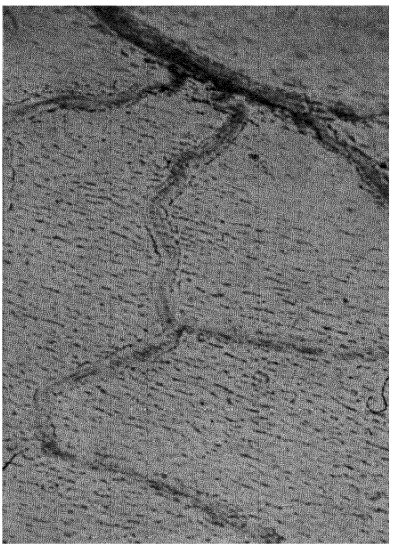
away from the heart are called "arteries." Those returning the blood to the heart are called "veins." The two sets connect with each other, so as to form a closed circuit, through an extensive network of minute, thin-walled vessels in the tissues, called "capillaries." This canal system as a whole forms two great loops linked through the heart in such a way that the blood must flow through each in making a complete circuit around the body. One loop consists of the circuit from the left side of the heart through the body capillaries and back to the right side of the heart. It is known as the "systemic" circulation. The other loop consists of the circuit from the right side of the heart through the lung capillaries and back to the left side of the heart. It is known as the "pulmonary" circulation.

On leaving the heart to enter the systemic, or body, circulation, the blood passes through the largest artery of the body. This is the aorta. It forms a great arch extending upward from the left ventricle and toward the left side of the chest cavity, then, turning downward along the back wall near the backbone, it pierces the diaphragm to enter the abdominal cavity. As it emerges from the heart, forming the aortic arch, the aorta is very large, having a diameter of about an inch. It immediately gives off several large branches. One of these supplies the head, chest, and right arm; another, the chest and left arm. A much smaller but extremely important branch supplies the heart itself. Within the abdomen, several other large branches are given off which supply the stomach and intestinal tract, the digestive glands, the spleen, and the urinogenital system. Finally, the aorta breaks up into branches going to the legs and to the region of the end of the spine.

With continued branching, the aorta grows progressively smaller in diameter. The diameter of the branches likewise tends to get smaller and smaller as they, too, branch. The larger arteries supplying the limbs, head, trunk, and some body organs are on the average about one-quarter of an inch in diameter. They continue to divide and subdivide until, as minute vessels called arterioles, they permeate all the tissues of the body. The arterioles themselves undergo further subdivision into many smaller branches, the capillaries. By the time the capillaries are reached the diameter of the vessels has decreased to an average of less than one-thousandth of an inch. Their length is on the average about one-hundredth of an inch. The capillaries are so numerous, however, that were their contents all spread out to form a continuous surface, they would cover an acre of ground.

The walls of the arteries are composed essentially of three layers. The innermost one is a thin membrane of smooth epithelial cells, called "endothelia," which permit the blood to flow with minimum friction. Outside this lining is a layer of muscular tissue which decreases in thickness as the arteries get smaller. The walls of the arterial vessels, therefore, are capable of contraction and relaxation, so that their diameter may be changed. Outside the muscular walls is a layer of connective tissue, which

is both tough and elastic, permitting the arteries to expand when necessary but resisting rupture even by very high internal pressures.



A network of blood capillaries branching off from an arteriole as photographed from the mesentary of a living frog. (Photomicrograph by B. Zweifach, New York University.)

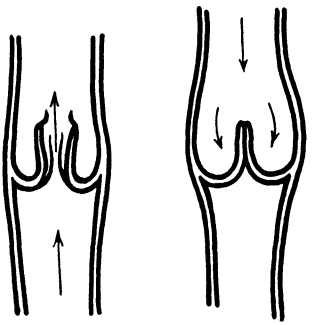
The thickness of the arterial walls decreases as the size of the vessels diminishes until the capillaries are reached. Here both the muscular and connective layers disappear, leaving only a microscopic layer of epithelial tissue. This thin membrane permits the exchange of materials between the blood in the capillaries and the tissue fluid outside.

As the blood courses through the larger arteries the pressure change with each heartbeat is quite pronounced. Such pressures may readily be felt by placing the finger on any artery near the skin surface, as, for example, the one on the thumb side of the wrist. However, there is a continuous decrease in this pulsating pressure as the distance from the heart increases. This is due to the friction encountered along the way and to the resistance offered by the arterial walls to their wave-like expansion and contraction following each heart beat. By the time the capillaries are reached the pulsating pressure has completely disappeared and the blood flows at an even pace.

The network of capillaries penetrates all the tissues of the body. As it moves along, the blood in the capillaries gives up food materials and oxygen to the tissue fluid and collects waste products from it, as has already been noted. The actual sight of the blood streaming through these fine vessels, or a clear mental picture of it, makes for a better understanding of the complex physical structure of the body.

This capillary network and circulation may be observed quite easily by looking through a microscope at some thin, living, animal tissue having a rich supply of blood vessels. This is an

experience that everyone should be fortunate enough to have. A suitable tissue is the gill structure of the mud puppy, an amphibian which is commonly found in many streams and ponds in the eastern part of the United States. The gills are so thin and transparent that the capillaries may easily be observed in them. The phenomenon may also be seen in the web of a frog's foot.



The one-way streets of the capillaries must have some outlet. They cannot terminate with dead ends. As a matter of fact, they unite to form small vessels carrying blood away from the tissues. At first, these are tiny venules corresponding to the arterioles. The venules drain into veins, which gradually increase in diameter. The veins are somewhat larger than the corresponding arteries, and their walls are thinner and less elastic. Eventually they come together to form the large vessels emptying into the heart. The large vein from the lower part of the body is known as the "inferior vena cava," while that from the arms and head is called the "superior vena cava." They unite to form one large vessel just before emptying into the right auricle.

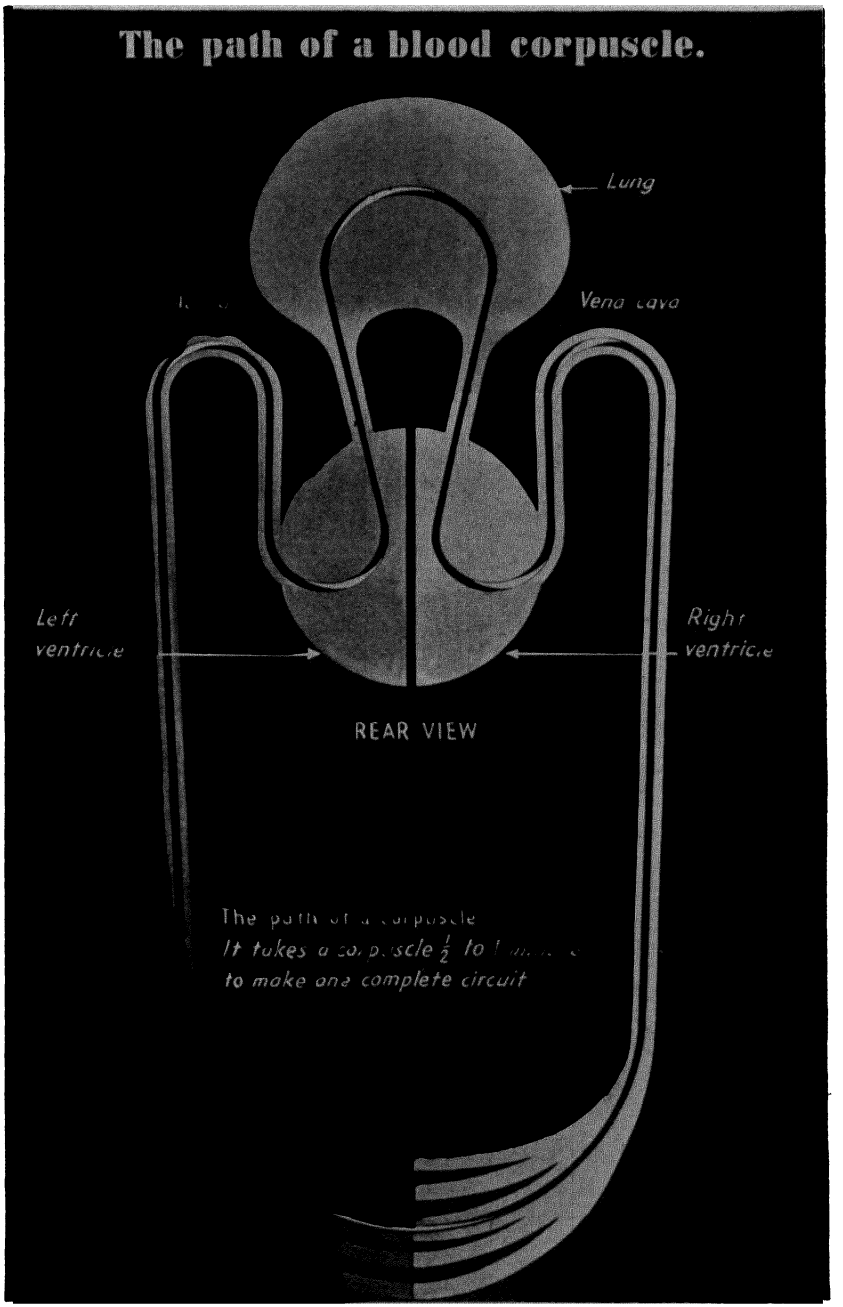
The blood continues to move along in the veins because of the impetus given it by the beating of the heart. However, this force is gradually diminished owing to friction and "loss of head" as the arteries branch. Other agencies aid the heart in moving the venous blood. Among these are the pocket-shaped valves with which the veins are richly supplied. These valves are arranged in such fashion that the blood can flow only toward the heart in the veins. Thus any piling up of the blood behind a valve causes it to open, permitting the blood to move on in the direction of the heart. Piling up ahead of the valve causes it to close, preventing the blood from returning toward the capillaries. In addition, the contraction of various skeletal muscles produces pressure on the veins, helping to move the blood onward. Such action is particularly valuable in returning the blood from the legs to the heart against the force of gravity. By the time the blood reaches the junction of the venae cavae, its pressure has

dropped nearly to zero and it moves evenly into the right auricle, mainly by gravitational pull. Thus one great loop of the circulation has been completed. The blood has delivered its cargo of oxygen and food materials to the tissue fluids surrounding the body cells. From this internal environment it has picked up another load of materials, this time mostly body wastes, and has returned with them to the right heart.

A part of the wastes picked up in the systemic circulation, namely, carbon dioxide and some water vapor, must be unloaded in another part of the circulatory path. Immediately, therefore, the blood leaves the right heart for the loop through the lungs. This is the pulmonary circulation. Blood leaving the right ventricle enters the large pulmonary artery. Almost immediately after leaving the heart this artery divides, one branch going to each lung. The two arteries so formed continue to diminish in size by branching, until the capillaries of the lungs are reached. In the lung capillaries, the blood rids itself of excess carbon dioxide and some water vapor and takes on a fresh supply of oxygen. It then flows into the pulmonary venules. The venules unite to form veins, which continue until finally they produce the large veins which empty into the left auricle.

The force which moves the blood through the pulmonary arteries is supplied by the contraction of the right ventricle. However, by the time the blood has passed through the lung capillaries its pressure has dropped nearly to zero, and it flows smoothly back to the heart because of the greater pressure behind it. This quick drop in pressure within the pulmonary vessels is effective in speeding up the circulation of the blood through the lungs.

The average time required for the blood to traverse the double loop of the circulatory system is relatively short. It varies from about thirty seconds to about one minute, depending upon what part of the body it traverses. Suppose we were to select some small sample of blood and to time it on its journey around the body. Starting in the right ventricle, by contraction of the heart the blood sample would be forced to the lungs. About ten seconds would be consumed in making the circuit to the lungs and back to the heart again, this time to the left auricle. If our particular sample were then to journey to the foot, by



The path of a blood corpuscle in making the circuit of the body, as illustrated at the New York World's Fair in 1939. (American Museum of Health photograph.)

way of the aorta and large arteries of the leg, it would return through the veins to the right auricle approximately fifty seconds later. Should it proceed to an organ lying nearer the heart, it would be back to the right auricle within a shorter interval of time and ready for its next circuit to the lungs.

It might be thought that in order to complete its circuit through the body in so short a time the blood would have to rush through its entire course at a precipitous speed. This is not actually so. Within the larger arteries and veins, to be sure, it does move rapidly. Near the heart, in the large aorta, for example, the blood travels at the rate of nearly three feet per second when the left ventricle contracts. In the large veins approaching the right auricle, it flows at the rate of about one and a half feet per second. As the capillaries are approached the speed decreases greatly. This results from the fact that, when a blood vessel divides, the combined area of cross section of its branches is greater than that of the original vessel. On entering the branches, therefore, the pressure head on the blood is reduced and it slows down, just as water in the wide part of a river flows more slowly than it does within a narrow gorge. Thus, a given sample of blood will consume about one second in traversing a capillary so short that it can be seen only with the aid of a microscope.

Unique Circulating Fluid

The blood is in many respects the most valuable and unique fluid in the body. It is not only the bearer of food and waste products; it contains within itself living tissue; that is, it contains cells. The main difference between the blood and any other tissue is that the cells of the blood are floating free in a liquid called "plasma." This is a yellowish fluid, of which approximately ninety per cent is water. It has in it certain proteins held in suspension and a number of materials in solution. The substances in solution are the food materials such as sugars, fats, and amino acids and various mineral salts such as chlorides, phosphates, and carbonates; there are also body wastes such as urea, uric acid, and ammonium. In addition, it contains some oxygen and carbon dioxide in solution, as well as a material which is able to produce a substance called "fibrin."

A remarkable thing about the plasma is that its composition remains highly constant, despite the fact that materials are added and removed at many points in the circulation. Often this exchange is extremely rapid. The constituents of the plasma react chemically among themselves in such a fashion that any change in the blood composition calls forth adjustments of these factors. Moreover, materials are added by certain organs, while substances are removed by others. The balance is restored and there is maintained the exact composition necessary for the life of the body cells.

A particularly important chemical property of the blood plasma is that it coagulates or clots when it is discharged from the blood vessels. This is a complex process, as yet not fully understood. Following a definite series of events, certain protein materials of the plasma break down to form fibrin. Fibrin is precipitated in hair-like strands possessing considerable strength. It forms a fine meshwork of threads in which the red and white corpuscles become entangled and on which the plasma coagulates. Thus a sort of dam to the blood stream is formed, the mass hardens, and a clot is produced.

Clotting occurs when the blood comes in contact with injured tissues or damaged cells and when it comes in contact with foreign surfaces which have physical properties different from those of the smooth lining of the blood vessels. The process is one which is vital to the life of the individual. When any wound occurs, it is important that the break in the circulatory system be stopped immediately by clotting; otherwise excessive loss of blood would soon occur. It is just as important that clotting should not occur within the regular blood channels. If such should happen, circulation would be hindered or stopped, and the results would be just as disastrous.

The visible breaks in the blood vessels, of course, are those that occur on the surface of the body. However, breaks can also take place in the deeper lying vessels. In either event clotting must stop the loss of blood until the damage is repaired. Internal breaks are sometimes caused by foreign particles or organisms which invade the tissues and destroy the capillaries at a given point. The organisms that produce syphilis probably furnish the most spectacular example, but they are in no sense the

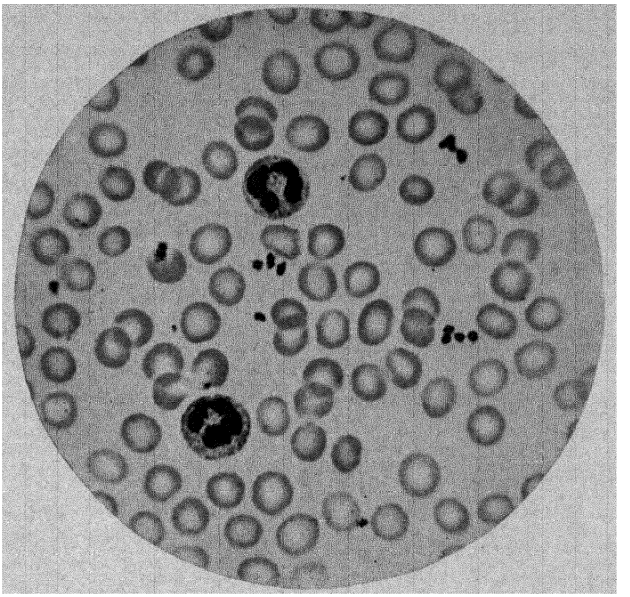
only ones. Where such internal breaks occur, blood clots temporarily check the germs, or at least prevent death from internal hemorrhage.

The worst malady associated with defective blood coagulation is the condition known as "hemophilia." In individuals afflicted with this condition the coagulation mechanism is deficient to the extent that clotting does not occur. Even the slightest wound internally or externally may result in a fatal hemorrhage. The malady has played an important role in history, for it has affected some of the royal houses of Europe, notably the late czar of Russia and the recent royal house of Spain. In 1938 former King Alfonso's son, the Count of Covadonga, died in the United States of excessive bleeding from a minor cut suffered in an automobile accident. The disease is a hereditary condition which affects only males and is transmitted directly to the afflicted individual by the maternal parent only.

Formed Elements of the Blood Stream

Although to the superficial observer the blood appears to be a liquid of uniform composition, when examined through the microscope it is seen to contain bodies of definite form and size. They are of three distinct and different kinds, two of which are readily identified. These are the red corpuscles and the white cells. The third type of formed element is more difficult to find and will not be discussed here. The red cells are by far the most numerous. In fact, an almost incredible number are found in the blood of a single individual, there being about eighty to a hundred billion to the cubic inch, or a grand total of some thirty trillion. They are, of course, correspondingly small in size. Human red blood corpuscles are biconcave disk-shaped objects about one three-thousandth of an inch in diameter, and approximately one-fourth as thick.

The red corpuscles are little more than thin-walled sacs containing a red-colored solution of potassium salts. Perhaps the most important chemical characteristic of the red cells is the presence in them of relatively large amounts of hemoglobin. This is a compound formed by the union of a protein substance (globin) with a complex iron-containing material (hematin). Hemoglobin has the peculiar property of combining easily with



Formed elements of the blood. The red corpuscles differ conspicuously from the larger white cells, not only in being more numerous but also in that they have no nucleus. The very small dark bodies are platelets. (Photomicrograph by Roy Allen.)

oxygen to form a loose compound. The compound is likewise broken down with the liberation of oxygen. This is just what happens when the corpuscle arrives in a region where the tissues are short in oxygen. The reaction is reversed in the lungs where the relative concentration of oxygen is higher in the tissues than in the red cropuscles, and a recombination with oxygen takes place. It is by virtue of the presence of the hemoglobin in the red corpuscles that the blood is able to transport sufficient oxygen from the lungs to all parts of the body.

The red corpuscles do not contain a nucleus or any evidence of nuclear substance as such. In this respect they differ fundamentally from typical living cells, and this is one reason for calling them corpuscles rather than cells. Not having a nucleus, they are incapable of reproducing themselves by cell division. Nevertheless, as a part of a living system, they must arise from living cells even though they are themselves of less than cellular grade. They must, therefore, be produced by other tissues in different parts of the body. They must likewise be replaced from the same source eventually, as they do not exist indefinitely.

It has been estimated that about one-thirtieth to one-tenth of the red corpuscles are destroyed daily. However, in a normal person, the total number in the blood remains remarkably constant from day to day. This means that ten million red cells are destroyed and replaced each and every second throughout one's entire life.

The formation of the red corpuscles takes place in the red marrow found in the bones of the body, chiefly in the ends of the long bones, for example, the ribs and limb bones. Within this red tissue are found specialized cells which are in a state of rapid cell division. These cells bear no resemblance to the mature red blood corpuscles. They are nucleated giant cells. Some of the daughter cells formed by division of the red marrow cells begin to develop hemoglobin within them. As these cells mature, their nuclei gradually disappear and their hemoglobin content increases. The mature red blood corpuscles formed in this manner then pass into the blood stream.

The fact that the number of red corpuscles in the body remains constant indicates that there must be some stimulus which acts upon the red marrow, causing it to produce more red corpuscles when needed. This stimulus is definitely regulated by the oxygen content of the blood. It seems to be a chemical substance which emanates from the liver. Thus, when a shortage of red corpuscles develops, the resulting lowered oxygen tension of the blood acts upon the liver, causing it to release this substance, which in turn stimulates the bone marrow. New red cells are produced and the balance is restored.

When there is a deficiency of this material produced by the liver, or when the red marrow does not function properly to produce new red cells, a shortage of red cells develops which cannot be overcome by the body. This results in a condition known as pernicious anemia. This is an insidious ailment that brings about a progressive weakening of the muscular tissues, deterioration of the cellular structure, and finally death, unless proper treatment is administered. The treatment consists essentially of administering liver extracts containing the red marrow-stimulating substance the body itself does not supply.

Such extracts are prepared from the liver of normal animals. The active principle appears to be produced by the action of the

normal digestive juice upon some protein component of the diet. This substance is stored in the liver. When these extracts are injected into the blood of an individual suffering from pernicious anemia they speed up the formation of red cells, even though the red marrow of the bones may be greatly reduced in such persons. By this treatment the symptoms are usually relieved. However, in most cases it is necessary to continue administration of the extracts if the person is to live.

The white cells are larger and fewer in number than the red corpuscles. They move more slowly through the plasma. In contrast to the red corpuscles, the white cells are nucleated. They are capable of moving about independently by pushing out root-like extensions of their bodies and flowing into them much as an amoeba does. By this process they are able to slip through the walls of the capillaries and move about in the tissues. They do this in large numbers when some foreign organism gets inside the body or when the skin has been broken by a wound or laceration.

White cells are constantly being destroyed in the body, though not so rapidly as the red corpuscles. Their number fluctuates widely, being greatest when a person has certain infections, for example, appendicitis. While they have nuclei, they do not reproduce by cell division; rather, they originate within the red marrow of the bones. Just what is the relationship of their origin to that of the red cells is not known. In the adult stages, however, the two are quite different.

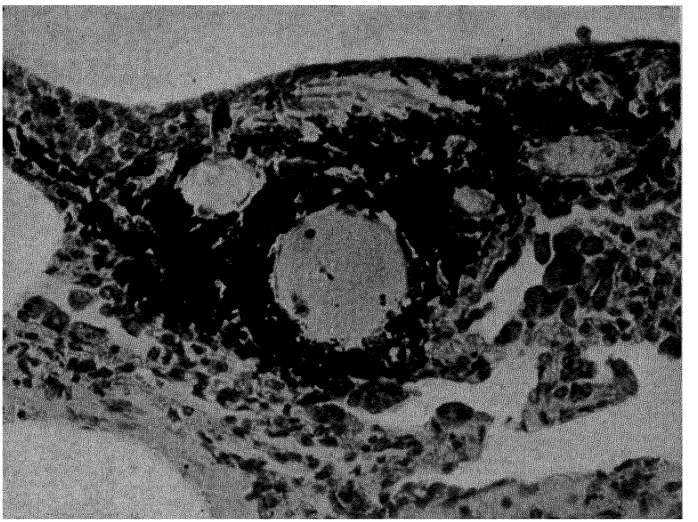
Even though fewer in number, the white cells are no less important than the red corpuscles. Their chief function so far as the body is concerned is to destroy bacteria. They can surround a foreign particle or organism and digest it much as an amoeba engulfs and digests its food. The white cells are found in largest numbers where bacteria have the best chance to enter the body, and they tend to congregate at points of bacterial infection. In such places the white cells slip through the walls of the capillaries, surround the bacteria, and proceed to digest them along with fragments of tissue cells killed by the action of the bacteria or by toxic substances produced by the bacteria. Thus, the fate of millions of bacteria which invade our bodies is to be eaten by the white cells.

A Helping Hand

An auxiliary to the circulatory system is the lymph system. This seems to be a secondary system for moving materials, principally coarser wastes, from the vicinity of the body cells and thus providing double assurance that unnecessary substances will not accumulate in places where they are unwanted. It is a sort of one-way drainage system from the tissue fluids surrounding the individual cells to the blood stream. The lymph system consists of a network of lymph capillaries which lie adjacent to the cells and which come together to form the lymph ducts. These ducts eventually combine to form two large vessels, one on either side of the neck. They empty into veins in the shoulder region not far from where these veins join the left auricle of the heart.

The lymph capillaries permeating the body tissues collect the lymph largely through a simple process of diffusion. The lymph is a watery fluid very similar in composition to the tissue fluid from which it is derived. In addition it contains numerous particles which are too large to diffuse through the walls of the blood capillaries. Included among such particles are bacteria and fragments of destroyed cells, materials that would soon clog the body if they were not carried away. Inside most of the lymph ducts are numerous valves so arranged as to prevent the lymph from backing up toward the capillaries. The lymph is, therefore, gradually moved along toward the veins by muscular movements of the body and eventually is returned to the blood stream near the heart.

At frequent intervals along the lymph ducts are found structures known as lymph nodes. These are essentially made up of a connective-tissue framework enclosing large numbers of white blood cells and amoeboid cells, which are capable of breaking down the larger particles contained in the lymph and of destroying bacteria. As the lymph trickles through the nodes, the large particles are filtered out so that only the proper materials return to the blood stream. The nodes in the lungs of city dwellers, for example, often become black with the soot and dirt filtered out of the lymph during a lifetime of breathing filthy air.



Lung tissue from a person who had lived most of his life in a large city where the air is often laden with smoke. The black material in the picture is carbon granules adhering to lung tissue cells. The light circles are cross sections of small bloodvessels. (Photomicrograph by G. C. Grand, New York University.)

Another function of the lymphatic system is to transport the fats that are absorbed from the small intestine through the villi. The fats are carried in the lymphatic system until the large veins near the heart are reached. Here they are deposited in the blood stream. In this manner, they are diverted from going directly to the liver, as do the other foods absorbed from the intestine. It is not clear just why the fats should be absorbed and transported in a different manner from other food materials. The explanation may lie in the fact that in the cells of the intestinal wall the fats are present in the form of an emulsion of fine droplets too large to diffuse through the walls of the blood capillaries but capable of penetrating the lymphatic walls.

Excretion and Elimination of Wastes

It is common knowledge that industrial operations nearly always involve the production of wastes. This is especially true in those industries which have a chemical basis. While research has pointed out uses for many of these by-products, improvements in production methods have not yet succeeded in eliminat-

ing them. It is to be inferred that a group of processes so manifold and complex as those which go to make up the metabolism of the human body would likewise yield a variety of waste substances. This is indeed the case. Unfortunately, provision has not been made for finding uses to which these by-products may be put in the body. Some of them are distinctly harmful to the living cells and if allowed to accumulate would ultimately cause death. Others are detrimental when present in greater than certain prescribed quantities. One of the important tasks of the body, therefore, is to rid itself of these toxic materials.

Two types of physiological processes play a part in accomplishing this end. One of them is termed elimination; the other, excretion. The main avenues of elimination are the passages leading to the exterior of the body from certain organs and the pores of the skin. Elimination is largely a mechanical process of forcing waste materials out of the body confines. Here it should be noted that materials in the lungs, rectum, and bladder are actually already outside of the body proper, since they no longer form a part of the internal environment of its cells. The mechanical changes involved in exhaling air from the lungs have previously been described. The emptying of the bladder is brought about by reflex contraction of its muscular walls.

The elimination of materials from the colon through the rectum rids the alimentary canal of undigested substances taken in with the food and not absorbed into the blood stream. In addition, the colon serves as an exit organ for certain metabolic wastes of the body. Excess amounts of calcium salts and salts of the heavier metals in the blood are excreted into the colon, from which they are eliminated from the body. Also, certain bile salts, particularly bile pigment resulting from destruction in the liver of the red blood cells, pass into the colon and are thus eliminated. The brownish color of the feces or colon excrement is produced by these and products of red-cell destruction. Large numbers of living and dead bacteria are also eliminated from the colon.

The dangers of colon poisoning have frequently received much attention, particularly in advertising cathartic and "help nature" remedies. Much of this represents an exaggeration of the facts. A knowledge of the general composition of the feces,

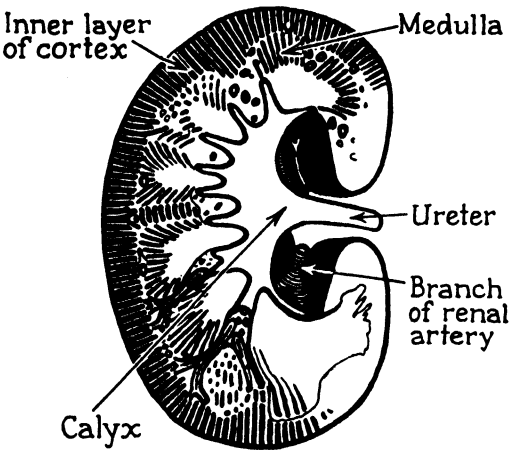
however, emphasizes the necessity of regular colon elimination. This is effected in most people naturally by including in the diet a variety of foods, some roughage (though not in excess), and considerable amounts of liquids. Such natural regularity of elimination is greatly to be desired above that produced by the use of artificial remedies.

Excretion is a process of removing the waste products of metabolism from the body fluids and passing them into temporary depositories, such as the bladder and the lower end of the alimentary canal. The principal excretions of the body are perspiration and urine. The first is excreted by the sweat glands of the skin; the latter by the kidneys.

Perspiration is a very dilute solution, chiefly of salt, or sodium chloride. It has only about one-eighth the concentration of solids found in the urine. On a comfortable day, or in a properly heated and ventilated room, about a pint of perspiration is excreted in a day. On a very hot day, or in a poorly ventilated and overheated room, this figure may rise to two or three quarts. Contrary to popular belief, the perspiration is of little importance in ridding the body of wastes. Even with the greatest activity of the sweat glands, the amount of urea eliminated per day in this way is less than one-tenth of the normal daily output in the urine. The chief function of the perspiration is to aid in regulation of the body temperature. Heat is dissipated in the evaporation of water from the skin, particularly in the evaporation of the perspiration. When functioning of the kidneys is impaired through disease, there is a compensatory increase in concentration of the perspiration, especially as regards the urea content. Unfortunately, this compensating adjustment is never sufficient to alter significantly the consequences of serious kidney failure.

The chief metabolic wastes of the body are carbon dioxide, water, and certain products of protein decomposition. We have already noted that carbon dioxide is removed from the blood by processes taking place in the lungs. Water is both a food requisite and a waste. It is also important as a carrier of other wastes in solution, as in the urine and perspiration. With the exception of the small quantity incorporated into the tissues in their growth, all the water which is taken into the body is passed out

again. In addition to the water lost in the perspiration and through evaporation from the general surface of the skin, a very considerable quantity, amounting to as much as a pint a day, is passed out by way of the lungs in the form of water vapor. Nevertheless, the urine constitutes the major portion of the water loss of the body, about a quart and a half being excreted daily by normal adults. It carries with it, in solution, the by-products of protein metabolism. Chief among these are urea, uric acid, sodium chloride, and the potassium salts of sulphuric and phosphoric acids.



Longitudinal section of the kidney showing main divisions. (Redrawn from Starling, "Human Physiology.")

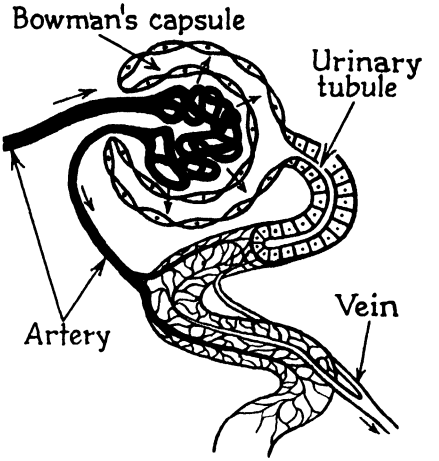
The Work of the Kidneys

The urine is formed through the work of the kidneys, which are the principal excretory organs of the body. In the removal of waste materials from the blood they are second in importance only to the lungs. They act partly as a great filtering system, separating from the blood many of the wastes that have been formed in other parts of the body and emptied into it. Even more than this, the kidneys regulate the composition of the blood and help to maintain the proper environment within the body necessary to life.

The kidneys are paired organs located at the back of the abdominal cavity just beneath the diaphragm and to the right and left of the spine. Each is a bean-shaped body, weighing a little less than a pound in most people. For their size these small organs do an enormous amount of work. The activity of any tissue in the body may be measured in terms of the amount of oxygen it consumes. It has been found that the kidneys use about nine per cent of all the oxygen consumed by the body although

they represent less than one per cent of its total weight. Correspondingly, the blood supply of the kidneys is exceptionally large in proportion to their size.

When cut in two, each kidney is seen to be a compact mass roughly divided into two regions, an outer, narrow zone called the "cortex," and a central portion called "medulla." At the base of the central region, and continuous with its inner surface, is a hollow portion, known as the "calyx," which is continuous with the ureter leading from the kidney.



Knot of arteries inside Bowman's capsule, and network of capillaries surrounding urinary tubule furnish the mechanism for filtering the blood of waste materials.

Microscopic examination of the organ reveals that it is made up of a very large number of minute tubules which open into the calyx. The tubules are the functional units of the kidney. They are straight in some places, very much coiled in others. They extend outward through the medulla toward the cortical zone, branching and tapering in diameter as they go. Each tubule ends in the cortex in a blind sac-like structure, known as "Bowman's capsule." This is a double-walled cup, shaped as though formed from a hollow sphere by pushing one half down inside the other. Each of the two walls thus formed consists of a thin membrane only one cell thick. The space between the walls is continuous with the tubule leading from the capsule. Within the hollow of the capsule and lying next to the inner membrane is a small knot of blood capillaries. Some four and a half million of these cups and capillary knots are present in each kidney. It is across the thin membranes of the capillary knots and the walls of Bowman's capsules that filtration of impurities from the blood takes place.

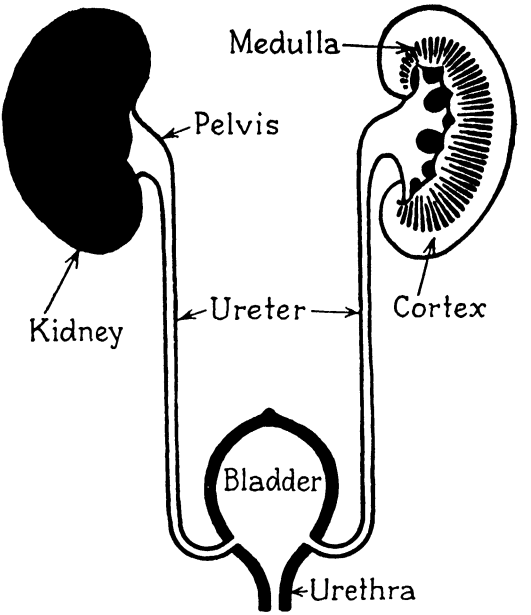
Blood enters each kidney from the dorsal aorta by a short but large artery; it leaves by a correspondingly large vein which empties into the inferior vena cava. Blood from the arteries which supply the kidneys flows into the capillary knots within

the Bowman's capsules under considerable pressure. This pressure is greater than in the capillaries in other parts of the body. It is as though it were maintained here actually to force materials through the capillary walls. Much water and substances dissolved in the water do filter through the capillaries and pass into the capsules. Chemical analysis of the material in the capsules shows that it has a very different composition from the urine finally eliminated from the kidney. It contains a great deal more water and considerably greater amounts of salt and sugar, in addition to urea, uric acid, and the various salts derived from the decomposition of proteins in metabolism. In fact, it has pretty much the composition of the blood plasma. A notable difference consists in the absence of the plasena proteins and the blood corpuscles, which do not normally pass through the capillary walls to any significant extent.

The step which immediately follows this first act of filtration is the one which determines the final composition of the urine. As the fluid from Bowman's capsules flows down the kidney tubules, reabsorption of certain substances takes place. This reabsorption occurs from the upper ends of the tubules, which are surrounded by networks draining into the kidney veins. It is quite obvious that one of the materials reabsorbed is water, since the urine is more concentrated than either the blood plasma or the fluid from Bowman's capsules. The movement of the water from the urine to the blood takes place in spite of the fact that there is less of it in the urine. Consequently, work must be done by the cells responsible for this movement, and, indeed, the structure of the tubular epithelial cells resembles that of secreting cells, which are characterized by their ability to do such work.

But this is not the only work done by the cells of the kidney tubules. All of the sugar and much of the salt is removed from the fluid and returned to the blood. On the other hand, urea is not returned, and its concentration in the urine is about seventy times greater than that in the blood. Likewise foreign materials, such as caffeine and alcohol, are never returned to the blood.

Should there be an excess of any of its normal constituents in the blood, the reabsorption process permits only the proper amounts of these materials to go back. For example, people



Relationship of the urinary organs.

suffering from diabetes have an excess of sugar in the blood. The cells of the tubules in such cases permit only a part of the sugar to return to the blood, the remainder being retained in the urine. Likewise, if there is an excess of any mineral or organic salts in the blood stream, some of these are retained in the urine, and only the proper amounts are allowed to return to the capillaries around the tubules. In this manner, the exact composition of the blood stream is regulated by the kidney. This also makes it possible, through analysis of the chemical composition of the urine, to diagnose accurately a person's general physical condition.

It is fortunate that man is equipped with two kidneys. They serve an exceedingly important role in the body processes. If there were only one and it became diseased or inoperative, death from the accumulated poisons would soon result. As it is, only a fraction of the total tubules are active at any one time. There is here a considerable margin of safety, and destruction of considerable kidney tissue by disease does not seriously impair the work of the kidneys. One kidney may even be removed, and the other will carry on the work of purifying the blood.

Thus the urine as finally excreted by the kidneys contains some water, urea (which is produced partly by cellular metabolism and partly by the breakdown of amino acids in the liver), some salts, excess sugars, and useless materials which get absorbed into the blood stream. This material flows down the small tubules and eventually empties into the calyx. From there it drains into a tube known as the ureter, which leads below to the bladder. There is one ureter from each kidney to the bladder through which urine continually drains. The bladder is a muscular bag which serves as a sort of storage tank and from which the waste liquid is eliminated through an exit tube known as the urethra.

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12: LIFE CONTINUES

The Process of Reproduction

PERHAPS the most remarkable property of living things is their ability to give rise to other living things. It is just as truly remarkable that in so doing all the different living forms always reproduce their own kind. It is a law of life that the general characteristics of the parents are retained and transmitted by the offspring, thus tending to preserve resemblances. On the other hand, heredity is not perfect. There is always some variation. With the exception of identical twins, triplets, etc., which occur only rarely, no two individuals are exactly alike, no matter how closely related. There is a balance in heredity between conservative and liberal tendencies. The general characteristics of the type are rigidly preserved, but their detailed expression in the individual is permitted to vary widely.

Because of the ability of living things to reproduce, life is continuous and in a sense immortal. This is as characteristic of

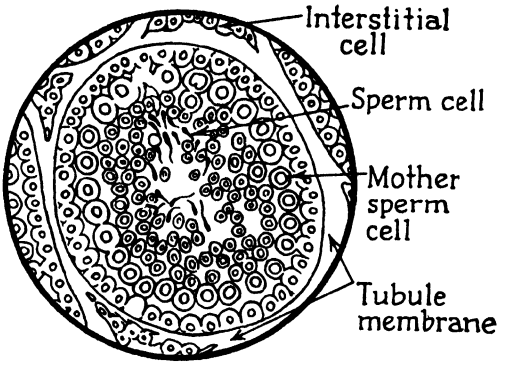
the lower animals as of man. Science has revealed a great deal in recent years about the inner mechanism and processes of reproduction. There is only one way by which reproduction can take place, namely, cell division. In man and all other higher animals, special cells are concerned. They are known as the reproductive cells. They are of two distinct types, sperm cells and egg cells, produced by male and female, respectively. Under normal conditions, there must be a union of these two kinds of cells, one of each type, before a new individual may be produced by cell division.

From a biological standpoint, the entire process of human reproduction is concerned with bringing together these two types of germ cells and with nourishing and protecting the product of their union so that growth and development may continue until such maturity is reached that the individual may care for himself. These are the essential facts of sexual reproduction. The continued existence of the human species, which is probably the first postulate of any philosophy of life, is dependent upon sexual expression. Through it the race survives. It is upon the basic biological aspects of the reproductive phase of life that the searchlight of science has been able to shed some light for us.

Production and Dissemination of Human Male Germ Cells

The body of every normal male person is provided with certain tissues and organs which serve to produce the male germ cells and to facilitate their union with the female germ cells. Likewise, every normal female person possesses certain tissues and organs concerned with production of the female germ cells and ensuring their union with those of the male, as well as special organs and tissues which receive the product of this union and provide for its early development. The germ cells are specialized and unique in many respects directly related to their function in reproduction. To distinguish them from the ordinary tissue cells of the body, they have been given a special name, the "gametes." The sperm cells are the male gametes, while the egg cells are the female gametes.

The mature sperm cells are minute structures about 0.00002 inch in diameter. It seems remarkable that a function so special-



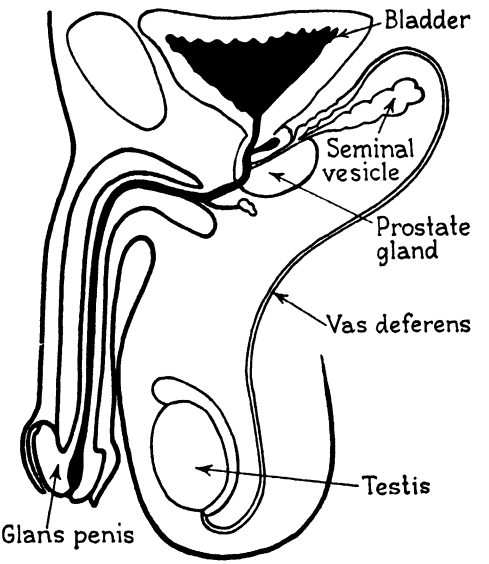
A transverse section of a seminiferous tubule shows sperm being formed from the sperm cells of the germinae epithelium by cell division and differentiation. (Redrawn from Gray, "Anatomy.")

ized and important as reproduction could be assigned to cells so small. The sperm cells are so small, in fact, that a drop of fresh seminal fluid, seen under a high-power microscope, swarms with them. It is estimated that about 200 million sperms are contained in the seminal fluid discharged at a single ejaculation. Each one consists of a head, which is little more than the cell nucleus in a very condensed state, and a whiplash tail. The tail is a fine filament of cytoplasm about ten times as long as the head and much narrower. Its lashing movement propels the sperm through the seminal fluid at the rate of about one-tenth of an inch per minute.

The sperm cells are produced in the testes. These are paired organs which serve a double purpose; not only do they produce the sperm cells, but they also secrete a male hormone. In many animals the testes are located within the abdominal cavity in about the same position as the primary female sex organs, or ovaries. In man and certain other animals, however, shortly after birth they descend into a fold of skin which forms a sac suspended from the pubic region. This sac is called the "scrotum."

Within each testis there are some eight hundred to a thousand small tubes, known as the seminiferous tubules, in which the sperm cells are produced. The walls of these tubules are made up of a tissue, known as "germinal epithelium," which is formed from the primordial germ cells set aside early in embryonic development. At puberty this tissue begins to produce mature

sperm cells by cell division and differentiation. Within the adult lifetime of a man some 340 billion sperms are thus produced. These germ cells, like all other cells of the body, are descended directly from the original fertilized egg cell. The route of male inheritance, therefore, is from the fertilized egg through the seminiferous tissue to the sperm cells. No other tissues of the body can produce sperms.



Diagrammatic representation of male reproductive organs.

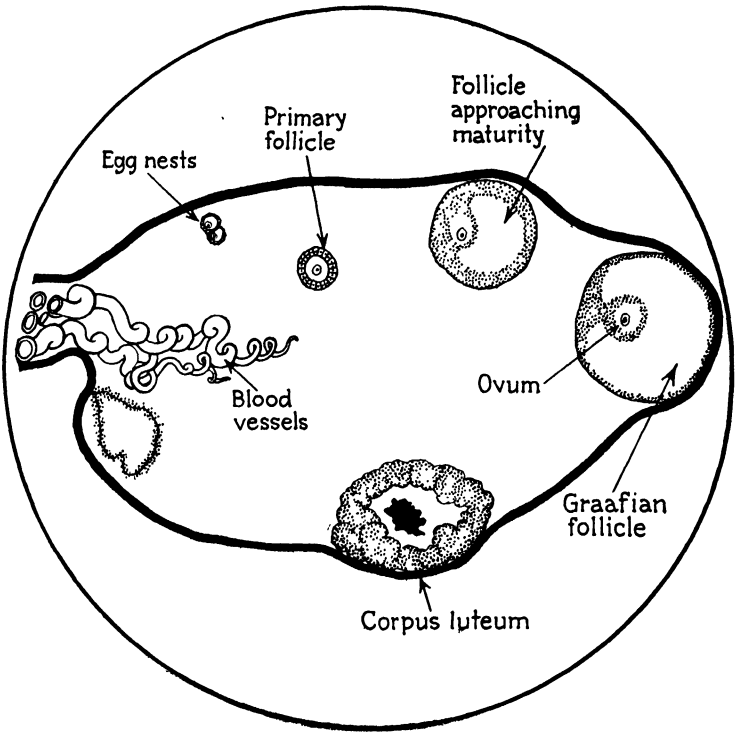
The mature sperms developed within the seminiferous tubules pass into the "epididymis," which is a long, fine tube that is coiled against the testis. This tube connects with a duct known as the "vas deferens." There is a pair of these ducts, one from each testis. They extend upward into the lower abdominal cavity, then, bending downward, eventually connect with the urethra. Near the base of each vas deferens, where it joins the urethra, is a sac-like structure, called the "seminal vesicle," which is variously described as a storage depot for sperms and as a gland contributing to the fluid in which they are suspended. It may serve either or both functions. It is well established that the prostate gland, which surrounds the urethra at the point of union with the vasa deferentia, secretes one of the constituents of the seminal fluid. Also contributing to this fluid are a pair of glands located on either side of the penis near the base, known as "Cowper's glands." All these structures, with the exception of the seminiferous tubules in which the germ cells are actually produced, are secondary reproductive organs. Their functions have to do directly or indirectly with facilitating movement of the sperm cells and providing for their transfer to the place where fertilization occurs.

Production of Human Female Germ Cells

The female germ cell, or ovum, is a rather generalized type of cell, roughly spherical in shape and relatively large in comparison with the sperm. Its diameter is about fifty times that of the sperm head, and its total volume is over a hundred thousand times greater. Its size is such that it is just visible to the unaided eye. It consists of a nucleus surrounded by a layer of granular cytoplasm, just as does any other typical cell. However, the cytoplasm of the egg cell is full of minute bits of yolk, or food substance for the growth of the early embryo. The ovum is enclosed within a delicate cell membrane, around which a thin layer of jelly-like substance develops when a sperm enters the cell. This substance effectively prevents the entrance of more than one sperm into the ovum. Unlike the sperm, the ovum is inactive; it is unable to move except as it is carried along in currents set up by surrounding structures.

The human egg cells are produced in paired organs, the ovaries. They correspond to the testes of the male and likewise have a double function. In addition to producing the ova, they also secrete the female sex hormones. Each ovary is a somewhat flattened organ, a little smaller than the testis, being less than two inches long, one inch wide, and about one-fourth of an inch thick at maturity. The ovaries are situated at the back and in the lower part of the abdomen near the pelvic walls, a position where the testes of the male develop before they descend to the scrotum shortly after birth.

The ovary is in some respects rather simple in structure. It consists principally of cells that are to become eggs or ova at maturity and fibrous material and other cells that serve for support and nourishment of these. The cells that are to produce the ripe ova come directly from tissue originating from the primordial germ cells which differentiate at an early stage in embryonic development. Soon after birth this tissue has produced about 400,000 of these immature eggs. By the time puberty is reached this number has been reduced to about 17,000 immature cells. Of these, about 200 in each ovary may reach maturity during the sexually active period of a woman's life. No others are ever formed. The path of heredity in the female is seen to pass



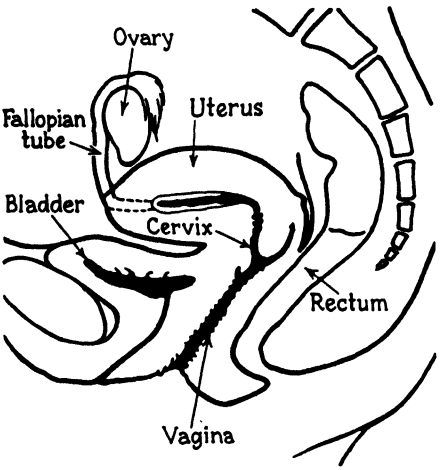
Simplified representation of development of ovum within the ovary. (Redrawn from Patten, "Embryology of The Pig.")

directly from the original fertilized ovum, by way of the developing cells of the ovary, to the mature ovum again.

The immature egg cells are not in tubules, as are the sperm of the male. Rather each ovum is surrounded by a number of nourishing and supporting cells, which form a hollow structure filled with fluid, called the "Graafian follicle." As the ovum and follicle mature, they move toward the surface of the ovary. There is no tubule opening to the surface of the ovary to provide an outlet for the ripe ovum. Instead, the follicle ruptures, breaking through the surface of the ovary and releasing the ripe ovum into the body cavity. Release of a mature ovum occurs about once in twenty-eight days, beginning at puberty and continuing until a woman has reached the age of about fifty, after which no more ova ripen and are released.

The ruptured follicle soon forms an actively secreting endocrine body known as the "corpus luteum." The chemical

substance secreted, called "progestin," is carried by the blood stream to the uterine tissues and brings about a preparation of the uterus for the reception of the fertilized egg. Should the discharged ovum not become fertilized, the corpus luteum soon degenerates into scar tissue. However, should the ovum become fertilized and attach itself to the uterine wall, the corpus luteum continues to secrete progestin during the period of pregnancy, this hormone being necessary for the growth of the embryo.

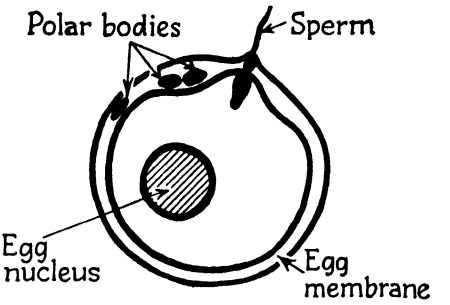


Diagrammatic representation of female reproductive organs.

The ovaries constitute the primary female organs of reproduction. The other parts of the female reproductive tract might be thought of as secondary structures. They receive the sperm of the male, provide for conducting the ovum to the place where fertilization occurs, furnish protection and nourishment to the growing fetus if fertilization should occur, and provide for birth of the embryo at the proper time.

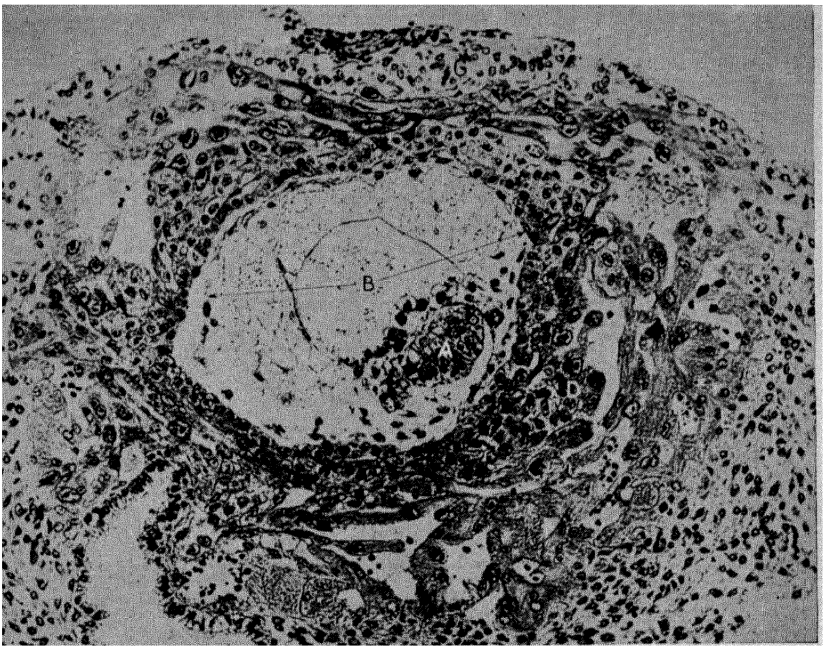
The ripe egg, after its escape from the ovary, is drawn into the horn-shaped opening of a duct known as the "Fallopian tube." There are two of these tubes, one from each ovary, which lead into the uterus, or womb. This is a thick-walled, muscular, pear-shaped sac about three inches long. If fertilization of the ovum takes place, it usually occurs as passage is made through the Fallopian tube. The ovum is moved through the tube by means of a feeble current which slowly carries it along until it enters the uterus. If it remains unfertilized, the ovum continues to be washed down the uterus. Within a few days it is discharged into the vagina through the muscular neck of the uterus, known as the "cervix." The vagina is a muscular canal extending obliquely downward and forward and opening to the outside of the body. Once the ovum is in the vagina, it soon dies and fertilization can no longer occur.

The maturing and discharge of the ova are governed by well-known biological laws. In typical instances only one egg cell matures at a time. The maturation process is completed by about the eighth day after menstruation ceases, at which time the ovum breaks loose from the ovary and enters the Fallopian tube. Here it remains from three to six days, during which time it is carried along to the uterus. The mature ovum may remain within the uterus for three days. It is only during the interval when the egg is in either the Fallopian tube or the uterus that fertilization may occur and usually only during the former. Unless fertilized, the ovum perishes at the end of its normal life, a period which, with slight variations, terminates about seven days after its discharge from the ovary. At about this time, some fifteen days after menstruation ceases, the ovum reaches the vagina. About thirteen days later menstruation begins again, and the cycle is repeated.



Human reproduction is started when the sperm cell of the male combines with the ovum cell of the female.

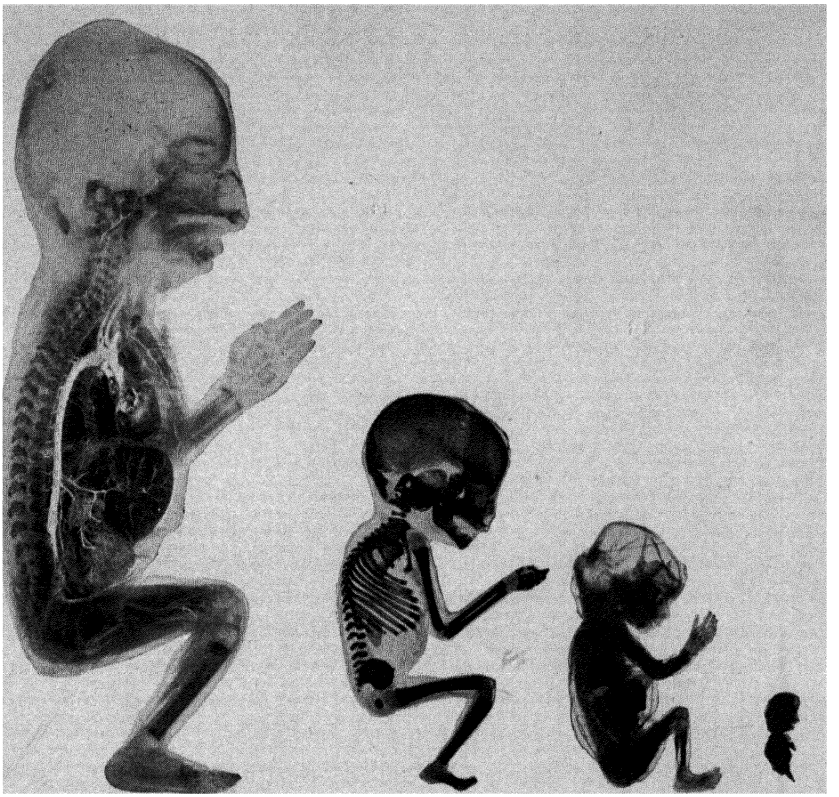
The process of fertilization is accomplished by the union of a sperm cell with the mature ovum. In order for this to occur sperms must be deposited within the vagina. From there they pass into the uterus, partly as a result of contractions of the vaginal wall and partly by a swimming motion of their own. This swimming motion is brought about by the lashing of the tail of the sperms acting against the liquid environment in which they are found. As the movement of fluids down the Fallopian tubes, uterus, and vagina is feeble, the sperms swim upward and enter the Fallopian tubes. This sperm migration usually requires a period of from one to six hours. However, the small sperm cells seem to possess a tenacious hold on life, and may remain alive within the female reproductive tract for about two days. If an ovum happens to be passing down the Fallopian tube or in the uterus at the time the sperms reach such a point, fertilization is likely to occur.



The tiny dark area labeled A is an eleven-day-old human embryo. It constitutes a remarkable discovery in that it is the youngest ever seen. The outer ring, indicated by the arrows B, is the shell of the ovum eroding and consuming the maternal tissues of the uterine wall. (Science Service photograph by Dr. A. T. Hertig of the Carnegie Institution of Washington.)

Development of the Human Embryo

If fertilization takes place, the fertilized egg begins to divide immediately, forming a cluster of cells. It seems that the very first task this cluster of cells sets for itself is to form tissues and structures to provide protection and facilitate growth of the embryo. This begins even before any of the cells start to differentiate into the original structures of a new human being. A cavity soon appears in the cluster from which is set off at one point an inner cell mass, and the remaining tissue forms a surface layer of cells that serves as a sort of feeding layer for the embryo soon to be developed from the inner cell mass. This hollow cluster then attaches itself to some spot in the uterus and literally bores its way into the uterine wall. This is accomplished by the cells of the feeding layer digesting or "eating" the maternal tissues. Once embedded, this layer grows at a rapid rate, sending



Relative sizes of human embryo at twenty-eight weeks, sixteen weeks, twelve weeks, and eight weeks. About one-half actual size. (Photographs by Sam Kaufman.)

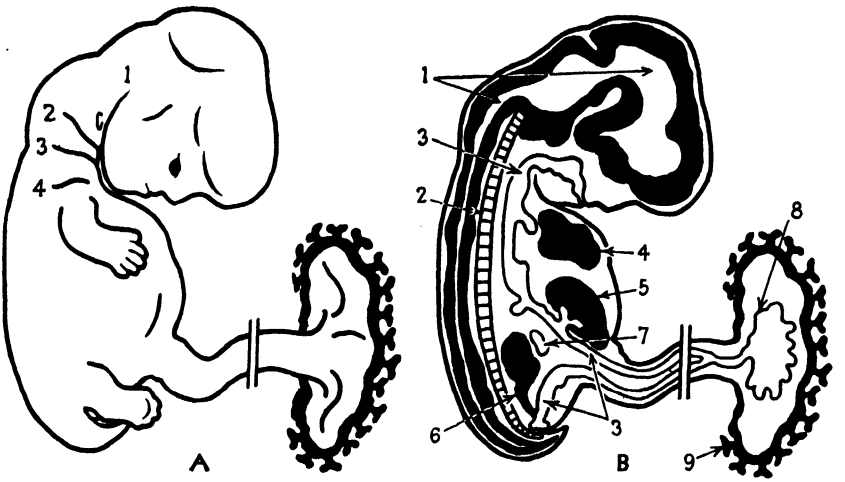
out villus-like processes into the uterine wall and forming a sac, known as the "chorion," that surrounds the entire cluster.

During the first two weeks the developing embryo seems to be fed by the digested material from the uterus. Then the thickened part of the chorion and the invaded tissue of the uterine wall cooperate to form a feeding organ, called the "placenta." It develops into a disk-shaped mass of tissue which is richly supplied with capillaries from the mother's circulatory system. The placenta is connected with the growing embryo through a narrow stalk of tissue which becomes the umbilical cord. This cord contains two arteries and a vein which join the blood vessels of the embryo with capillaries in the placenta adjacent to the mother's capillaries.

The placenta increases in size to keep pace with the growing embryo. Food materials and oxygen from the maternal blood are absorbed into the capillaries of the villi and are then transported to the embryo through the umbilical vein. Carbon dioxide and other metabolic wastes are brought to the placenta by the umbilical arteries, where they are transferred to the maternal circulation and excreted through the lungs and kidneys of the mother. It should be pointed out here that there is no direct physical connection between the circulatory system of the mother and that of the embryo, a belief that many people seem to hold.

Meanwhile, the inner mass of cells has been developing in a unique fashion. At first they produce two hollow sacs which are attached in only one region. Remarkably enough it is only the small group of cells at the line of contact of the two sacs that later grows into a human being. The upper cavity develops rapidly to form what is known as the "amnion," a sac that soon surrounds the entire embryo and lies just inside the chorion. This sac, incidentally, is useful only to the growing embryo and is shed at birth. Its function is to protect the embryo. To accomplish this it becomes filled with a watery solution which provides a fluid environment, thus preventing injury to the delicate embryo by taking up any undue shocks that the mother's body may receive. The lower compartment immediately forms an empty vesicle, called the "yolk sac," which becomes attached to the belly side of the growing embryo. However, the yolk sac in human development is no more than a vestige of a useful organ in lower animals, because it contains no yolk. During the second month of growth it becomes disconnected from the embryo and adheres only to the placenta, with which it is expelled at birth.

Thus during the very early stages of growth, provision is made for supplies and protection of the truly embryonic part of the developing tissues. Then the double-layered structure between the amniotic sac and the yolk sac begins definitely to build a human embryo. By the end of the fourth week it is about one-fourth of an inch long. The head region is marked, and limb buds have started. It is somewhat fish-like in appearance, having the beginnings of gill slits, a segmented back, and a tail. In fact, about eighty-five per cent of the development of all

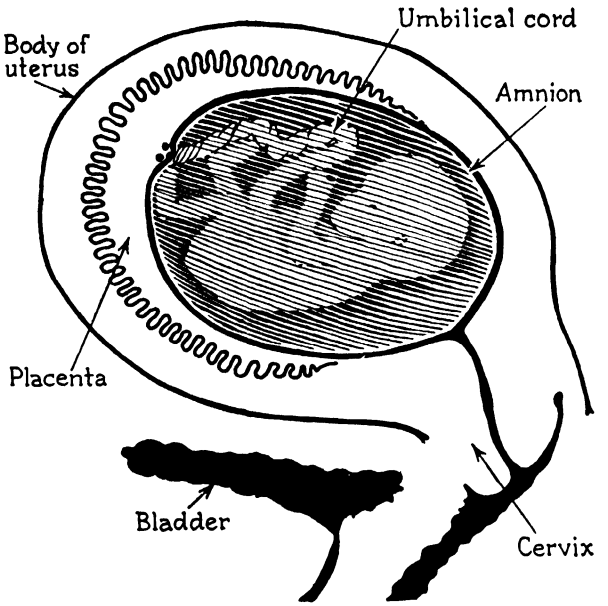


The human embryo is about one-half inch long at the end of five weeks' growth. At that time many of the organs of the body have begun to develop. Diagram A, represents outward appearance with umbilical cord and placenta indicated. The hand has differentiated more than the foot. Four external clefts are present as numbered. Diagram B is a longitudinal section showing major body parts: 1, brain and nerve cord; 2, notochord; 3, alimentary canal; 4, heart; 5, liver; 6, kidney; 7, gonad; 8, yolk sac; 9, villi on placenta to absorb nourishment from maternal uterine wall.

primary body structures has now been completed. At five weeks the embryo is almost one-half of an inch long. The head is now clearly differentiated, and the arms and legs are distinguishable with fingers on the hands. The feet, however, are slower in developing. This same gradient of development is also seen in the embryos of the lower vertebrates. For example, in amphibian embryos the fingers of the hands always develop earlier than the toes of the feet. Gill slits and a tail are still present after five weeks of development in the human embryo.

At the end of the eighth week the embryo is a little over one inch long. The face has begun to take shape, the eyes and ears have appeared, and the beginnings of all other organs of the body have been made. During the next seven months the embryo continues to grow and differentiate and gradually takes on the proportions seen at birth. Anatomically speaking, our lives are ninety-five per cent over at the time of birth.

Birth takes place at approximately forty weeks or 280 days after conception. However, exact knowledge in this respect is not available, and the time probably varies from about 270 to



Human fetus within the uterus. (After Logan Clendening.)

290 days. At about this time, the uterine walls begin to contract and force the amniotic sac containing its fluid and the fetus, or young child, down toward the cervix of the uterus. These contractions usually last from twelve to sixteen hours and cause some of the chief pain at childbirth. Meanwhile the bones of the pelvis separate along the mid-line of the body, and the muscles of the cervix gradually relax so as to permit the fetus to go through. Finally the amniotic sac breaks, and its fluid is discharged from the body through the vagina. Then the fetus passes through the cervix and vagina and is born, usually about an hour later. Approximately one-half to one hour later, the placenta and its attached membranes, constituting what is called the "afterbirth," pass out of the uterus and vagina. During the following six or eight weeks the reproductive organs return to their normal size and consistence.

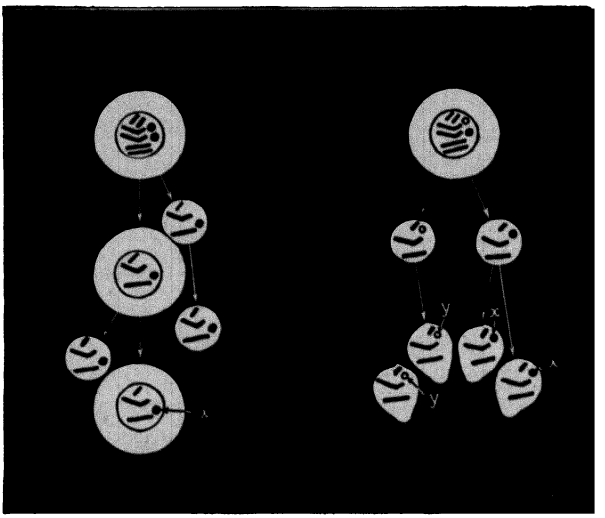
Childbirth is sometimes of serious consequence to the mother. This is more often the result of infection than any fundamental difficulty with the birth process. It is highly desirable that the expectant mother be in a hospital during the period of childbirth and be attended by a well-trained obstetrician. Such facilities

and medical aid can usually prevent any severe consequences resulting from the delivery. However, in many families in various parts of the country, the only assistance at childbirth is that provided by none too well-trained attendants and this under none too sanitary conditions. Mortality cases of the mothers under such conditions are usually large in number. It should be understood generally that such high mortality rates can be materially reduced by taking proper medical care of the mother during this critical period.

It is not uncommon for birth to occur before the normal term of development is completed. In such cases, the premature baby may be sufficiently well developed to live, if given the proper delicate care, and may grow into a normal and healthy child. Not infrequently, also, the fetus may cease developing after a few weeks and perish. In such cases, a normal abortion results, and the contents of the uterus are expelled without injury to the mother. If this takes place when the embryo is between five and seven months old, it is referred to as a miscarriage. The cause of such an event is usually some definite physical disturbance, such as inflammation of the genital organs, displacement of the uterus, infectious disease of the mother, or glandular upset. It is very unlikely, however, that mental agitation alone can cause a normal abortion or miscarriage, as is generally believed. The administration of drugs will usually not produce one. Induced abortion, or the deliberate surgical removal of the embryo, is technically perfected and may be employed in cases where the woman is physically unable to sustain pregnancy or childbirth or was a victim of rape. The operation is illegal, of course, in the United States and most other civilized countries if performed for other reasons.

Germ Cells

The mature germ cells, or sperm and ova, are unique cells in three remarkable respects. In the first place, they contain nuclei yet they cannot divide to form daughter cells as do most other nucleated cells, except under the special condition that the nuclei of a sperm and an ovum have been united in the process of fertilization. In the next place, after such union has occurred, the fertilized ovum does not give rise to similar germ cells by



Simplified representation of developing gametes, ovum on the left and sperm on the right.

cell division, but possesses the potentialities for producing a complete adult human being. Finally, these cells constitute the only direct physical link between parent and offspring and as such provide the physical basis for heredity and variation.

The nucleus of any typical human body cell contains forty-eight chromosomes. This is true of all so-called "somatic cells," such as skin cells, muscle cells, nerve cells, and so on. However, the nuclei of the mature germ cells, both male and female, have only one-half this number, or twenty-four. This reduction in the number of chromosomes is brought about by the manner in which the germ cells are formed. These cells arise from products of the division of the primordial germ cells of the testes and ovaries by two successive cell divisions of a peculiar character, known as the "maturation divisions." In the first maturation division to produce sperms, the forty-eight chromosomes of the parent cell move together to form twenty-four chromosome pairs. There is a rather close adherence (or synapsis) of the members of each chromosome pair. The cell then divides by the breaking apart of the pairs, one chromosome of each pair going to the nucleus of each of the two daughter cells. Consequently the nuclei have only twenty-four chromosomes. There is, however, much recent evidence to indicate that, before the separation of the pairs, each chromosome splits longitudinally to form two

sister halves. In most instances, the sister halves seem to remain closely bound together in this cell division process. In the event of such splitting the daughter cells will still contain twenty-four chromosomes, each consisting of two sister halves that have already formed. In the next maturation division each of the twenty-four chromosomes splits longitudinally, and one of the halves of each goes into the nuclei of the two resulting daughter cells; or the sister halves merely separate when the splitting has occurred earlier. The four daughter cells thus produced from the original germ cell contain twenty-four chromosomes and develop into mature sperms.

The maturation of ova takes place in essentially the same manner, except that in the first division the two daughter cells are very unequal in size. The larger one retains all the cytoplasm. The smaller cell is referred to as a polar body. The second division usually involves only the larger of the two cells thus formed. Like the first maturation division, one large and one small cell are formed. The larger cell leads to the production of the mature ovum, while the small one constitutes another polar body. The polar bodies remain attached to the mature ovum for a time but soon disintegrate. Thus only one functional ovum is formed as a result of the maturation divisions.

Unless fertilization occurs, the mature germ cells of both sexes soon perish and either degenerate or are passed out of the body. However, should a sperm come in contact with the ovum, its head (*i.e.*, nucleus) enters the ovum. The sperm nucleus grows rapidly by absorbing fluid from the substance of the ovum. It migrates toward the ovum nucleus and soon fuses with it. At this moment the forty-eight chromosomes are restored, and it is the real moment of fertilization. Cell division can now take place. In the first division of the fertilized egg nucleus, the maternal and paternal chromosomes become indistinguishably intermingled and conditions comparable to those in the normal body cell nucleus are reestablished.

Brief reflection upon this process shows the significance of the maturation divisions and of the eventual union of the sperm and ovum. Normal cell division can now begin, and the human embryo develops. Yet the constancy of forty-eight chromosomes is maintained, one-half of them being obtained from the mother

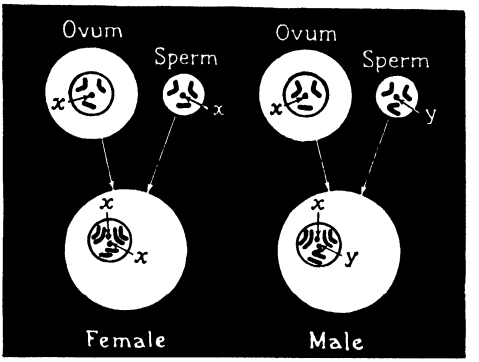
and one-half from the father. If no such reduction division occurred, the nuclei which unite in fertilization would each contain forty-eight chromosomes and the fertilized nucleus formed by their union would contain ninety-six chromosomes. Since the chromosomes are discrete bodies the fertilized nucleus would have to increase in size each time that fertilization took place in order to accommodate them. If the process of doubling the chromosome number were continued indefinitely, a sphere the size of the earth would eventually be too small for the nuclear material of a single germ cell.

Sex Determination

Of the forty-eight chromosomes which make up the normal number in the nucleus of a human body cell, two are structurally different from the rest. These two chromosomes are known to influence the sex of the individual and are therefore called the "sex chromosomes." In the nuclei of the cells of a female individual, the two sex chromosomes are identical in appearance. They have been called the X chromosomes. The chromosome complement of the nucleus of a female somatic cell may be written 46 + X + X, where the forty-six represents the normal chromosomes and the X + X are the two additional sex chromosomes. In the nuclei of the cells of a male, however, the sex chromosomes are quite different from each other. One of them is indistinguishable in size and shape from the sex chromosomes in a female. It is, therefore, an X chromosome. The other is very much smaller and different in structure. It is called the Y chromosome. The formula for the nucleus of a male somatic cell is 46 + X + Y, where, as before, the forty-six represents the normal chromosomes and X + Y the two additional sex chromosomes.

Keeping this in mind, let us see what happens during the course of the maturation divisions in the production of mature germ cells. The sex chromosomes are distributed to two different cells during the reduction division, one going to each cell. The nucleus of a mature ovum always contains twenty-three normal chromosomes and a single X chromosome, represented by 23 + X. However, two kinds of sperms are produced as a result of the reduction division in maturation. The nucleus of one of

them will receive the X chromosome, while the other will receive the Y chromosome. Accordingly, the chromosome composition of one will be 23 + X, while that of the other will be 23 + Y. Should an ovum be fertilized by a sperm containing the X chromosome, the resultant nucleus will have 46 + X + X chromosomes. This is the condition necessary to produce a female, and the child will be a girl. Should an ovum be fertilized by a sperm containing the Y chromosome, the resultant nucleus will have 46 + X + Y chromosomes. This is the condition necessary to produce a male, and the child will be a boy.



When an ovum is fertilized with a sperm containing the X chromosome, a female results. An ovum fertilized with a sperm bearing the Y chromosome produces a male.

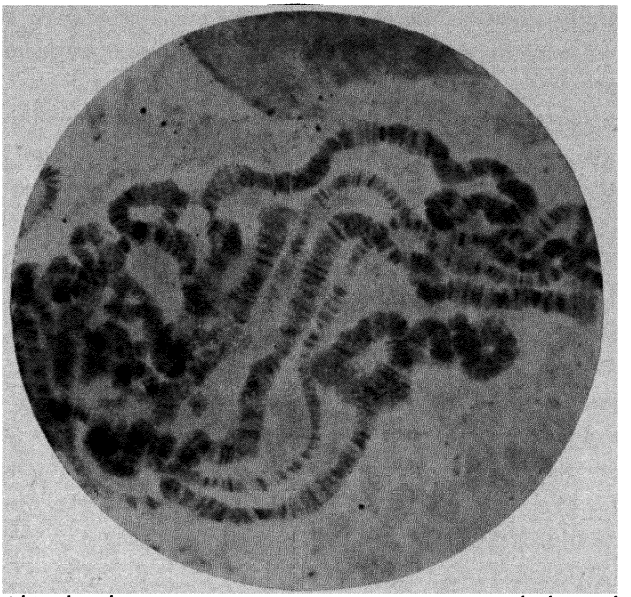
Since the two kinds of sperms are initially produced in equal numbers, the chances are even that in a large number of instances fertilization will be accomplished as often by a sperm bearing an X chromosome as by one bearing a Y chromosome. In the general population, therefore, as many girls as boys are born. There is little doubt that, normally, the modeling of the embryo to either the male or the female pattern is primarily dependent upon the chromosome composition given to the nucleus at the time of fertilization. It is also well known, however, that in rare cases the primary influence of the sex chromosomes may be overridden by effects of other hereditary factors possibly located in the other chromosomes, causing the offspring to be an intersexed individual. Just what these other factors are is not well understood at present.

The query as to whether man can control the sex of his offspring is still to be answered in the negative. It should be remembered that the fundamental factor that appears to determine the sex of the offspring is the composition of the nucleus established at the time of fertilization, particularly as regards the sex chromosomes. This is purely a chance factor. Another factor

believed by some to modify the sex of a child is the rate of metabolism of the embryonic cells at the time the sexual organs are being differentiated. It is known that in general males have a higher rate of metabolism than do females. The presence of a Y chromosome in the nuclei of the body cells may predispose to a high metabolic rate and the production of maleness. Correspondingly, the presence of two X chromosomes would give the body cells a lower rate of metabolism, inducing femaleness. If the influence of the sex chromosomes could be overridden, perhaps by chemical means, the sex of the embryo might be altered or controlled. On the basis of such reasoning, a number of doctors and people generally interested in sex determination have tested the effect of regulating the diet of mothers during the early weeks of pregnancy so as to produce a high or low rate of metabolism in the embryonic cells. If the reasoning upon which this treatment is based be correct, it should be possible in this manner to produce boys or girls at will. The results to date have not been consistent enough to warrant forming definite conclusions.

Another widely held idea is that the sex of a child is influenced by the acidity or alkalinity of the female reproductive tract at the time of conception. It is claimed that conditions of less acidity tend to favor the production of daughters. If this is true, it probably means that the sperms containing X chromosomes are a little more active in such a medium than those containing Y chromosomes, and, hence, are more likely to effect fertilization. In order to control the sex of offspring, then, it would only be necessary to determine the time in the menstrual cycle when the female reproductive tract was most or least acid and to make use of such information in selecting a time for conception. Artificial control of the conditions in the Fallopian tubes, uterus, and vagina at the time of fertilization might be achieved by the use of acid or alkaline douches.

Some slight statistical support for this idea has been obtained in breeding experiments with smaller mammals. Where hundreds of mice have been bred after an alkaline douche, a greater number of females than males have been observed among the offspring. When an acid douche has been used, on the other hand, a slight majority of the offspring have been males. However, for indi-



Located within the chromosomes are genes or genes groups, which are the bearers of heredity. Microphotograph of chromosomes in the salivary gland of the fruit fly, Drosophila, showing many genes loci. (Taken by Roy Allen.)

vidual litters no exact prediction could be made. When man himself has tried the plan, the few individual cases have not worked out with a high degree of certainty. Results seem to revert to the well-known law of chance variation in sex determination.

Inheriting Definite Characteristics

There is a definite and positive tendency for the offspring of all living things to resemble their parents rather closely. This is particularly true of fundamental traits, so that each species of creature reproduces its own kind. It is also true of very specific and individual traits. For example, resemblances in such things as the shape of the nose, size of the wrists, or color of the hair tend to be transmitted in human family groups. The expression of these hereditary characteristics is controlled by the nature of small bodies called "genes" which make up the chromosomes within the cell nuclei. The forty-eight chromosomes in the nucleus of the fertilized ovum contain large numbers of genes, each of which influences the development of one or more tissues, organs, or systems of the individual. Thus, there are genes which

call for the development of tall or short stature, for one or another eye color, for mental ability or lack of it, and so on for every attribute of the adult.

The results of carefully controlled breeding experiments with lower animals and with plants have shown that the expression of every hereditary trait is influenced by at least a pair of genes. One of these is located in a chromosome contributed to the fertilized nucleus by the ovum, the other in a chromosome contributed by the sperm. Therefore, the expression of every hereditary characteristic may be affected as much by maternal factors as by paternal ones. This is true of all traits, with the exception of certain ones which are governed by genes located in the sex chromosomes and which are therefore said to be sex-linked.

Evidence from the same sort of experiments indicates that the genes are arranged in a linear fashion within the chromosomes. Accordingly, the chromosomes may be regarded as strings of genes arranged in a manner not unlike beads in a necklace. The normal make-up of forty-eight chromosomes in the nucleus of every human body cell actually comprises twenty-four pairs of gene strings, although this becomes apparent only at the time of the maturation divisions in the formation of mature germ cells. The chromosomes of any given pair are said to be homologous, since each comprises a string of genes affecting the expression of the same hereditary traits. One member of such a homologous pair comes from the father, the other from the mother.

An enormous amount of experimental data has also been gathered which tends to show not only that the expression of a given hereditary trait is determined by one or more pairs of genes located in definite pairs of chromosomes, but also that the genes occupy exact positions in the chromosomes. For example, the chromosomes of the fast-breeding fruit fly, Drosophila, have been mapped with a degree of precision that is unbelievable to persons not acquainted with the extensive work of modern genetics. It is possible to locate the exact position in a chromosome of the gene that causes the eye of a fruit fly to be white rather than red. At another known location in the chromosome or in another chromosome will be a gene which produces black body color instead of gray, and so on. Several hundred heredi-

tary factors have been located in the chromosomes in this manner.

During the maturation divisions in the formation of mature ova and sperms from primordial germ cells, a remarkable separation of the homologous chromosomes is effected. In the early stages of the first maturation divisions the homologous chromosomes come to be arranged in pairs, as we have previously noted. The pairing takes place in such fashion, moreover, that genes influencing the expression of the same trait are directly opposite each other. In many instances immediately following this pairing there is a splitting of each of the homologous chromosomes into sister halves. Often there is a cross-over of corresponding parts of sister halves between homologous chromosomes. Then the cell divides by a separation of the homologous chromosomes, including what cross-overs have occurred. In the next division of the maturation process there is a separation of the sister halves to produce the nuclei of the mature germ cells. As a result of these two divisions, a mature germ cell contains only one of the two genes which influence the expression of a given trait in the offspring.

In the union of the sperm nucleus and egg nucleus, when fertilization occurs, the condition found in the nuclei of somatic cells is restored in the fertilized nucleus. It then contains the full complement of forty-eight chromosomes, consisting of twenty-four homologous pairs. Both maternal and paternal genes influencing the expression of the same traits are again present.

It is a curious fact that not all the genes which influence the expression of a given trait have the same ability to do so. Some genes appear to exert a more powerful influence than others. They are said to be dominant, or they are called dominant genes. A single such factor will determine the expression of a trait just as surely as will two. For example, brown eye color in man can be regarded, for practical purposes, as an expression of the influence of a dominant gene upon this trait. If a person receives the factor for brown eye color from either parent, that individual will have brown eyes, even though one parent may not have brown eyes. The alternative to brown eye color in man is generally some shade of blue. The gene which produces blue eye color does not exert so powerful an influence on development as does the factor

for brown. In order for the color of the eyes to be blue, it is necessary that both genes affecting the expression of this trait be of the type which produces blue color. Such a factor is said to be recessive, or to be a recessive gene.

The influence of a recessive gene is masked when a dominant gene which affects the same trait is present. Thus, in order for an individual to have blue eyes, he must receive a recessive factor for the expression of this trait from both parents. What has been stated provides an explanation for the occurrence of blue-eyed children among the offspring of parents both of whom are brown-eyed. Obviously, each parent must have the genes from his ancestors for both brown and blue eyes. Since the gene for brown eye color is dominant over that for blue, the parents will both have brown eyes. However, when sperms are formed in the seminiferous tubules of the male parent, half of them will receive the factor for blue eye color and half will receive that for brown. Similarly, when an egg is released from the ovary of the female parent, the probability that it will contain a factor for blue eye color is just as great as the probability that it will contain one for brown eye color. When fertilization occurs there is just as great a chance that the uniting germ cells will be alike as that they will be different with respect to the nature of the genes affecting eye color; that is, it is just as probable that a sperm bearing the factor for blue eyes will unite with an egg containing a similar factor, as that it will unite with an egg bearing the gene for brown eye color. The same reasoning may be applied in figuring the probability that a sperm bearing the gene for brown eye color will unite with an egg having a similar gene for this trait or will unite with an egg having the gene for blue eye color. In either case, brown eyes will result. Thus, the chance that the offspring will have blue eyes is one in four, because there are three combinations out of a possible four which will result in the production of brown-eyed offspring, owing to the factor of dominance.

The complicated machinery of sexual reproduction provides for the occurrence of variation in individuals. It has been calculated that the possible number of chromosome combinations when the human ovum is fertilized is over sixteen billions. The chance that any particular combination will be reproduced in

the fertilized ovum and thereby produce a given set of characteristics in the offspring is, accordingly, about one in sixteen billion. Furthermore, the exact gene composition of a given chromosome may be altered by the interchange of chromosome parts between homologous pairs of chromosomes during the early stages of reduction division in the production of mature germ cells. This interchange of parts is brought about by a cross-over of corresponding parts between homologous chromosomes. This increases the possible gene combinations at the time of fertilization to a figure approaching infinity. Thereby the chances become almost limitless that there will be some slight difference in the exact gene composition of any particular fertilized ovum from that of another fertilized ovum and that the individual resulting will have some traits that are characteristic of him alone. These remarkable facts make it possible to understand why each individual tends to be somewhat different from every other individual.

Heredity in Man

The discovery that has done more than anything else to reduce the manifold phenomena of heredity to law and order was made by an Austrian monk, Gregor Mendel, about the middle of the last century. In the gardens of his monastery he experimented for many years in crossing different varities of peas. He kept an accurate record of his results and published them in 1866. This paper ranks as one of the finest achievements in experimental research. However, his contemporaries did not appreciate its value. It was only after the turn of the present century, when more knowledge of chromosomes and genes had been discovered, that its real worth was realized.

Mendel's techniques have been applied since then to the crossing of different varieties of mice, rats, flies, dogs, horses, cattle, corn, tobacco, squash, and a great many other animals and plants. The results have served to strengthen the fundamental laws formulated by Mendel. It is impossible, of course, to apply Mendel's experimental methods to the study of human heredity. However, there is no reason to believe that man should be the one exception to these biological laws. In fact, where large numbers of accurate records of human matings and offspring

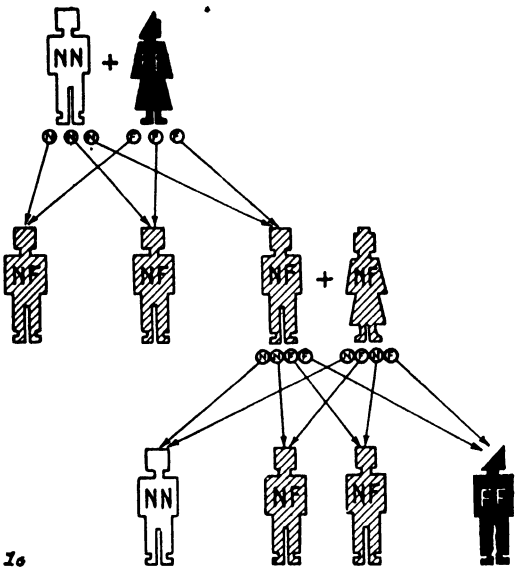
have been kept, the same principles of heredity are found to hold true.

These laws may be briefly explained and illustrated with a few well-established examples of the inheritance of specific human traits. One of these which has been extensively observed is feeble-mindedness. Of course, we are concerned here only with hereditary feeble-mindedness, not the many instances which have resulted from some injury before or after birth or from infectious disease; such feeble-mindedness is not inherited nor transmitted to the succeeding generations. It is also to be kept in mind that the quality of one's environment may have much to do with his mental development. The truth of the whole question seems to be that heredity fixes the limits of individual possibilities while the environment determines to what extent these possibilities are realized.

Let us suppose a family to be started through a marriage between a man of well-established normal traits and a feeble-minded woman. Let us designate the genes for normalcy by the letter *N* and those for feeble-mindedness by *f*. The man would be represented, therefore, by *NN* to designate the sets of genes from his two parents. The woman would be represented by *ff*, indicating she had received such genes from both parents. The children of this marriage appeared to be normal, since the normal genes are dominant and genes for feeble-mindedness are recessive. However, each child contained in his germ plasm the mixture of genes, *Nf*, and such a combination is known as a hybrid.

Suppose that one of these children later married a normal-appearing woman whose mother had been normal and whose father had been feeble-minded. Contrary to general appearances she, too, was a feeble-minded hybrid. Let us further suppose that they had four children; now comes the unpleasant surprise. One child of this third generation was feeble-minded. The mixing of the sets of genes to account for this is shown in the accompanying chart, which represents the statistical average of inheritance of characteristics when gene patterns are mixed in the offspring.

Since the man of the first marriage was normal, all his genes would call for normal-mindedness, as represented by the *N* in the small circles. All the genes of the feeble-minded woman of this marriage call for feeble-mindedness, as represented by the *f*



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Statistical average of inheritance of characteristics when gene patterns are mixed in the offspring.

in the small circles. The three children of this marriage get a mixture of *N* and *f* genes, as shown by the crossover lines. They are hybrid types, since each contains the feeble-minded genes as recessives. The marriage of one of the second generation to a feeble-minded hybrid permits of other combinations of these matching genes. Each of these individuals produces germ cells having either *N* or *f* genes, as shown by the small circles. Therefore their children would surely be made up by combinations of these genes. Of the four children of the third generation born to this union, one would be normal, with the *NN* grouping of genes; two would be hybrids, with *Nf* genes; and one would be feeble-minded, with the *ff* grouping of genes.

Dr. H. H. Goddard in one of his studies, entitled "Feeble-mindedness," reports 42 matings in which the persons marrying had the gene combinations of $Nf + ff$. There were 144 children whose mentality was known. Of these, 73 were normal and 71 were feeble-minded. This is very close to the expectation as would be predicted by the Mendelian laws of heredity. However, the details of representing the various gene combinations are too complex to be given here.

Perhaps the most interesting case of the inheritance of mental traits known in America is that of the Kallikak families, reported by Dr. Goddard. A Revolutionary War soldier named Martin Kallikak, of good ancestry, met a feeble-minded girl in a tavern. As a result of this rendezvous, the girl had an illegitimate son whom she called Martin Kallikak, Jr. Young Martin married a feeble-minded girl and raised a family of ten children. The progeny of this union by 1910 had reached 480 known individuals. Of these, only 46 are known to have been normal, while 143 were definitely feeble-minded.

However, there is another side to the story of the Kallikak family. After the episode with the feeble-minded girl, the soldier Martin finished the war and later married a Quaker woman of good ancestry. Seven children were born to this union, all of whom married into good families. Their direct descendants have reached the number of 496. They have included doctors, judges, educators, lawyers, and prominent citizens of many kinds. There are no cases on record of feeble-minded offspring among them.

A remarkable case of hereditary deformity is reported from Brazil. A man having a hereditary absence of hands and feet married a normal woman. This deformity seemed to be a dominant trait. Twelve children were born into the family, of whom six were likewise deformed. Two of the deformed died in infancy, but four of them lived to adulthood. No record is available of their matings or offspring.

In the case of stature inheritance, an interesting study is on record of a family of four generations of tall South African natives. A man six feet eight inches in height married a woman six feet four inches tall. Six children resulted, of whom one brother and sister later intermarried. Nine children were born to this union. Two pairs of these intermarried, and they had nine children who grew to adulthood. Of the twenty-four individuals resulting from these unions who were carefully measured, eleven were six feet or over, ten others were more than five feet nine inches tall, while three (all of the fourth generation) were five feet eight inches in height.

The examples that have been cited have been explained with considerable overemphasis on the simplicity of heredity. It is well known that the inheritance of any human trait as complex



The inheritance of white forelock in man for four generations is shown in this series of pictures. The first individual of this family who had the white forelock was Nils Rösland of Osteröy, Norway. Three of his children had this trait, two of whom are shown in the upper and lower left photographs. Seventeen grandchildren, two of whom are shown in the center photographs, inherited the trait, while twenty-four great-grandchildren, two shown in the upper and lower right pictures, inherited the characteristic. (Courtesy of Journal of Heredity.)

as mentality, or stature, or various other traits such as skin color, eye characteristics, or resistance to infectious diseases is the result of many different gene patterns. These produce many blendings and graduations of types between the extremes. However, these blendings are well understood and may be accurately accounted for when all the gene combinations of the immediate and distant relatives are known. They show conclusively that the gene patterns persist either as dominants or recessives through the succeeding generations and that the physical and mental make-up of an individual is determined by the particular heredi-

tary traits that were matched in the fertilized ovum cell from which he sprang.

REFERENCES FOR MORE EXTENDED READING

GILBERT, MARGARET SHEA: "Biography of the Unborn," The Williams and Wilkins Company, Baltimore, 1938.

This little book is the publication of a prize-winning essay on the general subject of human reproduction. It is a well-written story of human reproduction from the time of fertilization to birth. Numerous illustrations are used to illuminate the discussion. An interesting and vivid account is completely told in language that is devoid of the extensive use of technical terms.

TIETZ, E. B., and C. K. WEICHERT: "The Art and Science of Marriage," McGraw-Hill Book Company, Inc., New York, 1938.

This is a volume in the Whittlesey House Health Series, published under the editorship of Dr. Morris Fishbein, editor of the *Journal of the American Medical Association*. The book presents an analysis of the problems of marriage from both a mental and a biological point of view.

DAVENPORT, CHARLES B.: "How We Came by Our Bodies," Henry Holt & Company, Inc., N. Y., 1936.

First section of this well-written book is devoted to tracing development from a single cell to the complicated organism of the adult human being. The second part is a study of the mechanism by which development takes place, such as the structure of cells, genes, and heredity. The third part explains how physical changes in the body are passed on to succeeding generations through the genes. It is written in a popular style, yet adheres to scientific accuracy.

PARSHLEY, H. M.: "The Science of Human Reproduction," W. W. Norton & Company, Inc., New York, 1933.

The author has prepared here a frank and comprehensive discussion of the anatomy and physiology of human reproduction. The text is organized and written in a manner to provide a biological basis for a scientific attitude toward sex and its problems.

WIEMAN, H. L.: "An Introduction to Vertebrate Embryology," McGraw-Hill Book Company, Inc., New York, 1930, Chaps. X, XI.

These chapters constitute a discussion of embryonic development in man and an explanation of the growth of different organs and structures of the embryo at various ages, each section being well illustrated. This is an excellent reference for the student who wishes advanced knowledge of this subject.

HOLMES, S. J.: "Human Genetics and Its Social Import," McGraw-Hill Book Company, Inc., New York, 1936.

Chapters IV–VI deal with chromosomes and genes as the physical basis of heredity. Chapter IX is a general discussion of heredity in man. The remainder of the book is an extended and not too difficult discussion for those who are interested in social aspects of hereditary factors in man.

SCHEINFELD, AMRAN: "You and Heredity," Frederick A. Stokes Company, New York, 1939.

This is a book that was specifically written for the layman to show the applications of scientific findings to human heredity. Many aspects of heredity, such as eye color, ancestry and offspring, the Dionne quintuplets, are presented in a popular fashion while adhering to the best scientific information available on the subject of how and what we inherit.

STURTEVANT, A. H., and G. W. BEADLE: "An Introduction to Genetics," W. B. Saunders Company, Philadelphia, 1939.

This text in genetics is based primarily on studies that have been made on the fruit fly and maize. It has an extended amount of material on chromosomes and genes and is adaptable only to the reader who is a thorough student of the subject of genetics.

ALTENBURG, EDGAR: "How We Inherit," Henry Holt & Company, Inc., New York, 1938, Chaps. IV, V.

A concise, yet specific, discussion of the genes as the hereditary basis of inheritance and their influence in sex determination. The material is sufficiently nontechnical to be understood by the intelligent reader.

Nature Magazine, published by the American Nature Association, Washington, D. C.

This monthly magazine is devoted to stimulating public interest in nature and the out-of-doors. The articles are written in popular fashion, and some are relatively well illustrated. The subjects treated are usually those plants and animals with which the inquiring laymen has some little acquaintance.

The Journal of Heredity, published by American Genetic Association, Baltimore.

This is a monthly magazine that is devoted to promoting a knowledge of the laws of heredity and their application to the improvement of plants, animals, and human racial stocks. The articles are extensively illustrated and may be read with understanding by the intelligent layman.



13: SENSATIONS

By Which We Receive Communications from the Outside World

IT IS said that in most state and federal penitentiaries there is an efficient "underground" system of communication. It is nonmechanical, invisible to the uninstructed observer, and unsupervised, but it works. The prison authorities very definitely control the information from outside sources which comes to the inmates through the regular channels of communication. Usually this information is carefully censored. In addition to such regular channels of intelligence, however, the prisoners learn about what is going on in the outside world by devious means, which they alone know.

Many intelligent individuals are only dimly aware of the fact that a large part of what they believe to be true about

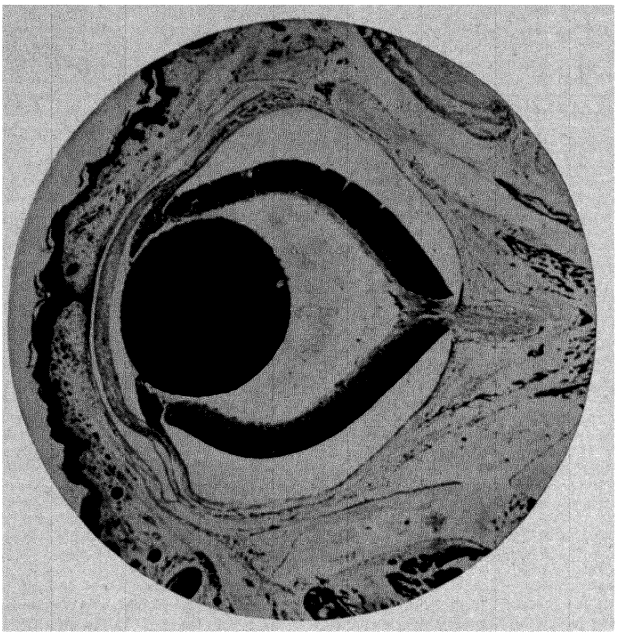
the world is determined not by impressions gained through the physical senses, but by integrating and coordinating mechanisms which function below the level of consciousness. This subconscious intelligence service may be likened to the so-called "grapevine" system by which prison inmates receive information denied them through official channels. It is true, nevertheless, that all our direct knowledge concerning the external physical world comes to us through our organs of sense. Besides being limited in number, these sense organs are susceptible only to certain special kinds of stimulation. They may be compared to the censored official channels of prison communication in that the sensory impressions which they transmit to the brain are modified as much by factors inherent in their own structure as by the physical character of the stimuli which excite them.

The essential part of any organ of special sense is a group of cells or tissues which have developed to an extraordinary degree the fundamental protoplasmic attribute of irritability. In contrast to the primitive protoplasm of the simplest living organisms, which is sensitive to all sorts of stimuli, the specialized sense organs of higher animals usually respond only to a very limited range of specific stimuli. The eyes respond to radiant energy between certain limits of wave length; the ears, to sound waves, also within a restricted range of wave lengths; the sense organs of the skin respond to mechanical and physical stimuli of certain intensities; and the organs of taste and smell, to chemicals dissolved in certain concentrations in the saliva of the mouth and in the mucous membranes of the nose, respectively.

In addition to the sensitive tissues, or receptors, the well-developed sense organs of higher organisms usually contain auxiliary tissues which are not particularly irritable but are designed to bring about proper contact between stimulus and sensory nerve. The fundamental characteristics of the special sense organs, namely, their limited responsiveness to a particular kind of stimulus and their composite structure, are clearly illustrated in the most highly developed of them all—the eyes.

Vision

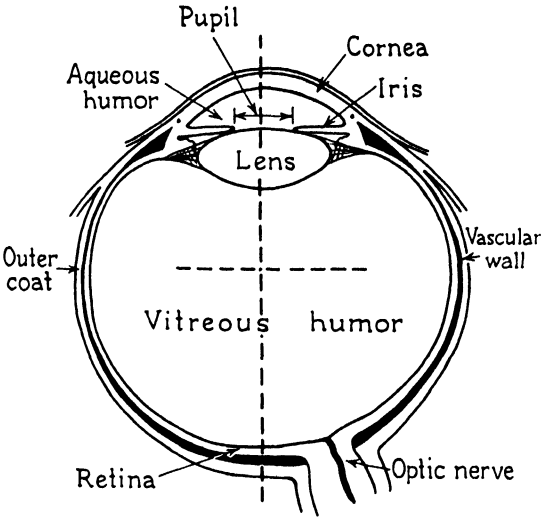
Undoubtedly most of our knowledge about the world in which we live comes to us through our eyes. We have only to



This low-magnification microphotograph of an actual section of the eye of a young mouse shows all the parts of the eye, closed eyelid (left), cornea, crystalline lens, retina, and optic nerve. (Science Service photograph.)

close them momentarily to appreciate the wealth of beauty and variety which our eyes bring to us and to realize how helpless we would be without them. The eyes are special sense organs designed to receive radiant energy and to convert it into the energy of nerve impulses. The optic nerves, which convey these impulses to the brain, contain over one-half of all the sensory nerve fibers in the body. The sensation created by the impact of radiant energy upon the eyes is what we know as light.

Although our behavior is more definitely influenced by the information we secure from light than by that from any other stimulus, the eyes, after all, constitute only a small part of the entire body. Even within the eye, the sensory receptors which give us visual imagery are confined within a small area. Most of the eye as an organ is composed of supporting tissue and structures to collect the light energy, control the intensity entering the eye, and to bring it to focus on the cells containing the optic nerve endings. The latter are the sensitive elements and are in reality an outgrowth of the brain. These receptive structures



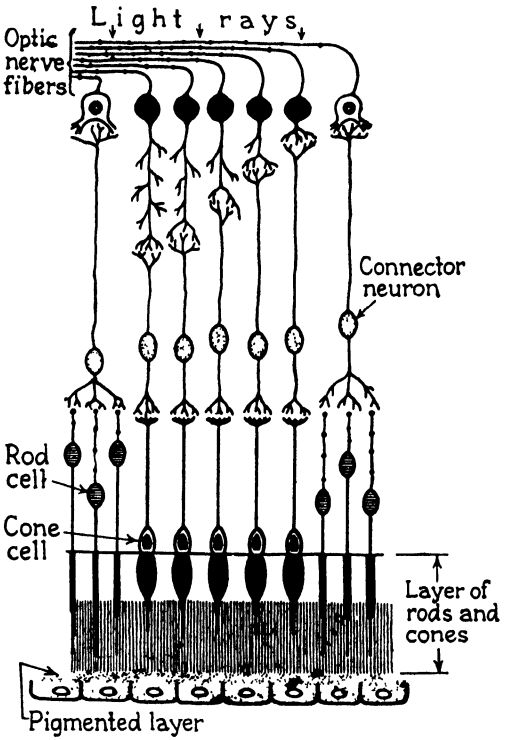
If the eyeball is sliced horizontally through the center, each hemisphere will be seen to be made of three distinct layers of material. (After Starling, "Human Physiology.")

are buried within the protective body of the eye and are surrounded by special tissues which originate from the skin.

The eyeball might be referred to as the camera box of the eye. It is lodged in a bony orbit of the skull, which forms a protection for it from mechanical injuries. It is a hollow, somewhat plastic sphere filled with a thick, transparent fluid, called the "vitreous humor." This fluid helps to maintain the shape of the eyeball. Should the eyeball be sliced through the center so as to form two hemispheres, it would be seen to consist of three distinct layers of material.

The outer layer of the eye is a tough membranous coat. About five-sixths of this layer constitutes the opaque "white of the eye," which is mostly out of sight in the orbit. The remaining one-sixth forms a transparent circular window, the "cornea," which covers the front face of the eyeball. The second or central layer of the eyeball is what is known as the "vascular wall." It is a thin membrane characterized by an abundance of blood and lymph vessels. The front part of this layer is the iris, in the center of which is a round opening, the pupil, through which the light enters the inner chamber. The iris is supplied with radial muscles which, by their contraction, enlarge the size of the pupil. Another

group of muscle fibers, arranged circularly about the pupillary margin, lessens the size of the pupil by contraction. Pigments of various kinds are present in the iris, giving the distinctive color to the eye.



Nerve cells and layers in the retina. The back of the retina consists of two layers: an outer layer of pigmented cells and, in front of this, the layer comprising the light receptors themselves—the rod- and cone-cells—facing to the back, away from the light.

Between the iris and the cornea there is a small chamber filled with watery fluid, the "aqueous humor," which bathes the surrounding tissues. Just behind the iris is the lens, consisting of dense, transparent tissue that serves to focus on the retina the rays of light that come from different objects being viewed.

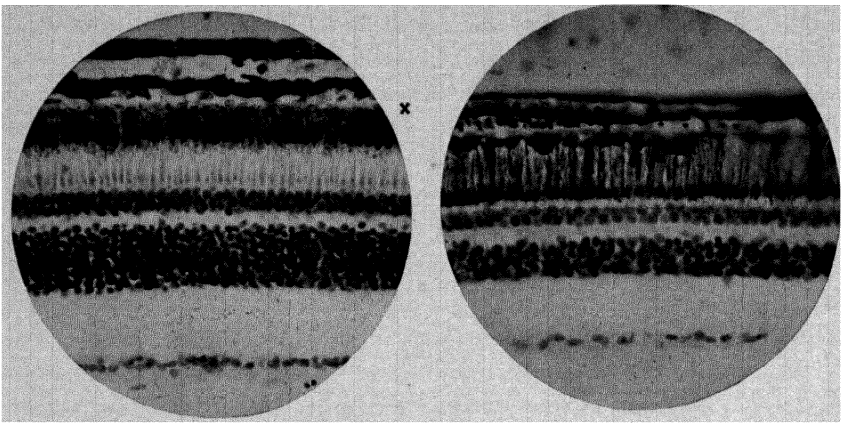
The inner wall of the eyeball is the "retinal layer." It extends around approximately two-thirds of the eyeball, forming a sort of cup with the opening toward the front. This wall is itself composite in structure. It may be roughly divided into two parts. The outermost portion at the back of the eye consists of two layers, an outer layer of pigmented cells and in front of this the layer comprising the light receptors themselves. These are the rods and cones. The rod- and cone-cells contain the specific sensory endings of the fibers of the optic nerve. A single optic nerve fiber may supply several rod or cone cells, especially toward the outer margin of the retina.

Strangely enough the sensory ends of the rods and cones do not face to the front of the eye but to the rear away from the

light; that is, the fibers of the optic nerve are linked to the ends toward the front of the eye. These nerve fibers, together with certain ganglion cells, form a layer facing the front of the eye. The nerve fibers pass through this layer until they reach the region of the optic nerve near the center of the retina. There they bend backward and pass through an opening in the retina to connect with the optic nerve. This point has no rods or cones and, of course, does not respond to light energy falling on it. When the rays from some object are focused on this point, the object is not seen. It is, therefore, called the "blind spot."

If this picture of the retina is clear, it is seen that the sensory part of the eye is turned wrong side out, so that the rods and cones face away from the source of light rather than toward it. The light rays, after being focused by the lens, must first pass through the layer of nerve cells and fibers of the retina, then the meshwork of rod and cone cells, before they fall on the sensitive ends of the latter. The rods and cones are distributed differently in the retina. In the region of the fovea, a point directly behind the pupil, it is estimated that there are 150,000 cones per square millimeter. This number decreases rapidly as the distance from the fovea increases. Thus, at a point 0.016 millimeter from the fovea the number per square millimeter is about 145,000; it is about 132,000 at twice that distance. On the other hand, there are practically no rods in the fovea, but the number per square millimeter increases rapidly toward the margin of the retina, then falls off again. There are approximately eighteen or twenty times as many rods as cones. At the retinal margin there are practically no cones at all, but only rods.

The rods convey sensations of light and darkness, but they do not play any part at all in color perception. They are the receptors primarily concerned with perception in very dim light. Sharp images are obtained only when light rays are focused on the region around the fovea, where the cones are most numerous. The outer zones of the retina, containing rods almost exclusively, produce only indistinct images. That the cones are more highly differentiated and specialized than the rods is shown by the fact that in all those nice discriminations of form and color which make the human eye such an efficient sense organ, it is the fovea, made up almost entirely of cones, that is principally concerned.



Section of the frog's retina, fixed before and after exposure to light. (1) In darkness, the pigment granules are collected around the base of the receptor cells at x. (2) On exposure to light, the pigment granules migrate out toward the light source, forming a protective layer about the receptor cells which prevents the escape of light from one cell to another. (Photomicrographs by Roy Allen.)

Color can be discerned in objects only when they are almost directly in front of the eye, so that the rays of light from them fall on these cones.

It may be wondered how light effects its stimulation of the optic nerve endings. The rods and cones have been found to be rather complex devices for bringing about this stimulation by means of photochemical changes. Within the rods there is a substance called "visual purple" because of its color. When light falls on it, a partial bleaching takes place in which it changes to a yellowish color. This photochemical reaction starts a series of chemical changes which set up nerve impulses in the optic nerve endings. The gradual improvement of vision after one has been in a dark room for a while seems to depend upon the behavior of visual purple. After one remains in the dark for a time, more visual purple is formed, and the rods become more sensitive.

Since the rods are thickest at a point a little off the center of the retina, a dimly lighted object slightly off to the side may be seen, whereas it becomes much dimmer or entirely invisible if looked at directly. This, no doubt, has had much to do with people seeing "ghosts" at night. A dim object at the side may be

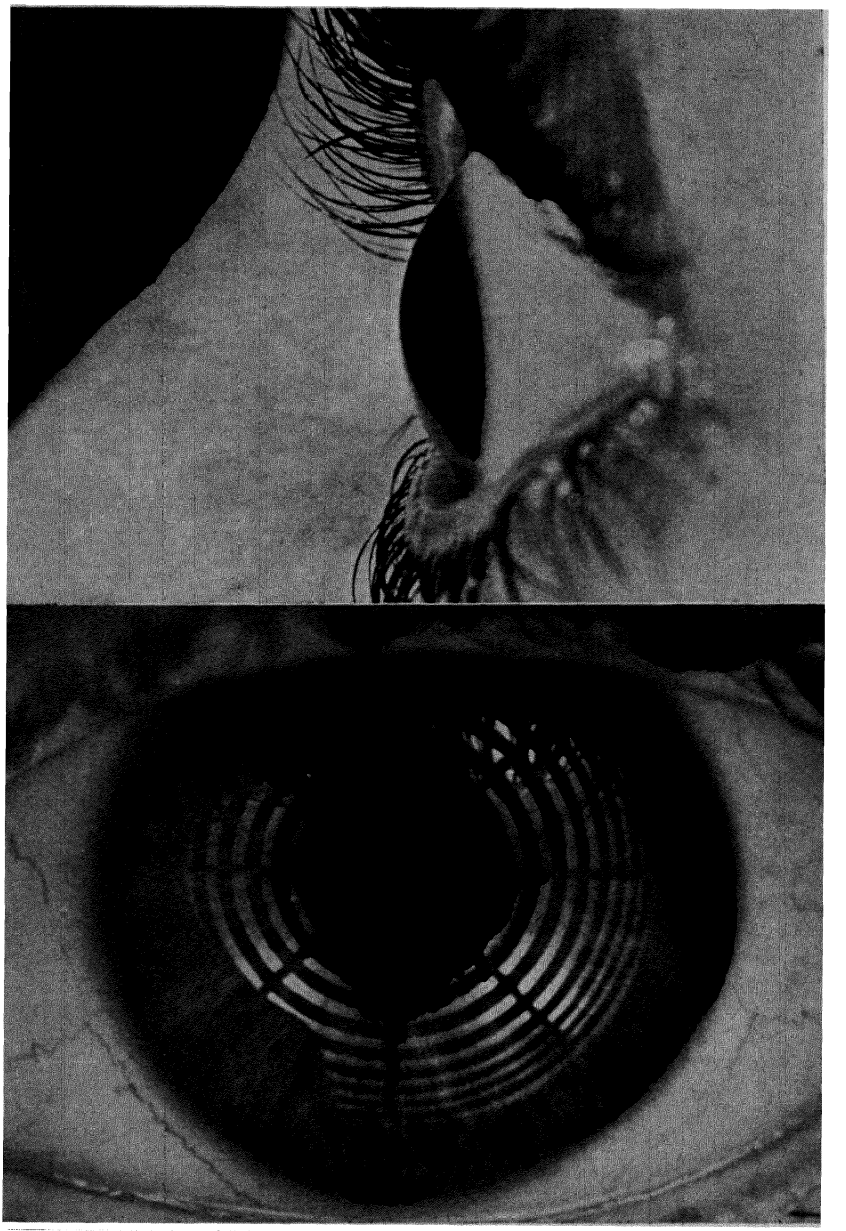
slightly visible, but "mysteriously" disappear when looked at directly.

Just how the cones permit us to distinguish form and color is not definitely known. They do not contain visual purple. Recently Dr. George Wald of Harvard University has isolated from the retinas of chicks, which contain cones almost exclusively, a substance which he calls "visual pink." The material had to be extracted in total darkness. On exposure to red light, a rapid bleaching took place. This could be demonstrated by spectroscopic comparison of solutions of the substance before and after exposure to the red light. That visual purple and visual pink are different is shown by the fact that red light is almost without effect upon visual purple, producing only a very slow bleaching.

The evidence seems to indicate that there are three kinds of cones, distributed about equally in the region of the fovea. When one of these different kinds of cones is stimulated to a greater degree than the other two a peculiar and characteristic color sensation is produced; red, green, or violet, as the case may be. When light of only the longer wave lengths enters the pupils of the eyes, the color sensation of red is evoked. Similarly, the medium wave lengths of light produce the sensation of green color, while the shorter wave lengths cause the color sensation of blue or violet. It is known that certain intensities of selected wave lengths of light in the red, green, and violet parts of the visible spectrum produce the sensation of white, apparently by stimulating the three types of cones simultaneously to the same relative extent. Other colors are believed to be perceived through stimulation of one or more of the different types of cones to unequal degrees.

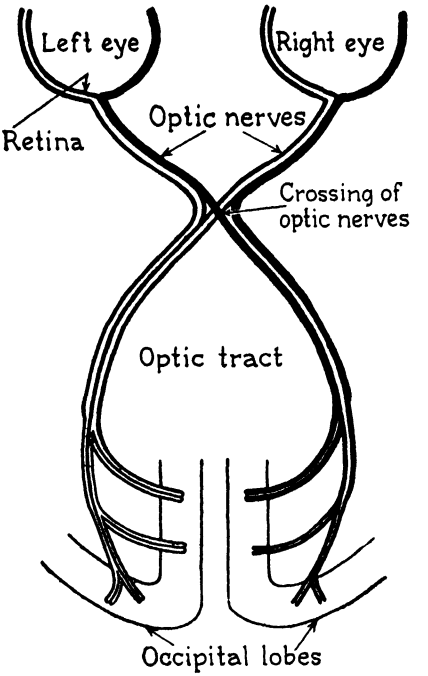
One of the most remarkable features of our vision is the ability to perceive distance or depth in objects. This is what is known as "stereoscopic vision," and it is possessed only by man, the great apes, and monkeys. It is made possible primarily by the fact that the eyes are so situated in the skull that they may look directly to the front and secondarily by a very ingenious crossing of the optic nerves before they enter the brain.

In all vertebrates except the primates, all the fibers of the optic nerve from each of the two eyes cross one another and go



The cornea of the normal eye is a thin transparent tissue covering the front of the eyeball. It is spherical in shape, as shown in the picture at the top. When a radial pattern is held in front of an eye with a perfect cornea, the pattern is reflected without distortion and may be so photographed, as shown in the lower picture. (Photographs by A. Marfaing, New York.)

to the opposite sides of the brain. Thus, the sensations from the right eye are received on the left side of the brain and those from the left eye on the right side of the brain. In man, apes, and monkeys, however, at the crossing point of the optic nerves, half of the fibers from each side turn at an angle and go to the corresponding side of the brain, while half of them cross and go to the opposite side of the brain, that is, nerve fibers from each eye enter the optic centers of both sides of the brain.



Stereoscopic vision is made possible partly by an ingenious crossing of the optic nerves before they enter the brain. (Redrawn from Carlson and Johnson, "The Machinery of the Body.")

As a consequence of this fact, the image produced by the stimulation of one eye is superimposed upon that produced by stimulation of the other. Thereby, we get the perception of distances and depth in objects. The principle is similar to that employed in the old-fashioned stereoscope, which gives the impression of depth and distances by superimposing the projections of two flat pictures of the same object which have been taken from different angles corresponding to those of the two eyes.

Correlated with the distribution of the fibers of the optic nerves to facilitate binocular vision, the motor control of the eye muscles is such that the movements of the two eyes are in unison. It might be thought that each eye, by virtue of possessing an independent set of motor muscles, is capable of movement without regard to the other eye. Actually, however, an independent movement of each eye is not possible at all. Quite remarkably, newborn babies do possess the ability to move one eye independently of the other. However, within a few months after birth, babies develop the ability to move the two eyes

in unison. It seems that from earliest infancy our efforts are concentrated toward achieving single and distinct vision with the two eyes, and one phase of this is that they be moved simultaneously. In some abnormal cases a muscle of one eye pulls more strongly than the corresponding muscle of the other eye so that the lines of sight of the two eyes are not correctly directed. This makes it impossible for the person to focus both eyes simultaneously on one object. Such a person is said to be cross-eyed. Under such conditions two images fall on the two retinas of the eyes, and the person would have double vision except that his brain soon learns to ignore one of the images.

The perfection of an optical mechanism for color perception and binocular vision was a circumstance of tremendous consequence in the early development of man and his culture. There can be no doubt of the necessity of such equipment as a condition for the development of skilled manipulative operations of the hands and fingers, for such movements are exhibited only by those forms which possess stereoscopic vision, namely, monkeys, the great apes, and man. With increasing assumption of an upright posture in walking, man's earliest forebears found their hands free to grasp objects. This freeing of the hands aided early man not only in locomotion but also in many other ways. Skilled manipulations developed from crude grasping movements with the appearance of close coordination between hand and eye.

Moreover, these factors in man's advance were reciprocal in their action. Widening the scope of uses of the hands tended ever more to force the exclusive adoption of bipedal locomotion and an erect body carriage. These habit changes, in turn, tended to broaden the field of man's vision and further to release the hands for new uses. Furthermore, skilled operations of the hands are associated with increased mental activity. Those individuals possessing the physical and mental attributes to excel along the new lines of activity tended to prevail over their less fortunate fellows. They tended to survive in the struggle for existence and, perhaps, to pass on to their offspring the very traits which conditioned their survival. In some such manner were developed the physical characteristics which make for skill and the mental organization which has been responsible for the development of

man's culture from the primitive beginnings represented in what we know of the old stone age to modern society with all its complexity.

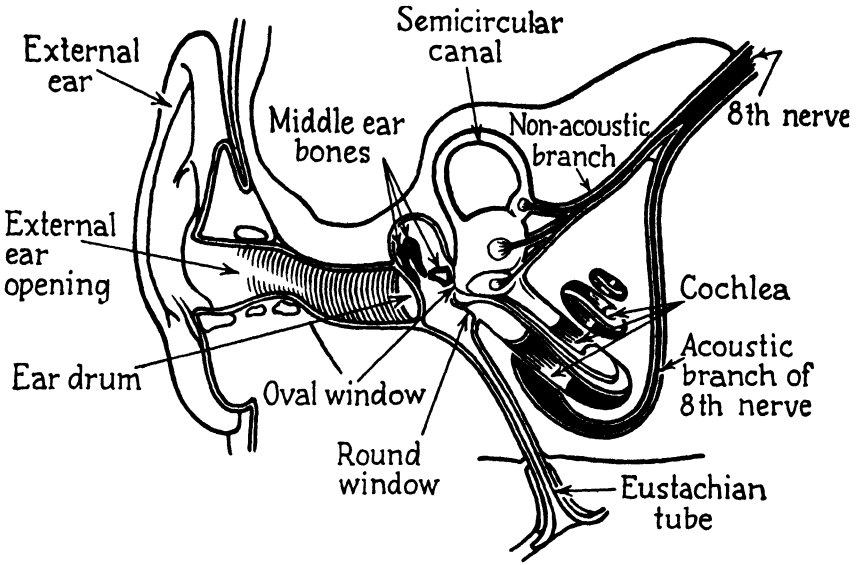
Hearing

Second only to visual impressions as a source of information about events in the world around us are sounds. These are sensations produced by waves or vibrations transmitted by the air. The organ by means of which sound waves are translated into nervous impulses is, of course, the ear. In the brain the impulses originating in the sensory fibers of the ear are interpreted as the sensation we call hearing.

The ear is usually described as consisting of three parts, the outer, middle and inner ear. It is the cochlea of the inner ear, however, which contains the sensory receptors that are stimulated by the sound vibrations. The other parts are conducting mechanisms which serve to convey the waves to the cochlea.

The outer ear consists simply of a cartilaginous funnel-like organ for collecting the sound vibrations and an auditory canal to lead it from the outside to the eardrum at the inner end of the canal. The eardrum is a thin membrane of muscle and connective-tissue fibers which separates the outer from the middle ear. The latter is an air-filled cavity from which an open canal, the Eustachian tube, leads into the throat. This canal is sometimes the cause of considerable trouble, as it forms a passage through which diseasé-producing organisms lodged in the mouth or throat can rather easily reach the middle ear, often leading to serious infections of this region which may back up into the cavities of the spongy mastoid bone.

The origin of the middle ear from the spiracle of fishes in the evolution of the mammalian skull has already been mentioned elsewhere. The Eustachian tube represents the portion of this first gill slit which connected with the throat. The middle ear chamber is bridged by three small bones, the hammer, anvil, and stirrup, whose origin and functions were described in a previous chapter. It is necessary to repeat here only that the mechanical vibrations of the eardrum, produced by the impact of the sound waves upon it, are transmitted through these three bones to the inner ear. In this transmission the vibrations are

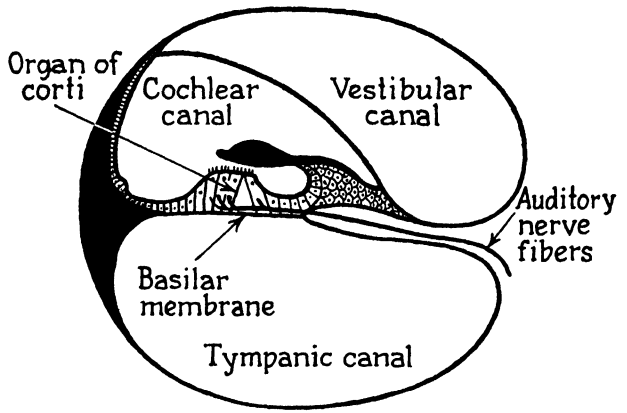


In a transverse section, the ear is seen to be a complex organ for collecting sound vibrations, amplifying and transmitting them, and converting their energy into the energy of nerve impulses.

amplified. The middle-ear bones act like a bent lever which theoretically has a mechanical advantage of 3 to 1. Friction between the bones, however, and the air pressure in the middle-ear cavity, tend to reduce this value by about one-half, so that the effective leverage is about 3 to 2.

In a previous chapter it was stated that the base of the stirrup bone forms an oval plate which closes an opening in the bony casing of the inner ear. This is the so-called "oval window." It is the upper one of two openings by which the bony labyrinth of the inner ear communicates with the middle-ear chamber. The other opening, the "round window," is closed by a tough membrane. The area of the oval window is about one-twentieth that of the eardrum. As a result, the pressure exerted by the eardrum is increased about twenty times at the oval window, making the final pressure of the stirrup moving in the oval window approximately thirty times that of the eardrum.

The bony labyrinth of the inner ear contains a spirally coiled structure known as the "cochlea." The coiling of this structure resembles that of a snail shell, from which it takes its name. It consists of a tube which gets progressively smaller and comes to



In a cross section of the cochlea, the organ of Corti may be seen to consist of ciliated cells resting on the basilar membrane. The cilia of these cells are in contact with an overhanging membrane. The ciliated cells are anatomically in connection with fibers of the auditory nerve. (After Carlson and Johnson, "The Machinery of the Body.")

a point at the apex. The tube is partitioned off into three parallel canals, which traverse its entire length and likewise taper toward the apex. The canals are filled with a fluid which vibrates in response to the vibrations transmitted to the stirrup from the eardrum.

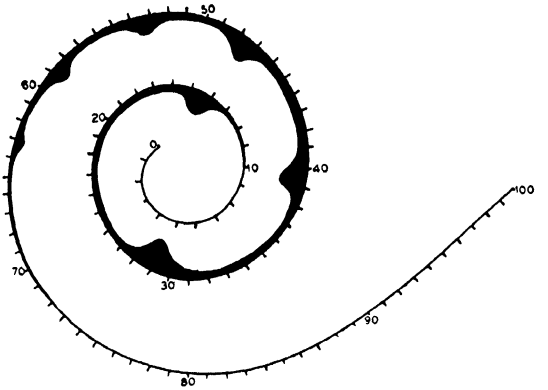
The middle canal (or cochlear canal) contains the true organ of hearing—the so-called "organ of Corti." The middle canal is separated from the upper and lower canals by membranous partitions. The lower one of these is the basilar membrane, on which the organ of Corti rests. The details of the structure of the cochlea are shown in the accompanying drawing. The organ of Corti is composed of "hair cells." These are in reality ciliated cells which are the end organs of the auditory nerves. There are some 15,000 to 50,000 of these ciliated cells in the human ear. They extend along the entire length of the cochlea from its base to its apex. The cells vary in size, the largest being.located near the tip. The cilia of the hair cells come in contact with an overhanging structure, or "roof" membrane.

The mechanism that has just been described provides the means whereby the vibrations of the eardrum are amplified and transmitted to the fluid of the cochlear canal. How are these vibrations converted into nerve impulses in the fibers of the auditory nerve? It seems clear that the hair cells of the organ of

Corti are directly involved, since they are anatomically in connection with the nerve fibers themselves. Moreover, they number roughly twice the number of pitches, or sound frequencies, to which the ear is attuned. How are they stimulated?

The basilar membrane, upon which the organ of Corti rests, is composed essentially of transverse connective-tissue fibers attached firmly to the walls of the cochlea and stretched taut, somewhat like the strings of a piano. The fibers differ in length at different levels of the cochlea, gradually becoming longer toward the apex of the spiral. The analogy is very close between the structure of this membrane and a musical instrument with strings of graded length and, correspondingly, of graded intrinsic vibration frequencies. It is thought, therefore, that the fibers of the basilar membrane, like the strings of the musical instrument, are set into vibration by sounds of the specific pitch corresponding to their own intrinsic frequencies. The hair cells resting on the fibers are thus set in motion and their cilia, which are in contact with the "roof" membrane, are stimulated so as to initiate impulses in the auditory nerve fibers. Sounds of different pitch, that is, of different frequency, are believed to stimulate hair cells in different regions of the cochlea. The mode of stimulation is analogous to that involved in the sense of touch.

This view has been confirmed to the extent that it has been shown clinically that tone deafness is associated with injury or destruction of the hair cells in a given restricted portion of the cochlea. Under these circumstances, the individual is unable to perceive certain tones. By sounding intensely loud high-pitched sounds into the ear of an experimental animal, moreover, it can be demonstrated that deafness for tones of high frequency can be produced, owing to the resulting injury to the organs of Corti near the base of the cochlea, where the fibers of the basilar membrane are shortest. Injuries at the apex, where the fibers are longest, similarly produced by loud low-pitched tones, cause deafness to low tones. Dr. Harvey Fletcher of the Bell Telephone Laboratories in New York has been able to plot the different parts of the cochlea which respond to the various sound frequencies within the range of normal hearing. He has shown that auditory patterns of vibrating cells along the cochlea are built up when we hear a sound of a given set of frequencies. As this



The auditory pattern in the cochlea produced by the 518-cycle fundamental note of a bugle playing "taps." The spiral represents the distance along the cochlea of the typical human ear. It is divided into 100 equal parts for purposes of identifying locations of nerve endings which respond to definite frequencies. The bulges on the diagram represent the positions of nerves which give the maximum response to the pure tones in this complex note of the bugle. (Drawing reproduced from "Auditory Patterns" by Dr. Harvey Fletcher, Bell Telephone Laboratories.)

sound changes into a different set of tones, the patterns likewise change, stimulating different nerve endings so that we perceive the changing notes.

Besides the cochlea, the labyrinth of the inner ear comprises other structures not concerned with the phenomena of hearing. Here, of course, reference is made to the organs having to do with the sense of balance, or equilibrium. These organs consist of the three semicircular canals and two tiny sac-like chambers with which they are associated, the "sacculus" and "utriculus." The semicircular canals arise from the walls of the utriculus. Each lies in a plane at right angles to the planes of each of the other two. The inner walls of the sacculus and utriculus are lined with ciliated or "hair" cells, from which arise the nonacoustic fibers of the auditory nerve leading to the brain. The cavities of the canals and sac-like structures are filled with a watery fluid, and, in addition, the utriculus and sacculus contain tiny stone-like bodies. These "ear stones" are secretions of calcium carbonate attached to the ends of the filaments of the hair cells. When the head is rotated or inclined it seems that the earstones in the sacculus or utriculus are displaced. The resulting slightly unequal pressure on the filaments of the hair cells stimulates the nerve

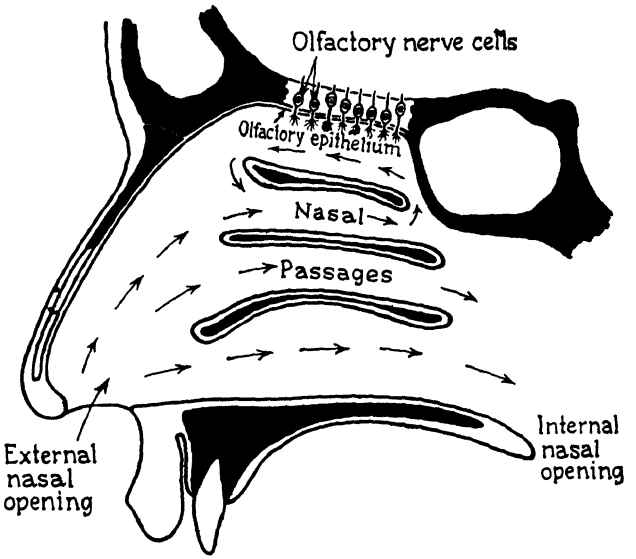
endings in them and the sensation of rotation or overbalance is experienced.

The semicircular canals are equipped with receptor organs, similar to the hair cells of the sacculus and utriculus, located in little swellings at their upper ends. Experimental evidence indicates that these receptors are stimulated by movements of the fluid in the canals. These movements are due to inertia, causing a lag in the movement of the fluid when the head or body is moved or rotated in any plane. Stimulation of the end organs, or receptors, not only makes us aware of the movement or rotation but also causes us to adjust ourselves to the change.

Chemical Senses

Chemical reactions brought about by actual contact of substances with certain nerve endings provide us with two senses, smell and taste. It might be said that gases are the substances smelled and liquids are the materials tasted. A solid substance must first be reduced to a liquid form or put into solution before it can be tasted; and, it seems that even gases must be dissolved in a liquid before they can be smelled. Both of the special senses of smell and taste are located near the entrances to the respiratory and digestive tracts, as if to act as sentinels and to pass upon the character of the materials taken into the body. Smell has the wider range of the two senses, since the odorous gases may travel considerable distances from their source and then affect the sensory nerve endings.

The sense of smell is probably one of the most primitive senses which animals possess. The olfactory apparatus, even in man, begins to develop at a very early stage in the growing embryo. In the human embryo it appears first at about the third week of development, and the organs are fully formed before birth. The sense of smell can be aroused by an exceedingly small amount of gas in the atmosphere, some gases being detected when the concentration is one part in about eight million. In lower animals, the sense of smell is much keener than this, and it is likely that it is their chief source of information about the external world. The sense of smell is now useful to man primarily in the pleasant or unpleasant sensations which it affords him and as a danger signal of irritating or poisonous gases.



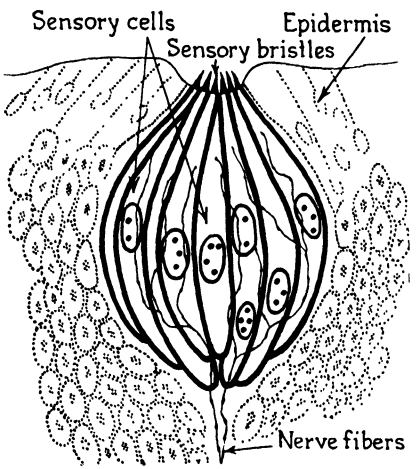
The receptors associated with the sense of smell are located in a patch of epithelial tissue, less than one square inch in area, in the upper part of the nasal cavities.

In the upper part of the nasal cavities there is a lining of epithelial tissue of somewhat less than one square inch in area. This tissue contains the receptor nerve structures for odorous substances. These structures are hair-like cells buried within the epithelial tissue. The cells are the end organs of nerve fibers which pierce the skull and pass back to the brain as the olfactory nerve. The olfactory epithelium is bathed in liquid and is somewhat out of line of the main air passages, so that it does not dry too much as air is drawn into the lungs. It seems that stimulation of the receptor cells depends upon the odorous chemicals going into solution in the liquid surrounding the cells, so that these materials may produce some chemical reaction with the hair cells.

The olfactory receptors are easily fatigued, and the sensation of any odor falls off rapidly in strength. This is particularly noticeable when one enters a room that has a definite odor. After being there for a few minutes the odor becomes imperceptible, yet it will be quite noticeable to another person just entering the same room. However, just how we distinguish the various odors is not well understood.

The structures for detecting taste are located chiefly on the upper side of the tongue, although a few are found on the roof of

the mouth and in the throat. They are known as "taste buds." Each of these buds is a small cluster of cells which is embedded in the mucous membrane of the tongue. Within each cluster there are a number of slender, elongated cells which are the end organs of nerves that convey to the brain the sense of taste. These cells are stimulated by substances taken into the mouth when such substances are dissolved.

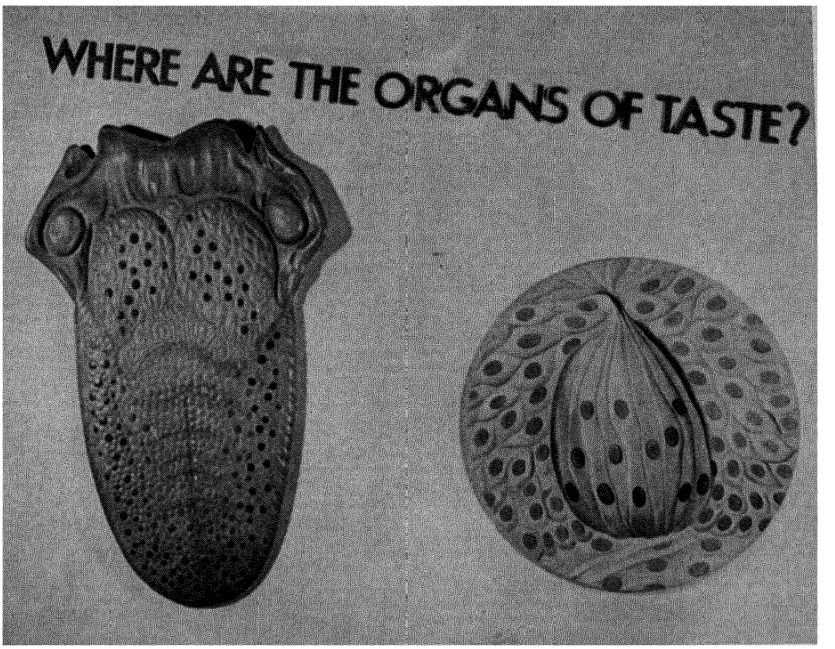


A taste bud. (Redrawn from Neale and Rand.)

It is believed that man distinguishes only four fundamental tastes, namely, sweet, salt, bitter, and sour. We are able to distinguish the "taste" of so many different substances mainly because of the ability to use other senses in conjunction with the sense of taste. Certainly the odor of foods is so closely associated with their taste that we smell them more than we taste them. The temperatures of foods are detected by thermal nerve endings which respond to heat and cold. Many such nerves are located in the mouth. In addition, the roughness or softness of foods produces certain touch sensations. All these we associate with taste and by them most foods are identified.

Skin Senses and Pain

It is generally said that man possesses five senses. Oftentimes a person is referred to as having a "sixth" sense when it is desired to draw attention to some property of perception peculiar to him. Actually, every person possesses a sixth sense, and many others in addition. The skin alone contains receptors for at least five different sensations, such as touch, pressure, pain, heat, and cold. The nerve endings which respond to these different stimuli vary in their distribution over the skin. Certain of them are concentrated more in one area than another. Others may be absent entirely from certain areas.



The organs of taste are small taste buds located chiefly on the upper side of the tongue, as shown by the dark spots in the picture above, and magnified at the right. (American Museum of Health photograph.)

The skin senses are probably the most universal of all means of communication with the outside world. Even though a person may voluntarily close his senses to light and sound, even taste and smell, he cannot escape physical contact with his surroundings. Touch also serves to confirm the impressions gained from the other senses. The areas of the skin that are most sensitive to touch are the underside of the finger tips, the palms, soles of the feet, lips, and external genitalia. In these regions there are numerous small capsules of tissue which contain the nerve endings that provide us with the sense of touch. Such nerve endings are less widely scattered in other parts of the skin, thus making those areas less sensitive to touch stimuli.

Changes in temperature are detected by special nerves, which in most cases have free nerve endings in the skin. These nerves are highly concentrated in the forehead, cheeks, and palms of the hands. One naturally opens the palms of his hands before a fire after coming in from the cold. There are two differ-

ent types of receptors, one for "hot" and one for "cold," in the skin. These are usually small areas about the size of a pin point. They contain nerves which respond to such temperatures and thereby produce these sensations. Some of these minute areas are on the back of the hand. Stimulating them, even by pressure from a sharp pencil, will produce the sensation of cold or warm, depending upon which area is pressed.

Pain is felt through specialized nerve endings. These are found scattered over all the skin and in many other parts of the body. However, these nerve endings are more concentrated in some areas than others. For example, there are relatively few of them in the inner wall of the cheek. While we may recognize pressure, heat, or cold there, we experience little of the sensation of pain. On the other hand, these nerves are highly concentrated in most parts of the skin, as well as in the teeth and the upper skeletal bones of the face. It has been rather carefully estimated that there are four million of these nerve endings in the skin alone, this number being more than four times as great as all other sensory nerves of the skin.

The pain nerves are not very extensive in the interior of the body. They seem to be located mainly in the throat, intestinal walls, bladder, and joints. They give us, in general, such pain sensations as thirst, hunger, aches of the stomach, colon, and bladder, and joint aches. From other regions little pain is experienced, except from certain deep-seated muscles. Even these pains are often very generalized rather than being local to some definite area. Much of the internal body may be cut in a surgical operation, or torn, burnt, or pinched in an accident, without producing pain.

Nerve Action

We have seen how we become acquainted with things and events in the world about us through the possession of special sense organs. We have seen, also, that these are groups of cells specialized in structure for the purpose of receiving energy in various forms from the outside world and translating this energy into nerve impulses which are conducted to the brain and there interpreted in terms of what we know as sensations. It would be natural at this point to inquire what nerve impulses are. How

does the energy falling on a sensory receptor reach the brain? Are there special kinds of impulses which transmit light rays or sound vibrations as such to the brain, or are nerve impulses a form of energy, alike in all nerves? We shall see that the latter alternative comes nearer to expressing the facts of nerve conduction.

A nerve may be compared with an insulated telephone cable composed of many wires in that it is a bundle of parallel fibers encased in a connective-tissue sheath. Here, however, the analogy ends. Numerous experiments have shown that a nerve impulse is not simply an electric current such as is concerned in telephonic communication. Moreover, it has been proved that conduction of a nerve impulse is not the same thing as that of an electric current. Each nerve fiber is an elongated outgrowth of a single living cell, not unlike a very long pseudopodium, or "false foot" of an amoeba. It contains in its electrolytically dissociated molecules all that is necessary for conducting an electric current: in fact, a nerve fiber will conduct electricity. However, a dead nerve fiber will also carry an electric current, but it will not transmit a nerve impulse. Injury to even a small section of a nerve will effectively prevent the passage across it of an impulse originating in the uninjured portions. Furthermore, while transmission of a nerve impulse is very rapid, it does not even approach the speed of an electric current.

The speed at which a nerve impulse travels may be measured by a very simple experiment first performed nearly a century ago by the great German physiologist, Hermann L. F. von Helmholtz. One of the large muscles of a frog's leg is dissected out and removed, together with the large nerve which supplies it. By touching the nerve with an electrode the muscle may be made to contract. There is a brief interval between the moment the stimulus is applied to the nerve and the beginning of contraction by the muscle. The interval is longer, moreover, when the point at which the nerve is stimulated is farther from the muscle. Let us suppose that the electrode is applied successively at two points along the nerve six centimeters apart. The difference of the two intervals between the time the nerve is stimulated and the time the muscle begins to contract is 0.0005 second. Since in this time the nerve impulse travels six centimeters along the

nerve, the rate of transmission must be 120 meters or about 400 feet per second.

Unlike the shortening and broadening of a muscle when it contracts, there are no visible changes in a nerve during passage of an impulse. Nevertheless, there are changes taking place which can be detected by indirect methods. There is an increase in the rate of oxygen consumption and carbon-dioxide production, indicating the occurrence of oxidations which presumably release the energy concerned in conduction of the nerve impulse. Heat is generated as a by-product of these oxidations. The most useful index of nerve conduction, however, is the electrical changes which accompany it. These changes are easily detected by connecting a suitable device for measuring current at two points along the nerve. The changes are found to spread from the point of stimulation to the end of the fiber.

The surface of a nerve fiber at rest is polarized; that is, the ions in the membrane of a nerve cell and its fiber are so arranged that the outer surface is positively charged while the inner surface is negatively charged. This polarization depends in part at least upon the impermeability of the membrane to the ions responsible for these electrical charges. The polarization, in turn, is thought to be concerned in maintaining the membrane semipermeable. Thus a breakdown of either one of these properties of the resting nerve would cause the breakdown of the other also. Excitation of a nerve fiber is believed to be associated with just such a breakdown of the semipermeability and polarization of its membrane.

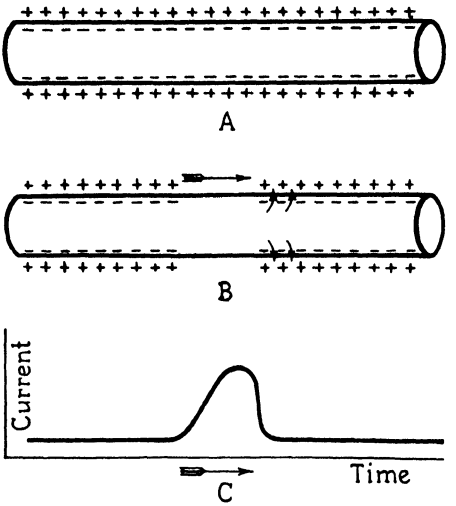
The stimulus which initiates a nerve impulse brings about depolarization of the surface of the nerve fiber at the point of origin. In this depolarized region the membrane of the nerve fiber is permeable to the ions in the adjacent as yet unactivated region. These ions migrate through the permeable gap and neutralize one another: that is, they combine to produce electrically neutral molecules. Another section of the nerve fiber is thus depolarized and the permeability of the membrane is altered, providing for the continuation of these changes in the succeeding portion. The passage of the impulse along the nerve fiber is preceded by a wave of electrical negativity resulting in the depolarization of the surface in the region in front of the

advancing impulse. The phenomena are illustrated diagrammatically in the following drawing.

It is clear that a nerve impulse is a physicochemical disturbance in the nerve fiber. Once started, it is self-propagating, like the burning of a powder fuse in which the burning portion ignites that just in front of it. The analogy to a powder fuse may be extended. Thus, whether set off by the application of heat or by a hammer blow, the combustion of the fuse is the same as regards both the rate and the nature of the chemical change. Moreover, the rate of burning is the same regardless of how much heat or how hard a blow was initially applied to start it; the only essential is that enough heat, or a hard enough blow, be applied to stimulate. Similarly, a nerve impulse is the same regardless of the nature of the initiating stimulus, the sensation produced, or the motor response elicited. Unless the stimulus received is sufficient in intensity, no impulse is set up. The stimulus of intensity just sufficient to initiate a nerve impulse is called the "threshold stimulus." The strength of the stimulus may be increased any amount above the threshold intensity without affecting the strength of the resulting nerve impulse in the single fiber, since the energy for conduction of the impulse comes from the nerve itself, not from the stimulus or activating agency.

Just as the kind of metal in a wire affects its electrical conductivity, or, to continue the analogy with a powder fuse, as the dampness or dryness of the powder affects its burning, so the nature, strength, and rate of transmission of a nerve impulse depends upon the condition of the nerve itself. This idea is embodied in the so-called "all-or-none law" of nerve action, which states that if a nerve fiber responds at all to a stimulus, it responds maximally for the condition of the fiber at that time. This may be proved experimentally by inserting delicate metal electrodes attached to a sensitive electrical meter in a small nerve at two points between which the fibers have been pulled apart under the microscope and all cut, except one. If, now, stimuli of graded intensity are applied on one side of the cut fibers, it will be found that the deflections of the galvanometer needle are always of the same magnitude, provided, of course, that the condition of the nerve does not change.

The wave of electrical negativity which precedes the impulse may be measured by this same means, and the resulting data may be plotted. The curve will appear as represented in the drawing. The front of this curve has a steep slope, showing that depolarization occurs quickly. The rest of the curve has a more gradual slope. It represents an entirely different process which occurs more slowly and which is without parallel in the analogy of nerve action to the burning of a powder fuse; that is, the nerve fiber will restore its polarity immediately after it has been depolarized and the nerve impulse has passed. The positive and negative charges are again established on outer and inner sides of the fiber surface. The slope of the back of the curve in the diagram represents the rate at which this restoration occurs.



A. The ions in the membrane of a resting nerve fiber are believed to be arranged so that the outer surface is positively charged, while the inner surface is negatively charged.

B. The transmission of a nerve impulse is accompanied by the ions passing through the membrane and temporarily neutralizing each other.

C. The passage of the nerve impulse along a fiber is preceded by a wave of relative electrical negativity. (After Carlson and Johnson, "The Machinery of the Body.")

When a powder fuse has once burned it cannot repeat the process. A nerve fiber, however, will conduct impulses initiated one after the other at intervals of as little as 0.005 to 0.001 second. Shortly after depolarization occurs at any point, the nerve fiber restores its surface so that again the outside bears a positive charge and the inside bears a negative charge. This restoration is accomplished by a reversal of the physicochemical changes involved in the transmission of an impulse. The actual changes involved in conduction of an impulse, that is, depolarization and increase in permeability of the surface of the fiber, require only about 0.0004 second. The remainder of the time

before another impulse may be transmitted is used by the nerve in restoring the polarized condition.

REFERENCES FOR MORE EXTENDED READINGS

CARLSON, ANTON J., and VICTOR JOHNSON: "The Machinery of the Body," University of Chicago Press, Chicago, 1937, Chap. XI.

This chapter contains a thorough elementary presentation of the anatomy and physiology of the sense organs with numerous diagrams and drawings.

MITCHELL, PHILIP H.: "A Textbook of General Physiology," McGraw-Hill Book Company, Inc., New York, 1932, Chap. VI.

This is a standard textbook of general physiology. The chapter referred to contains an elementary account of the sense organs for students of college level.

PLUNKET, C. R.: "Elements of Modern Biology," Henry Holt & Company, Inc., New York, 1937, Part III.

This well-known text for a beginning course in biology contains in Part III a concise and specific treatment of the sensory organs, stimulation and response, coordination of body functions, and behavior of organisms as regards their habits and intelligence.

DASHIELL, J. F.: "Fundamentals of General Psychology," Houghton Mifflin Company, Boston, 1937, Chaps. IX, X.

The chapters referred to are an excellent elementary discussion of the physical structure of the sensory organs and the physical nature of nerve action. They contain, in addition, a more detailed and advanced account of sensory perception and its relation to behavior.

HERRICH, C. J.: "Introduction to Neurology," W. B. Saunders Company, Philadelphia, 1927, Chaps. III–VI.

The author has written a book that has been for many years a standard text for college courses in neurology. It is one of the best comprehensive elementary texts. The chapters referred to relate to the structure and functioning of neurons and the sensory receptors and to the general physiology of the nervous system.

HARTRIDGE, H., in Ernest H. Starling: "Principles of Human Physiology," 5th ed., Lea & Febiger, Philadelphia, 1936, Chap. VIII.

Here is a standard reference text for gifted or advanced students. It is written with great clarity but sparsely illustrated.

HECHT, SELIG: "The Nature of the Photochemical Process," Chap. XI in Carl Murchison, "Handbook of Experimental Psychology," rev. ed., Clark University Press, Worcester, Mass., 1934.

This text is a concise account of the physical and chemical processes underlying vision, written by one of the foremost investigators of visual phenomena among modern physiologists. The material presented is of a technical nature but is organized with the maximum clarity and brevity.

American Journal of Ophthalmology, published by George Banta Publishing Company, Menasha, Wis.

This is a professional journal devoted to research articles and clinical reports related to structure, functioning, and diseases of the eye and related tissues.

The Journal of Comparative Neurology, published by the Wistar Institute of Anatomy and Biology, Philadelphia.

This journal is issued bimonthly and is devoted to articles on research in the field of nerve structure and functioning.



14: CORRELATING MECHANISMS

How the Body Is Integrated into a Smoothly Operating Unit

FEW persons living in the United States today realize the tremendously important role which modern means of communication play in their daily lives. Americans take for granted their fine roads and automobiles, their railroads, postal system, and airlines, the telephone, and the radio. It is only when one of these fails conspicuously in the performance of its expected duties that we become keenly aware of its importance. Similarly, most people become conscious of the existence of means of communication among the parts of their own bodies only when something goes wrong with one of them. The circulatory system, which has already been discussed, provides an obvious example of such a bodily channel of communication, roughly analogous in its functions to the railroads and other carriers of the nation's heavy goods. Two other important communicating systems of the body remain to be discussed. These are the nervous system

and the ductless glands, roughly comparable in their functions with the telephone and postal systems, respectively.

The Nervous System

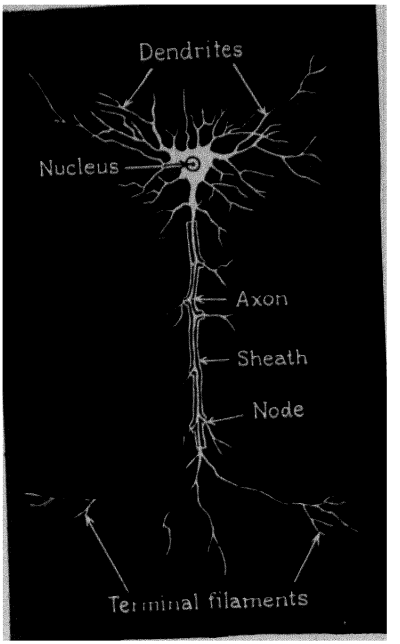
From its primary use as a means of communication, the telephone has come to play an extremely important part in the integration and coordination of business and industry. An official in the New York office of a California firm can get in touch with the "home office" in a few minutes by telephone, where by letter the transaction would require at least forty-eight hours. This has had important effects on the decentralization of industry, making it possible for a manufacturer to locate his plant near the sources of raw materials while maintaining his executive offices in one of the big centers of commerce, such as New York, Chicago, or San Francisco.

The human body presents an organization no less complex than that of modern industry. The specialized tissues, organs, and systems of the body are composed of billions of cells which are themselves units in a very real sense. Even the most specialized cells and tissues are capable of a limited independent existence. Coordination of their activities is essential to the welfare of the body. This coordination is brought about chiefly through the nervous system. In higher animals, especially vertebrates, the nervous system comprises a brain, located in the skull; a spinal cord, enclosed in the vertebral column and directly connected with the brain; and numerous nerves, extending out from the brain and spinal cord to all parts of the body.

The primary function of the nervous system, like that of the telephone, is to transmit messages. The nervous system, however, particularly the cortex of the brain, is able to arrange the nerve impulses into definite patterns. Stimulus and response are thus integrated so that the body functions as a whole. In addition, man is able to select his responses in such a manner as to represent intelligent behavior. A brief survey of the physical structure of the nervous system and of the simplest kinds of nervous coordination will give some insight into how this is accomplished.

Structure of the Nervous System

The structural units of the nervous system are the highly specialized nerve cells or neurons. In addition to these there are other types of cells which support them and provide them with nourishment. Of interest here is the specialized type, the nerve cells proper.

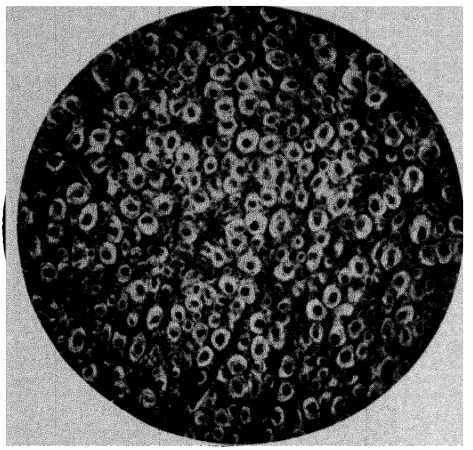


Representative nerve cell.

Nerve cells are characterized by having many branched processes which extend out from the mass of protoplasm surrounding the nucleus. It is these projections, or fibers, which permit the nerve cells to perform their special functions. One of the projections is usually relatively very long and slender. This is the "axon." It is the main trunk which carries impulses away from the cell body. The other processes are usually short and are known as "dendrites." They serve to carry impulses toward the cell body. There are a few exceptions to this general condition of the axon's being longer than the dendrites. The most important are in the case of the spinal nerves and in certain nerves that arise from centers lying just outside the spinal cord, in which the axons are short and the dendrites are long. The accompanying drawing is an illustration of a rather typical nerve cell.

Some nerve cells are very large and complex. An example is the neurons which conduct impulses to the muscles of the foot, causing them to contract. They have axons which are over three feet long in man. Some of the neurons which carry impulses from the joints of the toes have axons and dendrites which combined are nearly six feet long. These neurons are, however, the giant cells of the nervous system. They are single cells and have all the

properties of a single cell, such as the ability to regenerate a lost part of the axon or dendrite, if not too much of it is missing. This explains why mutilated nerve endings in the skin or muscles will often be repaired after a minor injury to the tissue.



Cross section of a large nerve. The medullary sheath of myelinated fibers, which has a whitish appearance in the picture, may be compared to the insulation covering a telephone wire, while the fibers, shown as dark spots, correspond to the wires. (Photomicrograph by Roy Allen.)

Nerve cells are of two types, so far as function is concerned. One type is the sensory nerves, which respond to external stimuli. The other is the motor nerves, which conduct impulses to a muscle or other effector cell, causing it to respond by contracting or other appropriate action. Stimuli are received by the dendrites of sensory nerve cells and converted into nerve impulses, which are transmitted to the brain or spinal cord through a branched ending of the axon. Similarly, impulses are received by the dendrites of motor nerve cells and transmitted to the effector through branched endings of the axon.

The term "nerve" as usually employed refers to a bundle of fibers or processes from many nerve cells. For example, the sciatic nerve is the large nerve which supplies nearly the whole of the skin of the leg and the muscles of the back and thigh and those of the leg and foot. It is made up of thousands of nerve fibers going to different parts of the leg. Each fiber passes to some muscle or section of the skin. It resembles very much a telephone cable of many wires, each one supplying the telephone of a different subscriber. Thus, a single motor nerve may supply as many as 150 muscle fibers.

Most nerves are very similar in their make-up or structure. By special methods of examination it may be shown that each component fiber or axon is surrounded by its own covering or sheath. This consists of two layers. The inner layer, next to the

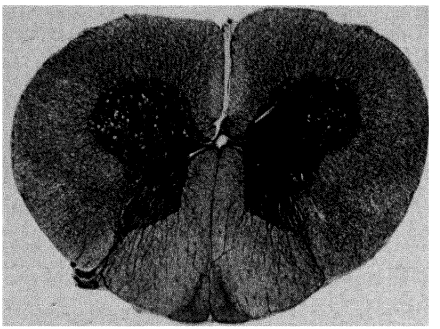
axon itself, is made up of a white fatty material, which gives a whitish appearance to the nerve. This inner layer is known as the "myelin sheath." It is not a continuous cylinder surrounding the axon over its entire length. At regular intervals it is interrupted, giving a segmented appearance. The outer part of the nerve sheath is a thin, transparent layer composed of fused cells.

The reasons for the segmented arrangement of the nerve sheath are not clear. It is known, however, that myelinated fibers conduct nerve impulses more rapidly than do nonmyelinated fibers. Thus, as already noted, an ordinary motor impulse travels along a myelinated fiber at the rate of about 400 feet per second. The nonmyelinated fibers of the visceral or autonomic nerves, on the other hand, conduct impulses at about 100 feet or less per second. It appears that the presence of the myelin sheath speeds up the transmission of the nerve impulse. The mechanism may be similar to that which accounts for the more rapid conduction of an electrical impulse along an iron wire, when the wire is enclosed in several segments of glass tubing arranged to simulate the nodes of a myelinated fiber. Instead of passing along the wire longitudinally, as it does when the surrounding glass tubing is continuous, the current jumps from one node to the next, greatly accelerating the rate of transmission.

The nerve cells are frequently gathered together in small groups, those occurring outside of the brain and spinal cord being known as "ganglia." The cells are not physically connected to each other, but dendrites of one cell are in close proximity to the terminal fibers of the axon of another. Some of the ganglion cells send axons to the spinal cord and brain, while others send their axons to motor end organs such as the muscles. The largest ganglion is in the abdomen and is known as the "solar plexus." These nerve centers control certain definite organs. Especially is this true of the ganglia which lie outside the spinal cord and brain, such as the solar plexus. The latter controls the blood supply to a part of the abdominal cavity.

The spinal cord is enclosed within the vertebral column. It is made up of combinations of nerve fibers from the brain and many ganglia. Its main function is to control the trunk and limbs and to transmit nerve impulses from the body to the brain

and vice versa. Normally the spinal cord is under direct control of the brain, but it may act independently of it. Thus walking soon becomes a more or less unconscious effort.



In cross section the spinal cord is seen to be composed of a central portion of gray matter and an outer portion of white matter. (Photomicrograph by Roy Allen.)

In cross section the spinal cord is seen to be composed of a central gray portion surrounded by white matter. The gray material is roughly arranged in the shape of a butterfly or the letter *H*. It is composed of nerve-cell bodies and nonmyelinated fibers. The white matter is made up of myelinated fibers whose fatty sheaths give it its color. These fibers are of several types. There are ascending and descending fibers, which conduct impulses from all parts of the cord to the controlling centers of the brain and from the brain to the spinal cord. In addition there are fibers of intermediate or connecting neurons which link the brain and spinal cord with ganglia located outside them.

The brain in vertebrates completely fills the skull. It is directly connected with the spinal cord at the base of the skull. In the lower vertebrates its chief function is to control the head, heart, and lungs in much the same manner as the spinal cord controls the rest of the body. Its operation is primitive, automatic, and unconscious. In the higher vertebrates, and particularly in the great apes and man, the frontal portions of the brain are enormously expanded, overshadowing the more primitive portions in their development. These expanded portions form the cerebrum or cerebral hemispheres, in which are the centers of sensory perception and the higher mental processes of thought and reasoning. Both the cerebrum and the more primitive portions of the brain are made up of nerve cells and nerve fibers.

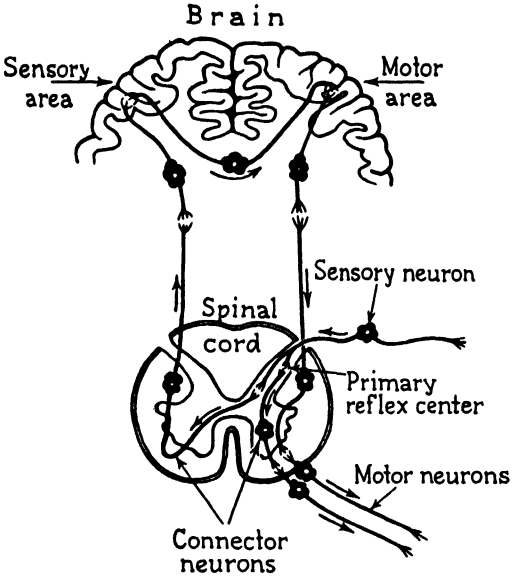
The brain, spinal cord, and certain ganglia constitute the central nervous system. In some respects they correspond to the switchboards in a central telephone exchange, which connect the wires of an incoming call to those of the party desired. In

other respects, the central nervous system may be compared with the editorial offices of a large newspaper. For example, one of the functions of the brain and spinal cord is to "edit" reports about the outside world which it receives via sensory nerves from the eye, ear, nose, etc. Another function of the central nervous system is "executive" in character; that is, the brain and spinal cord "formulate the policy" of the body and give "orders" which travel over the motor nerves to various kinds of end organs, there to be translated into some sort of activity.

Reflex Action

The simplest kind of nerve-controlled activity would involve five components: (1) a sense organ, (2) a sensory nerve, (3) a ganglion or other nerve center, (4) a motor nerve, and (5) a muscle or other structure capable of some such response as movement, cessation of movement, or secretion. The simple mechanism in such a case might be thought of as a stimulus-response action, represented by an *S-R* bond. Actually, no nerve-controlled behavior is as simple as this, but it illustrates the principle involved.

What happens, for example, when one's finger is burned by a gas flame? The pain receptors in the skin are stimulated, initiating an impulse which travels up one or more fibers of the sensory nerves from the burnt finger to a nerve center located in the spinal cord. In the nerve center, functional connection is established with the appropriate motor neurons so that the impulse is relayed along the motor nerves of the arm. At the motor nerve endings the muscles of the arm are stimulated to contract, and the finger is quickly withdrawn from the flame. This is a simple *S-R* bond. It is an example of a reflex. However, more happens in this case than the simple reflex action of removing the finger from the flame. The impulse initiated in the pain receptors of the skin is also transmitted, by way of connecting neurons, from the primary reflex center to other centers until finally it reaches a certain part of the middle region of the brain. Here it is translated into sensation, and the person becomes conscious both of the pain and of its localization. This sensation probably is not realized until after the finger has been automati-



A simple reflex arc and an accompanying pathway to the brain.

cally withdrawn from the flame. The action is illustrated in the accompanying diagram.

The reflex arc is the functional unit of the nervous system. The essential steps in any reflex action have been presented in the illustrative example describing what happens when we burn our fingers in a gas flame. These steps may be summarized briefly as follows. A receptor organ is stimulated, giving rise to an impulse, which travels along a sensory nerve fiber to a ganglion or other nerve center. Here functional connection is established with a motor neuron and the impulse is transferred to a motor nerve fiber. At the motor ending an effector organ is stimulated, causing a characteristic response such as contraction or relaxation of a muscle or discharge of a gland.

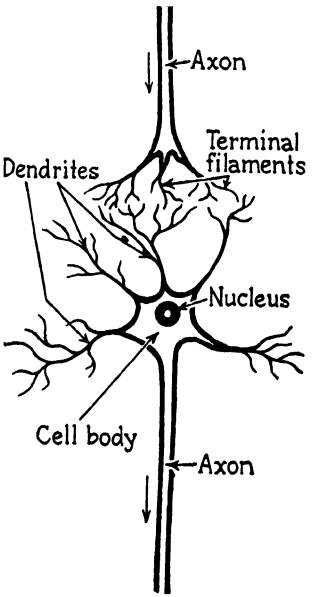
Reflexes vary in several respects, one of the most obvious differences among them being one of complexity. A typical example of a simple reflex is the knee jerk. This is the sudden straightening of the leg when tapped sharply but lightly just below the kneecap. The movement is caused by the stretching of the broad tendon at the knee joint which serves for the attachment of the muscles that extend the lower leg. The tendon and the extensor muscles contain receptors sensitive to stretch. On

stimulation of these receptors by stretching, the very muscles in which they are located are activated, causing the leg to be straightened with a jerk. A more complicated type of reflex is called forth when a person turns his ankle while walking. The injured leg is immediately flexed or drawn up while the opposite leg is extended or straightened. Simultaneously, the weight of the body is shifted from the injured to the sound leg. The reaction is automatic in a young person. It is a defensive adaptation designed to prevent falling. Although turning an ankle is frequently accompanied by pain, the reflex called forth is not dependent upon the sensation. Thus, a similar response can be elicited experimentally in lower animals even after the brain has been removed.

The most complex reflexes involve highly integrated activity on the part of many muscles. They result in well-coordinated movements which give the impression of higher nervous control and purposiveness. It is possible to demonstrate, however, that such movements are entirely involuntary. If, for example, the brain of a frog is removed under anesthesia, the animal may be placed on a table and after a few minutes will be found capable of maintaining a normal posture. When mildly stimulated by touching an electrode to the back, the decerebrated animal will hop away exactly as a normal frog would do under similar conditions. There can be no question of sensation or volition in the case of the decerebrated frog, since the centers of sensory perception and voluntary control have been taken away.

Reflexes may be classified in several ways, depending upon the point of view of the person doing the classification. An anatomist classifies them on the basis of what level or levels of the spinal cord or brain are involved or what pathways in the central nervous system are followed and to what extent. Physiologically, reflexes may be grouped according to the kind and location of the receptors involved. Thus one group of reflexes is called forth by stimulation of the special sense organs; another group is initiated by stimuli arising in the viscera, or internal organs; and still another has its origin in receptors located in the muscles, tendons, joints, or parts of the ear having to do with the positions of the body and its parts. Finally, there is a psychological basis for classification of reflexes as unlearned, innate,

or "unconditioned" types; and learned, acquired, or "conditioned" types.



A synapse is a kind of nerve bridge. It is a point where the terminal filaments of the axon of one nerve cell lie close to the dendrites of another.

Association Paths

The brain, spinal cord, and certain ganglia have been compared with switchboards in a central telephone exchange in that they provide for the transfer of nerve impulses from one neuron to another. In these nerve centers the terminal filaments of the axon of one nerve cell lie closely to the dendrites of another. There is no direct physical connection, but nerve impulses are conducted from the axon of the one cell to the dendrites of the other. This kind of nerve bridge is known as a "synapse," and whenever neurons are brought into such relationship a synaptic connection is established. The manner in which nerve impulses are conducted across this bridge is not definitely known. Some evidence shows the mechanism is physicochemical in nature; that is, the passage of the nerve impulse across the synapse is accompanied by colloidal phase reversal in the protoplasm of the nerve cell, not unlike the hardening or coagulation of egg white by heat. In contrast to the changes produced in egg white by cooking, the colloidal changes in the nerve cell are reversible.

Even the simplest reflex action involves at least one synaptic connection. Complex reflexes may involve very many such connections. It should be noted that synapses are seldom, if ever, wholly independent of one another. A sensory nerve may have several end branches in its axon which excite a number of different nerves through many synaptic connections. Just which synapse will be used and which response will be made depends upon many conditions. In general, the more a synapse is used, the more readily it is made, and so a given response will



Complex reflex action and a precise coordination of eye and muscular movements result from a high degree of nerve organization in the cerebrum, cerebellum, and spinal cord. With a swish of his skates and a lunge of his body, Dave Kerr of the Rangers hockey team grabs the flying puck to prevent a score by the opposing team. (Life Magazine.)

follow a given stimulus. This is the way in which a habit is established.

Each synaptic connection makes possible some different response or mental process. In the brain alone there is a possibility of a very large number of these nerve connections and hence as many different mental activities. It is possible to calculate the total number of different synapses which could occur in an average human brain. This has been done by Professor C. J. Herrick of the University of Chicago in his interesting book, "The Brains of Rats and Man." The figure necessary to express this number would require 2,783,000 places. That is, it is 10 raised to the 278,300th power. This means that it is possible for

everyone to know that many things or to go through that many mental processes. Very few people ever develop and use all their mental capacities.

When synaptic connections have been established, they build up what are called "association paths"; that is, certain reactions, motor or mental, tend to follow given stimuli and these stimuli may be from a physical sensation or they may be memories, former experiences, or impressions. Association paths are not due to simple or single nerve bridges, but usually involve many such connections, so that our forms of behavior become very complex.

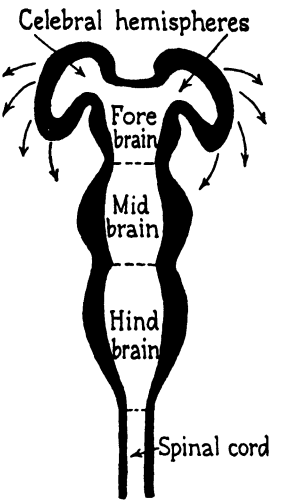
However, most of the things a person does, the emotions he feels, the attitudes he has, result from the association paths which are developed in his brain as he acquires his experience and his education. For example, one's sentiments of or attitudes toward patriotism result from various association paths which have been formed in his brain. A person's method of work or study, whether careless and lax or thorough and accurate, is in large measure the result of definite types of association paths. In other words, normal behavior is partly explained on the basis of the establishment of certain kinds of synaptic connections.

The Brain

In the evolution of higher animals from lower ones there has been a marked tendency for the nervous centers to migrate to the head region, which thereby has come to exert ever greater control over the rest of the body. This tendency has reached its culmination in the vertebrates, and especially in man, with the concentration of central nervous elements to form a brain.

In structure, the brain roughly resembles the spinal cord. Indeed, it may be regarded essentially as an extension of the cord into the skull or head region, since in embryonic development it arises as an expansion of the head end of the hollow tube from which the spinal cord differentiates. This expanded portion of the early embryonic nerve tube may be called the "brain stem." It soon becomes partially divided off, as shown in the drawing, so that three regions are recognizable. These are the forebrain, midbrain, and hindbrain. They persist in the adult animal, where they can be distinguished on the basis of structural differences and differences in function, as well as from their mode

of embryonic origin. The brain stem is the primitive brain of lower vertebrates as contrasted with parts acquired more recently in the evolution of higher forms, especially monkeys, apes, and man. In these higher vertebrates, control of the body is taken over largely by the cerebrum and cerebellum, which arise in the embryo as paired outpocketings from the upper right and left sides of the brain stem. The cerebrum is derived from the forebrain region, as shown in the drawing, while the cerebellum develops from the hindbrain. The outgrowths extend rapidly to the sides, upward, and backward, until they cover the primitive brain almost completely. The greatest development occurs in the cerebrum, which comes to overlie the greater part of the cerebellum.



In a horizontal section of the developing brain, three regions are recognizable. (After Carlson and Johnson, "The Machinery of the Body.")

The gray and white matter of the brain are reversed from the positions they occupy in the spinal cord. The gray matter forms the cortex at the surface of the brain, whereas in the cord it lies inside the white matter. The latter is made up primarily of fiber tracts from the spinal cord, which extend into the brain, and an exceedingly complex network of fiber tracts, which connect the various brain centers with one another. The cortex contains numerous "centers," or groups of nerve-cell bodies, which give it its characteristic gray color. The gray matter also contains the cell bodies of the motor nerve components of twelve head nerves. These nerves supply the special sense organs and associated structures responsible for their adjustment and movements. The sensory components of the cranial nerves arise from nerve cells located in ganglia lying either just outside the brain or in the sensory structures themselves.

The brain stem is the seat of numerous reflex centers in lower vertebrates. The centers which control respiration, heartbeat, swallowing, vomiting, and various other visceral reflexes are located in the hindbrain. Here also are found the centers controlling the postural reflexes having to do with balance and

regulation of the body's upright position, with the sensory components of the nonacoustic branch of the auditory nerve being distributed to the postural reflex centers. The midbrain contains the centers of visual and auditory reflexes, that is, adjustments of the eyes in focusing, regulation of the pupil diameter and regulation of the tension on the eardrum. In lower vertebrates the reflex centers for general muscular tone and posture are also located in the midbrain. In monkeys, apes, and man the centers controlling muscular tone are moved up into the forebrain.

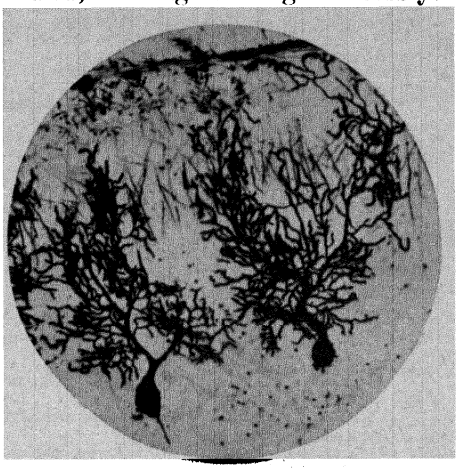
The chief function of the cerebellum relates to the coordination of skeletal muscular activities. Its size is roughly proportional to the complexity of movements of the skeletal muscles. When the surface of the cerebellum is stimulated artificially by the application of electrodes, muscular responses are called forth which, as far as observed, are limited to skeletal muscles. The movements elicited are rather generalized in character. Apparently, there is never any actual sensation associated with stimulation of the cerebellum, and its destruction by disease or accident produces no sensory defects. There is a certain degree of localization of function. Thus stimulation of the mid-region produces movements of the head, neck and trunk, while stimulation of either hemisphere causes no movements of the limbs on the corresponding side of the animal. This localization is not associated, however, with any visible differentiation in internal structure.

Persons whose cerebellum has been damaged by disease exhibit certain definite defects of muscular activity, but there is no real paralysis; that is, movements are still possible, but they are not well coordinated. Movements which are ordinarily performed smoothly and surely are done hesitantly or jerkily. They are broken up into their component movements. Movements requiring delicate coordination, such as writing, drawing, or picking up small objects, cannot be performed at all. Speech may be impaired, and there frequently is disturbance of balance. Experimental destruction of the cerebellum in lower animals yields similar evidence of its coordinating and integrating function. If, for example, the cerebellum of a pigeon is removed, the bird is unable to walk or fly, although movements of the legs and wings

still occur. These movements, however, are quite uncoordinated, and the bird merely thrashes around, beating its wings aimlessly.

Localization of Function in the Cerebrum

The part of the brain which remains to be discussed is the cerebrum, concerned with sensory perception and the so-called "higher mental processes." The possession and use of this structure have served, more than any other factor or factors, to place man definitely above the lower animals. It is chiefly in the degree of differentiation and functioning of the cerebral hemispheres that a sound physical and quantitative basis can be found for setting man apart from the great apes. In the structure and function of other bodily systems, man is essentially like the least specialized of the lower forms. Even in the functioning of the cerebral cortex the difference between man and his nearest animal relatives is largely one of degree. The capacity to learn, that is, to modify behavior according to experience, is found in all vertebrates and even in a rudimentary way in lower forms. Thus nearly everyone is familiar with unmistakable instances of learning in domestic animals such as the horse, the dog, and the cat.



These ganglion cells from the cerebrum are a particularly complex type, having many branched fibers extending out from the cell proper. (Photomicrograph by Roy Allen.)

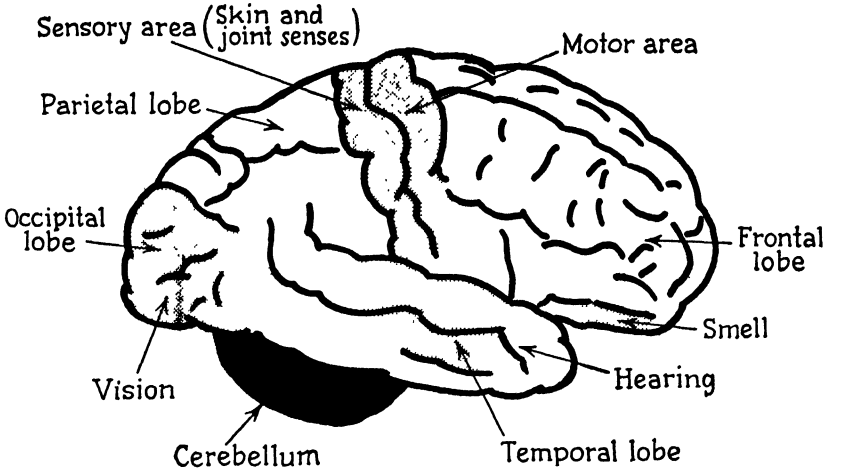
What is customarily referred to as intelligent behavior is correlated in a very general way with certain anatomical features of the cerebrum. Thus the functional potentialities of the brain are roughly indicated by its size. The total volume of the normal human brain averages about 1,500 cubic centimeters, whereas for the highest apes the corresponding figure is about 600 cubic centimeters. It is not the absolute size of the brain which is important, however, nor even the relative size in proportion to that of the body. Obviously, the ratio of the volume of a rat's

brain to his body is greater than the corresponding ratio for a man. The most significant index of brain size seems to be the ratio of the weight of the brain to that of the spinal cord. This ratio is less than 1 in lower vertebrates; from 2 to 4 in lower mammals; about 15 in apes; and 55 in man!

Another general anatomical index of the complexity of cerebral function lies in the complexity of the surface convolutions of the brain. The ridges and fissures which mark the cerebral cortex are produced as a result of the more rapid growth of this region than of the underlying parts, throwing the surface into folds. In general, this differential growth and consequent folding has occurred to a lesser extent in the brains of lower vertebrates, which therefore have a smoother brain surface than does man. The difference in degree of complexity of the convolutions is not great enough, however, among different people of human races to reflect significant differences in intelligence. While on this basis the brain of an absolute idiot may be recognizable, nevertheless even a trained specialist cannot distinguish between the brain of an average individual and that of a genius.

Among the brain convolutions, certain deeper fissures divide each cerebral hemisphere anatomically into four large areas or lobes—the frontal, parietal, occipital, and temporal lobes—as shown in the accompanying drawing. Superficially, these regions are indistinguishable in structure. Internally, however, there are definite differences, both in composition and in arrangement, which are evident on microscopic examination. Even within each of these four major areas there are local differences, which have been correlated with differences of function in some instances. It must not be thought, however, that different kinds of emotions, feelings, and thought processes, such as judgment or mathematical ability, are located in special brain areas. This belief was once rather widely entertained and is the basis of the idea of phrenology or "science of the bumps." It is now known that there is nothing to this. It is not possible, for example, to tell by feeling the bumps on a person's head whether or not he will make a great musician or statesman or whether he is a highly emotional individual.

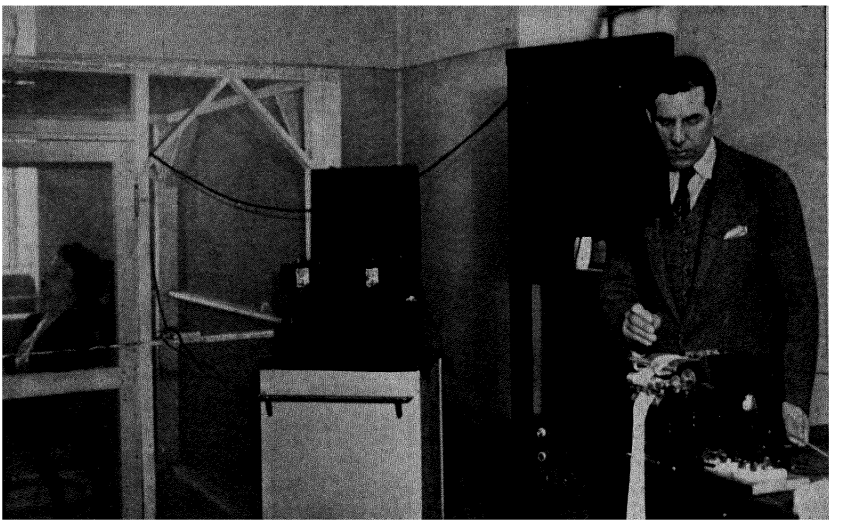
Modern views of localization of cortical function are based upon experimental evidence from many different sources. One



From the combined information obtained as a result of clinical studies and several types of experiments, it has been possible to map out certain areas of the cerebral cortex and to assign to them definite general functions.

of the most valuable methods of study has been observation of the effects produced by artificial stimulation of specific regions in the exposed cortex of anesthetized animals. Thus, when a particular group of muscles respond by contraction or relaxation upon stimulation of a certain local area of the cortex, it is reasonable to suppose that this area controls the movements brought about by these muscles. Stimulation of certain areas under local anesthesia has also been practiced with human subjects. Under these conditions, when the conscious subject responds with the statement that he sees light or hears sounds, it seems probable that the sensory areas for visual or auditory perception have been located. Another fruitful source of information has been observation of the behavior of animals following surgical removal of a part of the cortex. In this way it was found that complete muscular paralysis results from the removal of certain areas of the parietal lobe, which must therefore control the skeletal muscles. A closely related method of study has been the observation and analysis of human behavior where post-mortem findings have revealed destruction of local areas of the cortex due to disease or accident.

From the combined information obtained by these different methods it has been possible to map out certain areas of the



Recording the brain waves of a student at New York University. (Herman Young.)

cerebral cortex and to assign to them definite general functions, as shown in the foregoing drawing. It will be noticed that the functions whose areas have been established are largely sensory or simple motor types. The higher mental processes, so far as is now known, take place over a large part of the entire cortex or surface of the cerebrum.

Brain Waves

One very unusual condition of the brain has been discovered in recent years. This is that there are constant low-frequency electric vibrations in the brain, in addition to the regular nerve impulses which pass through it. These vibrations are the widely heralded brain waves, frequently referred to as the "Berger rhythm." These electric vibrations in the brain of man were discovered by Dr. Hans Berger of Germany in 1929. Since that time many research workers in various countries, particularly in the United States and England, have studied these waves intensively. It is now known that if you could view the working of your own brain, as well as that of any other person, it would be possible to see these small electric waves emanating from it.

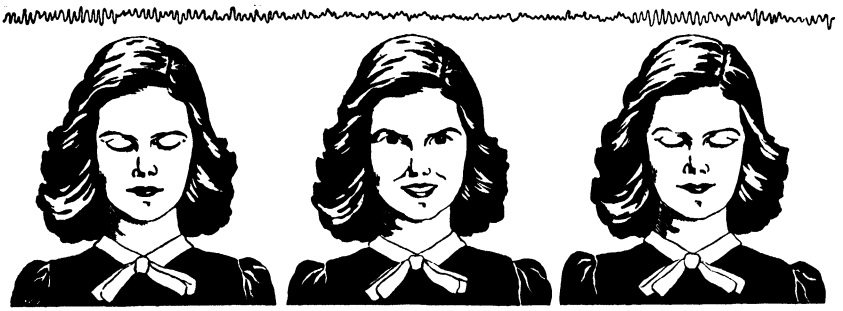
The brain waves are detected and recorded by an extremely sensitive electric apparatus. Such equipment consists of small

metal plates that are attached to the outside of the scalp by means of adhesive tape or glue and are connected by wires to a powerful electric amplifier. This amplifier strengthens the brain currents to make them strong enough to operate an electrically driven recording device, such as a writing pen. The amplification required for this purpose is of the order of about ten thousand billion times. Under such conditions it is desirable to have the person screened in from all outside electrical disturbances. The recorder can be made to write the brain wave record on a strip of paper or a photographic film. Such an apparatus is usually referred to as a brain-wave machine, or electroencephalograph.

By using such equipment it is possible to show that the brain waves of different normal persons clearly differ from each other in character. In general, however, all such records have certain basic features in common. The most prominent waves have a frequency of 9 to 12 vibrations per second and are known as the "alpha" waves. The most extreme variation from these is seen in certain individuals who have waves of a frequency from 25 to 35 complete waves a second; these are called "beta" waves. Most normal people come within these two classes.

A large proportion of people who have had their brain waves tested show the alpha rhythms. In general it seems that it is the people who are living and working under considerable mental tension that have the beta waves, while most others have the alpha waves. However, not enough is yet known about the brain waves to attempt to use them for any sort of classification of people according to mental temperaments.

The alpha waves have the unique property of responding to light and sound stimuli; the beta waves show no such response. Suppose that a person who has the alpha type is having his brain waves measured. It is found that the waves are most pronounced when the person sits completely relaxed with his mind in quiet repose and his eyes closed. The room should be free from noise and the mind not engaged in any concentrated thinking. Under such conditions the electric pen writes a wavy-line record of the vibrations that surge from the brain in wave-like rhythm. Should the person open his eyes the alpha waves will disappear, and when the eyes are closed the waves begin again to come



Alpha brain-wave record secured under conditions represented in the drawings beneath the three variations in the wave form.

through in regular fashion. The sudden ringing of a bell or other pronounced sound causes the waves to die out while the sound is in progress.

Another unique property of the alpha waves is that they are affected by concentrated thinking, such as working a mental arithmetic problem. The waves die out as soon as a person begins to puzzle through the problem. When the problem is solved and the mind again relaxes, the original waves return. It is possible to tell from the brain waves when a person begins to do concentrated thinking and when he stops, but it is not possible to tell what he is thinking. Professor Lee Travis of the University of Iowa reported in 1938 that he could measure when students were daydreaming or were paying close attention to the class lecture. His deductions were, of course, based upon the degree of change in the alpha rhythm, as it is known that the extent to which waves are neutralized is in proportion to the degree of concentration of thinking.

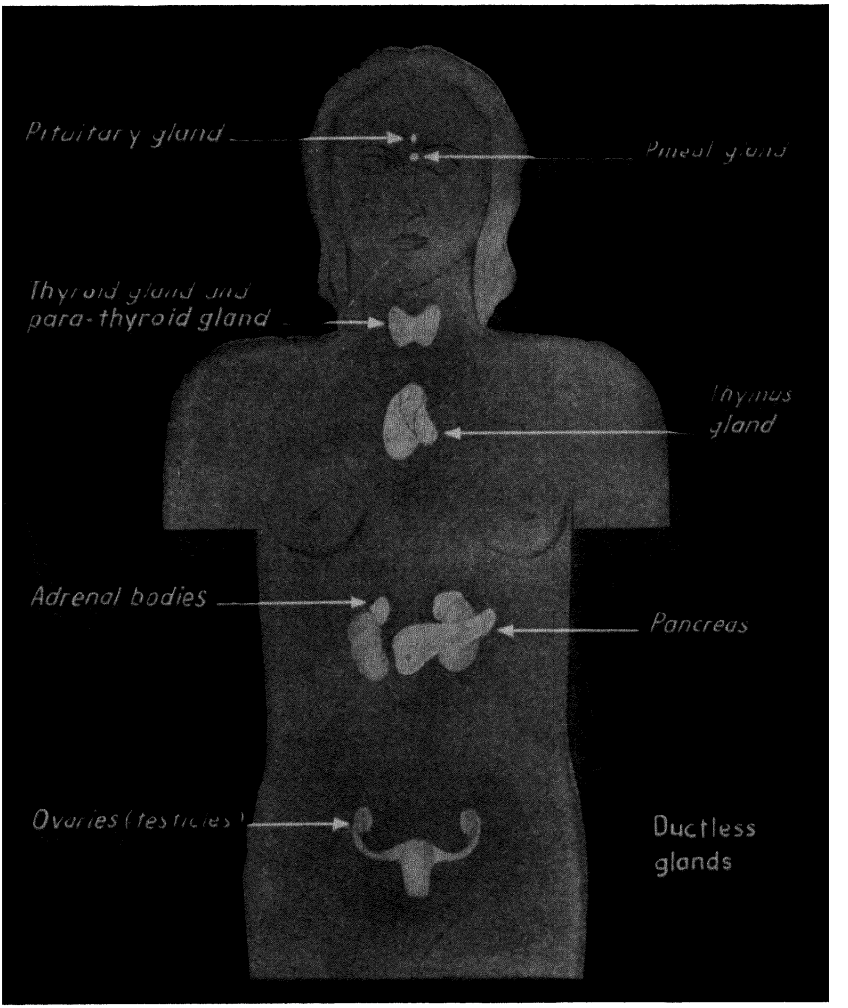
In extensive studies of brain waves made by Doctors Hallowell Davis, F. A. Gibbs, and William Lennox of the Harvard Medical School, it has been shown that people with various mental diseases have brain-wave patterns which are typical for a given disease and which are entirely different from the waves of normal people; that is, for example, when a person has an epileptic seizure his brain-wave pattern is completely changed. It has been found that these changes are so pronounced and characteristic that it is possible to predict when a person is going to have a seizure, in some cases many hours in advance, by studying his brain waves.

Brain-wave records are now being used to discover and to locate brain tumors where other methods have failed. A brain tumor or other cause of abnormal pressure at some spot on the brain tends to produce characteristic changes in the brain waves. One case is reported from the Harvard Medical School of a patient suffering from dementia praecox who was sent in for routine measurement of his brain waves. Careful study of these waves indicated that the patient was suffering from some physiologically abnormal condition. The electrodes were then moved from place to place over the head until a spot was reached where the brain waves showed a definite change. An X-ray photograph later revealed a tumor, which was removed by an operation.

The meaning and significance of the brain waves are at present not understood with any degree of certainty, so recent and incomplete is this investigation. It is certain that they are not representative of a person's conscious mental processes, such as receiving stimuli or thinking. They are not related to degrees of intelligence of normal people. Dr. George Kreezer of Cornell University reported in 1939 that he had discovered that highly intelligent persons have brain-wave patterns that are different from those of persons of average and low mentality. However, his findings have not been verified by others. In fact, other experimenters have failed to find any relationship between brain waves and intelligence. Dr. R. W. Gerard of the University of Chicago Medical School believes that these waves show the brain is in continuous action; that is, it is a dynamic organ. He says that all individual nerve currents which terminate in the brain act together to produce the waves and that the body is integrated into a single unit by the nervous system, with the brain dominating all other parts electrically.

Chemical Agents of Body Control

In the opening paragraphs of this chapter the brain, spinal cord, and nerves were compared with the telephone as a great system of communication and control. Two other means of bodily intercourse were mentioned, which operate together to regulate many activities within the organism. The circulatory system was compared with the railroads as a means of transpor-



General location in the body of the ductless glands as shown at the New York World's Fair in 1939. (American Museum of Health.)

tation. The other system, which utilizes the great circulatory network as a carrier, comprises the endocrine organs or ductless glands. These have been compared with the national postal system. Together they constitute an exceedingly delicately balanced and complex regulatory mechanism. Although separate and definite functions have been assigned to the different glands, it seems highly improbable that any one of them ever acts alone. Changes in the functioning of one endocrine organ have been

found to affect others, and these in turn to affect still others, so that a disturbance in any one may upset the whole system.

The ductless glands take their name from the fact that they do not discharge their products directly through tubes or ducts. Instead, these products are absorbed into the blood circulating through the capillaries in the glands. The secretions of the endocrine organs are chemical substances which circulate with the blood and produce important and profound effects, not only upon various parts of the body but also upon the growth and functioning of the entire organism. These chemicals are usually referred to as hormones. There are probably very many hormones, but the most important are those produced by the pituitary gland, the thyroid and parathyroid glands, the thymus, the adrenals, the pancreas, and the sex glands. Of these, the pancreas and sex glands perform special functions as ducted glands besides this one of internal secretion. The others, however, seem to have no other work.

The pituitary gland is located just beneath the brain in the floor of the skull. It is sometimes referred to as the driver gland, since it exerts a positive control over many of the organs and activities of the body. The gland consists of two separate and distinct parts known as the "anterior lobe" and "posterior lobe." Each of these secretes one or more chemical substances or hormones.

One of the hormones of the anterior lobe regulates the growth of the bones, especially the long bones of the limbs and ribs. Abnormal activity of the anterior lobe with respect to production of this hormone results in excessive growth of the bones. If this occurs after adulthood has been reached, it is characterized by an overgrowth of the bones of the head, hands, and feet. If it occurs during childhood, the result is an excessive growth of the limbs and trunk bones, producing gigantism. Arrested functioning of the anterior lobe causes a lack of development of the bones of growing children, resulting in dwarfism.

Another of the anterior-lobe hormones controls the development and normal functioning of the sex glands. Deficiencies of this hormone are associated with a lack of development of the reproductive organs and secondary sexual characteristics in

young persons, with atrophy or regression of these in adults. In addition, the anterior lobe of the pituitary secretes hormones which regulate the growth and functioning of the thyroid gland and adrenal bodies and another, called prolactin, which controls the development of the mammary glands during the later stages of pregnancy.



Robert Wadlow at the age of twenty-one was 8 feet 8.5 inches tall, and at the time of his death, when he was twenty-two, he had grown to a height of 8 feet 10.3 inches, as a result of abnormal activity of the pituitary gland. (International News.)

The posterior lobe of the pituitary operates to control general bodily welfare. It secretes a hormone which causes constriction of the blood vessels and brings about a rise in blood pressure. This substance also regulates the water balance of the body through its effect upon the secretion of urine and upon milk flow of the mammary glands in women immediately preceding and following the birth of a child. The posterior lobe also produces a hormone which stimulates smooth muscle to contract.

The thyroid gland is situated in the front part of the neck. It consists of two large lobes, one on either side of the larynx. The chemical which it secretes is known as "thyroxin." This substance is peculiar among bodily products in that it contains a large amount of iodine, sixty-five per cent by weight. The chief function of this chemical seems to be to regulate the basal metabolism of the body. In this way it regulates every activity of the

individual, including mental development and ability. It has been said that less than one two-thousandth of an ounce of thyroxin is all that stands between Einstein and imbecility. The same applies to every normal person. Deficiency of iodine in the diet disturbs the balance of the thyroid gland. Iodine is necessary for the production of thyroxin, and a lack of sufficient iodine in the food of a person usually results in enlargement of the gland. This condition is known as goiter. Obviously, it can be corrected by supplying iodine in the food.

Failure of the thyroid gland to develop properly or its atrophy in later life produces serious consequences. A child whose thyroid fails to develop and function properly becomes a "cretin." Such individuals never grow up. Although they may live to be thirty years old, they present a childish physique. They are dwarfed, pot-bellied, and ugly, with the mentality of a child of four or five years. If the condition is discovered soon enough, and if it is not too severe, it may be corrected by feeding thyroxin or the fresh thyroid glands of a sheep or a calf. Atrophy of the thyroid in later life produces mental dullness and obesity associated with a lowered metabolic rate.

Overfunction of the thyroid leads to an excess of thyroxin in the blood. This condition is associated with improper regulation of thyroid activity by the pituitary gland. It results in an increased metabolic rate, leading to nervousness, increased blood pressure, and enlargement of the thyroid itself so that the gland presses against the blood vessels and nerves in the neck region. This causes irregular heart action, a pronounced protrusion of the eyes, and the various other symptoms of exophthalmic goiter.

The parathyroid glands are four small bodies which are situated near the thyroid, two on each side. Their function is entirely different from the thyroid, however. One of the hormones secreted by these glands regulates the development of the bones. It does this by controlling the calcium content of the blood and thereby the rate of deposition of calcium carbonate in the bones. Malfunctioning of the parathyroids results in abnormal bone growth. Removal of the parathyroid glands causes a condition of excessive excitability, resulting in violent muscular contractions called "tetany." This can be treated by administering an extract of the glands.

The thymus gland is present in the infant. It reaches its greatest relative development shortly after birth and gradually disappears as adulthood is approached, its substance being replaced by fatty tissue. It is situated below the thyroid and lies mostly in the thorax. Its secretion seems to affect metabolism, especially that of the sex organs. Just how it works is not well known. Recently it has been determined that repeated injections of thymus extracts in experimental animals accelerate the growth and attainment of sexual maturity. When the treatment is continued for several generations, sexual maturity comes progressively earlier. However, removal of the thymus gland in young animals seems to have little or no effect upon development. Its exact function in the body is far from being well understood.

There are two adrenal glands, one located just above each kidney. Each gland has two parts. The inner part secretes "adrenalin," which controls the action of the heart under fear, anger, and similar emotional stresses as well as under normal conditions. This secretion also circulates through the liver and stimulates the release of carbohydrates for the muscles. Under conditions of emotional excitement adrenalin is discharged into the blood and produces the following results: (1) an increased heartbeat, (2) greater flow of blood to the brain and muscles, and (3) an increased discharge of muscle food from the liver.

The outer part of the adrenals, called the "cortex," produces a different chemical, "cortin." This hormone is indispensable to life. A gradual failure of the cortex to function produces a fatal condition known as "Addison's disease." It is characterized by physical languor, anemia, feeble heart action, a peculiar bronze discoloration of the skin, and eventually death. Removal of the cortex in experimental animals is soon followed by death, unless the cortical hormone is regularly injected. Cortin has a decided influence on the sex organs and the secondary sexual characteristics. It is not known exactly how this effect is produced. An overaction of the cortex in childhood leads to a condition in which there is a precocious sexual development. The male element is usually emphasized regardless of the sex of the child. A female child under these conditions develops a masculine voice, has the male distribution of body hair, and fails to menstruate. Should such overactivity develop after a woman

has reached adulthood, somewhat the same conditions are observed, particularly growth of facial hair, masculine voice, and radical change of the reproductive organs.

The pancreas, in addition to secreting the powerful digestive fluid, pancreatic juice, also acts as a ductless gland. It produces an internal secretion, called "insulin," which is absorbed into the blood stream. Insulin is necessary in the blood for the normal metabolism of sugar. If sufficient insulin is not present, the sugar cannot be used by the body and it accumulates in the blood and is excreted in the urine. These are the symptoms of the disease called "diabetes." In severe cases the body rapidly wastes away and the patient dies in a diabetic coma. Insulin may be prepared from the fresh pancreas of other animals. This prepared insulin may be injected into the blood of a diabetic patient, eliminating the symptoms of the disease. However, in order to be effective, it is necessary that the insulin be injected three times daily as long as the patient lives or suffers from the disease. Insulin does not cure diabetes, it corrects the distressing symptoms of the sufferer.

The sex glands, or gonads, are the testes of the male and the ovaries of the female. They produce the germ cells necessary for reproduction. In addition, they secrete hormones which control the secondary sexual characteristics. Among these are the deep voice and facial hair of men; the broad hips and well-developed breasts of women. Removal or maladjustment of the gonads always results in definite changes in these secondary sexual characteristics. In addition to the hormone controlling development of the secondary sexual characteristics, the ovaries in the female secrete another substance which is concerned with the phenomena of pregnancy. This is the substance called "progestin," which causes enlargement and vascular congestion of the uterus in preparation for implantation of the fertilized egg.

Within recent years the sex hormones have been isolated and chemically analyzed, so that their composition is known. In addition, these hormones have been made synthetically in the laboratory. It has been found that they are closely related chemically to substances capable of producing cancers in experimental animals. Gland chemicals, such as thyroxin, adrenalin, and sex-gland chemicals or other such substances sometimes are

used as medicines. They may be very useful. Apparently, they are the same in all the higher animals, and animal extracts are the ones which are used in medicine. However, gland chemicals are powerful and dangerous. No gland preparation should be taken except upon the advice and under the care of an expert physician.

REFERENCES FOR MORE EXTENDED READING

STILES, P. G.: "Human Physiology," rev. by G. C. Ring, W. B. Saunders Company, Philadelphia, 1939, Chaps. VII, VIII, IX, XII, XXVIII.

In these chapters are to be found a clear and concise description of the nervous system and its function of coordinating the body processes, together with a brief account of the endocrine glands and their secretions.

BEST, C. H., and N. B. TAYLOR: "The Human Body and Its Functions," Henry Holt & Company, Inc., New York, 1932, Secs. VII, IX.

There is much in this text for hospital and public health nurses that will be of interest to the intelligent layman. The sections referred to deal with the structure and coordinating function of the central nervous system and the effects of the endocrine secretions on coordination of growth and functioning of the body. They are clearly and simply illustrated.

CARLSON, ANTON J., and VICTOR JOHNSON: "The Machinery of the Body," University of Chicago Press, Chicago, 1937, Chap. X.

This chapter contains a thorough elementary presentation of the anatomy and physiology of the nervous system.

MITCHELL, PHILIP R.: "A Textbook of General Physiology," McGraw-Hill Book Company, Inc., New York, 1932, Chaps. III–V.

The chapters to which the student is referred contain a detailed account of the nature of nerve cells, nerves, nervous transmission, reflex action, and the central nervous system.

ROGERS, CHARLES G.: "Textbook of Comparative Physiology," McGraw-Hill Book Company, Inc., New York, 1938, Chap. XVII.

An interesting account of the regulatory mechanisms of the body written from the comparative viewpoint.

STARLING, ERNEST H.: "Principles of Human Physiology," 5th ed., Lea & Febiger, Philadelphia, 1936, Chaps. VI, VII.

These chapters contain a complete detailed account of the nervous system, except the sensory receptors.

CAMERON, A. T.: "Recent Advances in Endocrinology," P. Blakiston's Son & Company, Inc., Philadelphia, 1934.

This is an excellent survey of endocrine glands and their secretions, together with their effects on body growth and functioning. Some of the clinical aspects of endo-

crinology are also discussed. The book is a relatively nontechnical treatment of the knowledge available in this field up to 1933.

References to brain-wave investigations may be found in a number of professional journals, among which are the following: *Brain*, Vols. 57, 58; *Journal of Experimental Psychology*, Vol. 19; *Journal of General Psychology*, Vol. 14; *Science*, Vols. 81, 82, 84, 85, 87, 90; *The Lancet*, August, 1936. A popularized summary was published in *The American Weekly*, May 21, 1939.

Endocrinology, published by Association for the Study of Internal Secretions, Harvard Medical School, Boston.

This is a monthly magazine which contains a review of current endocrine literature and reports on clinical and experimental endocrine medicine and biology.



15: KEEPING WELL

Through a Knowledge of the Nature and Treatment of Disease

IN THE fifth chapter of the Book of Job it is written that "Man is born unto trouble." This revelation not only penetrates the extent of human suffering but also implies one of the fundamental laws of life from which man is not immune. This is the fact that animal life exists by feeding upon other living things. When one creature attempts to feed upon another, trouble or disease usually overtakes the victim selected. If the attempt is successful, death results for the creature serving as food. Man's body is continually being invaded by innumerable living organisms which attempt to live there and feed upon his tissue substance. When this invasion is successful, man experiences trouble. Some of his body tissue is destroyed, and disease results. Even

death may occur. However, in most cases the human body is able to overcome and kill the foreign organisms before they have caused him noticeable trouble, and thus he remains healthy.

Many other disturbances also bring about human disease. The complicated physical structure which constitutes the body requires constant adjustment and repair in order to function properly. If the cells and organs do not maintain perfect balance and adapt themselves harmoniously to their internal and external environment the abnormal conditions interfere with the life activities of specific cells or the entire body. A variation from this balance and the proper internal environment may result from long-continued abuse of some particular organs by improper health habits. In such cases, disease of some nature is likely to overtake the individual. It must be said, however, that the human body is able to adjust itself to a wide variety of conditions, so that normally we enjoy health rather than suffer from disease.

Causes of Disease

Occasionally we do get sick, and it is necessary for medical science to come to our assistance. In such cases the treatment administered is usually something to help the body cure itself. In order to understand clearly and to appreciate the provisions which the body has for warding off and curing disease, it is necessary to know what causes disease, at least the more common forms of disease. To explain what these causes are is not so simple as to ask the question. In fact, there are a great many causes of disease, since disease itself is not a simple thing. Rather it consists of a great variety of complexities which come about when there is some interference with the normal activity of the body cells.

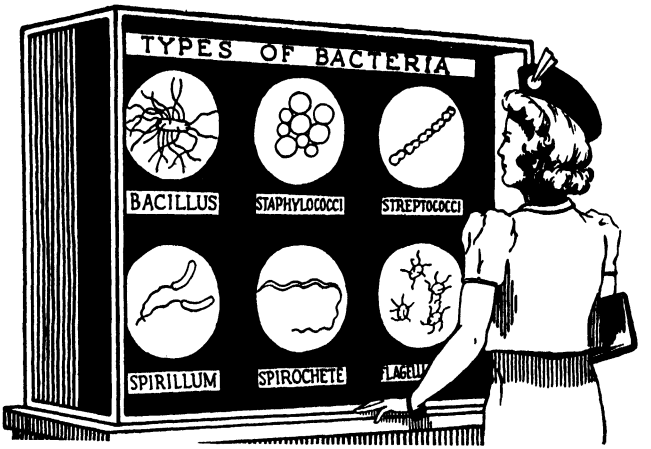
These causes may be some change within the internal environment of the body cells because of the improper functioning of an organ or improper diet. Some diseases result from the inevitable wearing out and destruction of the body cells in old age. However, the most common and widespread diseases are due to tiny organisms, called "germs," getting into the body in large numbers. The chief germs, as far as human disease is concerned, belong to the group called "bacteria." This is one of the great

evolutionary groups of life on the earth which seems to lie about midway between the plant and the animal kingdoms; however, bacteria are usually classified as a form of plant microorganism.

Many of the diseases from which man suffers would be unknown were this form of life not on the earth to keep continually invading his body. Disease is, after all, an abnormal condition; that is, it is abnormal in the sense that living organisms are so constituted that, given proper food and a favorable environment, they live their span of life without any serious trouble. But when one organism begins to invest another and becomes a parasite, then a struggle between the two begins which usually results in one overcoming the other.

There are several instances in nature where two or more organisms of different types exist in such close biologic association as to be considered living together. However, they have so adjusted themselves that they work under mutual cooperation with no harm to each other and in some cases to definite advantages. One type of such association is commensalism, which means "eating at the same table." For example, the shark sucker is a small fish which can attach itself to the body of the shark by means of a sucker at the top of its head. Thus, it gets free transportation and food discarded by the larger animal. In commensalism no harm results to either of the individuals as a result of the association, and usually there may be some small advantage to one of them. Symbiosis is an internal partnership in which each assists the other in their mutual existence. One important example is the bacteria that live inside the root tissues of leguminous plants and provide the plants with usable nitrogen and carbon. In some respects the same is true of certain bacteria which live inside the human digestive tract. The body supplies them with food and a suitable environment in which to live, and they repay by destroying certain strictly disease-producing bacteria.

However, in most cases when one creature invades the body of another there is a battle between them which continues until one or the other is killed. This is true of many kinds of bacteria which attack the body of man. The result is disease and death for man, or the death of the bacteria in his body. The disease-producing bacteria are here, and man has been unable to exter-



Bacteria vary in size and shape.

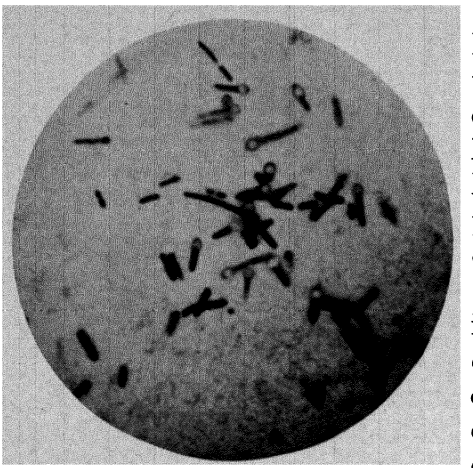
minate those which are harmful to him. He probably will never be able to do so. Therefore he should understand how best to protect his body from them. Modern medicine has gone a long way in that direction.

Nature of Bacteria

The bacteria have certain very definite characteristics. They are extremely small, the smallest living creatures on the earth. They are probably the simplest and most primitive form of life now in existence. In some respects they are like the individual cells of the body and in other respects more like one-celled plants. However, they are much smaller and more competent at many jobs. They are present everywhere on the earth. They are found in the tropics and at the poles. They are on the mountain tops and in the deepest sunless mines. The water people drink and the food they eat carry them in great numbers. The dust particles of the air are infested with them, as are the bodies of most all living or dead and decaying organisms.

Their sizes and shapes are varied. Some are almost as large as small one-celled plants. Others are too small to be seen with the highest power microscope. Some are motile, while others cannot move. Some are round spheres or are like disks. These are different varieties of what are called "cocci" bacteria. Some are like rods. These are the "bacilli" bacteria. Some are bent like a roll, and still others are like a spiral thread. These are called

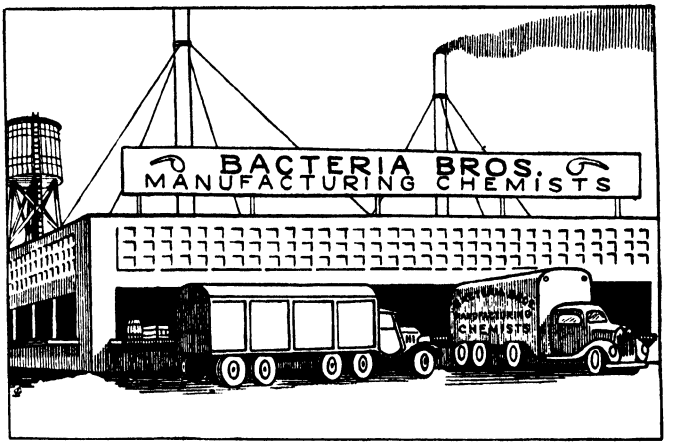
"spirilla." Many of them have projecting filaments somewhat like the tail of human sperm cells; still others have many such filaments. These are "flagella" bacteria. Some of these types are shown in the accompanying drawing. No one knows exactly how many kinds there are. There are probably many millions of different species of bacteria.



The causitive agent of tetanus or lockjaw, shown above, is a typical sporeforming bacterium. The spores are the round objects at the ends of the bacteria. (Photomicrograph by Roy Allen.)

Bacteria may reproduce in a fashion that is somewhat different from that of other cells. In general, the reproduction is by the process of cell division which is common to other living cells. However, when food is scarce or other conditions are unfavorable, a bacterium passes into a peculiar condition. This is a condition in which a great many tiny cell-like objects form inside the body of the bacterium. They are called spores, or bacterial "seeds." The spores remain in the body of the bacterium for a time. Then the cell disintegrates and the spores are set free. When conditions are again favorable, each spore develops into a bacterium of the same kind as the parent.

These spores can withstand much more severe conditions, such as extreme heat, extreme cold, and antiseptics, than can the ordinary bacteria. There are some spores which can stand boiling water for as long as sixteen hours. These are the *Clostridium botulinum*, which may cause poison in canned foods. Spores can withstand great drying for months or even years. Spores are one form in which the disease germs float in the air. In this condition they may exist for many months. Such spores may travel with air currents over large portions of the earth. There is a record of bacteria spores having been blown from Australia to New Zealand, a distance of over 2,000 miles.



Different bacteria produce many chemical products.

When food is plentiful and other conditions are favorable, the bacteria reproduce by a straightforward process of cell division. This process is very rapid. It has been calculated that if a single bacterium reproduced by cell division at the rate of one division per hour under favorable conditions so that all could remain alive, in three days the resultant mass would equal 7,000 tons. If they reproduced at their normal rate, which is much faster than one per hour, and all could remain alive, in three days their total volume would equal the volume of the earth. One germ dropped into a glass of milk would accomplish this amazing result, if it were not stopped somewhere along the line. Of course, something always does stop bacterial growth. Usually this is an overcrowding of the bacteria in the medium; for example, in a glass of milk. Another limit is the lack of food. Like other creatures, bacteria must eat in order to grow and reproduce.

Bacteria are very able chemists when many different species are considered together. They can decompose by chemical action almost all kinds of organic tissue or substances. For example, they can decompose cellulose, which is the woody fiber of plants. They manufacture substances which sour milk, turn wine into vinegar, or make flavors in different kinds of cheese and sauerkraut. Disease bacteria in the body produce certain chemicals which poison the body, causing sickness or death. It is these chemicals which cause the trouble in the case of most diseases. This is the condition, for example, in diphtheria. In other

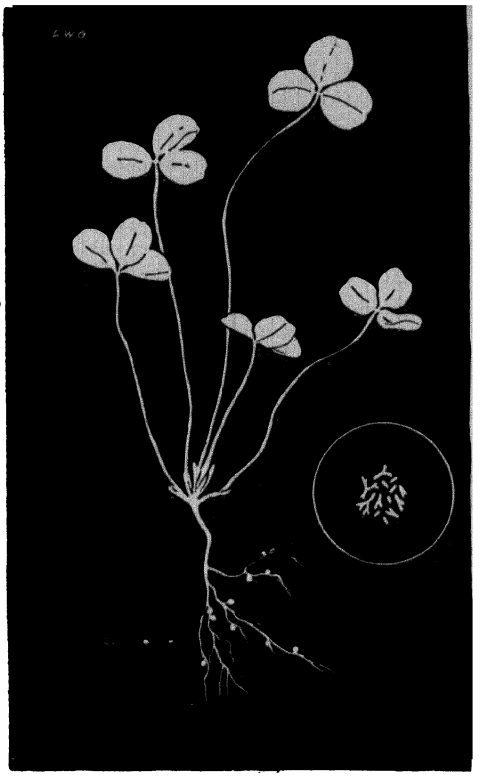
diseases, however, such as tuberculosis, it seems to be the slow persistent work of the bacteria themselves which destroy the tissues and produce death.

Bacteria have a most extraordinary manner of digesting their food. It is done outside their bodies. All types of bacteria give off digestive juices or enzymes that digest the food upon which they live very much as do the human digestive organs. This food may be dead plant or animal tissue or even living tissue. The process is the same. For example, the tuberculosis bacilli first digest certain living parts of the human body, then absorb the digested material into the bacterial body cell. Practically all bacteria which invade the body absorb some protein from some of the living cells. The absorbed protein is either assimilated by the bacteria or oxidized for the release of energy.

Before closing the discussion of the nature of bacteria it should be understood that not all bacteria are harmful; in fact, many kinds of these tiny creatures are our helpers. Some bacteria, for example, destroy dead plant and animal matter, preventing it from soon covering the entire earth. This is about the only method by which organic refuse is decomposed and returned to the simple inorganic compounds of the earth. If this were not so, within a few years the earth's surface would be covered with several feet of such dead material. The thickness of this layer would increase as time went on, if life continued to exist on the earth under these conditions, which, of course, it could not possibly do.

Again, certain bacteria in milk change the milk sugar to lactic acid. The presence of lactic acid in cream increases the yield of butter and improves the flavor. Lactic-acid bacteria are necessary for the production of sour-milk cheeses, such as the Swiss and Camembert varieties. The special flavors of these cheeses is partly due to lactic-acid fermentation. Meat is made tender by the action of bacterial enzymes. When meat is fresh, that is, soon after the animal is killed, it is tough and more or less tasteless. The enzymes attack the muscles, loosen the fiber of the muscles and connective tissue, and produce chemical compounds which give the meat flavor. So meat is usually kept for some time to permit this action. However, the process must not go too far, or products which are objectionable are formed.

Plants which grow in the soil remove large quantities of nitrates. When these plants are removed by man or other animals, they take with them the nitrates in the form of proteins. Soon the nitrates of the soil would entirely be depleted and the land become unproductive were there no way of replacing it. This is accomplished mainly by "nitrogen-fixing" bacteria, which live in the roots of clover, alfalfa, and other similar plants. These bacteria absorb nitrogen from the air and convert it into ammonia, which is used to form their own proteins. Upon the death of these bacteria, their proteins are converted into soil nitrates by other bacteria, much the same as is done with the proteins in the dead bodies of other organisms.



"Nitrogen fixing" bacteria residing in the nodules on the roots of leguminus plants aid in restoring nitrates to the soil.

Infectious Diseases

Many of the diseases from which man suffers may be transmitted from one individual to another. We refer to them as the "infectious" diseases. They are produced when bacteria or some other organisms invade the body and attack some tissues or organs. Perhaps the most prevalent disease of northern climates is the common cold. It is produced by a variety of organisms which invade the soft tissues of the nose, throat, and eyes. One of these organisms is a coccus type of bacteria; another is without doubt one of the filtrable viruses. Once in these tissues in sufficient numbers, these bacteria produce chemical products

that are poisonous to the body. Some of these circulate in the blood, producing headaches and other aches of a cold. The efforts of the body to remove these organisms and their poisons result in discharges from the membranes, such as water from the eyes and mucus from the nose and throat.

Pneumonia is a similar infection, really invasion, of the tissues of the lungs by another species of cocci bacteria. Typhoid fever is an infection of the lining of the bowel by a bacillus bacteria known as the *Bacillus typhosus.* Diphtheria is an infection of the throat by still another type of bacillus. Spinal meningitis is an infection by bacteria, too small to be visible under a high-power microscope, of the spinal cord and a part of the brain. Many other diseases are due to other kinds of bacteria. Different diseases are caused by different kinds or species of bacteria. These different species of bacteria respond to different treatment and conditions; therefore each disease is a study within itself. No patented medicine or general treatment is a "cure-all" for many different diseases.

Within recent years other organisms have been discovered which are known to be the causes of some of the most serious infectious diseases. These organisms are the filtrable viruses, so called because they are so small that they will pass through a porcelain filter. They are too small to be seen, even with a high-power microscope. There are many kinds of filtrable viruses. When they get into the body they cause infections or diseases, each strain producing its own infection. Smallpox is a virus infection. Measles is produced by another virus. Yellow fever is another virus disease; so are influenza and infantile paralysis.

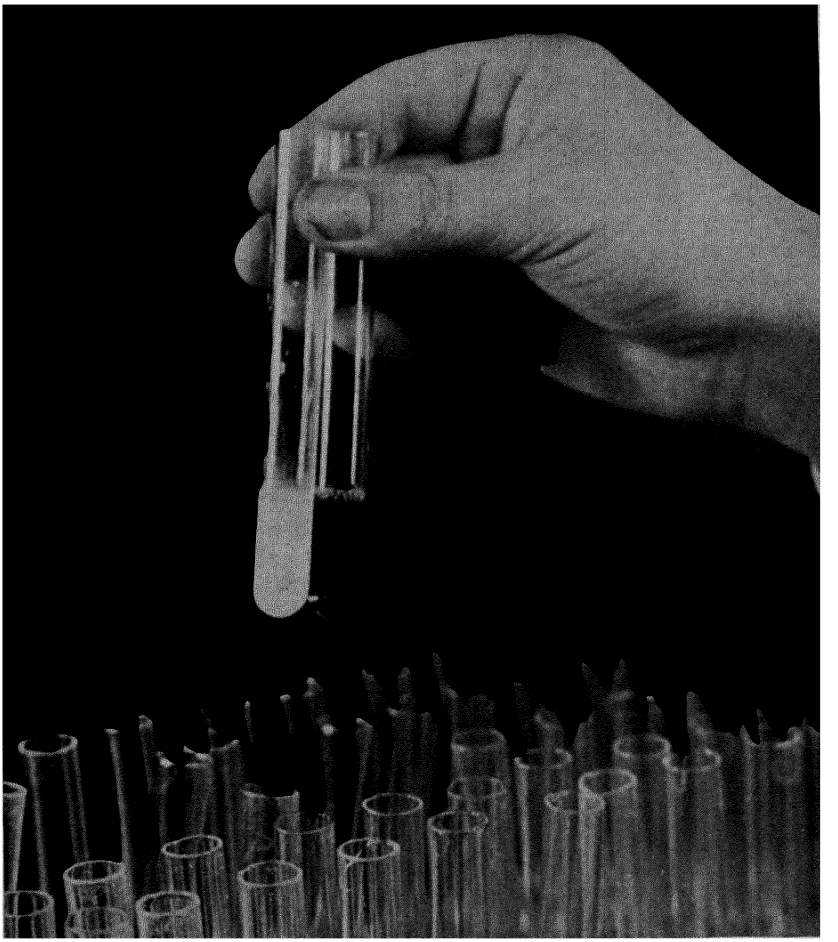
Syphilis is a disease produced by the presence in the body of one-cell organisms called "spirochaeta." They have a sort of corkscrew appearance when viewed under a high-power microscope. These organisms are considered by some as being bacteria, by others as being animal protozoans. They seem to be midway between the two groups in their physical structure and development. They will reside and flourish in many tissues of the body. They usually enter the body through the thin membranes lining the reproductive organs. However, they may enter through an abrasion of the skin or protective tissue. They find their way into the blood stream and then migrate to some favorable

tissue, which they infest. Fortunately, however, for man the spirochaeta can live only in a moist mucous medium. When they are deposited where drying action occurs they soon die. Infection from toilets, drinking cups, and crowded cars is not common.

The disease manifests itself in three rather distinct phases, unless it is properly treated. The first stage is characterized by the formation of a small, hard elevation, called a "chancre," at the point where the infection entered the body. This will persist for a short time, then disappear. In the course of about two or three months the second stage begins. The spirochaeta have invaded other parts of the body. The lymph glands may swell, or there may be a breaking out of a rash on the skin; also there may be fever. Either one or all these symptoms may appear. These symptoms usually disappear within a few weeks or months, either with or without treatment. Without treatment, however, the organisms start to migrate to the vital organs of the body and later will begin to destroy these organs. This is the third stage of the disease. Usually treatment then is not effective. They may cause hardening of the arteries and attack the heart, kidneys, liver, stomach, and finally the brain. The result is slow, lingering death.

Effective treatment of the disease is possible when it is begun in the early stages of syphilitic infection. It consists primarily of injection of arsenic compounds into the blood to kill the organisms in the tissues. Such treatment must be continued under expert medical care over a period of years in order to insure a cure. There is no other way. Since the symptoms of syphilis are so elusive, it is very difficult for anyone to be sure he does not have the infection unless he takes the Wassermann test. This is a chemical test of the blood that is always accurate in determining the presence or absence of the spirochaeta. In order to eradicate the disease from the individual as well as the general population, it is necessary that it be detected in its early stages and treated in accordance with well-established medical practice.

Some diseases are due to animal parasites or protozoans. Such, for example, is malaria. In this disease a small animal gets into the blood, damages or eats the red corpuscles, and sets free a poison in the blood. These protozoa usually are introduced

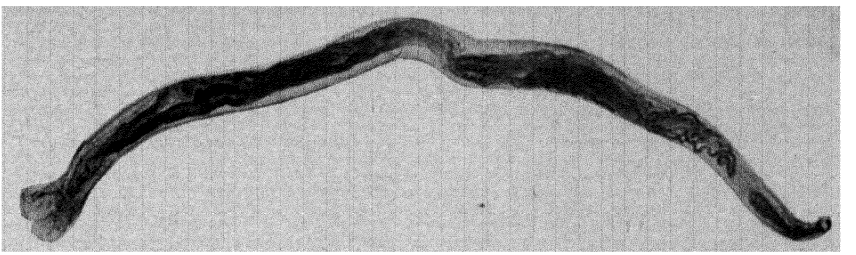


Blood test for syphillis. The cloudy white solution shows a positive test, while the clear red (dark in photograph) is negative. (U. S. Public Health Service.)

into the blood by the bite of a mosquito carrying the micro-organism. The discovery of this relationship stands out as one of the great advancements in medical science. People of many lands will long honor the memory of Major Ronald Ross for his work in this respect.

Major Ross was a surgeon stationed with the British army in India, where some three million natives as well as many Englishmen were dying each year from malaria. He finally discovered that, when a mosquito bit a person or a bird suffer-

ing from the disease, tiny nodules developed in the mosquito's digestive tract and that mosquitos biting persons not having



Photomicrograph of male hookworm by Roy Allen, showing body structure and sucker foot at right.

the disease did not have such lumps. These nodules were discovered to grow rapidly, then burst, and from them a swarm of microorganisms would stream out to the glands and proboscus of the mosquito. When such mosquitos were then allowed to bite a person or a bird, the germs were deposited in the blood stream, and malaria resulted. From these discoveries it is now known that the most effective method of preventing the spread of malaria is to destroy the breeding places of the mosquitoes. Such practice has already made the disease relatively uncommon in the United States.

African sleeping sickness is another similar disease. Here tiny worm-like protozoa get into the blood and destroy the red corpuscles, thus cutting off the oxygen supply of the body. The brain and nervous system are the first to be affected by this shortage of oxygen, hence the patient becomes more or less unconscious long before death. The other organs needing a large supply of oxygen are the kidneys. They begin to suffer and are unable to perform their function of ridding the body of wastes and regulating the composition of the blood. Death inevitably results unless the organisms are removed from the blood before too great damage is done.

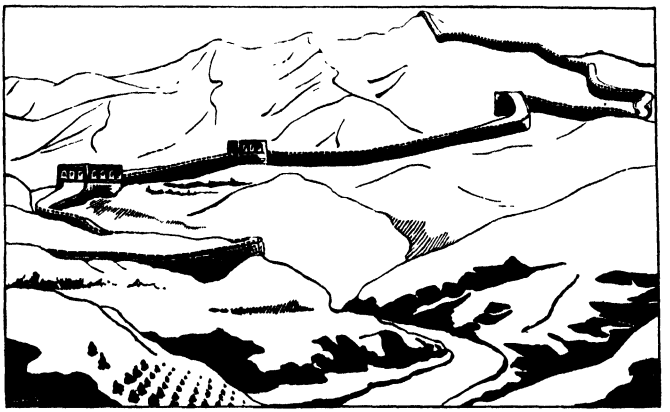
One of the infectious diseases that has afflicted great populations in certain sections of the United States as well as many foreign countries is the malady caused by hookworms in the intestine. The hookworm is scientifically called *Necator americanus*, which means "the American killer." It is usually about one-half an inch long. When they infect man, they penetrate

the body tissues until they reach the intestine. There the worms grasp bits of the intestinal lining and suck in blood and tissue fluids. They produce a sort of starving effect upon the individual. Symptoms of the disease are anemia, laziness, and a general lack of physical and mental vigor. Infection in children leads to retardation of physical and mental development. The disease is seldom fatal but it may spread through large populations, causing them to live the dullest and most unproductive lives.

Hookworms are spread from one individual to another by feces contamination. The eggs produced by the worms in the intestine are excreted from the body in the feces. In certain great areas of countries, particularly in China, India, and parts of Southern United States, it had been the practice up to the immediate past to leave human feces on the open ground. Hookworm eggs existing in such feces hatch into tiny larvae. These larvae in crawling around on the ground come in contact with the soles of bare-foot persons. They penetrate the skin and eventually make their way to the digestive tract, where they grow into adult hookworms and the cycle starts again. To eradicate the disease it is necessary to teach the people to use exclusively properly constructed toilet facilities. Some of the earth's great unsung heroes have been the doctors, nurses, and social workers who have influenced whole populations to stamp out the disease by such practices.

Defenses against Bacterial Diseases

The body has four more or less distinct defenses against disease bacteria and a few disease protozoans. One of these is a sort of protective wall, to be compared in some ways to the great walls the ancient Chinese built around their cities and provinces to protect them from foes who were less adept than their modern adversaries. This protective covering consists of the skin and the mucous linings of the lungs and digestive tract. The skin is a tough, dry substance that is impervious to the tiny organisms that continually swarm around us. Even the multitude of such creatures that regularly get into the lungs, eyes, and stomach have great difficulty in penetrating the membranes lining these organs. These membranes secrete a mucus which entangles the bacteria. Thus they are finally thrown off the body. In addition,



One of defenses the body has against bacterial diseases is the skin, a sort of protective wall that might be compared in some respects to the great walls the ancient Chinese built around their cities and provinces.

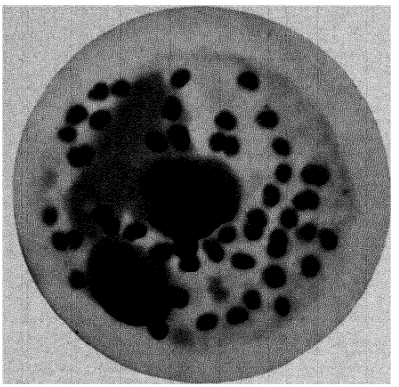
the digestive tract secretes chemicals which are destructive to the millions of bacteria that are taken in with the food we eat.

The next, and first internal, line of bodily defense consists of the white corpuscles of the blood. They might be compared to the policemen of a city, protecting its citizens against its dangerous characters. When bacteria in large numbers enter the body at any point the white corpuscles gather there in large numbers. They are probably summoned by the chemical poison in the blood produced by the first invading bacteria. They endeavor to remove the bacteria by eating them. In this process they usually surround the bacteria with their body cells and digest them. This is very much the same process as the amoeba follows in its normal feeding.

This feeding process may kill the white corpuscles but the "arrest" works and the body is rid for the time being of bacteria. To be thus engulfed and eaten by the white corpuscles probably is the lot of most of the billions of bacteria that we eat or drink or inhale or get into cuts every hour of the day. Only when for some reason the white corpuscles fail to do their job successfully do we realize that a germ has invaded us at all.

In some cases, the white corpuscles can restrict an infection, if not repel it. An abscess, for example, is usually an invasion by bacteria of the staphylococcus type, which the white corpuscles have walled off with their own bodies. In this case the

trouble is only local. The yellowish discharge from such an abscess consists of a considerable amount of body tissue fluids that have been carried to the site by the blood, and the bodies of millions of white corpuscles which have given their lives in the struggle. A boil is similar, except usually the infection is by a different staphylococcus bacteria.

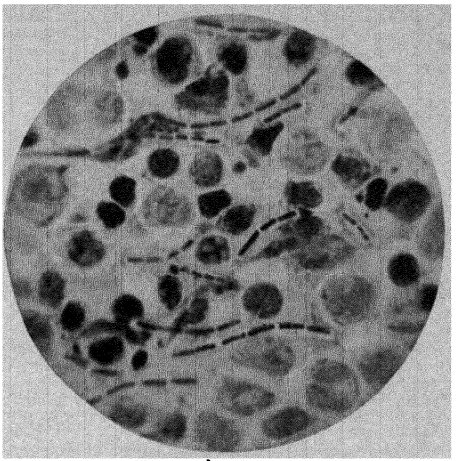


This photomicrograph shows a white blood cell which has engulfed a large number of gonorrhea bacteria. The bacteria are the smaller black objects. (Photograph by Roy Allen.)

The body's second internal defense against bacteria is fever. All body cells possess in some degree the same power as the white corpuscles to destroy bacteria. These self-protective powers, like the ability of a citizen to fight a burglar if no policeman is at hand or if he fails, are greatly increased by heat. The human body cannot be heated to a high temperature with safety, but it is all right to heat it to 102 or 103°F. The normal temperature is 98.6°F. Accordingly, one of nature's defenses is to heat the body by fever, because the body cells become more active at higher temperatures. In this manner the germ-repelling powers of the white corpuscles and other cells become greater. The fever is believed to be caused by effects of the bacterial chemicals working on the glands. Fever, when not too high, is a desirable thing, therefore, when one is sick.

The body has still another, often more efficient, defense against bacteria and some viruses. This is called immunity. There are some diseases which one has only once. An example is smallpox. In fact, one seldom has smallpox at all after once having had a mild form of the disease produced by vaccination. This vaccination is the process of putting into the blood stream a small quantity of the smallpox virus after they have been weakened or killed. The presence of the weakened germs causes the body cells to manfacture a chemical substance that is destructive to smallpox virus should they later enter the body in large numbers. Such a chemical is known as an antitoxin. Other

disease viruses or bacteria stimulate the body cells to manufacture different antitoxins that are antagonistic to these specific germs. Such a chemical destroys the bacteria present. Furthermore, the antitoxin may remain permanently in the blood stream and destroy any future similar organisms which enter the body. This is a sort of protective chemical warfare conducted by the body cells against bacteria and similar infectious agents.



The rod-shaped objects are anthrax bacilli in tissue. This organism also illustrates one feature of certain bacteria, namely, the ability to form a protective capsule of fatty material surrounding the cell. (Photomicrograph by Roy Allen.)

This immunity is built up temporarily when the body has any bacterial disease. With many diseases it does not last. This is illustrated in diseases like a cold. The first day one has a cold it spreads, attacks new tissues each hour, saturates the body with its bacterial poisons. After a few days it stops spreading. One begins to feel better. The body's cold antitoxins are getting to work. This takes a little time, but soon one is cured of the disease. This immunity to colds soon disappears. After a few days the bacteria and virus-repelling antitoxins have faded out of the blood, and one can catch cold again. However, some diseases produce an immunity which lasts the remainder of one's life. Measles and diphtheria produce antitoxins which remain in the blood stream more or less permanently. The organisms that produce these diseases are usually not able, therefore, to infest the body in sufficient numbers to cause the diseases a second time.

It is possible to bring about artificial immunity by injecting into the body various serums or antitoxins. In treating diphtheria, caused by one of the most virulent and deadly germs, an antitoxin is injected into the blood stream of the person having the disease. This antitoxin serum is the same chemical which the body itself would produce to kill the bacteria, if it were given

time. However, the injection works much quicker. Without it the person is usually killed by the bacteria before his body can produce sufficient antitoxin to destroy the bacteria. This serum is secured by causing some animal, usually a horse, which does not die from the disease, to have diphtheria. The horse's body manufactures the same antitoxin as the human body. The horse's blood is drawn off and the chemical is extracted from it.

This is known as the antitoxin treatment. In dangerous cases of diphtheria a toxin-antitoxin treatment is used. In this treatment the antitoxin is injected as before. In addition some toxin, that is, poison produced by the diphtheria bacteria but not the live bacteria themselves, is injected at the same time. This poison causes the body to produce its own antitoxin more rapidly, and at the same time the toxin does relatively little harm to the individual.

In some cases injections are used to stimulate the manufacture of the antigerm chemicals in the human body before the bacteria enter and thus prevent one from having the disease. Such is the inoculation against typhoid. This serum consists of dead typhoid bacteria, *Bacillus typhosus*. Their presence in the body does little or no harm, but it does cause the body to manufacture typhoid antitoxin, which will kill any live typhoid bacilli which enter. Typhoid antitoxin thus produced remains in the blood stream from one to three years.

The question is often asked, why do some people "catch" disease, like colds, more easily than others? There are at least two reasons for this. One is lowered defense abilities of the body, resulting from illness which has weakened the white corpuscles, the body cells, or the fever mechanism; or the body may be in a generally poor physical condition. The second reason is the presence of a very large or virulent group of the bacteria or viruses that infect a person. From the individual standpoint, therefore, the chief factor in avoiding bacterial disease is high resistance. This high resistance is largely determined by one's practice in proper eating, health habits, and care of the body.

Functional Diseases

The infectious diseases do not include all the ailments with which mankind suffers. There is another type of disorder which

is usually referred to as the "functional" diseases. In such diseases no known foreign organisms play any significant part. Some of these are diseases common to old age. Some others result from improper diet, they being generally referred to as the "deficiency" diseases.



Remarkable photograph of a cancer cell "drinking." The fluid is taken in by the ruffle-like edge and appears as clear globules in the cell. (Microphotograph by Warren H. Lewis, Carnegie Institution of Washington.)

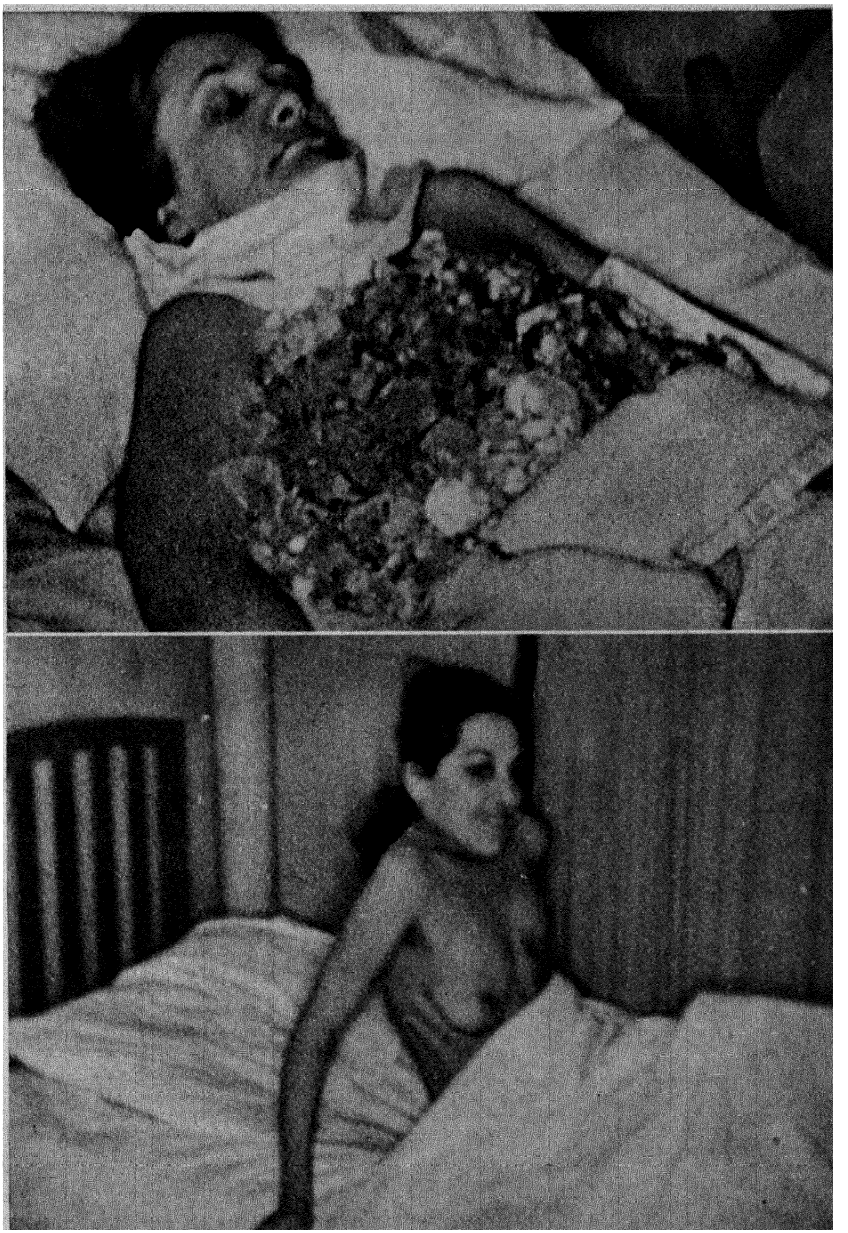
Some of the diseases which produce the greatest mortality are those that develop as one approaches old age. These represent the slow disintegration of the body tissues. Such disintegration may be affected by some previous bacterial impairment, hereditary traits, or personal habits. Regardless of these, the body tissues do wear out, and death eventually overtakes one. As the average life of a people is increased by the elimination of premature "accidental" deaths from infection or improper care in childhood, the deaths from diseases of old age increase. Such conditions now definitely exist in the United States. The most common of the diseases of later life are cancer, heart diseases, and kidney diseases. The percentage of deaths from these diseases has increased greatly during the last generation.

Cancer is a condition in which a group of cells begins to grow and multiply at an enormous rate. Just why and how they begin is not well known. They invade and destroy the surrounding tissue, producing in its place a tumorous growth. Some of the cancerous cells may break off and enter the blood system or lymphatic system, where they spread to other parts of the body. Should they lodge in some particular area, the growth would be repeated. After a time any cancerous growth interferes with the effected parts of the body to the extent that these parts cannot function, or the cancer saps the vitality of the entire body. In such cases death inevitably comes to relieve the patient from his suffering.

The only cure for cancer known at present is to remove the cancerous tissue from the body by surgical methods or to destroy it by X-ray and radium treatment. These methods will usually cure a local cancer. If such treatment is applied before the cancerous tissue has invaded the circulating systems and other parts of the body, the cure is effective and permanent. However, if the tumorous cells have migrated to other parts of the body, another cancer will soon develop. In such cases, cure is usually impossible. A part of the fight against cancer, then, is to discover it and treat it while it is still localized. At least, that is the situation at present. When cancer is discovered in its initial stages, it can be cured. Any person of adult age or over should report immediately any symptoms he may have of cancer, such as persistent sores or lumps, or disorders in the digestive tract.

Disorders of the heart become more pronounced as age increases. One of the most common disturbances results from an inadequate supply of blood to the heart-muscle capillaries. The general hardening of the body arteries, which is a natural condition of advancing age, may reduce the blood supply to the heart muscles to the extent that these muscles cease to function, or there may be an occlusion of the arteries supplying the heart muscles. Should this produce a clotting or rupture of the vessel, the blood supply is stopped, and death will result in a few minutes. Damages to the heart muscles may be produced as an aftereffect of certain infections. Scarlet fever or diphtheria bacteria produce toxins which leave the heart muscles scarred. In later life this damage may seriously interfere with proper heart action.

Defective valves of the heart constitute an important group of heart disorders and sometimes they result in fatalities. The valves may have been rendered defective by syphilis spirochaeta having invaded the muscular tissue. Leaky valves may also be the aftereffects of rheumatic fever. This disease does not affect the heart at the time it is noticeable in the joints. However, it is thought that some of the bacteria lodge in the heart, where they slowly multiply and years later produce the heart disease. In many other cases, defective valves appear to develop from natural deterioration.



Fighting cancer pain with "frozen sleep." The patient is packed in ice and the body temperature is lowered to about 82 degrees. After a period of "hibernation" due to the reduced temperature, the patient awakes with the pain relieved, and with no memory of the "sleep." (International News.)

Kidney diseases can be brought about by many contributing factors which accumulate with advancing age. When the kidneys become so damaged that wastes are improperly removed from the blood stream, weakness and uremic poison results, and this usually ends with death. Infectious agents are often responsible for kidney damage. Bacteria from a sore throat sometimes invade the kidneys and produce a gradually increasing destruction of the glands. The hardening of the arteries will reduce the blood supply to the kidneys and produce disintegration of the cells from lack of oxygen and nourishment. High blood pressure also is likely to produce chronic kidney disorders.

As age increases there is a tendency for some of the solid materials which the kidneys filter from the blood to be deposited in these organs, forming stones. These obstruct the passage of urine and produce kidney degeneration after long standing. An effective method of treatment for this disorder is to remove the stones and diseased parts. As has previously been mentioned there is a sufficiently large number of the Bowman's capsules and capillary knots to permit the removal of a part of them without greatly endangering the work of the kidneys.

Vitamins and the Deficiency Diseases

Vitamin deficiency diseases have been known since the Middle Ages. However, a knowledge of their real relationship to minute quantities of certain specific materials in foods has come as a result of scientific discoveries made within the last twenty five years or so. Ancient sailors on long sea voyages were well acquainted with the painful and bleeding disease of scurvy. They knew, too, that the malady was cured when they reached land and could get a diet containing fresh fruits and vegetables. What the real relationship was between the disease and diet however, they did not know.

The disease called "beriberi" has long been prevalent in the Orient, where the diet was largely confined to polished rice. In certain years during the past century about one-third of the men in the Japanese navy would fall victims of the disease. The discovery that it was caused by a deficient diet was made by a Dutch physician stationed with the Dutch army in Java near a hospital for the disease about 1900. Since then its prevention and



Parasitic infection is in no sense limited to man. Shown above are two turtles that have been attacked by the parasitic leech Placobdella.

cure by including certain food materials in the diet has become known throughout the world.

The vitamins, then, are substances that exist in small quantities in different foods. The discovery of most of them has been associated with some particular disease. However, we now think of them as being requirements for normal health rather than as connected with some malady. The lessons they have taught have been largely that a diet of a variety of natural foods is essential to physical well-being. It is desirable that a variety of foods be carefully selected so as to provide a proper balance of vitamins as well as other food elements. This variety is much to be preferred to some restricted diet of highly prepared foods, however cheap or palatable they may be.

There has been such an extensive discussion of vitamins in the popular press and in advertisements within recent years that almost every one has become "vitamin-conscious." Many firms have attempted to increase the sale of their food products by claiming that they are particularly rich in some one or more of the vitamins or that they contain a vitamin in concentrated

form. Such statements are usually based upon scientific evidence. However, one very important condition regarding the vitamin needs of the body is overlooked, and, because of this, erroneous and even dangerous impressions are sometimes created. This condition is that the action of vitamins in the body is often an interrelated and dependent process. They are related in that certain vitamins seem to depend upon others for their desired effects; they are often also, dependent upon other food elements of carbohydrates, fats, proteins, and minerals for proper reaction in the body. The ingestion of vitamins in concentrated and specialized forms, therefore, is likely to be of little value unless administered under the care of a competent physician.

The term "vitamin" arose from a name suggested in 1912 by Dr. Casimir Funk, who believed that these food elements belonged to a group of nitrogen-containing chemicals known as the "amines." Since they are considered essential to life, the prefix "vit" was added, producing the word "vitamine." However, it was later discovered that all these substances are not amines, and the word was changed to vitamin. The vitamins are a group of organic chemicals which act as catalysts in the body, producing certain chemical and physiological reactions which cannot occur without them.

These substances are not all chemically related to each other, but they may be classified as derivatives of (1) the amine substances, (2) fatty alcohols, (3) sugars, or (4) carotene substances. There are now a great many of the vitamins known to be essential to general health and well-being, all of which are identified by letters. The chief ones are vitamins A, B complex, C, D complex, and E. In addition, others have been discovered to be required in small amounts, these being known as F, H, K, and P.

Perhaps it is in order to mention that vitamins are not a panacea for all the ills of man, but their importance in helping man attain a higher level of buoyant health should be emphasized. Although each vitamin has a specific part to play, it is now well known that any practice of taking vitamins in individual "doses" is of little value. Some knowledge of their general distribution in various foodstuffs and their effects upon the body may be of value to everyone.

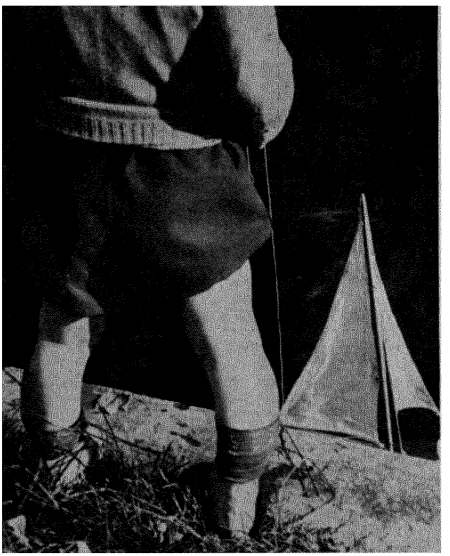
Vitamin A is necessary for growth of the young; it increases resistance of the body to infections of the respiratory and urinary tracts and maintains appetite and normal digestion. A complete lack of the vitamin causes a dangerous eye disease, in which there is almost complete destruction of the eye tissue by replacement with an abnormal cellular growth. During the World War it was discovered that a large number of Danish children who were on restricted diets not containing butter and whole milk developed the disease. When fresh butter was added to the diet, the disease disappeared. Milder deficiencies of the vitamin may produce physical weakness, formation of kidney and gallstones, night blindness, and sterility. This vitamin seems to be closely related to a chemical called carotene, which makes the yellow color in carrots. The vitamin is present in a variety of green vegetables, apricots, prunes, butter, milk, cheese, beef liver, and kidneys.

Vitamin B complex includes a number of vitamins, all of which were once thought to belong to vitamin B. In addition, what was formerly designated as vitamin G is now known to be a part of this complex. The entire group now includes vitamins B_1, B_2, B_3, B_4, B_5, B_6.

B_1 is the vitamin that is necessary to produce a normal condition and normal functioning of nerve tissue. It also promotes growth, aids digestion and absorption of foods, and increases resistance to infection. A complete lack of it causes the dreaded disease beriberi. This disease is characterized by atrophic paralysis of the legs and arms, dropsy, and heart trouble, accompanied by a degeneration of the nervous system. The disease is largely prevented now in some of the countries where it was once prevalent by a substitution of unpolished rice and unbleached flour as the staple diet. This is particularly true in the Philippines, where many beriberi hospitals have now been closed, largely because of the lack of patients. Vitamin B_1 is present in such foods as nuts, whole grains, peas, grapes, spinach, liver, and eggs.

B_2 is itself a mixture, one factor of which promotes growth. The other factor prevents the disease of pellagra and is sometimes designated B_6. Pellagra is characterized by eruptions on the hands, arms, or neck and other symptoms. The disease may

result eventually in insanity or death. A mild deficiency of vitamin B_2 produces low vitality and slow growth of the young and interferes with muscular action. Both of these vitamins are present in a number of vegetables, particularly those of the green-leaf type. They are also present in liver, kidney, veal, and eggs.



Lack of vitamin D produces rickets in children, characterized by poor development and malformation of the bones. (Courtesy of Standard Brands, Inc.)

The other B vitamins have been found to produce certain effects in experimental animals, and indications are that they represent different chemical substances. One of those seems to be effective in regulating the formation of red blood cells and the prevention of anemia. However, at present knowledge of these other B vitamins is in a nebulous state, and actually we possess little definite information about them.

Vitamin C is a substance that favors good bone and tooth formation and endurance. It maintains the health of blood vessels, improves appetite, and stimulates growth; it is also, involved in the mechanism for the prevention of bacterial infection. A shortage of this vitamin causes general weakness, headaches, slow healing of wounds, and joint pains. A complete lack produces scurvy, characterized by multiple hemorrhages, anemia, progressive body weakness, mental decay, and delirium. The vitamin is found in oranges, lemons, peppers, cabbage, spinach, and tomatoes.

Vitamin D is sometimes referred to as the "sunshine vitamin," since it is produced in certain fatty substances of animal tissue by the effects of ultraviolet radiation. However, it should be kept in mind that ultraviolet radiation is itself not a vitamin, a mistaken idea that many people seem to have. The composi-

tion of vitamin D is unknown, but it seems to be related to the fatty alcohols. It is believed that it contains five or six factors rather than being a single substance. It regulates the metabolism of calcium and phosphorus and is essential to bone growth and tooth formation. It promotes normal glandular function and maintains the proper calcium level in the blood. It is practically absent from most vegetables, and its most potent source is fish-liver oils. However, the body itself will manufacture a sufficient amount of it when there is a reasonable amount of exposure to sunlight.

There is still much to be discovered about vitamin E, especially regarding its effect on the human body. It has been found to regulate sexual maturity and functioning in experimental animals. There is some clinical evidence to show that a complete lack of it produces sterility or sexual impotence in both men and women, but there is at present far from universal agreement on such effects. The natural sources of the vitamin are lettuce, spinach, whole wheat, peanuts, milk, eggs, and lean meats.

Certain other vitamins have been discovered to have an effect upon experimental animals. These have been labeled F, H, K, and P. It is likely that in the future they may be found to be related to certain human physiological processes and may prove to be the causes of a few elusive human disorders that are at present not well understood by medical science.

The very extensive work that has been done in the study of vitamins during the last quarter century has given us wide and valuable knowledge of their specific effects upon normal health and body functioning. The vitamins are so interrelated that a normal diet should contain all of them in approximately the proper amounts. These conditions are usually satisfied when one eats the natural foods which the body has become adapted to through long ages of its development.

The problem of vitamin supply for most people, then, is mainly one of eating a variety of foods. Such foods should include some fresh fruits and vegetables, some dairy products, some bread and potatoes, and as wide a choice of different kinds of meats as is available. This variety is not necessary in each meal, of course, but should be included in one's regular eating habits.

When such habits are practiced one is practically sure to obtain all the vitamins necessary, not only for the prevention of the deficiency diseases but also for normal health.



Intelligent care of the body will provide for most individuals a large measure of superior vitality. (Courtesy of Selby Shoe Company.)

Maintaining Health

The best way to prevent having disease is to keep the body healthy. This is not so foolish a truism as it may seem on first reading. The human body, while an extremely delicate and complicated mechanism, is so constituted as to be able to ward off disease when it is kept in a perfectly normal condition. Some of the ways the body has for fighting bacterial infection have just been explained. It has been seen that many other ailments to which mankind is subject are also prevented when the body is functioning properly. Health, in its broader sense, means more than freedom from disease. There is a difference between buoyant health and merely not being sick. The superior vitality of some people need not be accepted by others as a measure of luck which can only be inherited. Intelligent care of the body will provide for each individual a large measure of this vitality.

The relation of nutrition to health constitutes, in some respects, the most remarkable discovery of modern times. It is of concern now not only that food be free from poisons but also that it be considered from the point of providing the body with all the elements necessary for growth, energy, and protective purposes. It is now known that for an adult engaged in various kinds of activities definite amounts of energy expressed in

calories are needed. All foods which man eats have been analyzed in terms of their energy values as well as their vitamin and mineral contents, so that it is possible, if one desires, to regulate one's diet accurately.

Directly related to health is physical exercise. This involves more than mere gymnastics; however, it does not mean a strenuous athletic program. Physical education for health includes some outdoor activities in the form of games or hobbies which provide some measure of mental relaxation as well as physical exercise. Walking, swimming, dancing, or tennis constitute activities which even busy people in a crowded city may participate in and enjoy to some extent. For the average adult such forms of exercise are to be recommended more than strenuous competitive athletic games.

A periodic physical examination by a physician is important. Any deficiency or maladjustment in the body may then be detected before it becomes serious, and a remedy applied. Yearly physical examinations of children are now provided in most primary and secondary schools. To a certain extent this practice is followed in colleges. Some life insurance companies provide their policyholders with a free medical examination every two or three years. However, whether one secures such an examination through the school health department, insurance companies, or from his personal physician, it is a valuable protective physical analysis which should be obtained at least once yearly by every person.

REFERENCES FOR MORE EXTENDED READING

BIGGER, JOSEPH W.: "Man against Microbe," The Macmillan Company, New York, 1939.

In addition to a short history of microbiology, with emphasis on its relationship to mankind, the author discusses the nature of disease germs, their characteristics, how studied, and how acquired and resisted by the human body.

RIESMAN, DAVID: "Medicine in Modern Society," Princeton University Press, Princeton, N. J., 1939.

The author has written here a short history of medicine up to the present which includes a summary of discoveries about most modern diseases. However, the book is more than a history. It gives a thought-provoking analysis of the effectiveness and proper position of medicine in our modern social order.

ZINSSER, HANS: "Rats, Lice and History," Little, Brown & Company, Boston, 1935.

This book is primarily an account of typus fever, its causes, manner of transmission, and the plagues it has produced. The style of writing utilizes a wide command of language and is thereby interesting, although somewhat laborious for the untrained to follow.

FULOP-MILLER, RENE: "Triumph over Pain," Bobbs-Merrill Company, Indianapolis, 1938.

This book contains an interestingly written history of almost all attempts to eliminate pain connected with medical treatment and operations.

WALL, F. P., and L. D. ZEIDBERG: "Health Guides and Guards," Prentice Hall, Inc., New York, 1936.

Here is a concise and practical book of hygiene. The structure and functions of different parts of the body are briefly treated, and specific information of their proper care is clearly set forth.

DIEHL, HAROLD S.: "Healthful Living," McGraw-Hill Book Company, Inc. New York, 1940.

This is primarily a textbook for college courses in hygiene. It contains a wealth of information of value to everyone interested in developing and preserving the body to the best possible advantage.

FROBISHER, MARTIN: "Fundamentals of Bacteriology," W. B. Saunders Company, Philadelphia, 1937.

The author has written here a text for students of bacteriology which gives a grasp of the essential facts concerning both pathogenic and nonpathogenic bacteria. While the book includes a considerable amount of technical detail, it contains many accounts of interest to the intelligent layman.

STITT, E. R.: "Practical Bacteriology, Blood Work and Animal Parasitology," P. Blakiston's Son & Company, Philadelphia, 1927.

This is primarily a laboratory manual for advanced students of bacteriology and interns. It is a good reference for less specialized persons who may wish to secure some particular information in this field.

Hygeia, published by the American Medical Association, Chicago.

This monthly magazine contains popularized articles relating to health conditions and practices, general body welfare, and frequently an article discussing body structure.

Journal of the American Medical Association, published by the American Medical Association, Chicago.

The Journal is a professional magazine that is published weekly. It is devoted to research and clinical reports on a wide variety of subjects within the field of medicine, some of which are of interest to the intelligent layman.



16: THE LONG ROAD

In the Development of Human Culture

THE subject of this chapter is the title of a delightful little book written by Dr. Fay-Cooper Cole of the University of Chicago and published for the Century of Progress Exposition in 1933. It is a brief account written in simple but descriptive language of man's hard struggle from savagery to civilization. In it is told the story of the beginnings and development of many of our cultural heritages, as it has been told more extensively in many other publications. Such publications give some descriptions of the cultural remains which prehistoric mankind left to form a part of the debris of the earth's crust long ages before he learned to write. They also represent our modern attempts to reconstruct the picture of man's early past as accurately as possible on the information we now possess.

As might be expected, the earth itself is the best witness of how man lived in the early days of his development. Primitive man at the very outset developed kinds of tools from the objects of nature which he found. Later more elaborate and effective instruments were designed. Pottery and baskets were added, as well as clothing. As he moved from place to place in search of food, the articles were often left behind. A surprise attack or sudden death brought about the leaving of still others. Many times our remote ancestors built houses, temples, burials, even cities. Then as time went on, these treasures and structures became covered over by soil and rock and by dust borne by wind and water or by volcanic eruptions and thus became a part of the earth's crust.

Many of these remains have been preserved to the present time and are now being excavated. They constitute the only records of primitive man's activities. Their careful handling and unbiased interpretation can give us the only accurate understanding we will ever have of prehistoric human activities. While the discovery of these records is in no sense complete at present, sufficient discoveries have been made to give some insight into the origins and development of human culture.

Chronology of Cultural Development

Man has been on the earth for quite a long time. Our present information intimates it has been about a million years. Throughout most of this great age he has been fashioning tools, or making pottery, or domesticating plants and animals, or building cities. The way and extent to which he did these things has been one of progress. This progress divides itself naturally into periods in which the developments continued along certain lines. Gradually new developments would arise. Man's ways of doing things would slowly change. The old order eventually passed, and a new period would be ushered in. There are, then, great periods or ages in human cultural development. The periods are named and their boundaries determined chiefly by the materials which were used in the making of tools and instruments. These periods are based primarily on the cultural development of man in Europe. They do not follow the divisions of geologic history, except insofar as geologic factors affected

Four distinct cultural periods are clearly recognized. These are the Paleolithic, or Old Stone Age; the Neolithic, or New Stone Age; the Bronze Age; and the Iron Age. Each of these ages is further subdivided into epochs. These epochs are determined in most part by the types of implements made, regarding both form and methods of manufacture. The Paleolithic age consists of the Pre-Chellean, Chellean, Acheulean, Mousterian, Aurignacian, and Magdalenian epochs. The Neolithic age includes the Campignian, Asturian, and Azilian epochs. In the Bronze Age four numbered epochs are generally recognized; while in the Iron Age the Hallstatt and LaTène epochs are well defined.

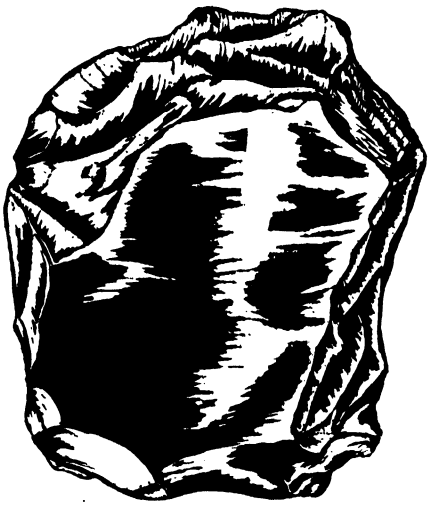
The Paleolithic is practically coextensive with the Pleistocene geologic epoch. It began with the making of the earliest crude stones at least a half million years ago, and continued until the beginning of the New Stone Age. This age probably began in Asia about twenty thousand years ago. The Bronze Age began with the use of copper in Chaldea some seven thousand years ago, while the Iron Age began with the first use of that metal in the Tigris and Euphrates valleys about 1200 B.C. These cultural ages, together with their approximate dates and relation to the Ice Ages of the Pleistocene, should be familiar to everyone who desires to get even a general understanding of man's early cultural development. In addition, the epochs of the latter part of the Old Stone Age should be remembered in their proper chronological order and some idea of their significant developments kept in mind.

In making an extensive study of cultural development, it is more convenient to consider in detail each one of these periods and man's accomplishments during those times. However, for a brief account it is more significant to trace the growth of some of our most important heritages perpendicularly through these periods and note the important steps in their development. This method will be followed here.

Tools through the Ages

Perhaps the first development man made that started him on the long road to modern culture was the fashioning and use of tools. He learned early to make crude instruments, which served as aids in securing food or in warding off his enemies. Few other

animals have ever used tools of any sort to supplement their physical body in maintaining an existence or in protecting themselves. Certainly none have ever fashioned such tools or modified their environment through this development. However, some of the very oldest rocks that contain human fossils also contain stones that had been chipped and carried to those areas by man. The deposits near Peking, China, from which the oldest known human remains were excavated, yielded approximately two thousand pieces of crudely shaped tools made of stone or bone. Some of these were flint stones that had been shaped into rough picks or axes by striking off flakes with other stones. Most of them were short, thick, and of irregular form, the edges being poorly shaped. However, they served a purpose that was better than no weapons at all. These implements are at least nearly a half million years old and are the earliest known human tools.



One of the earliest known human tools was a crudely chipped flint stone. (Redrawn from Black, "Fossil Man in China.")

At a much later age, man in Europe was using flint and bone tools, often leaving them buried in the earth's debris as he perished. Now some of them have been excavated and give us a clear picture of the development of tools throughout the ages before written, historical civilization began. Near the middle of the Paleolithic age the *coup de poing*, or hand ax, came into general use. These hand axes had one end somewhat rounded, with a rather well-shaped point at the other end. Some of them showed a high degree of skill in chipping. Probably the best workmanship in making chipped hand axes was first reached by the Neanderthal people during the middle part of the Paleolithic age, as represented by the Mousterian cultural epoch in France. It may be thought that these stone axes were crude and ineffective tools. However, the opposite is more nearly true. In a recent

experiment in Denmark a carpenter who had never seen a stone ax was given one of these prehistoric implements with which to work. In ten hours working time he cut down twenty-six pine trees. In eighty-one days he had hewn them into boards and timbers and built a house, using no tools except the prehistoric stone ones supplied him.

In addition to the hand ax, other kinds of useful implements are found. There are stone scrapers, arrow points, and lance heads. Neanderthal man showed far more skill than peoples before him in making such tools. He would mine the flint in crude pieces, then knock large, thin flakes from the pieces. These thin flakes, some as long as seven inches, were then chipped into the desired shape for scrapers, points, or lance heads.

With the beginning of the Aurignacian epoch a decided advance is noted in the making of tools. By this time Neanderthal man was beginning to disappear, and a new race of men appeared in Europe from Asia. These were the Cro-Magnons. The kit of tools of man up to this date had been extremely simple, consisting almost entirely of hand axes, scrapers, lance heads, and points. The big-brained Cro-Magnons brought with them many new advances in the art of toolmaking. These were improvements they had perfected, at least to a considerable extent, before coming into Europe. They must have considered Neanderthal tools primitive and crude.

The Cro-Magnons not only made implements from flint, but they also used bone, horn, and ivory very extensively. These new materials permitted the manufacture of finer and more delicate instruments, as well as a much wider variety of tools. From the antlers of reindeer they made javelin points of varying size. These were often ornamented along the sides with engravings and carvings. Harpoons ranging from two to fifteen inches long were fashioned out of reindeer horn. The harpoons had well-defined rows of barbs cut on one side or on both sides with a dagger-like point at the forward end. They were evidently widely used for spearing large fish, which were numerous in the streams at that time. Cylindrical chisels of reindeer horn were common. They too, were often richly decorated with engraving.

Bone needles must have been extensively and almost universally used by the Cro-Magnons, as many of them have been

found in most of their deposits. Long, slender bones would be brought to a fine point by being polished with stone. In some cases there would be a hole or eye at the other end, made by a sharp flint drill. These needles, along with bone awls, indicate a refinement in the making and finishing of clothing. Apparently animal skins remained the only clothing material, but these skins must have been cut and sewn into a variety of garments.



Laurel-leaf blade. (Redrawn from MacCurdy, "Human Origins.")

Flint was used for making chisels, drills, knives, and crucibles in addition to the more common uses of axes, points, and scrapers. The stone crucibles were adapted to the grinding of mineral pigments which the Cro-Magnons are known to have used extensively in color decoration and painting. The following epoch, Solutrean, witnessed some of the finest examples of flint chipping that have come down from ancient times. These were the laurel-leaf blades, which were deftly chipped to a remarkable degree of thinness. Many of them attained an almost perfect degree of symmetry. Some of these spearheads were shaped with a lateral base notch, probably for fitting into a shaft to make a sword or a javelin. Others were chipped on one edge only, with a notch or handle on the other, forming an instrument similar to a knife or razor.

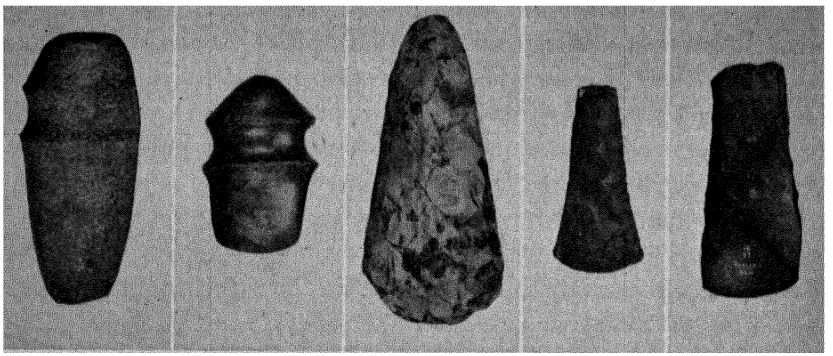
With these finer and wider varieties of tools, these people were able to secure their food more easily and to make more use of their environment. In some parts of Europe the big game of the Cro-Magnon hunters was the mammoth which was common there as the glaciers receded. They must have been extremely adept at spearing these large elephants. One camp site recently excavated in Moravia has yielded more than two thousand mammoth vertebrae. At another site a tomb containing twenty human bodies was found. It was constructed entirely of the shoulder blades of mammoth. Another extensive deposit of cultural remains of this epoch is one near the village of Solutré in Southern France. In some of the levels of these remains are found

great fireplaces with flint utensils and the remains of what apparently were abundant feasts. The animal bones include the horse, wolf, fox, hyena, bear, badger, wild cattle, reindeer, and mammoth. The improved tools of the late Paleolithic apparently served man well for collecting a wide variety of game for food.

Such, in general, was the development and use of tools during the Paleolithic or Old Stone Age, a period lasting for over a half million years down to the decline of Cro-Magnon man. As we have seen, most of the advances were made during the last few thousand years of this period. The stone tools of this age were all made by chipping the flint until the desired shape was secured. Apparently during all these centuries man in Europe conceived of no other or better way of shaping his stone tools than to chip them.

However, at about the time when the Cro-Magnon peoples were at their zenith there was being developed in Northern Africa and Southwestern Asia a new technique for shaping stone tools. Later this technique was introduced into Europe by the slow migration of peoples into that country. This technique was polishing the stone. The general shape of the ax was first made by chipping. Then the edge was ground or polished by rubbing it against other stones. This gave a sharper cutting edge. Later the whole ax was polished, making a still better instrument. Likewise other stone implements, daggers, knives, and spear points, were polished. This finer grade of workmanship of stone tools by peoples who followed Cro-Magnon man into Europe established a new period in cultural development. It is called the Neolithic or New Stone Age.

The introduction of the new technique of polishing stone into Europe was by no means sudden or universal. For many centuries it was only sparingly used. During this transition period there was a decided decline in the art and extent of fashioning implements of all sorts. This period is sometimes looked upon as the "dark ages" in prehistoric times. These conditions were effected not only by a transition in techniques of making tools but by many other changing factors. The climate of Europe was shifting to a milder one. The animals of postglacial times were disappearing; dense forests and grasslands came into existence. New modes of life were in order. It took the peoples of Europe, particularly those migrating into this area, considerable time to



Examples of different stages in making polished stone axes during the New Stone Age. (American Museum of Natural History.)

establish a new order of living. Making tools was only one phase of it.

However, as these new cultures developed, finely made polished stone tools became more universally used. Flint was mined and exchanged on a commercial basis for the first time in man's history. Some of the finest and most extensive deposits of polished axes, knives, and spear points have been found in village sites along lake shores or streams far from the flint beds. Flint mined in Southern France has been traced by its peculiar color to Belgium, Switzerland, and Italy as an article of exchange in Neolithic times.

Another revolutionary advance in the making of tools and other implements was made by man before the time of recorded history. This was the discovery and use of copper and its alloy, bronze. Copper was first used in Egypt and Southwestern Asia about 5000 B.C. Soon after this the art of extracting copper from its ores was discovered and methods of casting it by melting it and pouring it into molds. With this early discovery our modern industrial civilization really began, even though it was many centuries before it acquired much momentum. Copper began to be used for making weapons, tools, razors, and decorations and in constructing buildings and vehicles of transportation.

Ceramic and Textile Arts

During the Neolithic age there was developed another phase of human culture that was of vast importance to mankind.

This was the making of pots and jars from clay. During all the previous thousands of years man had been on earth he had not discovered how to make pottery. Even Cro-Magnon man, regardless of his many other accomplishments, seemed never to have developed the idea. However, Cro-Magnon was essentially a hunter and cave dweller. The climatic and geographic conditions of Europe at the times when he lived there were such as to favor this type of existence. The forests and caves were not conducive to developing the ceramic arts.



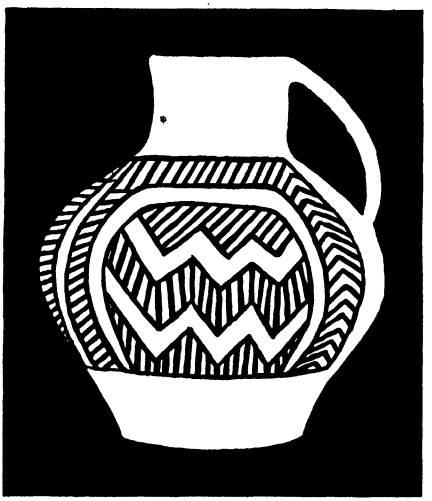
Early Neolithic pottery. (From a photograph by J. Schranil of early banded pottery found in Bohemia.)

But as Cro-Magnon man was superseded in Europe by other peoples, coming by different routes from the east, pottery was introduced. These new races were the people who had discovered how to make pottery, probably in the warmer, drier climates of Southwestern Asia and Northern Africa. They brought this knowledge and industry with them into Europe. With pottery at his disposal, man was able to store his food effectively. This made him less dependent upon following and hunting wild game. It allowed him to establish definite homes rather than to continue being a wanderer. Where his food was stored, there he would continue to live. Man for the first time in his long history became a community dweller.

Some of the most extensive of the early Neolithic communities were the pile villages along the lakes of Switzerland and Germany. These consisted of homes built over the water's edge on wooden piles that had been driven into the lake bed for a foundation. At that time the lake levels in those countries were somewhat lower than they are at present. Accordingly, many of the pile villages were long ago covered with rising waters, and some have been preserved in fair condition to the present time. The first of these was discovered in 1845, when an extremely dry season in Europe caused the lakes of Switzerland to be lowered below the level of the ancient dwellings. Since then a great many others have been discovered.

The lake villagers must have lived a peaceful and prosperous life, as judged from the remains they left behind. Their homes

were comfortable wood shelters. They had wooden furniture and wooden tools as well as many implements made of stone, horn, and bone. They made pottery in various shapes and sizes, bowls, jars, and dishes. Many large, baked clay kettles that were adapted to cooking foods or storing large quantities of grain have been found in some of the village remains. Although the earlier types were crudely made without the potter's wheel and unevenly burned without a baking oven, these pottery vessels must have made the household life much easier and more stable. They served well to transport and store food and water.



Late Neolithic pottery was often finely made and decorated in a variety of ways. (Redrawn from MacCurdy, "Human Origins.")

As Neolithic times continued, the art of making pottery progressed rapidly. This invention was admirably adapted to serve both a utilitarian and an artistic purpose. Before the beginnings of written civilization Neolithic man had become adept at making fine pottery and decorating it in a great variety of ways.

Another development of Neolithic times was the weaving of textiles and the making of cloth garments. It is not known whether the invention of weaving preceded or followed the first making of pottery. They probably both came into practice somewhat simultaneously. The earliest known specimens of textile fabrics are those that have been found in the remains of the lake dwellings of Switzerland. These were the homes of relatively early Neolithic peoples. These remains are sufficiently extensive to give a good picture of the development of the textile art at that time.

The materials used included both flax and wool. The art included not only the spinning of thread and yarn, but also weaving, knitting, embroidering, and basket making. Samples of all these have been found. Some of the deposits also included

raw flax fiber, coarse linen thread, and thick ropes. Neolithic spindle wheels and loom weights of stone and clay were found. Remarkably enough, these loom weights were very similar to those used on early Greek looms several thousand years later. It is believed by some, therefore, that the lake dwellers' looms must have been very much like those of the Greeks since the weights of both were so similar; and, as preserved specimens of the Greek looms have been found, we can judge what the Neolithic looms must have looked like.

Agriculture and Domestication of Animals

At the very outset of his existence, man was dependent upon wild life for his food. This consisted of the flesh of such animals as he could capture, supplemented by berries, nuts, seeds, and fruits when they were in season. This of necessity made him a wanderer. He had to follow the game he cherished. While this probably served to take his footsteps over much of the earth, it kept him in a dependent and barbaric stage. The vicissitudes of the hunt kept him a nomad, subject to the uncertainties which it involved. Even should fortune favor him and an abundance of food come into his possession, early man had no way to store or preserve it.

It was only during Neolithic times that mankind learned to make pots for carrying and storing food. This tended to keep him nearer his stored supplies. He began to settle down. He did not entirely forsake the hunt, but he began to domesticate animals and to cultivate plants.

The first animal to be domesticated was the dog, it being tamed from the wolf that was common in all countries. Remains of domesticated dogs have been found in practically all Neolithic deposits, and today the dog remains the most universally domesticated of animals. Paleolithic man at much earlier times represented the ox and horse in many of his paintings and works of sculpture; however, there is no direct evidence to indicate that he ever domesticated these animals or any others. It is, therefore, generally agreed that Neolithic man was the first to tame and use animals.

The hog was another animal that was domesticated in early Neolithic times. It must have been kept close around the village homes as a source of food. The horse had become a domestic

animal by the time the Bronze Age was ushered in, as it was extensively used then as a beast of burden. It is likely that it was also domesticated to some extent in Neolithic times, although there is no direct evidence of this. Before the Neolithic age, the horse was one of the staples of diet. However, there is no evidence that Neolithic man used it for food, probably because he had begun to use it as a work animal. The other animals that man had tamed and taken into his fold during the Neolithic age included cattle, sheep, and goats. Altogether, about 170 different species of animals had been tamed and were being used by man when recorded history began.

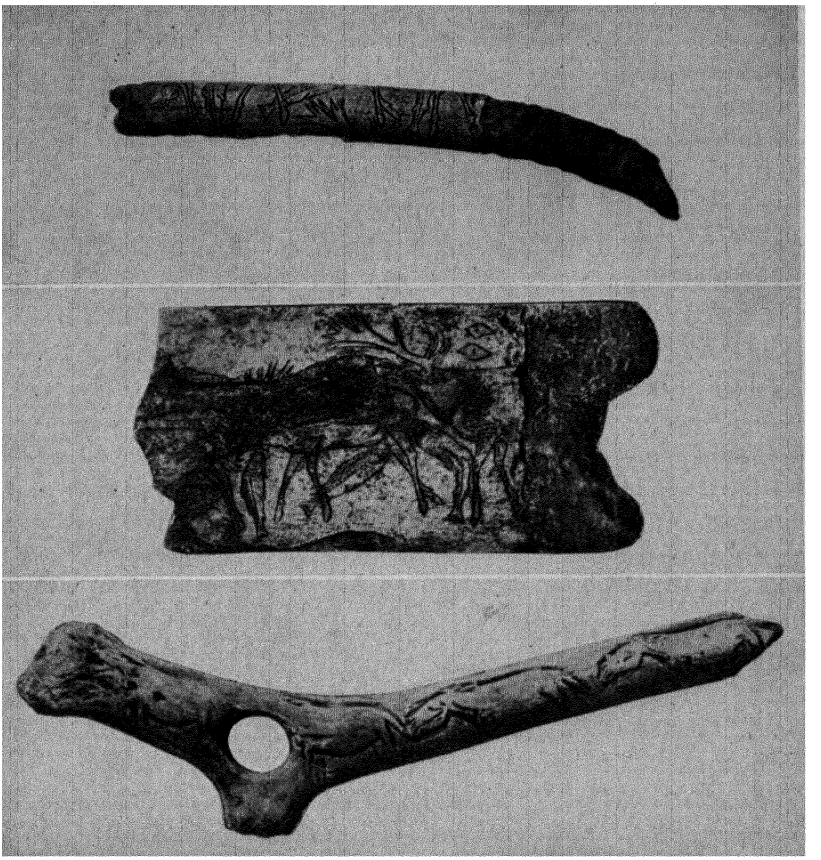
The cultivation of plants was also introduced into Europe during Neolithic times. The knowledge of certain grains as desirable elements of food and an understanding of how to cultivate them were evidently brought in from Southwestern Asia with the Neolithic migrations. One variety of barley found in the lake-dwelling ruins of Switzerland, Germany, and Denmark was the same as was cultivated by the ancient Greeks and Romans. One kind of Neolithic wheat was identical with an Egyptian wheat. Other fragments of plants and seeds found widely scattered in Neolithic deposits are millet, flax, peas, apples, pears, oats, grapes, strawberries. Thus, these peoples were using and cultivating quite a wide variety of field products.

Very little is known of the earliest Neolithic agriculture. However, these people most likely cultivated the fields near the villages, using crude wooden tools for working the soil.

The factors of domestication of plants and animals along with the development of pottery and the invention of weaving had a very profound effect on man's cultural development. They were all first developed by Neolithic man and seemed to have been introduced into Europe from Asia or Northern Africa. Wherever they began to be used, communities began to grow, and eventually great cities developed which showed many remarkable prehistoric cultures.

Development of Art and Writing

The artistic nature of man is made evident to us long before the time of recorded history. Works of art have been found dating back as far as the Aurignacian epoch of the Old Stone Age.



Examples of Old Stone Age engraving on bone and stone. (American Museum of Natural History.)

Since that time many new phases and perfections of artistic accomplishments have been developed. Man's production of works of art has not been in a steady, ever-widening stream. There were periods when art flourished and periods of lesser developments, just as there have been in historical times. However, artistic abilities have never been lost.

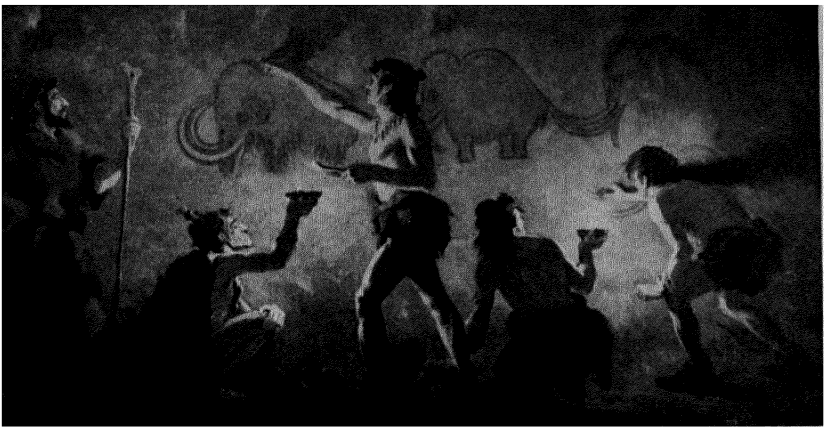
Some of the first works of art consisted of engravings of human and animal forms on bone and ivory. The harpoons of reindeer horn were highly decorated. The ivory javelin thrower, often made in the form of a lioness, shows delicacy and beauty in its carvings. The bison form was frequently carved, as well as

the forms of birds. The bone dagger, carved as a model of a reindeer, represents a high degree of perfection in sculpture. Many of these have been found in the caves of France. The human form was sometimes pictured in well-made sculpture in stone. Most of these are the works of Cro-Magnon man during the latter part of the Old Stone Age.

A remarkable example of Paleolithic sculpture was discovered in 1912 in a cave in the Pyrenees Mountains. The cave had been completely closed off long ago by a formation of stalactites across the entrance. No human being had been in its recesses for thousands of years. Yet there on the floor were the figures of two bisons, modeled in clay in as fine a fashion as any modern sculpture. The footprints of the artists remain on the hardened floor. Another bison figure was being modeled, and marks of the artist's fingers are to be seen on the scattered clay parts. It seems in every way as if the artists had just stepped out for a few minutes; yet thousands of years have elapsed since they discontinued their work.

However, it is in the paintings in caves that Paleolithic art reaches its golden stage of development. These paintings, again, are mostly the works of Cro-Magnon man. They are found in the caves of France and Spain. The paintings of one generation are frequently overlaid with those of later generations. As time went on the workmanship was greatly improved. The first were reliefs, outlined with charcoal and done as monochromes. Later were added polychromes in red, brown, and many shades of yellow. Many animals were depicted. Some of the finest of these paintings are found in the caverns of Marsoulas and Font-de-Gaume in France and of Altamira in Spain.

In the drawings of these caves as well as many others there is always manifested a seriousness of purpose and almost a reverence in the workmanship. There is an absence of trivial work and meaningless drawings. Each drawing seems to have been executed with the greatest of care. Probably only the Cro-Magnon artists were allowed to enter the darker and more remote caverns where the greatest paintings are found. These artists were no doubt looked upon as a class that was especially gifted by nature, and they probably were accorded considerable privileges and distinctions. It would appear that the love of art



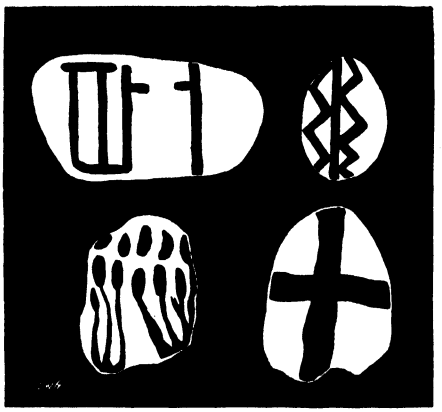
Cro-Magnon artists painting the woolly mammoth. (Photograph by Ewing Galloway of a painting by Charles R. Knight in the American Museum of Natural History.)

for art's sake was the controlling factor in inspiring and executing these paintings and drawings, a love akin to that which inspired the early Greeks in their great works.

With the disappearance of the Cro-Magnons, painting suffered a decline. It was not to reach such development again until long after recorded civilization began. Likewise there was a decline in engraving and sculpture. It was as if an age of culture had ended. It was a period of adjustments to new conditions. But the peoples of the later Neolithic age developed another means of artistic expression which reached great heights in many instances. This was in the modeling of fine pottery and the decoration of this pottery in relief and with paintings. The Neolithic pottery was decorated with lines and bands to form a variety of patterns, some of which were of exquisite design.

Neolithic sculptured figures of the human female are found in the valleys of the Marne and Seine. These, however, hardly compare in workmanship with similar Paleolithic sculpture of Cro-Magnon man. Neolithic man also decorated many of his burial places. On one of the large granite rocks forming the cover of a burial place in Locmariaquer, France, and on some of the supporting stones are found remarkable sculptured figures. In fact, many thousands of specimens of Neolithic engraving and sculpture have been found. Such artwork was widely practiced, even though little of it represents outstanding quality.

The Neolithic and Bronze ages are sometimes referred to as dark ages in the realm of art. However, there were definite contributions made during the last part of the Bronze Age in sculpture and architecture. A fine example of sepulture ornamentation is found in a tomb at Kivik in Switzerland. Many of the bronze vases, shields, and chariots of this age are elaborate in design and extensively decorated with delicately shaped figures. At the beginning of the Iron Age recorded history had begun, and any account of developments during this time does not come within the scope of this discussion.



Illustrations of Azilian painted pebbles. (Redrawn from Osborn, "Men of the Old Stone Age.")

Perhaps by far the most important thing that was going on in all these centuries was the development of writing. It was a new tool of the human mind which gave an enormous enlargement to its range of action and a new means of continuity. The beginning of a system of writing was probably made toward the end of the Paleolithic period. During the Magdalenian epoch small stones were engraved with circles, many of which were dotted. Animal bones of this age were engraved with many signs which were alphabetical in form. Painted pebbles belonging to the early Neolithic period are numerous. These apparently represented a system of writing. In fact, it is believed by some that a number of these symbols form the basis of letters in the later writing of the Phoenicians, Greeks, and Romans. However, it is exceedingly difficult to prove any such relationship.

The development of writing beyond mere pictographs must necessarily have followed the development of a spoken language. The origin of language is shrouded in the uncertainties of the past. Just how it began will probably never be known. It may have originated through imitation of animal sounds. It may have been a slow evolution from sounds uttered by man in emotional

states of joy, sorrow, anger, and pain. Or it may have grown up from vocal expressions emitted by the group as they worked together at something in unison. But whatever its origins were, it involved the representation of objects or ideas with sounds. It seems that in developing the art of writing the most difficult thing was to represent sounds and the ideas they conveyed with some sort of symbols.

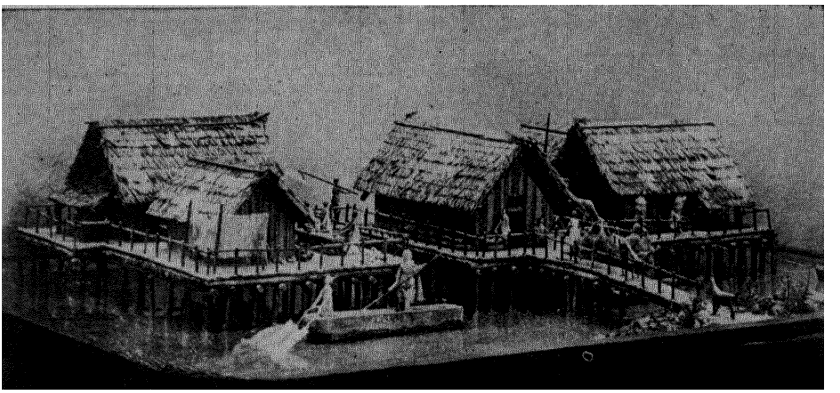
For thousands of years writing consisted of a series of symbols which pictured objects without a highly definite indication of their relationships. The early Egyptian writing was largely pictographic. Then the form of the picture was abbreviated. A part of an animal, for example, represented the whole animal. Still later the abbreviation continued until finally a mere symbol stood for a particular object. The latest prehistoric attempts were to represent syllables and letters with symbols. Egyptian writing became a beautiful but complicated and awkward combination of pictures, abbreviated pictures, and symbols.

As early as 6,000 years ago the Sumerians had perfected a rather complete system of writing. This system predated the Semitic language of the ancient Assyrians. The Sumerians lived in the Tigris and Euphrates valleys and developed a flourishing culture before the time of the Assyrian and Egyptian civilizations. The Sumerians used first the pictorial script, which they later developed into cuneiform signs. These signs were used not only to express the idea represented by the pictures, but also to express the sound of the word in other relations which did not involve the original pictures at all. Thus it became a phonetic system of language. The Phoenicians later improved upon this cuneiform system of writing, which in time came to be the basis for modern systems of written expression.

From all of this, one thing is evident; that is, modern alphabets were slow developments and they began in their fundamentals with prehistoric peoples.

From Caves to Cathedrals

During the long stretch of time when Neanderthal and Cro-Magnon peoples were flourishing in Europe, the most popular place of abode was in the caves or beneath well-sheltered rock cliffs. These were the natural sites that would provide some pro-



Restoration of lake dwellings by M. Götzinger. (American Museum of Natural History.)

tection from the weather elements. It is natural that man would seek them as dwelling places, since, because of his nature, such protection is of grave concern to him. However, it seems that a long period in human history had elapsed before man even used the caves, as no evidences have been found of their consistent use before the time of Neanderthal man. But once the caves were "discovered" and cave dwelling became the vogue, they served man in Europe as a home for over fifty thousand years. If there were any artificially made dwellings dotting the landscape during all these centuries, they must have been exceedingly temporary and crude. Not the faintest trace of any of them remains. It was only during Neolithic times that man began to construct homes, burial tombs and markers, and places for ceremonies and worship.

The first evidences of human building operations are the remains of crude dwelling places dating back to the early Neolithic age. They were simple huts over a shallow pit in the ground. They were constructed by digging a round pit a few feet deep, walling it with poles or stones up to a few feet above the ground, and covering the structure with branches and a coating of clay. Frequently a number of such houses have been found close together, these earliest villages being along waterfronts in Central Europe. These earlier houses were followed by the pile villages which were built entirely above ground, either over the water's edge along some lake or river or over land with a small brook beneath.

These pile villages became quite numerous about six to ten thousand years ago and must have sheltered a considerable portion of the late Neolithic population. One of the most elaborate of the villages and one of the first to be discovered was one on an old lake shore of Switzerland. Since then their remains have been found in Germany, France, Italy, and Austria as well as in England, Ireland, and Scotland. Most of the villages were small, probably being limited to one or a few family groups; some however, were of considerable size. One of the largest was on Lake Constance in what is now Southern Germany. It covered an area of about 230,000 square feet. The number of piles driven into the ground is estimated to have been about 60,000. In these pile villages the floors were supported on beams fastened to the upright piles, and the walls were made of upright slabs or timbers. The roof was supported on poles and probably consisted of branches or grasses.

Simultaneous with the building of pile villages, Neolithic man constructed large stone edifices in other parts of the country. Such buildings were usually on the more fertile plains away from the streams and lakes of the mountain valleys. Remains of such structures have been found in France and England. They probably were used for ceremonial and religious purposes and were evidently the gathering places of large groups of people from all the near-by communities. One of the largest was Avebury in England. It was a complex of stone circles rather than a closed house, built upon a circular embankment of earth which was one-fourth of a mile in diameter. From this central theme two avenues each lined with stones extended about a mile to the south and southeast to enclose a flat-topped and nearly round hill.

Of similar design and of a somewhat later period is Stonehenge in England. It, too, consists of a series of circles marked by stone walls or large stone trilithons. The outer circle originally consisted of thirty large upright stones connected on top by a continuous band of stones. This circle was ninety-eight feet in diameter and inside it were smaller circles and semicircles of stones. At the center was a large stone which has been called the "Alter Stone." Stonehenge was constructed at least four thousand years ago, and parts of it still remain.

Dr. James Breasted in "The Conquest of Civilization" concisely points out the significance of these edifices as follows:

> Furthermore, the stone structures furnish us very interesting glimpses of the life of the Neolithic towns. Some of them suggest to us whole communities coming out from the towns on feast days and marching to such places as the huge stone circle at Stonehenge. It has been thought that here they held contests and athletic games in honor of the dead chief buried within the stone circles. Festival processions may have once marched down the long avenues, marked out by mighty stones. Today, silent and forsaken, they stretch for miles across the fields of modern farmers, to remind us of forgotten human joys, of ancient customs, and of beliefs long revered by the vanished peoples of Stone Age Europe.[1]

During this period tombs for burial became plentiful. These are well represented by the dolmens of France. They were constructed of stone slabs. The walls were upright stones, and the roofs were large stone slabs. Some of the dolmens are as much as 350 feet long and thirty feet high. Many of the covering stones were very large, some of them being over sixty feet long, twenty feet wide, and eight feet thick, weighing many tons. To place these stones on their pillars several feet above the ground was an engineering feat of no mean order.

A great engineering people lived on the island of Crete in the Mediterranean Sea as early as six or seven thousand years ago. They built many intricate structures. Their palaces were rugged structures of stone and were decorated with frescoes. They knew the principles of drainage, and many of their buildings had sewage disposal systems quite modern in their arrangement. These people were not some new and superior race, but they developed from earlier Neolithic stoneworkers, as is evidenced by some of their remains that have been excavated. One of the cities surrounded a large hill about ninety feet high which was long thought to be a natural elevation. However, recent excavations have shown that one city was built on top of the ruins of another and that earlier cities continued down to the base of the hill. At the lowest levels have been found the ruins of an early Neolithic village, with the crude tools and culture of their times.

The arch and vault were probably first invented by prehistoric Assyrians, the Sumerians. The arch was in use in the

[1] Breasted, James H., "The Conquest of Civilization," Harper & Brothers, New York, 1938, p. 40.

Tigris and Euphrates valleys at least 5,000 years before the time of Nebuchadnezzar. Since there was a lack of stone and timber in this country, building materials were chiefly sun-dried clay bricks. This necessitated the use of an arch for building any large structures. Some of these early temples were remarkable for their great height, built chiefly on the pyramid plan, their large external mass, and the brilliant coloring of the receding stories.

This brief discussion has mentioned only a few of the cultural developments of man. Perhaps sufficient has been said to show that the fundamental beginnings of most of our modern culture can be traced back into the dimly lighted past. These beginnings came about through a slow process of evolution and they were worked out under the hard and unrelenting conditions of nature. The road to civilization has not been easy.

Early Man in America

The cultural development of man in Europe is of particular significance to people in America because these cultural heritages form the basis of modern life here. Our present American civilization began at the point of development which European culture had reached at the time of settlement of this country. However, a culture had been developed by a people which inhabited the whole of this continent long before the time of Columbus. That culture was soon destroyed by the white man. It is of particular interest to us now in throwing some light on the development of early man in America and in giving some appreciation of the achievements of a race that was quickly vanquished by our immediate forefathers.

Just when man first appeared in North America is a question of great uncertainty at present. It is a question about which there is as much controversy among anthropologists as there has ever been among physicists about the nature of cosmic rays. Many facts indicate that man has been here since Pleistocene times, that is, for twenty-five thousand years or more. They are discoveries of human skeletons and artifacts in deposits that seem to be that old. However, it has not been possible to date these deposits with a high degree of certainty, and exactly how old they are is still somewhat undetermined. Furthermore, many



Mammoth pit near Clovis, N.M., restored in exact position as found. Bones are of an extinct mammoth which was common in America during the Pleistocene epoch. Some of the small objects are human artifacts found with the bones. (Reuben Goldberg.)

of the discoveries have some particular feature about them that could mark them as being rather recent. Therefore, a great many students of the question hold that man first came to America not more than about five thousand years ago.

It is generally agreed that these first people migrated to America by way of the Bering Straits and Alaska from the frozen and barren stretches of Siberia. From Alaska, man wandered over the whole of North America and far into South America. This is a wide stretch of land, and migrations were slow. But some five thousand or more years is sufficient time for primitive people to cover such magnificent distances. These early Americans were surely a nomad people, only the last two or three thousand years showing any evidences of community or sedentary life. The earliest definitely dated dwelling in the United States is an Indian house in Arizona which is dated A.D. 660. However, man had been on this continent long before that time. He had even developed flourishing cities before the beginning of the Christian era.

The best indication of man's real antiquity in America is the remains of human origins which are found in burials associated with the bones of long-extinct animals. In an old lake bed near Clovis, New Mexico, have been found stone spear points, knives, and scrapers in the same strata with bones of mammoth, extinct horses, and camels. These animals have not been in North America since shortly after the receding of the last ice sheet, about twenty-five thousand years ago. It is difficult to account for this association of human relics except by concluding that man was living in America at that time. There were buried in the same strata the bones of mammoth and about twenty flint knives which showed signs of having been heated by fire. Only man makes hearth fires and cooks his food. There is no other known explanation of such charred remains. All this is excellent indirect evidence that man was in America during Pleistocene times.

Perhaps the most spectacular evidences of man in America during the Pleistocene are some of the human skeletons that have been discovered. One of these is the so-called "Minnesota man." In Minnesota a female human skeleton has been found beneath a layer of glacial-lake clays that was the bottom of a lake which was in existence there during glacial times. The lake has long since been filled in and is now a part of the rolling country. The skeleton of this young lady was lying on its side with the head and shoulders somewhat lower than the rest of the body, the angle corresponding to the inclination of the stratum in which it was found. This is quite an unnatural position for a primitive burial. It is claimed by some that the girl was drowned in the lake and her body sank to the bottom, there to be covered over by clays and sand. As the glacier receded farther, the lake finally disappeared and the present low hills were formed over the skeleton.

A number of objects of cultural development were found with this skeleton. These consisted of a dagger of elk antler and a number of shells believed to have been worn for decoration. One was a conch shell, apparently worn as a pendant suspended at the girdle. A number of smaller shells and bones were found which might have been worn as a necklace or carried for their magical value. The dagger had been carefully shaped from the

antler, and its position seemed to indicate that it had been suspended from the neck by a thong. Dr. A. E. Jenks of the University of Minnesota, who described this skeleton, is firmly of the belief that it was deposited some 18,000 to 20,000 years ago and represents an Indian group of people living in America at that time.

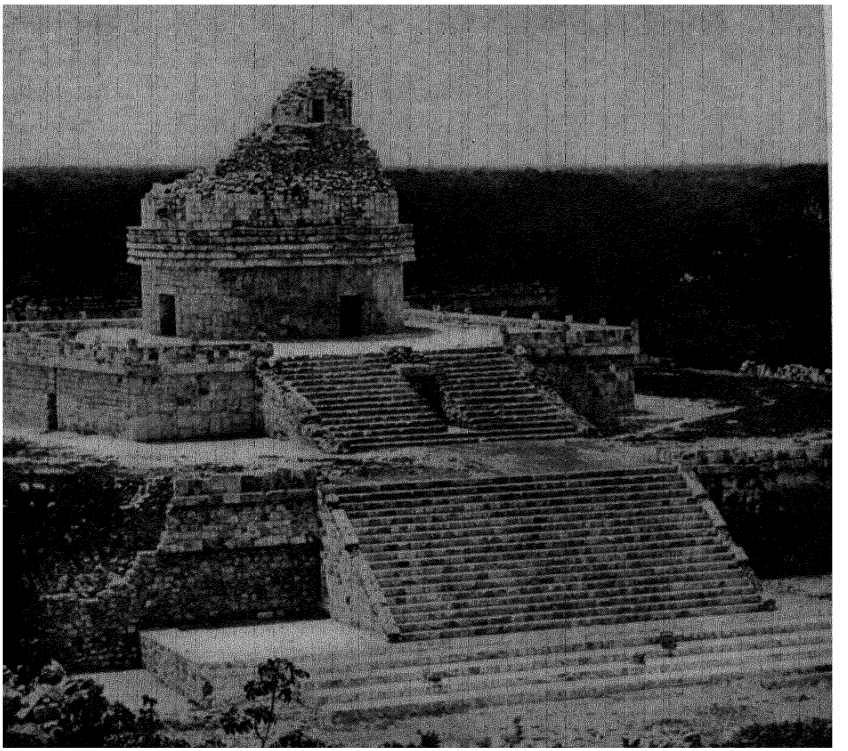


Reconstruction of head of Minnesota girl, believed by some to have lived during late Pleistocene times.

There is every reason to believe that the skeleton was laid down at the time the clays were forming and was not enterred at a much later burial. Unfortunately, the discovery was made by a road building crew, which made no careful note of whether the layers above the burial had ever been broken. There will probably always remain some doubt as to whether it was a natural or a man-made burial.

Human skeletons seeming to have Pleistocene antiquity have been found in other parts of the United States. As our information in this respect increases, it will be possible to determine more accurately how long man has been in America. A large number of spear points have been found in the United States which are definitely unlike any of those belonging to Indians who have lived here during the last two thousand years. These have been extensively studied and classified. Some 350 such specimens are known to archaeologists, and these have been collected in over thirty different states. If the story these weapons seem to tell is true, then these ancient hunters were well scattered throughout the United States long before the time of any accurately dated ruins or remains.

However, American scientists demand proof beyond reasonable doubt before accepting the idea that man lived in America during Pleistocene times. At present many anthropologists insist that he came to these shores not more than five thousand years ago. Just when man first appeared in America is a question which will have to be answered in the future. Many lines of investigation now in progress, such as excavations of ancient deposits,



Partially restored famous ruin in the Mayan city of Chichen Itzá. The beautiful and unique round building may have been used as a watch tower, astronomical observatory, or temple. (Carnegie Institution of Washington.)

studies of plant distribution, and soil analysis may shed much light on this interesting problem.

Indian Cultures

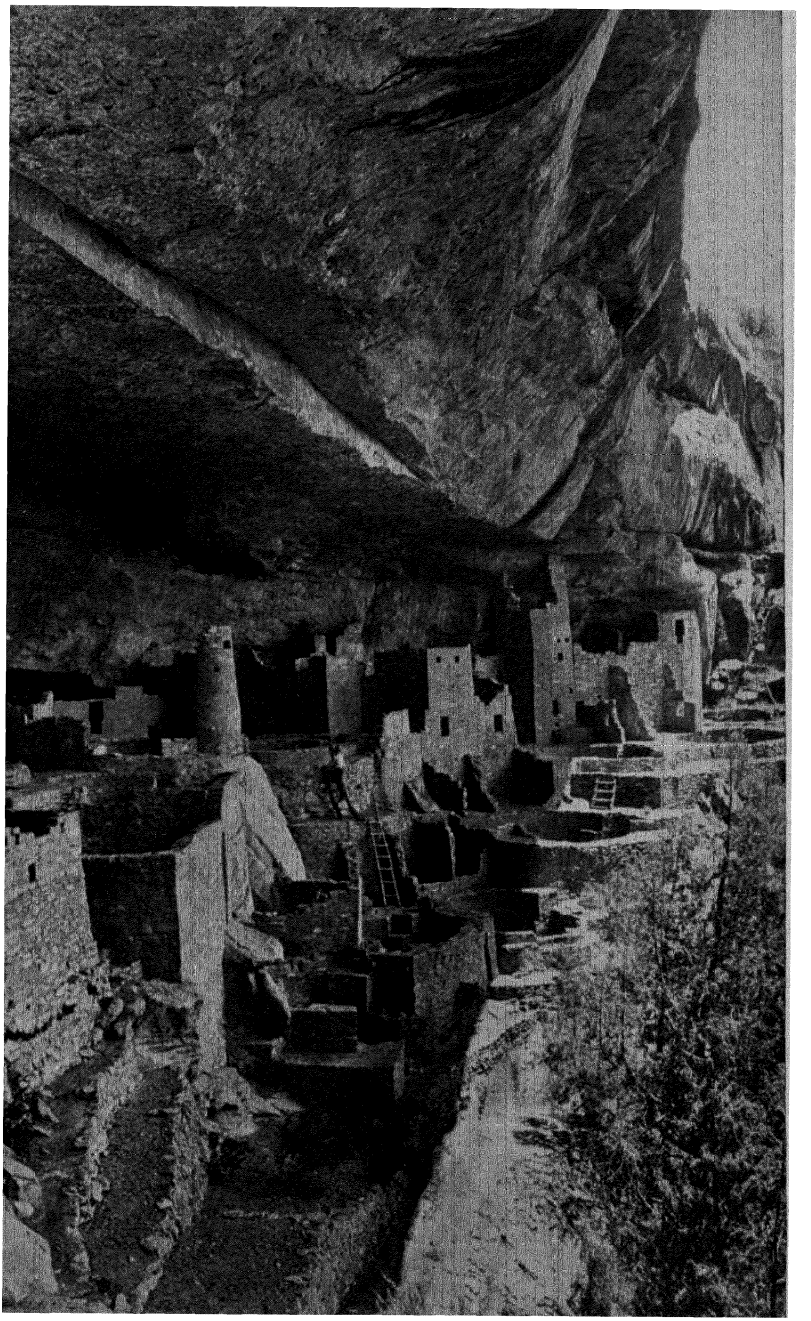
Regardless of the exact time when man first appeared on these shores, it is a fact that the Indians had made many cultural developments long before the coming of Columbus. These developments were made here almost independently of any early influence from Europe or Asia. We have learned a great deal in recent times about colorful Indian civilizations which flourished as early as two thousand years ago. These were civilizations that were in progress in Mexico, Southwestern United States, Central America, and Peru.

For example, a burial and temple have been discovered in Panama which have revealed a brilliant civilization existing there perhaps before the time of Christ. The burial consisted of a chieftain's skeleton, along with those of twenty female skeletons, probably those of his wives. It seemed to have been their unhappy lot to have to die at the time the king passed on to his final reward. The burial also contained a glittering display of gold ornaments and nearly two thousand other objects, arrowheads, axes, knives, mirrors, and pottery.

In Yucatán, the Mayan culture had been extensively developed for many centuries before American historical times. The Mayan civilization began in A.D. 333 and continued until the people were finally conquered by the Spaniards in 1541. The Mayan culture at its height was represented by more than one hundred cities and towns, the largest having populations of several thousand people. Some twenty or more of these great communities have now been excavated and partly restored. The capital city for several centuries was Chichen Itzá (meaning "Holy Well"), and it had several magnificent temples and public buildings. It probably was the Mayans' greatest city for a thousand years.

These people had an extensive agriculture and had domesticated many animals, including bees and fowl. They wove cotton so fine that the ruthless Spaniards mistook it for silk. They made large canoes and traded with Cuba. They had hieroglyphic books, a calendar system, and a considerable amount of astronomical knowledge.

The Aztec culture of Mexico was a little later than the Mayan. It resembled the Mayan culture but was somewhat more highly developed. The agriculture of the Aztecs was more extensive; their cities were fortified and skillfully constructed. They made tools of brass as well as of stone. They had books of paper and a system of schools. Excavations in the heart of Mexico City have revealed the ruins of the Old Aztec capital which stood on the site of the modern city. At Monte Alban in Mexico a whole city has been excavated. This revealed temples built in such a manner that the architects must have been familiar with many of the facts of astronomy. The city also showed a court where ball games of a kind were held.



Cliff Palace, largest of the Pueblo ruins at Mesa Verde National Park. (Science Service.)

The Aztec and Mayan cultures were about at their height at the time of the coming of the Spaniards. Not only did these newcomers to America destroy the culture and cities of these people, but they burned their books and obliterated their written records, after having killed their priests, medical men, and government leaders. As a result of this destruction much of the history of these early people can never be reconstructed.

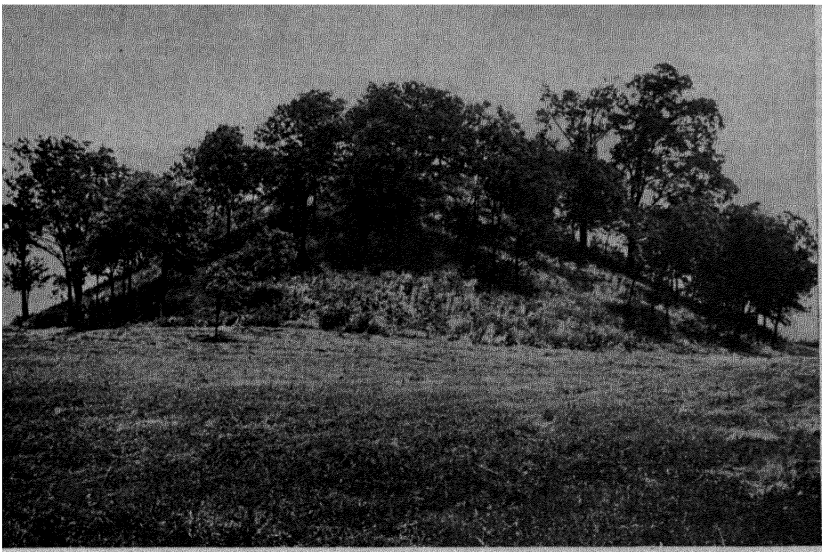


The Pueblo Indians made fine pottery which was often decorated in exquisite designs, such as represented above in a piece dating back to about 1100 A.D.

In the United States definitely dated native civilizations extended from A.D. 660 to 1565. These are found in the Southwest. The first peoples there are called Basket Maker Indians. Their cave dwellings and subterranean houses are found extensively over several states. These Indians are believed to have lived there long before the earliest dated house of A.D. 660. Evidences found at Mesa Verde in Colorado indicate that some of the caves there were occupied by an agricultural people as early as 1000 B.C.

Following the Basket Maker Indians were the Pueblo Indians. These were an emergent group of people who built the pueblos, or houses of stone, mostly in the sheltered caves of the deep canyons. Pueblos began to be constructed about A.D. 800. The earliest of the larger pueblos is Pueblo Bonito, the "city beautiful," begun in 919 and abandoned in 1130. The largest single ancient cliff dwelling is at Kiet Siel in northwestern Arizona, consisting of 155 rooms. It was completed in 1294. The largest and most spectacular group of pueblo ruins in the United States is at Mesa Verde. These were built in several caves and contain over 500 rooms. Many others of smaller size are scattered throughout the Southwest.

These structures are all built of sandstone, often fastened together with huge wood beams and roofed with reeds from the



A prehistoric Indian mound near Dayton, Ohio. (Ewing Galloway.)



A prehistoric Indian mound near Knoxville, Tenn., being excavated. (Ewing Galloway.)

near-by canyons. The masonry shows a high degree of engineering skill. The stones and trees were all transported up precipitous cliffs, some a hundred feet or more high. The oldest continuously inhabited site in the United States is the pueblo at Oraibi in the

Hopi Indian Reservation in Arizona. This village was begun in 1370 and is still occupied by the Hopi Indians.

Recent excavations in the Tennessee Valley and other parts of the Southeast have yielded much light on the history and development of the Early Mound Builders of Central North America. Some of these mounds have three to ten levels of Indian occupancy, indicating a long history for the site; that is, a mound would be built by the Indians and a village constructed on it. Then when the village was abandoned another tribe would build the mound higher and erect another village. Later this would be abandoned and another tribe would come in to repeat the process. Some of the mounds covered several acres of ground.

In one mound found in Alabama the top level of the site contained Cherokee pipes, pottery, and weaving mixed with glass beads and scraps of iron. The beads and iron are white man's articles and probably tell the story of De Soto's coming in 1540. The lower levels contain only Indian-made articles, marking sharply the pre-Spanish era from the era of exploration and conquest.

Mound Builders' relics are found all over the lower Mississippi Valley. At their highest point the Mound Builders had great skill at carving stone, weaving cloth and dyeing patterns into it, hammering copper into ornamental objects, and growing farm crops. What materials they did not have they obtained by trade, even from across the Rocky Mountains, a distance of over a thousand miles. Now it is known that the spectacular culture of the Mound Builders was not that of a superior, vanished race, but was that of the Indians who occupied the territory up to the time of the white man's coming.

So, little by little, the story of the American Indians is being disclosed. Just when man first arrived on this continent is now unknown. It certainly was not later than five thousand years ago. It may have been over twenty-five thousand years ago. Cultural development had advanced on a wide scale; however, with only minor exceptions, it was all of the Stone Age type.

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Discovery is a monthly popular journal of knowledge. The articles cover many fields of science. They are usually well illustrated and written in a popular style.

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A quarterly journal which includes an extensive range of articles in the field of archaeology, all of which are usually extensively illustrated. It contains authentic and interestingly written series of articles relating to many phases of archaeological discoveries.

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