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Foundations of Biology

mentality; and so it may have been with the prehuman ancestors. (Figs. 473, 476, 477.)

Antecedent to the common ancestor of the anthropoid apes and man were more and more primitive forms—tarsioids or lemuroids—and so back, receding still further into the past to an insectivorous stem from which the primates originally emerged. It is perhaps somewhat in deference to man that the primates are usually placed as the culminating order of mammals and so of the vertebrate series, because in spite of their larger brain and the uses they make of it the primates retain many primitive characters that elsewhere are found only in the lowly mammalian order, Insectivora. (Fig. 293.)

No useful purpose will be served here by delving further into the geologic past for still earlier antecedent forms, because behind the insectivores the actual record becomes increasingly obscure. However, it seems certain that the insectivores were evolved from still more primitive mammals during the Mesozoic Age, the Age of Reptiles, and that the earliest mammals arose from the reptilian stock.

In the study of man as a primate and his relationships with the anthropoid apes, one is on firmer ground. This relationship is supported by many independent but interlocking lines of evidence, such as the similarities in structure of the brain and viscera, of the musculature and the skeleton in general, and of the hands and feet in particular. The differences are almost entirely in proportions. Man has a larger brain and brain case relative to the facial portion of the skull, smaller development of the canine teeth, complete adaptation of the structure of the vertebral column to the upright position, greater length of the legs as compared with the arms, and almost complete loss of the ability



FIG. 478. Feet of anthropoid apes and man. (From Schultz.)

and climatic changes occurred, and the forests became restricted; one may assume that the primates which had not already made a retreat were impelled to renounce, in part, the arboreal habitat for a terrestrial one.

Thus the precursors of man made the next great necessary change to the ground: an environment which was provocative of many adaptations, in particular the erect body with hind limbs supporting the entire weight. This necessitated considerable mechanical readjustment, including the alternating curvature of the vertebral column for the nicer balance of the larger cranium. Moreover, the development of the brain, furthered by the emancipation of the hands from their part in locomotion and by changes in the vocal organs leading to speech, eventually paved the way to the emergence of culture from the biosocial foundations of pre-man—to invention, communication, and social habituation. In the course of the ages man arrived. (Figs. 96, 101.)

FOSSIL MAN

Human evolution, unlike that of other organisms, presents two clear-cut aspects: the physical and the mental. Man's physical evolution was exceedingly slow, but his cultural development, once started, proceeded with increasing momentum. Both can be traced with some assurance from the actual fossil remains of prehistoric man and the relics of his handiwork.

When one realizes how slight are the chances for the remains of prehistoric man to become fossilized and, if preserved, to be unearthed today, and, furthermore, how short is the time that interest has centered in the problem, it seems remarkable that the record is not more fragmentary than it actually is. Some of the important fossil forms are of the greatest significance, though experts are by no means unanimous in regard to the interpretation of details. At present it is premature to attempt to reach a decision in regard to the specific Early Pleistocene ancestors of modern man, but there is reasonable assurance that the problem will eventually be solved. Man probably developed from different centers, each branch taking its own course more or less independently of the others. At all events his emergence is essentially a Pleistocene story. Some representative "fossil men" may be reviewed.

Java Man. In deposits of the Middle Pleistocene of Java, some half a million years old, there have been discovered during the last sixty years



ANTONY VAN LEEUWENHOEK, 1632–1723. Discoverer of the world of microscopic life where the plant and animal kingdoms merge.

cific, thereby establishing the system of BINOMIAL NOMENCLATURE. Linnaeus' success with botanical taxonomy led him to extend the principles to animals and even to the so-called mineral kingdom: the latter showing at a glance his lack of appreciation of any genetic relationship between organic species. Linnaeus believed that species, genera, and even higher groups represented distinct acts of creation, nevertheless his greatest works, the *Species Plantarum* and *Systema Naturae*, are of outstanding importance in biological history and by common consent establish the base line for priority in botanical and zoological nomenclature.

COMPARATIVE ANATOMY

Owing to the less marked structural differentiation of plants in comparison with animals, plant anatomy lends itself less readily to descriptive analysis, so that an epoch in the study of comparative anatomy is better defined in zoology than in the sister science, botany.

Comparative anatomy as an important aspect of zoological work, in fact as a science in itself, was the result of the lifework of CUVIER (1769-1832) of Paris. It is true that some of his predecessors had reached a broad point of view in anatomical study, but Cuvier's claim to fame rests on the remarkable breadth of his investigations, his survey of the comparative anatomy of the whole series of animal forms. Not content merely with the living, he made himself the first real master of the anatomy of fossil vertebrates, as his contemporary LAMARCK was of fossil invertebrates. (Figs. 265, 501, 515.)

Cuvier's grasp of anatomy was due to his emphasizing, as Aristotle had done before him, the functional unity of the organism: that the interdependence of organs results from the interdependence of function, structure and function being two aspects of the living machine which go hand in hand. Cuvier's famous principle of correlation—

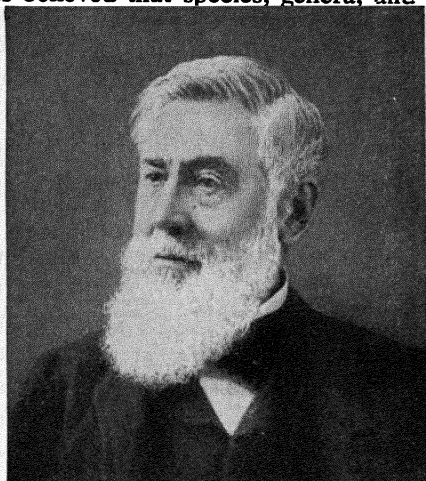


FIG. 500. Asa Gray (1810-1888). The foremost American botanist of the nineteenth century.

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Preface to the Seventh Edition

The first edition of the *Foundations* appeared in 1922. Its success was immediate, and its popularity has been maintained through six editions and for more than 25 years. To be asked by Professor Woodruff and the publishers to prepare the seventh edition is a high honor and a heavy responsibility—a responsibility associated with maintaining the high standards of my colleague: a great teacher and biologist. It is my earnest hope that the challenge has been adequately, if not brilliantly, met; to this end, I have given my best endeavors and a great deal of time during the preceding months.

The content of the seventh edition has been considerably increased by the addition of selected new material. This is especially true of the several chapters devoted to vertebrate structure and function. In planning for the correct presentation of the material, it has seemed desirable to divide several of the longer chapters into two parts; there are now 35 chapters as compared with 29 chapters in the previous edition. This change, it is believed, will result in more adaptable assignments and therefore increased student interest.

In his plans for the new edition, Professor Woodruff considered making several changes in the order of presentation. Careful attention has accordingly been given to this problem in order to secure the best possible continuity and integration of the textual and illustrative materials so as to make a logical, coordinated, and interesting story of biology. This endeavor has resulted in the following changes:

(a) Transfer of the chapters on "Survey of the Plant Kingdom," "Survey of the Invertebrates," and "Survey of the Vertebrates" to positions near the end of the volume. These chapters are preceded by the

chapter on the "Origin of Life" and followed by the chapter devoted to the "Human Background."

(b) The material on reproduction has now been brought together and arranged in a sequence of six chapters as follows: "Reproduction and Cell Division"; "Reproduction and Gamete Formation"; "Reproduction and Fertilization"; "Animal Development (I)"; "Animal Development (II)"; "Plant Reproduction." The chapters on reproduction and development are followed by the discussions of genetics, origin of species, organic adaptation, and human welfare.

Particular consideration has been given to the selection of new illustrations and also to revitalizing and redrawing a great many of the figures included in the new edition. Fortunately it was possible to secure professional assistance for this purpose. Many of the legends have been enlarged to make them more descriptive, particularly when the figures are not fully described in the text. The *Foundations* has always been noted for the extraordinary collection of illustrations as originally chosen by Professor Woodruff.

The rearrangement of the chapters makes the volume well-adapted for a semester course in general biology with the omission of certain chapters, notably those concerned with the description and classification of the plant and animal kingdoms, or for a full-year course with all material included. The book may also be used for a semester course in animal biology without destroying the essential continuity of the chapters. The inclusion of new titles in the Bibliography and the enlargement of the Glossary by the addition of a considerable number of new terms, particularly those which have come into use in biology during the past decade, should greatly increase the value of these sections.

The invaluable services of Yvette Gittleson, Assistant Editor of the *American Scientist*, are gratefully acknowledged, as are those of Jean Day Zallinger for the preparation of many illustrations. Editorial and secretarial assistance has been efficiently given by Charlotte B. Emmer and Elinor R. Smith, and Dorothy Lull has largely carried the heavy burden of the index. To all these and many others, particularly my colleagues in the department of zoology, the author welcomes this opportunity to extend his sincere thanks.

GEORGE A. BAITSELL

NEW HAVEN, CONNECTICUT

From Preface to the First Edition

The present volume brings together in brief form the fundamental principles of biology for the college student and the general reader.

It is well recognized that there is no adequate substitute for detailed laboratory work on the structure and physiology of representative organisms as a means of affording a first-hand knowledge of the facts and methods of biology. However, the author has realized with increasing force that the student's correlation of the laboratory data from day to day and accordingly his appreciation of the broader aspects of the subject are greatly enhanced by a synchronous running account of the underlying principles. The material in this volume has proved to be of great value for this purpose in a course on General Biology elected each year by several hundred Yale undergraduates.

The large problems of life are common to both zoology and botany, and therefore both animals and plants have been drawn upon for illustration and discussion. This method of presentation accords with the author's conviction that the general biological viewpoint is the most favorable means of approach both to a broad knowledge of living phenomena as a part of a liberal education, and to more advanced studies in zoology and botany which are prerequisite for medicine, forestry, etc. As is natural, however, the zoological aspect has been emphasized since it affords indispensable data for the interpretation of man himself. For courses in general zoology, therefore, the book will be found adequate in its treatment of animals, while the chapters on plants may readily be omitted without breaking the continuity of the discussion.

The author is indebted, of course, to innumerable sources for the

vii

facts and principles outlined. The content has grown by accessions year by year. Nearly all the standard treatises have been drawn upon, but those which have been most generally suggestive are listed in the bibliographies of the respective chapters.

The author has availed himself of the constructive criticism generously given by Professor B. W. Kunkel of Lafayette College, Professor E. H. Cameron of the University of Illinois, and his colleagues at Yale, Professors R. G. Harrison, W. R. Coe, A. Petrunkevitch, F. P. Underhill, Henry Laurens, G. A. Batsell, W. W. Swingle, and Dr. J. W. Buchanan, who have read the book either in manuscript or in the mimeographed form in which it has been used by the Yale classes. Finally, the author's indebtedness to the criticism and cooperation of his wife, Margaret Mitchell Woodruff, must not remain unmentioned, though it cannot be adequately expressed.

The original illustrations as well as those from other sources which have been modified or merely redrawn are, with a few exceptions, the work of Mr. R. E. Harrison, Yale, 1923. In most cases these figures have been selected because of their proved pedagogic value. Acknowledgments are due the authors and publishers of the following works, from which illustrations have been reproduced by permission: Coulter, Barnes, and Cowles' Textbook of Botany, Coulter's Plant Life and Plant Uses (American Book Co.); Kellicott's Social Direction of Human Evolution, Jordan and Kellogg's Evolution and Animal Life, Darwin's Life and Selected Letters, Huxley's Life and Letters (D. Appleton & Co.); Folsom's Entomology, Gager's Fundamentals of Botany (P. Blakiston's Sons & Co.); Jennings' Behavior of the Lower Organisms (Columbia University Press); Bergen's Foundations of Botany, Bergen and Caldwell's Practical Botany, Bergen and Davis' Principles of Botany, Densmore's General Botany, Hough and Sedgwick's The Human Mechanism, Linville and Kelly's General Zoölogy (Ginn & Co.); Kellicott's General Embryology, Sedgwick and Wilson's General Biology (Henry Holt & Co.); Morgan's Physical Basis of Heredity (J. P. Lippincott & Co.); Romanes' Darwin and After Darwin (Open Court Publishing Co.); Conklin's Heredity and Environment in the Development of Men (Princeton University Press); Conn and Buntington's Physiology and Hygiene (Silver, Burdett & Co.); Coulter's Evolution of Sex in Plants (University of Chicago Press); Abbott's General Biology, Buchanan and Buchanan's Bacteriology, Campbell's University Textbook of Botany, Ganong's Textbook of Botany for Colleges,

Hegner's College Zoölogy, and Introduction to Zoölogy, Holmes' Biology of the Frog, Huxley's Physiology, Lankester's Treatise on Zoölogy, Lull's Organic Evolution, Packard's Textbook of Entomology, Parker's The Elementary Nervous System, Parker and Haswell's Textbook of Zoölogy, Parker and Parker's Practical Zoölogy, Scott's The Theory of Evolution, Shipley and McBride's Zoölogy, Verworn's General Physiology, Walter's Genetics, and The Human Skeleton, Wiedersheim's Comparative Anatomy of Vertebrates, Wilson's The Cell (The Macmillan Co.). To The Macmillan Company is also due the author's appreciation of the liberal attitude which they have assumed in all the arrangements attendant upon the publication of the book.

L. L. WOODRUFF

YALE UNIVERSITY

May, 1922

From Preface to the Fourth Edition

Acknowledgments are due to the authors and publishers of the following works, who generously have supplied some of the new illustrations included in this edition: Calkins' Biology of the Protozoa (Lea & Febiger); Chapman's Handbook of the Birds of Eastern North America (D. Appleton & Co.); Chandler's Animal Parasites and Human Disease, Curtis and Guthrie's General Zoölogy (John Wiley & Sons); Martin's Human Body (Henry Holt & Co.); Morgan's Evolution and Genetics (Princeton University Press); Metcalf and Flint's Destructive and Useful Insects (McGraw-Hill Book Co.); Lindsey's Evolution and Genetics, Newman's General Zoölogy, Smith, Overton, Gilbert, Denniston, Bryan, and Allen's General Botany (The Macmillan Co.); Rockefeller Foundation's Annual Report; and Thompson's Concerning Evolution, and Wilson's Physical Basis of Life (Yale University Press).

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CHAPTER I

The Scope of Biology

Science is, in its source, eternal; in its scope, unmeasurable; in its problem, endless; in its goal, unattainable.

—*von Baer*

The oldest as well as the most obvious classification of the objects composing the world about us is into nonliving and living. The knowledge accumulated during many centuries in regard to nonliving materials is now represented in the physical sciences, whereas that of the living comprises the content of BIOLOGY, the science of matter in the living state. Biology has as its ultimate objective the description of living phenomena in terms of what may be regarded as basic concepts of science—matter and energy acting in time and space; but it is needless to say that the attainment of this high aim is not imminent in any department of knowledge, and least so in the science of living things. Living organisms exhibit energy relationships which go beyond the boundaries of physics and chemistry today: relationships which represent a condition that in its highest manifestations is expressed in what we call our life.

BIOLOGICAL SCIENCES

The foundations for the scientific study of living nature were laid by Aristotle and Theophrastus over 2000 years ago. On the basis of collecting, classifying, dissecting, and pondering they reached important generalizations, some of which still remain as a firm basis of fact, and they precociously raised some of the broad questions which are still being investigated. From the time of the Greeks until about the fifteenth century there were many additions to the body of knowledge, but fact and fancy were so intermingled that the truth was largely obscured. (Figs. 491, 492.)

The feeling that though man is of nature he is still distinct from it,

was stated at the revival of learning, during the sixteenth century and later, in the broad classification of all knowledge into "history of nature" and "history of man": the former recording the "history of such facts or effects of nature as have no dependence on man's will, such as the histories of metals, plants, animals, regions, and the like"; the history of man treating of the voluntary actions of men in communities. Thus all record of facts was either natural history or civil history. From the general field of natural history the sciences of astronomy, physics, chemistry, geology, and biology became separated as relatively independent bodies of facts as each gained content, clearness, and individuality. Astronomy, physics, and chemistry were set apart first owing to the fact that their material was more readily susceptible to mathematical and experimental treatment; this left the histories of the earth, animals, and plants, or the observational sciences, as the residue for natural history.

It remained, however, for Lamarck and Treviranus, during the opening years of the nineteenth century, to attain a vision of the unity of animal and plant life and to designate this area as biology. Biology is something more than a union of plant science, BOTANY, and animal science, ZOOLOGY; for biology, in addition to describing the characteristics of plants and animals, endeavors to make clear the general principles common to both groups. (Fig. 515.)

The biologist has as his field the study of living things: what they are, what they do, and how they do it. He asks how this animal or that plant is constructed and how it works, and he attempts to answer these basic questions. He may also ask why an organism is so constructed and why it works the way it does, but the answers to these questions lie outside the field of observational science.

These queries of the biologist reflect the two primary standpoints from which biological phenomena may be studied: the *morphological*, in which interest centers upon the form and structure of living things; and the *physiological*, in which attention is concentrated upon the functions performed—the mechanical and chemical engineering of living machines. Clearly, however, it is impossible to draw a hard and fast distinction between morphology and physiology because, basically, structure must be interpreted in terms of function and vice versa. But again, the fields of morphology and physiology naturally resolve themselves into special departments of study, depending on the level of analysis of structure or of function which is emphasized: MORPHOLOGY

stresses the general form of the animal or plant; ANATOMY, the gross structure of individual parts, or *organs*; HISTOLOGY, the microscopic structure of *tissues* in the organs; CYTOLOGY, the microscopic structure of *cells*, the component elements of tissues and *protoplasm*, the unique material of life. Similarly, PHYSIOLOGY investigates the activities of animals and plants, the functions of organs, the properties of tissues, the phases of cell life, and finally the physicochemical characteristics of protoplasm. Furthermore, the development of the individual (EM-

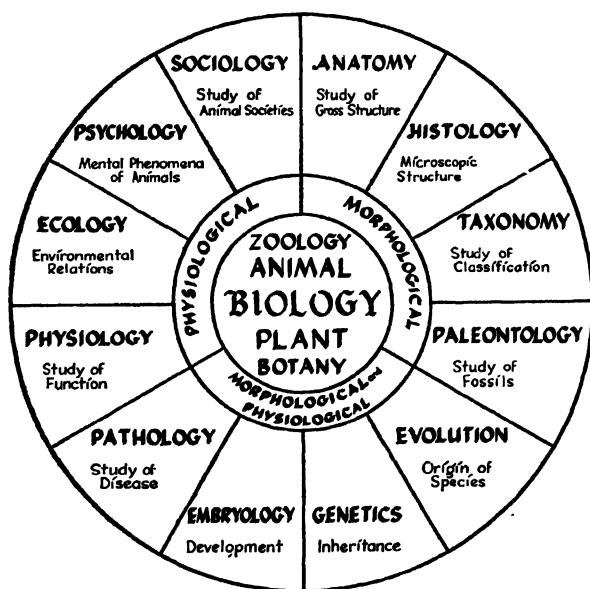


FIG. 1. The chief divisions of biology.

BRYOLOGY), the method of transmission of characters from parents to offspring (GENETICS), and the origin of species (ORGANIC EVOLUTION) are other basic fields which must be considered from both the structural and functional aspects if continuous progress is to be made toward a comprehensive appreciation of life. (Fig. 1.)

Just as the various physical sciences have expanded and become specialized until they are beyond the grasp of a single man, so knowledge about biology and its subdivisions, the biological sciences as listed above, is now distributed among many specialists. Specialization has resulted in narrowing and isolating the fields of study, as deeper

levels of investigation have been reached in all sciences, but there is necessarily a tendency for the basic phenomena of life to meet on the common ground of the fundamental sciences, physics and chemistry. In the last analysis the biologist must assume, as a working hypothesis, that the properties of protoplasm are the resultant of the properties and inter-relationships of the chemical elements which compose it, but he must not suppose that physics and chemistry when added together are equivalent to biology. Rather he must grasp the cardinal fact that with new relations the properties of things change, the properties of protoplasm depend on and emerge from those of its chemical constituents only when the latter are actually in the protoplasmic complex.

It has been said that "in one direction, supported by chemistry and physics, biology becomes biochemistry and biophysics. In another direction it becomes the basis of the psychical sciences which relate to human nature, of psychology and sociology." Indeed, it is not an exaggeration to regard all knowledge as really biological, since the process of knowing is a life process which is fundamental to every art and its practice, to every science and its application, and to every philosophy and its exposition.

Whether the "riddle of life" will ultimately be solved is a question which everyone would like to answer, but only the rash would attempt to predict. Suffice it to say that biologists who are on the frontier of progress today are directing their attention solely to the description and measurement of the phenomena exhibited by living things, those phenomena which distinguish life from lifeless, in an attempt to associate these characteristics with the established and more readily accessible phenomena of which some exact knowledge is available in the realm of the nonliving. But this statement should by no means be taken to indicate that biologists do not recognize the stupendous problems they face, or do not appreciate fully—indeed more fully than others—the broad space that separates even the simplest forms of life from the inorganic world.

In this volume, however, our main interest is not in discussing the theoretical goal of biology, but in drawing with bold strokes an outline picture of the present-day knowledge of this subject, including the cumulative results of the application of the scientific method to problems of life. This method is not peculiar to science, but is merely a perfected concentration of our human resources of observation, experimentation, and reflection. So far this has been a most productive method and

certainly has given no evidence that its usefulness is being exhausted. However, it should be realized that "in ultimate analysis everything is incomprehensible, and the whole object of science is simply to reduce the fundamental incomprehensibilities to the smallest possible number."

BIOLOGY AND HUMAN PROGRESS

At this moment it is desirable to emphasize that biology also supplies certain fundamental principles which are of universal application, principles of such great importance that they have revolutionized modern thought and action in nearly every field of human endeavor, and influence the entire mental outlook of civilized man on the world about him. Biology is an important agent in the adjustment of human life to human life conditions, and life persists solely by reason of the adequacy of such adaptations. Specifically, biology supplies the indispensable foundations of medicine, and also the foundations of agriculture. Together these bring us health, food, and raiment.

In this way biology meets many of the physical needs of mankind and so adds enormously to the basis of human welfare, but it also has another equally important aspect. The appeal of biology for a high position as a contributor to the progress of humanity combines its practical gifts with the more subtle development of aesthetic values which naturally flow from the pregnant thought of the unity of nature: the oneness of life. Involved is the firm and ever-increasing sense of control as knowledge grows, which "robs life of none of its mystery but rather serves to link it securely with the larger mystery of the universe and the Infinite back of it all." Man, though one with all living beings, has the unique and all-important power consciously to study the ways and to direct the forces of nature, and to adapt himself to them.

The value of a knowledge of biological principles and of the order of nature in general, cannot be better emphasized than by the words of Huxley, the founder of modern methods of biological teaching, who wrote: "Suppose it were perfectly certain that the life and fortune of every one of us would, one day or other, depend upon his winning or losing a game of chess. Don't you think that we should all consider it to be a primary duty to learn at least the names and moves of the pieces; to have a notion of a gambit, and a keen eye for all the means of giving and getting out of check? Do you not think we should look with a disapprobation amounting to scorn, upon the father who allowed his child, or the state which allowed its members, to grow up without

knowing a pawn from a knight? Yet it is a very plain and elementary truth, that the life, the fortune, and the happiness of every one of us, and, more or less, of those who are connected with us, do depend upon our knowing something of the rules of a game infinitely more difficult and complicated than chess. It is a game which has been played for untold ages, every man and woman of us being one of the two players in a game of his or her own. The chessboard is the world, the pieces are the phenomena of the universe, the rules of the game are what we call the laws of Nature. The player on the other side is hidden from us. We know that his play is always fair, just and patient. But also we know, to our cost, that he never overlooks a mistake, or makes the smallest allowance for ignorance. To the man who plays well, the highest stakes are paid, with that sort of overflowing generosity with which the strong shows delight in strength. And one who plays ill is checkmated—without haste, but without remorse.”

CHAPTER II

Cellular Organization of Life

The most important discoveries of the laws, methods, and progress of Nature have nearly always sprung from the examination of the smallest objects which she contains, and from apparently the most insignificant enquiries.

—Lamarck

With a synoptic view of the scope and importance of biology in mind, we may now turn directly to the study of life itself in the only form in which it is known: the bodies of plants and animals.

When examined under the microscope, a thin slice of material from the skin of a frog and a slice from the leaf of a bean plant show the same general structure. Each bit of tissue appears to be composed of innumerable tiny structural units, no two of which are exactly alike even in the same piece, though all the units are similar enough to be one and the same type of unit. If the study is extended to other portions of the bean or the frog or, indeed, to any portion of any familiar plant or animal, or even to the human body, essentially similar units of struc-

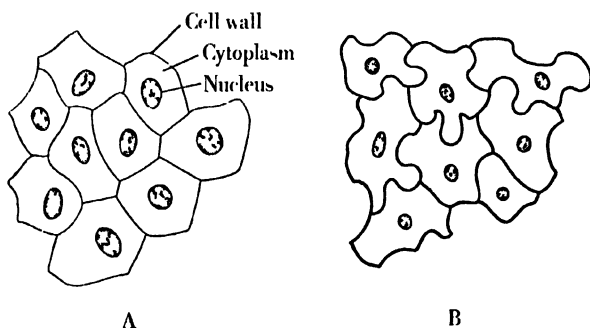


FIG. 2. Cells as seen from a surface view with the compound microscope, at a magnification of about 50 diameters. A, surface view of epidermal cells from frog skin; B, surface view of epidermal cells from plant leaf.

ture will be found in every case. In fact, the bodies of all living things consist either of a single microscopic unit, the CELL, or of hundreds, often billions, of essentially similar cellular units. (Figs. 2, 3.)

Each cell is itself a center for all the fundamental vital processes; each cell is alive. This fact is obvious when, as in a UNICELLULAR plant or animal, a cell forms the whole body, but it is not so apparent when the cell is only one of myriads associated together to form a MULTI-CELLULAR organism. Actually the life of the organism as a whole is, in final analysis, the product of that existing in the component cells: the expression of their harmonious cooperation in the maintenance of the essential life functions. Accordingly cells are the basic structural and functional units of the actual living material, protoplasm.

Such being the case, we reach the first great biological generalization: all animals and plants have the same elementary cellular structure. Indeed, the specific basic differentiations in the living materials of the various parts of animals and plants are made possible largely because the protoplasm is disposed in microscopic units, the cells.

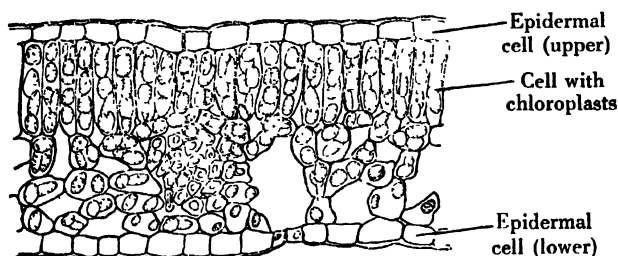


FIG. 3. Section through a leaf showing upper and lower epidermis and the arrangement of the internal leaf tissues, as observed with a compound microscope.

THE CELL

In view of the structural diversity existing among the many types of animals and plants, it is not surprising to find that there are considerable, even great, variations in their component cells. In fact, the characteristics of an organism or of a part of an organism are determined by those of the cells. Nevertheless, there are certain fundamental cell characters which are common to all cells—by virtue of which they are cells—and it is important to emphasize these basic features. (Fig. 4.)

A cell in its simplest form is a tiny, more or less spherical mass of protoplasm. Such are the eggs of various animals and the complete

body of some of the lowest plants and animals. Cells forming the units of multicellular organisms, however, frequently exhibit more or less hexagonal surfaces and eight- or fourteen-sided figures, on account of stresses and strains incident to their position among other cells. Furthermore, specializations and differentiations, for one purpose or another, produce shapes which are characteristic of different parts of the organism, as, for example, the long spindle-shaped cells of involuntary muscle tissue and the widely branching cells in the brains of animals. Broadly

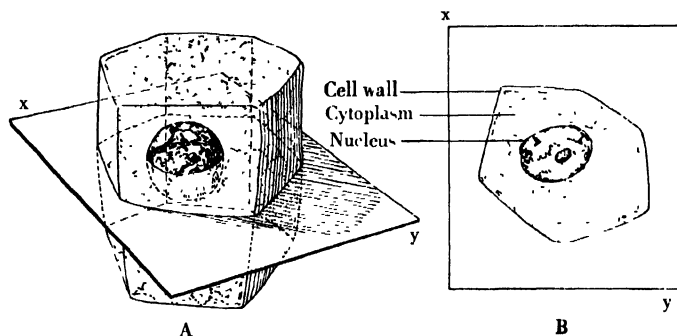


FIG. 4. Diagrams of an octahedral cell (6 sides plus top and bottom), shown in A as a solid body and in B in optical section through the plane x-y. See also Fig. 15.

speaking, the greater diversity of cell form is found in animals, whereas in plants, owing to the general presence of rigid cell walls surrounding the protoplasm, the cells more frequently exhibit symmetrical, angular outlines. (Figs. 5, 6.)

The word "cell" is a relic of the time when the cell wall was regarded as the most important part of the unit, and the protoplasmic contents, if observed at all, were considered as only of secondary importance. Now it is recognized that many cells, such as in a unicellular amoeba and in white blood cells, are essentially naked masses of protoplasm. In other words, protoplasm is the actual living part of a cell, and the cell wall is typically a nonliving accessory which more or less sharply separates one unit mass of protoplasm from another similar unit and supplies rigidity and form to the group of cells as a whole. (Fig. 495.)

Protoplasm, as the living material of cells, is highly organized into various complex structures, some of which are inherent in all cells and

others only in cells adapted for special functions. For the present, however, it is only necessary to emphasize that the protoplasm of all typical cells is differentiated into two chief regions: the **CYTOPLASM**, or general ground substance, which makes up the bulk of a cell; and the **NUCLEUS**, a more or less clearly defined spherical body, situated near the center of the cytoplasmic mass.

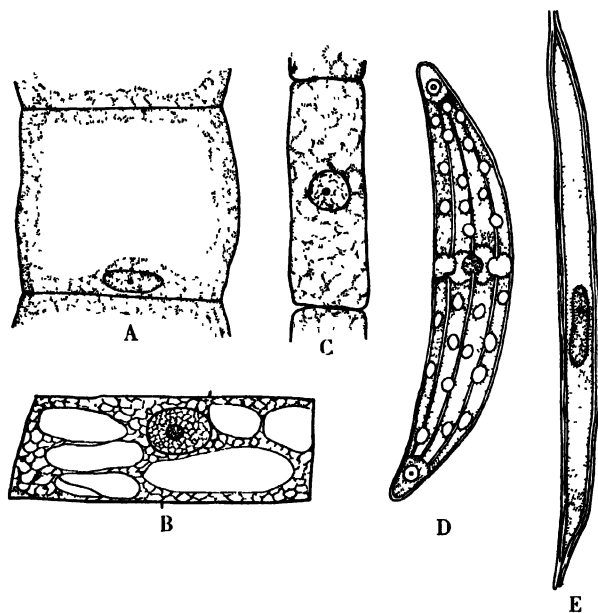


FIG. 5. Drawings of various types of typical plant cells as observed under high magnification. A, B, C, cells from tissues of seed plants; D, a unicellular plant, a desmid; E, plant cell with thickened (woody) walls. See also Fig. 34.

Cytoplasm and nucleus, considered from the functional point of view, represent a *physiological division of labor* within the confines of a cell. Experiments have shown that they are mutually necessary for cell life. Removal of the nucleus puts an end to constructive processes within the cell—assimilation, repair, and growth—and thus leads rapidly to death. The evidence indicates that the nucleus is the controlling center in cell activity, hence a primary factor in growth and development, and in the transmission of specific qualities from cell to cell, and so from one generation to the next. A cell is the smallest unit of living matter capable of continued independent life and growth.

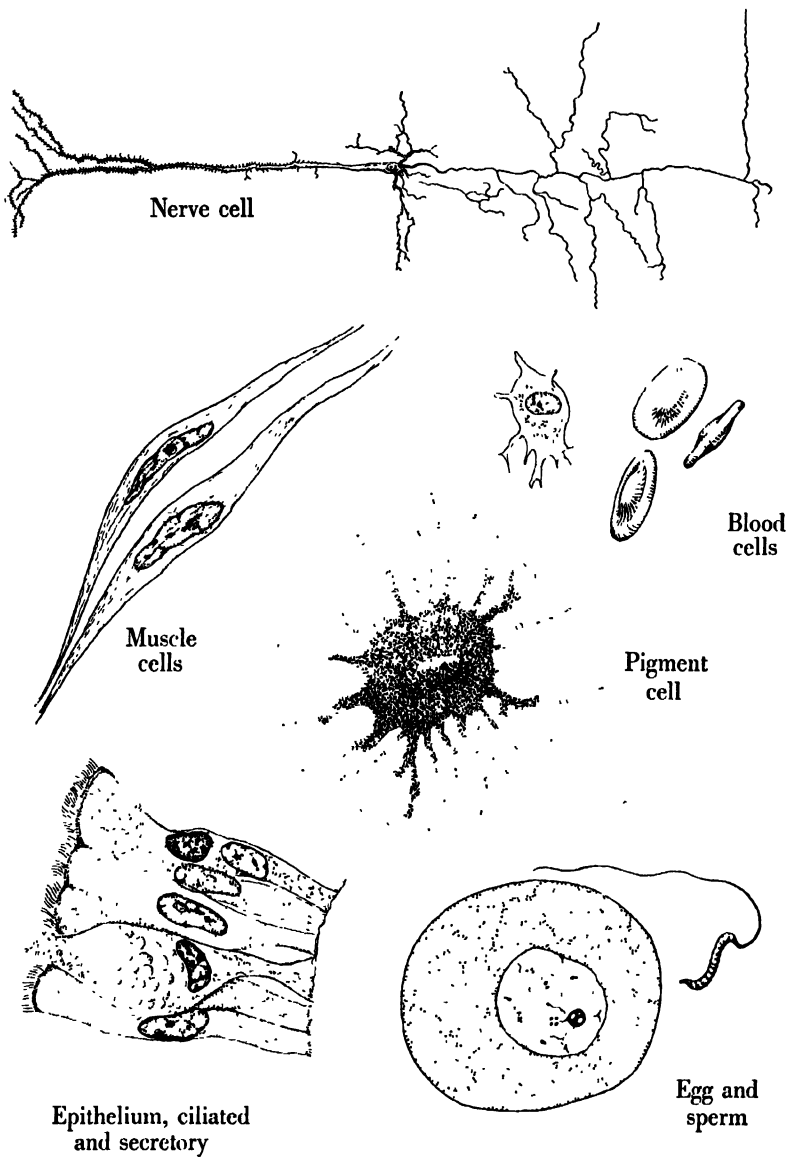


FIG. 6. Drawings of various types of animal cells, including nerve cell, muscle cells, blood cells, pigment cell, epithelial cells, and germinal cells (egg and sperm). Highly magnified. See also Fig. 12.

CELL DIVISION

All the evidence indicates that, at the present time at least, living matter always arises from pre-existing living matter. That is, the protoplasm in the cells grows, so that the cells grow, and, having attained a certain size, each cell reproduces by dividing into two essentially equal parts. As a result there are two cells; the parent cell has lost its identity in its offspring. Cell division is reproduction. Indeed, in the final analysis reproduction is always cell division, though in the higher animals and plants this primary fact is largely obscured by accompanying phenomena. (Fig. 7.)

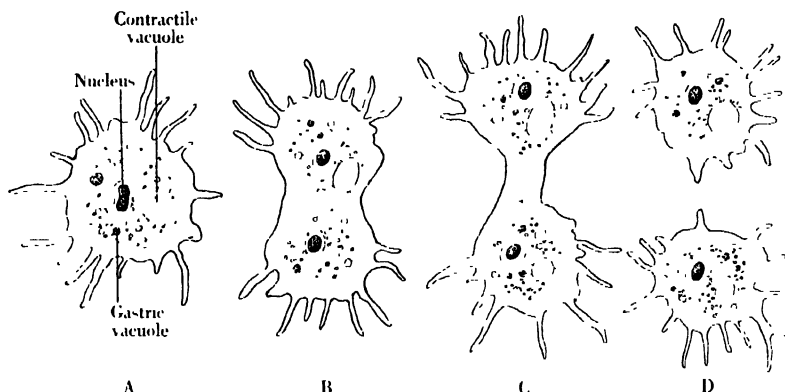


FIG. 7. An active amoeba undergoing reproduction by cell division (binary fission) as shown in four successive stages, A, B, C, D. Note that the single nucleus of stage A first divides to form two nuclei, which is followed by division of the cytoplasm. Highly magnified. See also Figs. 13, 16, 18. (Modified after Schultze.)

The process of cell division involves division of both the cytoplasm and the nucleus. We must therefore enlarge our definition of a cell as a small mass of protoplasm differentiated into cytoplasm and nucleus, by adding that both cytoplasm and nucleus arise through the division of the corresponding elements of a pre-existing cell.

We shall later have occasion to make a study of the details of cell division, known as MITOSIS. (Figs. 158, 159.) From what has been stated already, however, it must occur to the reader that, since cells arise only by division, those of the present day, whether complete free-living organisms or units composing the bodies of higher plants

and animals, including man, are actually lineal descendants in an unbroken series from the beginning of cellular life on the earth.

THE MULTICELLULAR ORGANISM

Every individual, with minor exceptions to be noted later, begins its existence as a single cell, either as a **SPORE** from one parent, or as a **ZYGOTE** formed by a fusion of two cells (**GAMETES**) each typically derived from a separate parent individual, one gamete from the male parent, the other from the female parent. The first method, with origin from a single spore cell is known as **UNIPARENTAL**, or **ASEXUAL**, reproduction, and the latter from gametes as **BIPARENTAL**, or **SEXUAL**, reproduction. The union of the male and female gametes (**SPERM** and **EGG**), in sexual reproduction to form a new individual, or zygote, is termed **FERTILIZATION**. Both asexual and sexual methods of reproduction are widespread among plants and animals, frequently alternating in regular sequence in the same species to give a life cycle with an **ALTERNATION OF GENERATIONS**. (Fig. 211.)

The most remarkable fact about a reproductive cell is its power to develop into a complete new organism similar to the parent from which it has separated. Both the spore and the fertilized egg (zygote) are designed, one may say, to go through a series of changes which transforms an apparently simple cell into an obviously complex multicellular plant or animal with all the tissues and organs characteristic of the species. It will be helpful, at this point, to review the typical method by which the development of a multicellular organism is accomplished.

Briefly, the general method of development is cell division accompanied by differentiation. The spore (asexual) or the zygote (sexual) by a succession of cell divisions, termed **CLEAVAGE**, changes from a one-cell stage to a two-cell stage and then, with more or less regularity, to four-cell, eight-cell, sixteen-cell stages, etc. If these cells became separated after each division, the same general condition would arise as in a unicellular type, where each complete organism is a free-living cell. Or again, if cleavage merely resulted in a group of exactly similar cells, there would arise a **COLONY** of attached unicellular individuals of identical structural pattern, rather than a multicellular organism, with differentiation between various cell types.

Colonial forms are numerous among the lower plants and animals,

and show nearly all grades of complexity from simple associations of a few identical cells, as for example in *Spondylomorum*, to groups of many thousands of cells in which some of the cells are specialized for certain functions. (Fig. 8.) *Volvox* affords an instructive example of

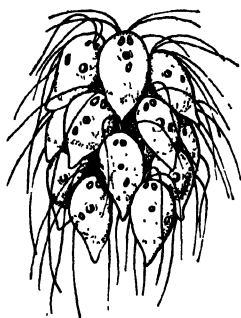


FIG. 8. A simple colonial organism (*Spondylomorum*). The 16 cells of the colony are all alike, each cell maintaining all the functions of life, including reproduction.

the latter condition. The majority of the cells, ten thousand or more, forming the relatively large spherical colony are flagellated individuals. Each cell lives a practically independent existence in organic union with its fellows. The chief contribution of each cell to the economy of the colony results from the lashing of protoplasmic extensions (FLAGELIA) which propels the colony through the water. Under certain conditions, however, some of the cells in a *Volvox* colony become specialized for reproduction, both asexual and sexual, and form new colonies. Here then is a differentiation between reproductive (GERM) cells and body (SOMATIC) cells, and a foreshadowing of that further specialization and physiological division of labor

between cells which is the most characteristic feature of the METAPHYTA and METAZOA, as the multicellular plants and animals are sometimes called. (Fig. 9.)

In fact, the complex bodies of multicellular organisms are made possible by cell cooperation and cell differentiation (*intercellular differentiation*). For instance, all protoplasm possesses the primary attribute of contractility, but the capacity for contraction is very greatly developed in the muscle cells of animals, and to a certain extent at the expense of other powers. But this intercellular differentiation would be ineffective were not innumerable similarly specialized cells grouped together, or marshaled to perform a certain function. The power of a muscle results from the combined action of its component muscle cells. Differentiation, but without cooperation between cells, occurs in one-celled organisms (*intracellular differentiation*). *Paramecium* has highly specialized parts; other Protozoa have even more, perhaps the limit of possibilities of the single cell. (Fig. 10.) But the multicellular body solves the problems of intracellular specialization by assigning special functions to groups of cells rather than to parts of one cell.

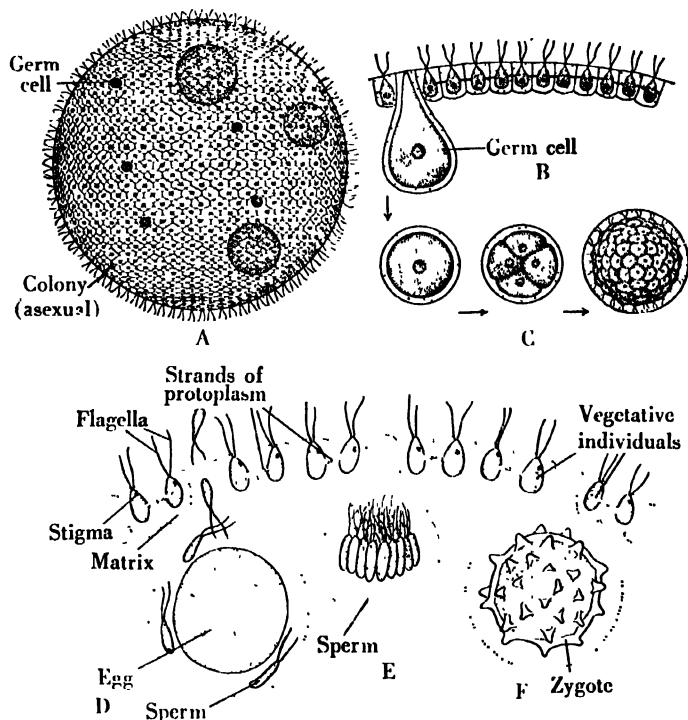


FIG 9. Volvox. A, adult colony, enclosing three young asexual colonies and germ cells; B, portion of wall of colony with large germ cell and several flagellated body cells; C, stages in asexual development of colony; D, E, F, sexual reproduction by formation of egg D and sperm E. Union of egg and sperm produces zygote F, which is resistant to unfavorable conditions. Later it will develop into an adult colony. (From Marsland-Plunkett. Modified.)

Cell division, or cleavage, involving intercellular differentiation and physiological division of labor is the keynote of development in both the higher animals and plants. Taking animal development as an example, we find, in general, that the cells which arise from the cleaving zygote soon become arranged so that they form the surface of a hollow sphere of cells, known as the **BLASTULA**. All the cells in a blastula at first appear essentially similar, but soon certain cells at one pole of the blastula become invaginated until the central cavity of the blastula, termed the **BLASTOCOEL**, is largely obliterated. Accordingly there results the **GASTRULA** stage which may be roughly compared to a double-walled sac, with an opening to the exterior termed the **BLASTOPORE**.

The outer gastrula layer is known as the **ECTODERM**, and the inner layer, which lines the newly formed gastrula cavity (**ENTERIC CAVITY**), as the **ENDODERM**. The ectoderm comprises cells which are already somewhat differentiated among themselves for special purposes, but which, as a whole, form a primary tissue with general functions of its own, chiefly sensory and locomotor. Similarly the endoderm consists

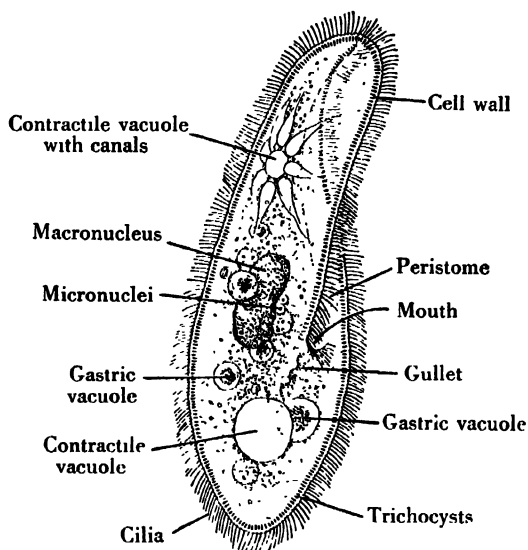


FIG. 10. *Paramecium aurelia*. One of the common ciliated, unicellular animals, frequently found in laboratory cultures made with pond water. Highly magnified. See also Fig. 57.

of cells which, as a group, form the nutritive cells of the embryonic animal. (Fig. 11.)

In the gastrula stage of most animals, a third layer of cells, the **MESODERM**, develops between the ectoderm and endoderm. In this way the three primary tissues, or **GERM LAYERS**, are established which are characteristic of the developing animal. From these the specialized tissues which compose the various organs of the adult are derived. For example, by cell division and differentiation the ectoderm gives rise to the outer layers of skin and to the central nervous system, the mesoderm to the muscular tissues, the supporting tissues, and the blood vascular system, whereas the endoderm forms the nutritive cells which line the alimentary canal throughout the life of the organism.

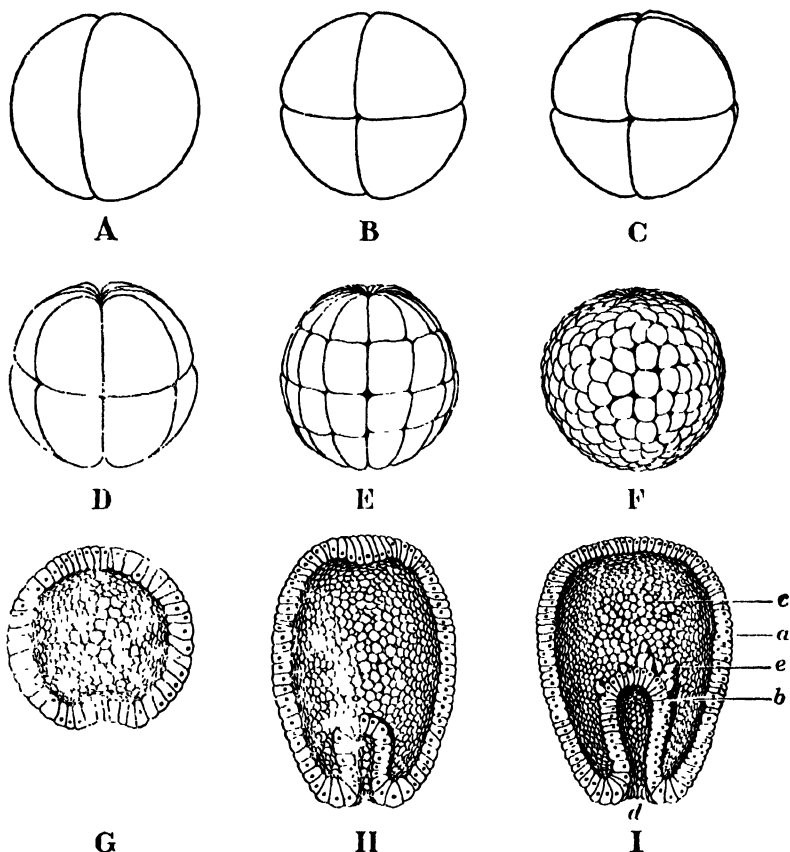


FIG. 11. Diagrams to illustrate the general method of early animal development. A-F, cleavage and formation of the blastula; G, section of blastula showing the central blastocoel and the beginning of gastrulation; H-I, early and later gastrula stages. *a*, ectoderm; *b*, endoderm; *c*, blastocoel; *d*, blastopore, leading into the enteric cavity; *e*, cells arising from the endoderm, destined to form the mesoderm.

This grouping of differentiated cells into the definite tissues is at the basis of the architecture of multicellular animals and plants, and this fact brings us to another level in the analysis of their structure. Although the unit of organization is the cell, these are associated in tissues, which function as physiological units of a higher order: a division of labor among the cells that makes possible the multicellular body with its attendant complexity. A tissue may be defined as a group

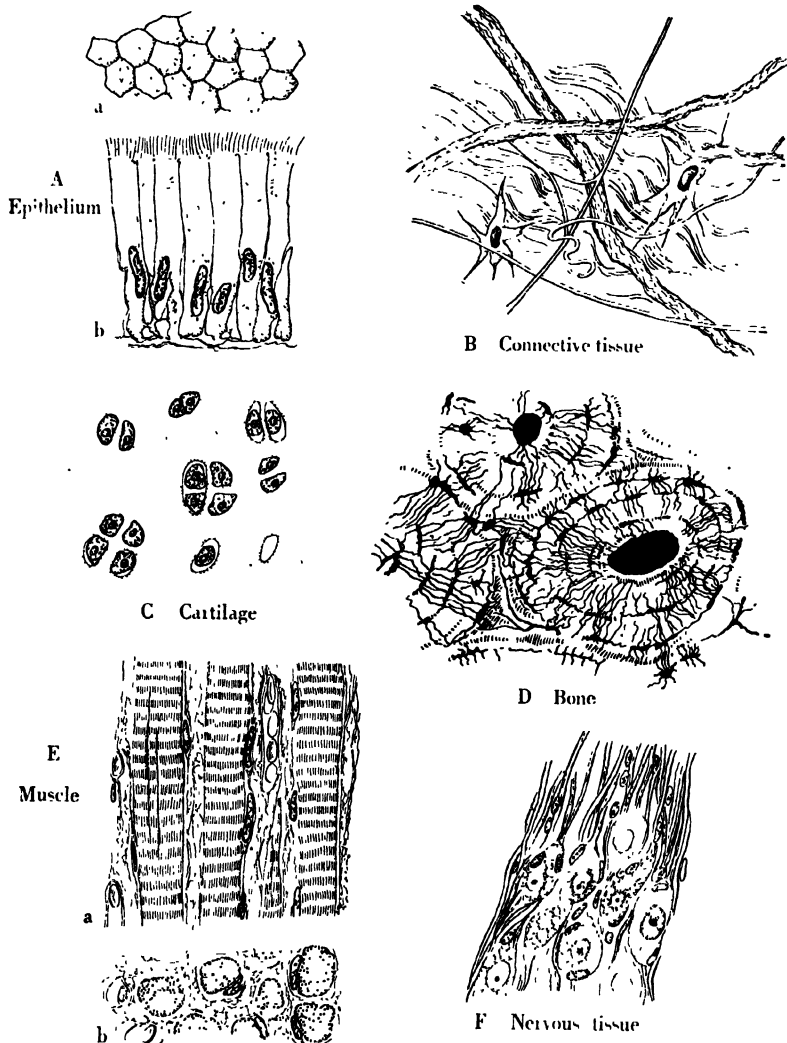


FIG. 12. Drawings of various representative animal tissues as may be observed from stained preparations studied under the microscope. A, epithelium (simple ciliated, columnar) from human intestine: a, surface view; b, longitudinal section; B, connective tissue (subcutaneous) from rabbit, showing cells and fibers (elastic and fibrillated); C, cartilage, showing cells in spaces in hyaline matrix; D, bone: section of human humerus showing structure of matrix in which the bone cells lie (marrow cavity [dark] in center); E, muscle (striated): a, longitudinal section; b, cross section; F, nervous tissue: bipolar nerve cells from ganglion of auditory nerve of cat. All figures are highly magnified.

of essentially similar cells and their derivatives, specialized to perform a certain function. Examples include such tissues as bone, muscle, and nerve in animals, and wood and pith in plants. (Fig. 12.)

Since the similar cell components of multicellular organisms are grouped to form tissues, it follows that the major functional units, or **ORGANS**, of the animal or plant body are basically formed of tissues. In other words, an organ is an association of tissues which has assumed a definite form for the performance of a certain function: for example, the human hand, composed of bone, muscle, nerve, etc., or the plant stem, composed of bark, wood, pith, etc.

As one would naturally expect, among the lowest Metaphyta and Metazoa there are organisms in which the body is relatively simple, without highly differentiated tissues and organs, but in most animals specialization is carried still another step forward by a grouping of the organs devoted to the performance of some one specific function into an **ORGAN SYSTEM**. An animal has many definite voluntary muscles, each of which is an organ but which collectively constitute a working unit, the muscular system; or, again, the animal has stomach, intestine, liver, etc., forming the digestive system. In the highest plants, on the contrary, cellular differentiation has not progressed in the same way, nor so far, since the plant body is composed of tissue systems rather than organ systems. This fact will be evident when the structure of the plant and animal body has been considered.

In truth, the multicellular plant or animal, considered as a whole, is the resultant of the action and interaction of many systems, organs, tissues, and, in the final analysis, of a multitude of cooperating protoplasmic cellular units: more than a hundred thousand billion in man. In addition the fact must not be overlooked that the whole is greater than its parts. The cells merge their individuality in that of the complete organism, and so long as they remain associated they are to be regarded, not as individuals, but rather as specialized centers of action and reaction of the living body itself, by means of which functional division of labor is made possible. (pp. 25, 31.)

CHAPTER III

The Physical Basis of Life

Over the structure of the chemical molecule rises the structure of the living substance as a broader and higher kind of organization.

—Hertwig

The realization that all animals and plants possess a fundamentally similar organization—with cells as the structural and physiological units—leads quite naturally to an intensive study of protoplasm, the material of which cells are composed and the physical basis of life itself.

The old saying that the materials forming the human body change completely every seven years is a tacit recognition that lifeless material, taken in the form of food, is gradually transformed into living matter under the influence of the body tissues. Indeed, just as a geyser retains its individuality from moment to moment, though it is at no two instants composed of the same molecules of water identically placed, so the living individual is a focus into which materials enter, serve their purpose for a time, and then emerge to become dissipated in the environment. But at this point the analogy stops, for in the living organism the materials which enter as food, endowed with POTENTIAL ENERGY, are rearranged and changed until specific molecular combinations result, which in turn are transformed into integral parts of the organization of life itself. However, to live is to work, and work means expenditure, the transformation of potential energy into KINETIC ENERGY, with the result that waste materials, in relatively simple form and largely devoid of utilizable energy, are returned to the realm of the nonliving. And note, a living organism must continuously utilize energy in order merely to maintain itself. Cessation is death.

Here, then, is found a fact of prime importance: so far as we know, living matter, protoplasm, is merely ordinary matter that has temporarily assumed unique physicochemical relationships that display the

remarkable multiphase series of phenomena which collectively are recognized as life.

However, nonliving matter is always closely associated with living matter in the bodies of animals and plants. Indeed, the two are frequently so intimately related that it is difficult to distinguish sharply between living and lifeless. Obviously, in the human body, for instance, the visible parts of hair and nails, a large part of bone tissue, and the liquid part of blood are nonliving material. Moreover, the nonliving is not confined to gross structures, for the dead among the living is still revealed at all levels until the magnifying power of the microscope fails us. (Fig. 11, *D.*)

THE PROTOPLASM CONCEPT

In spite of the continuous stream of matter and energy flowing through the living individual, the physical and chemical study of living matter, from whatever source it is taken, from the lowest plant to man, reveals a striking similarity in its fundamental features, and this condition is the basis of the protoplasm concept as held by modern biologists.

As the finer structure of animals and plants came within the range of vision through improvements in microscope lenses, it was gradually recognized that the ultimate living substance appeared to be a granular, viscid fluid. This discovery started a long series of studies on the

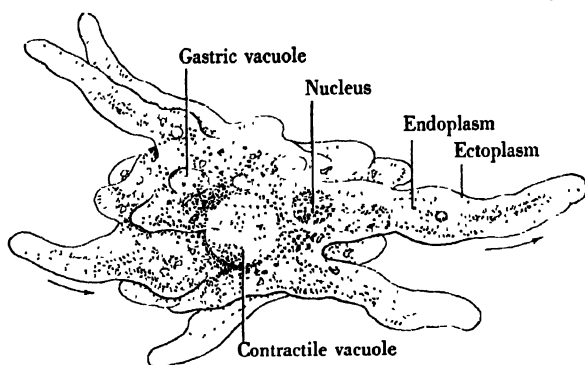


FIG. 13. *Amoeba proteus*, a minute unicellular animal regarded as one of the most primitive types. The protoplasm is not enclosed in a rigid cell wall, and irregular projections (pseudopodia) are formed from time to time for use in locomotion and nutrition, as may be required. Drawn from life under high magnification.

materials of the bodies of unicellular organisms, such as amoeba, and of the cellular elements of higher animals and plants. (Fig. 13.) These investigations finally led, about a century ago, to a complete demonstration of the full morphological and physiological significance of protoplasm. There is, in truth, an essentially similar living material for

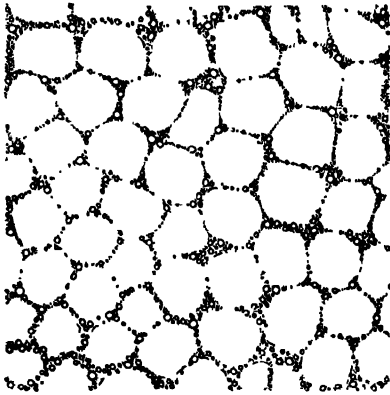


FIG. 14. Drawing of living protoplasm from a starfish egg under very high magnification. This exhibits the foam-like (alveolar) structure, which is due to the vesicular arrangement of a homogeneous ground substance with innumerable embedded particles. See also Fig. 15. (After Wilson. Redrawn.)

both animals and plants, a common physical basis of life. (Fig. 14.) This reduction of all life phenomena to a common protoplasmic denominator laid the foundations for, indeed, actually established, the life science, biology.

Although a common physical basis of life is recognized, it is important to remember that the protoplasm of no two animals or plants or, indeed, of different parts of the same animal or plant is exactly the same. Identity of protoplasm would mean identity of structure and function: identity of life itself. The protoplasm concept merely emphasizes that, after allowances are made for all

the variations, the similarities in all living organisms far outnumber the dissimilarities in this "agent of vital manifestations."

The physical chemists tell us that protoplasm consists of matter in the colloidal state, a condition of matter that chemists have long been familiar with in the inorganic world. A COLLOID may be described as matter divided into particles larger than one molecule and dispersed in a continuous medium of different matter. Therefore butter and cream are both colloids: the former consisting of water finely divided and suspended in oil, and the latter essentially of finely divided oil in water. Protoplasm, however, is a stupendously more complex colloidal system than other colloids, for it is an association of very many substances, some in simple and others in highly complex molecular form, so finely divided that they are invisible with the ordinary microscope. Protoplasm is essentially a colloidal dispersion of organic compounds in water.

Colloidal systems in general are characterized by tremendous surface activity, the result of energy relations between the contact surfaces of the particles of the different component substances. This being so, and protoplasm being a colloid composed of very many different kinds of materials, the total surface area between suspended substances and suspending media is very great, affording the requisite conditions for a highly complex system of energy relations. And when we add to this the fact that, at such surfaces, chemical changes, some involving changes in electric potential, occur; and also that "mechanical changes are induced by precipitation, coagulation, and constant redistribution between the suspending media and the substances in suspension, we begin to get at least a glimpse of the exceedingly intricate and delicate *energy-transforming system* that protoplasm really is." To work out these complex relationships is one of the major tasks still remaining for the biologist, chemist, and physicist.

The statement that protoplasm is a colloidal system leaves the reader without any conception of its appearance. As a matter of fact it is as difficult to describe the appearance of protoplasm as it is to define it. Protoplasm must be seen under the microscope to be appreciated. With a moderate magnification, it exhibits a rather characteristic picture, appearing like a translucent, colorless, viscid fluid containing many minute granules as well as clear areas, or vacuoles. If protoplasm is examined in water it exhibits no tendency to mix with the surrounding medium, though investigations show that OSMOTIC interchanges are constantly going on during life. For this reason it is impossible to consider protoplasm except in connection with its surroundings, whatever they may be, variations in environment and variations in activities being reflected directly or indirectly in its appearance.

Under the highest magnifications, it can be noted that the finer structure of protoplasm differs, not only from one specimen to another, but also in the same cell under slightly different physiological conditions. At one time it has the appearance of a fairly definite honeycomb or netlike structure (*reticulum*), the meshes of which enclose a more fluid substance; at another time, a foamlike (*alveolar*) appearance, owing to a more liquid substance scattered or emulsified as spherical bodies in a less liquid continuous medium; again, at other times, the denser portion seems to take the form of minute threads, or *fibers*, or of tiny *granules* distributed in a fluid matrix. (Fig. 14.)

These variations in appearance have given rise to various theories

which emphasize one or another as the universal basis responsible for the physical structure of protoplasm, from which the other appearances are merely secondarily derived. The trend of recent work indicates that although the general similarity of protoplasmic activity, wherever we find it, might lead us to expect to find also a visible fundamental structural basis, such does not exist within the range of magnifications at our command. Reticular, alveolar, and other structures which our microscopes reveal are possibly merely surface ripples from underlying physicochemical changes in the colloidal system which have proved unfathomable.

However, just as the invention of the compound microscope about three and a half centuries ago made possible the discovery of cells and the study of protoplasm, so today by means of new tools and techniques, the closed door to molecular biology has been opened. With the advent of the ultramicroscope and the ultraviolet microscope, the limits of magnification were no longer determined by the wave length of ordinary light, and the recently developed electron microscope affords magnifications far exceeding those of any optical system. Furthermore the ultracentrifuge is able to separate out minute dispersed particles hitherto unmanageable. Also the spectroscope is now showing the presence of traces of biologically important chemical elements and aiding in the analysis of the exact composition of organic compounds, while the X ray is affording almost infinitesimally fine measurements and patterns in the realm of living material.

So biology is starting on new trails with the description and analysis of biological phenomena, not merely in terms of cells, but in terms of important parts of cells and even in terms of molecular structure and forces. But "it should not be expected, of course, that continual fragmentation will of itself necessarily reveal the true inner meaning of life processes." A plant or animal may well be, and apparently is, something more than the sum of its parts: the *organismal* point of view is being increasingly insisted upon by many biologists. Life is an expression of functional unity in which the parts cooperate for the maintenance of the whole in continuously changing surroundings. The various vital phenomena are manifestations of the *whole* and are elusive when it is resolved into elements, whether these be physical, chemical, or morphological. The continuing problem in all nature is still the organism. (pp. 25, 31.)

CHARACTERISTICS OF LIVING MATTER

Since the phenomena of life are always the results of protoplasmic activity, it is obvious that we must examine protoplasm for the primary attributes of living matter. The properties which are uniquely characteristic of living matter are: *cellular organization*, *chemical composition*, *metabolism* involving the powers of *maintenance*, *growth*, *repair*, and *reproduction*, and *irritability* resulting in the power of adaptation.

ORGANIZATION

It has been emphasized in the previous chapter that living things are not homogeneous, but possess structural and physiological ORGANIZATION, centered in the cell as the universal unit. Animals and plants are composed of various tissues and organs specifically adapted for certain purposes. They exhibit "a viable unity" and so stand in sharp contrast with objects comprising the inorganic world, such as rocks and rivers. Accordingly animals and plants are referred to as ORGANISMS. Moreover, as we have seen, the organizational units of all living things are cells, and so it follows that cell structure is a direct or indirect expression of all the unique life characteristics that we are about to survey. Certain details of cell structure are necessary for an appreciation of the organization of organisms.

It will be recalled that the protoplasm of all typical cells is differentiated into two chief parts: the *cytoplasm*, or general groundwork which makes up the bulk of the cell; and the *nucleus*, a more or less clearly defined spherical body, situated near the center of the cytoplasm. (Figs. 4, 15.)

Cytoplasm. The cytoplasm may be considered the less specialized protoplasm of the cell, and its appearance and other characteristics are those which have been outlined in our discussion of protoplasm. With that relationship in mind, we may further describe cytoplasm as consisting of a meshwork, composed of innumerable, minute granules which permeate an apparently homogeneous ground substance, or *HYALOPASM*. Distributed throughout the cytoplasm are usually various lifeless inclusions such as granules of food, droplets of water or oil, vacuoles of cell sap, crystals, and various other materials which are to be, or have been, a part of the living complex, or are by-products of the vital processes. These passive materials are frequently referred

to as METAPLASM; it is quite evident, however, that such a term stands for no essential morphological part of the cell, and we have no absolute criterion to distinguish between some granules which are regarded as metaplastic in nature and others which are ordinarily considered active elements of the cytoplasm. But there are various bodies in the cytoplasm, in addition to the nucleus, which are undoubtedly active. Chief among these are the CENTROSOME, which has an essential function in cell reproduction, and the PLASTIDS, MITOCHONDRIA, and GOIGI BODIES, which are involved in special physiological activities of the cell. (Fig. 15.)

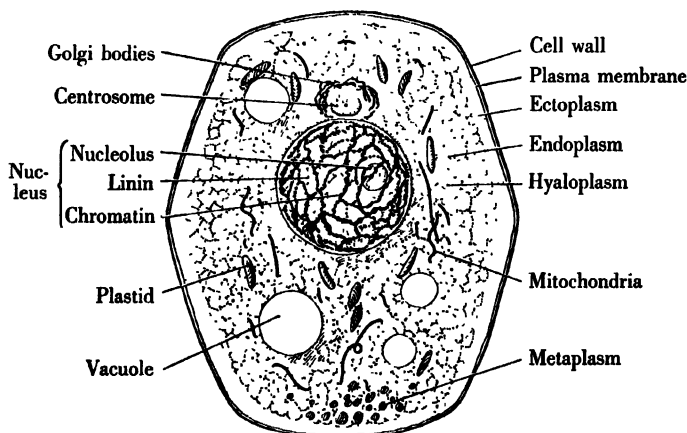


FIG. 15. Diagram of a section near the center of a typical animal cell, such as may be observed in a permanent stained preparation under high magnification.

The cytoplasm, since it forms the general groundwork, is that part of the cell which comes most closely into relations with the environment, and accordingly near the surface it is frequently somewhat modified in texture and consistency so that a definite outer region, or ECTOPLASM, may be distinguished from an inner region, or ENDOPLASM. The ectoplasm is limited externally by a PLASMA MEMBRANE just beneath the cell wall. The plasma membrane is certainly a part of the living cytoplasm, but the outer cell wall is definitely nonliving, though in many cases it is a direct transformation of the living material which grows and, in connection with the plasma membrane, has an important part in controlling the flow of matter and energy to and from the cell and its surroundings.

Nucleus. As already mentioned, within the cytoplasmic mass there is an area of clearly differentiated material which usually has a spherical form, bounded by a membrane, so that it appears as a definite body of protoplasm called the nucleus. The structural basis of the nucleus consists of a homogeneous ground substance, or KARYOLYMPH, which is permeated by a meshwork that usually appears to consist of two substances, LININ and CHROMATIN, which are closely related chemically. Chromatin is the highly characteristic nuclear material which takes various forms during different phases of cell activity but generally gives the appearance either of a network of tiny granules with one or more dense "knots" of chromatin, or of a number of definite bodies known as CHROMOSOMES. Frequently there are one or more conspicuous, spherical, achromatic bodies in the nucleus known as NUCLEOLI which are derived from the chromosomes. Later it will be necessary to describe some of the important changes in chromatin arrangement that occur during various phases of cell activity, especially during cell division, but it is sufficient at this point to emphasize that the nucleus is a differentiated area of the cell protoplasm which is the arena of the chromatin. All in all, the nucleus probably represents the most complex type of organization in the organism.

CHEMICAL COMPOSITION

It is impossible to make an analysis of living matter because the disturbance of its molecular organization by chemical reagents kills it. Therefore our knowledge of its chemical composition has of necessity been derived from a study of "dead" protoplasm. However, since in the transformation from the living to the nonliving state there is clearly no loss of weight, it follows that the complete material basis of life is still available for examination. In other words, the death of protoplasm is a result of *disorganization*.

Chemical analysis of protoplasm shows that it invariably comprises the elements OXYGEN, CARBON, HYDROGEN, NITROGEN, PHOSPHORUS, SULFUR, CALCIUM, MAGNESIUM, SODIUM, POTASSIUM, IRON, and CHLORINE. Probably other elements are always included; certainly some others are found normally in the protoplasm of certain parts of various species of animals and plants. Thus, in addition to the elements just mentioned which form by far the larger part of the human body, there are also present traces of a number of other elements, such as iodine, copper, cobalt, nickel, zinc, manganese, and fluorine.

The average composition of the human body, including cellular and intercellular material, is about as follows:

Oxygen	65.00%
Carbon	18.00
Hydrogen	10.00
Nitrogen	3.00
Calcium	2.00
Phosphorus	1.00
Potassium	0.35
Sulfur	0.25
Sodium	0.15
Chlorine	0.15
Magnesium	0.05
Iron	0.004

At first glance there is nothing very striking about this list of elements. They are all common ones with which the chemist is familiar in the nonliving world. The elements in a human body are not worth more than a couple of dollars! Furthermore, quantitatively the most important compound is nothing more complex than water (H_2O), which composes more than two-thirds of the human body. But there are *combinations* of the elements which are highly significant and characteristic, and result from the capacity of carbon, hydrogen, and oxygen, or carbon and hydrogen together, to form the numerous complex compounds which in turn supply the basis for intimate associations with other elements. As a matter of fact, the bulk of protoplasm is composed of carbon, oxygen, hydrogen, and nitrogen associated with each other in an apparently infinite series of relationships, in which the carbon seems to be the indispensable bond that links all other elements in organic unity. Some of these compounds are relatively simple, but the majority consist of elaborate atomic arrangements, and not a few represent molecular complexes of hundreds and even thousands of atoms.

The COMPOUNDS OF CARBON which are characteristic of protoplasm fall into three chief groups: proteins, carbohydrates, and fats.

PROTEINS invariably consist of the elements carbon, oxygen, hydrogen, nitrogen, and usually sulfur, and frequently phosphorus, iron, etc. Examples are GLIADIN ($C_{685}H_{1068}N_{196}O_{211}S_5$) of wheat, ALBUMIN of the white of egg, CASEIN of milk, and MYOSIN of lean meat. The nitrogen particularly distinguishes proteins from the other compounds of the living complex and, as we shall see later when considering the chemical processes in animals and plants, is largely responsible for

their commanding position as the chemical pivot around which revolve a multitude of reactions characteristic of biological phenomena. Study of the relationship of nitrogen to the other chemical elements of proteins has revealed that the protein molecule is basically a huge complex of linked AMINO ACIDS, an amino acid being an organic acid in which one hydrogen atom is replaced by the amino group, NH_2 .

The amino acids are the nitrogenous compounds, the building blocks, from which organisms construct proteins and then protoplasm. An animal, for example, with various proteins available in its food, chemically disrupts them into their amino acid constituents, and then takes an amino acid here and another there to construct the specific proteins it requires. If individual amino acids are supplied, the animal employs them. The body can, however, synthesize about half the amino acids, though usually not at a rate sufficient for active growth. Accordingly, as will be seen later, animals are largely dependent on plants for the essential amino acids.

Although there are less than two dozen different amino acids found in proteins, an almost infinite number of the latter can be built by various combinations of amino acids through their extraordinary ability to link together in chains. Most proteins contain practically all the amino acids, some are deficient in one or more, others are particularly rich in one of them, while still others contain amino acids peculiar to themselves.

Furthermore, besides the so-called simple proteins composed solely of amino acids, there are many which comprise in addition other radicals, such as the hemoglobins which contain hematin and the nucleoproteins with nucleic acid. Indeed, it seems highly probable that the specific structure of each animal and plant depends upon the chemical specificity of its proteins, but for our purposes it is sufficient to recognize that the presence of proteins and the power of forming them is a prime chemical characteristic of living matter. Apparently these huge complex molecules with their high lability and consequent tendency to chemical change are fundamentally associated with the plasticity and responsiveness of the protoplasmic system itself.

CARBOHYDRATES consist of various combinations of carbon, hydrogen, and oxygen, the latter elements typically being present in the proportion found in water (H_2O). Though simpler in chemical structure than proteins, they range in complexity from the simple sugars, or monosaccharides such as GLUCOSE and FRUCTOSE, to polysaccharides

such as STARCH, GLYCOGEN, and CELLULOSE. Cotton and paper are nearly pure cellulose.

FATS are composed of the same elements as carbohydrates, but in quite different arrangements. The proportion of oxygen is always less, and therefore they are more oxidizable and richer in potential energy. Fats represent the union of an acid (fatty acid) and glycerol. Common examples are found in butter, cod liver oil, olive oil, etc. Various other lipids, closely related to but more complex than the true fats, are represented by the LECITHINS and CHOLESTEROL, universally present in protoplasm.

Proteins, carbohydrates, and fats comprise large classes of substances which are distinctly characteristic of living matter and are not found in nature except as the result of protoplasmic activity, although biochemists can now artificially construct certain fats and carbohydrates as well as the amino acid constituents of some proteins. Proteins undoubtedly have the most important place in the organization of protoplasm, while the carbohydrates and fats contribute largely to the supply of available energy. However, it is impossible to draw a hard and fast distinction in regard to their respective contributions because, as we shall see later, carbohydrates form the foundation upon which proteins are built by green plants.

Proteins, carbohydrates, and fats are frequently referred to as the foodstuffs, but it will be recognized that, while these constitute the chief groups, all the constituents of protoplasm must be available. Accordingly, inorganic salts, water, and free oxygen are really foodstuffs too. Furthermore, another class of organic substances, the VITAMINS, are absolutely necessary. These accessory food substances are still usually referred to as vitamins A, B, C, etc., though now the chemical constitution of many of them is known. An inadequate amount of a particular vitamin in the diet gradually results in abnormalities and may result in death if the deficiency is not corrected. Scurvy, for instance, is a disease induced by the lack of vitamin C, which is also known as ascorbic acid. Finally, an immense group of organic catalyzers, called ENZYMES, must be mentioned. These are not food substances but special proteinlike bodies formed in organisms where they function in inducing and accelerating chemical processes. (Fig. 107; pp. 148-149; 153-154.)

However, after all has been said, our knowledge of the chemical complexities of protoplasm offers only an inadequate conception of

their relationship to life. Moreover, it appears that there is relatively little increase in chemical and physical complexity from the lowest to the highest organisms. Rather has evolution taken place in terms of organization.

METABOLISM

It has been emphasized that living matter is continually changing, and this fundamental fact is reflected in nearly all attempts to define life. Aristotle described life as "the assemblage of operations of nutrition, growth, and destruction"; deBlainville, as a "twofold internal movement of composition and decomposition"; and Spencer, as "the continuous adjustment of internal relations to external relations."

This interaction consists of chemical and physical processes in which combustion, or oxidation, is of primary importance. Over a century ago it was shown that animal heat results from a slow burning of the materials of the body, involving the intake of oxygen and the liberation of carbon dioxide; and further, that for a given consumption of oxygen and liberation of carbon dioxide, about the same amount of heat is produced by an animal as by a burning candle. In other words, the oxidation of the complex compounds which enter the body as food is definitely proportional to the amount of energy that the body gives out, just in the same way as the amount of work performed by a steam engine and the amount of heat it liberates bear a strict proportion to the consumption of fuel. As someone has well said, "the symbol of the organism is the burning bush of old."

But the foundations for a MECHANISTIC interpretation of life are to date very fragmentary. The synthesis of physicochemical facts about the parts of organisms cannot reconstruct the living being because the analytical method of investigation disregards and destroys organization, and organization is life. When only physical and chemical methods are employed, only physical and chemical facts are forthcoming. "The whole is not to be understood by an analysis of its parts any more than an architectural masterpiece can be comprehended by chemical and physical analysis of the stones of which it is built. The conception of the organism as a physicochemical machine encounters the insuperable difficulties of explaining a machine which runs itself, repairs itself, alters itself to meet the exigencies of surrounding conditions, and reproduces itself; and what is still worse, attains its final form by developing from a simple beginning through an orderly

sequence of forms and evolves through time into a succession of machines of ever-increasing complexity of construction."

One naturally asks whether metabolic processes involve a special form of energy, a "vital force," which is quite different from chemical and physical energy, and which controls form and development and directs activities. This is the philosophically important question of VITALISM. From the standpoint of biology we may say that no instrument yet devised has detected such energy, and until some unique vital energy can be made evident to one of the human senses, it does not fall within the scope of science: science can neither deny nor affirm its existence. Perhaps for the moment it is sufficient to realize that unique phenomena may emerge from new relationships; relationships change the properties of things. The properties of molecules are those which the atoms have when they are in the molecule, and the phenomena of life depend on, and emerge from, the physicochemical constituents of protoplasm when, and only when, these constituents are organized as protoplasm. A living cell exhibits "many unpredictable properties beyond those of the mere sum of its individual constituent molecules and compounds, or the additive resultants to be derived from any arrangement of them." Biology is indeed committed to a thoroughgoing physico-chemical analysis of organic structure and function, but it is not committed to a reduction of its concepts to physico-chemical levels. (pp. 24, 646-647.)

However, it is important to note that many of the grosser phenomena of life are being gradually restated in terms of the physical sciences. So it appears clear that the organism is a system for transforming energy, transforming the potential energy stored in chemical compounds of its own substance into the various vital processes of living, into work performed. It is in this transfer of energy from one form to another that we find exhibited the activities which are most distinctive of living things. In these processes of metabolism many complex substances rich in potential energy, which have entered as food and have been, in whole or part, added to the protoplasmic system, are reduced to simpler and simpler compounds and finally, with their energy content nearly or entirely exhausted, are eliminated as EXCRETIONS. Obviously, if life is to persist, this continual waste must be counterbalanced by a proportionate intake of food in order to renew the supply of energy and to provide the materials which, after preliminary changes, are made into an integral part of the living organism.

MAINTENANCE AND GROWTH

In this manner the living animal or plant is partially consuming and rebuilding itself continually; metabolism is a dual process. When constructive metabolism, ANABOLISM, keeps pace with destructive metabolism, KATABOLISM, the individual remains essentially unchanged—it balances its account physiologically; this MAINTENANCE is the normal condition of adult life. But one of the most obvious results of constructive metabolism is growth, or permanent increase in the size of the individual. Growth as a rule is most rapid during the early part of the individual's existence, or youth. Indeed, at birth a child is about a billion times larger than the egg cell from which it has developed. Later in life, when maturity has been attained, growth chiefly occurs in making good, in so far as may be, the wear and tear incidental to living, and in providing for reproduction.

Growth, as well as maintenance, means that the organism takes the materials which it receives in the form of food, transforms them, and fits them into the protoplasmic organization here and there throughout as needed. This INTERSTITIAL GROWTH by chemical synthesis is in striking contrast to the growth, for example, of crystals that increase in size merely by the addition to the surface of new material of the same kind from the saturated solution, the mother liquid, in which they are suspended. "Crystal growth is passive; organic growth is active." Protoplasm, with materials and energy taken from its environment, constructs more protoplasm, and endows the nonliving with its own unique organization. It makes more life stuff and, if the available materials are adequate, the living substance tends to increase indefinitely, or until the specific limits of the cell or organism are attained. This protoplasmic growth, involving increase of both cytoplasm and nucleus, is characteristic of living matter. It is cell growth and precedes reproduction.

REPRODUCTION

So far as is known, living matter arises only through the activities of pre-existing living matter. We have seen that this transformation is continually going on in anabolic processes in the animal or plant, and brings about repair and growth of the individual; but it is in reproduction that what may be termed the overgrowth of the individual results in the production of a new one.

The phenomena of reproduction and growth are therefore intrinsically the same; each is the result of a preponderance of the constructive phase of metabolism. The single cell, whether a whole organism or a single unit of a complex body, increases in volume up to a certain limit and then divides. In the former case two new individuals replace the parent cell; in the latter, the complex body has been increased to the extent of one cell. In both cases cell division has resulted in cell reproduction. Thus cell division, preceded by growth of cytoplasm and nucleus, is always reproduction, though it is customary and convenient to restrict the term reproduction to cell divisions which result in the formation of new individuals—single cells or groups of cells which sooner or later separate from the parent organism and develop the new generation. Reproduction provides for the continuation of the race. (Fig. 7.)

IRRITABILITY AND ADAPTATION

The discussion of metabolism has emphasized the close interrelationship between the living organism and its surroundings, and the dependence of life upon the interplay and interchange between protoplasm and its environment. As a matter of fact the plant or animal retains its individuality—lives—solely by its powers of developing and maintaining exquisite adjustments, ADAPTATIONS, to its surroundings. This results from the IRRITABILITY of living substance: its inherent capacity for reacting to environmental changes by changes in the equilibrium of its matter and energy. The inciting changes, known as STIMULI, may be chemical, electrical, thermal, photic, or mechanical, but the nature of the response is determined rather by the fundamental character of protoplasm itself than by the nature of the stimulus. Muscle cells respond by contracting, regardless of the nature of the stimulus.

The reactions of organisms usually result in MOVEMENT, one of the most obvious manifestations of life. Movement depends in every instance upon tumultuous ultramicroscopic physicochemical changes of protoplasm itself. It is to these changes that, in the last analysis, we must look for the energy which brings about the visible movements in animals and plants.

The obvious movement of the higher animals is, of course, the result of the contraction (shortening and broadening) of the individual muscle cells forming the muscular system. However, movements also occur in other cells of the body, for example, the flowing move-

ment of the white blood cells which is similar to that of certain unicellular animals, the amoebae, and so is known as AMOEBOID movement. (Fig. 16.) The protoplasm of an active amoeba is one of the most striking and beautiful sights under the microscope; the cell ceaselessly changing its form as one outflowing, or PSEUDOPODIUM, follows another, and the whole cell advances in the direction of the main stream. When particles of food are met, the pseudopodia flow around them, and when they have been digested within the cell, the protoplasm moves onward leaving the waste material behind. In many



FIG. 16. A small, very active amoeba showing rapid changes in shape resulting in the formation of pseudopodia. The clear outer layer of ectoplasm flows first and is followed by the inner, more granular endoplasm containing the nucleus (dark sphere) and contractile vacuole (light sphere). Highly magnified. (Modified, after Verworn.)

other unicellular animals, such as *Paramecium*, an active, internal circulation, or CYCLOSIS, of the protoplasm is visible, and the cells of certain multicellular plants, such as *Elodea*, afford remarkable exhibitions of rotation and circulation of protoplasm. (Fig. 10.)

Moreover, locomotion in *Paramecium* and related species is effected by myriads of short, vibratile, threadlike prolongations of the cytoplasm, termed CILIA; whereas other unicellular forms, such as *Euglena*, move by long whiplike processes, or FLAGELLA. Finally, ciliated cells form definite membranes that serve various important purposes in the bodies of higher animals. Thus the food and respiratory currents of mollusks, such as the clam, are induced by ciliary action, and certain internal passages of the human body are provided with cilia for the transport of materials. (Figs. 6, 10, 390.)

These and all other reactions of living matter result from its irritability and involve not only *response* to a stimulus but also *conduction*, so that the cell, or group of cells, as a whole is directly or indirectly influenced—a condition which attains its fullest expression in the

higher animals with a nervous system. Every organism responds as a coordinated unit: an individual. It adapts itself structurally and functionally to the necessities of its existence. This power of adaptation, as exhibited in active adjustment between internal and external relations, overshadows every manifestation of life and contributes more than any other factor to the imposing gap that separates the organism from the inorganic world.

The properties described above—unique organization, chemical composition, metabolism involving the power of maintenance, growth, and reproduction, and irritability resulting in the power of adaptation—are individually and collectively characteristic of living matter. Any formal objections that may be raised to the diagnostic character of one or another of these characteristics serve only to emphasize the unique conditions associated with the living state.

In our discussion so far, an endeavor has been made to describe the characteristics of life in terms of organizational units, the cells, and of the physical basis, protoplasm. But we have not attempted formally to define life or protoplasm because they are unique and it is impossible to resort to the trick of comparing them with something else; and because the expressions protoplasm and life are generalizations. Protoplasm indicates that all animals and plants have an essentially similar foundation, and life indicates that they exhibit certain characteristic actions and reactions. The living organism is characterized by a permanence and continuity of individuality correlated with specific behavior, and these it transmits to other materials which it makes a part of itself, and to its offspring at reproduction. "What is more impressive than the duration of frail living matter, showing a stability far greater than the physiographic features of the earth's surface, unless it be the richness of its evolution within the period of its duration." Perhaps the existence of life must be considered as an elementary fact that cannot be explained, but must be taken as a starting point in biology, as, in a similar way, the quantum of energy and the existence of elementary particles form the foundation of atomic physics.

CHAPTER IV

Metabolism of Organisms

Nature, which governs the whole, will soon change all things which thou seest, and out of their substance will make other things and again other things from the substance of them, in order that the world may be ever new.

—*Marcus Aurelius*

Life is known to us only in the form of individual organisms. It is therefore fitting next to consider certain concrete examples of unicellular plants and animals, which exhibit in relatively simple form within the confines of a single cell, the essentials of all the fundamental life processes. Many of these processes we shall later have occasion to describe in their complex expressions in the higher organisms. Our present interest in these simple forms is chiefly to illustrate the complex nutritional interdependence existing among three great groups of organisms: green plants, animals, and colorless plants. At first glance it may appear that a large multicellular organism, such as a tree or a horse, would afford a more suitable example, but since the fundamental distinction between plants and animals is chiefly a question of metabolism, there are advantages in studying the problem in single cells, where attention is not distracted by complexity of structure.

GREEN PLANTS

Unicellular green plants are distributed all over the world and adapted to maintain life under a great variety of conditions. These microscopic types are found, for example, forming green coatings on the bark of trees, and scums on puddles and ponds, or being blown about in dust by wind. Of the many hundreds of species *Protococcus vulgaris* is selected for consideration because of the simplicity of its structure and life history, and because it is readily obtained for study.

PROTOCOCCUS

Protococcus as a unicellular plant is invisible to the naked eye, but like many other microscopic forms, it makes up in numbers for the small size of the individual. (Fig. 17.)

Examined under a microscope, the organism is seen to consist of a more or less spherical mass of protoplasm with a nucleus centrally located. Most of the cytoplasm surrounding the nucleus is specialized to form a PLASTID which contains green pigments; this frequently gives a greenish color to moist surfaces of rocks, tree trunks, fence posts, and flower pots. The entire organism is enclosed within a distinct, rigid cell wall, secreted by the protoplasm and composed of CELLULOSE, a starch-like carbohydrate especially characteristic of plants.

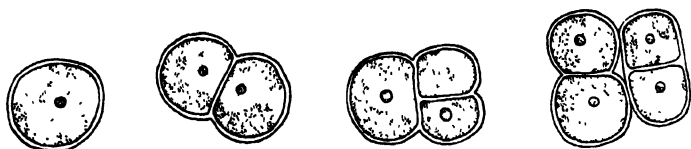


FIG. 17. *Protococcus vulgaris*: a primitive, unicellular green plant, as shown by the cell at the left. Temporary cell groups of two or more cells are also formed when a cell divides and the daughter cells remain attached. Highly magnified.

Since *Protococcus* is a single cell, we find reproduction exhibited in simplest terms: under favorable conditions the cell divides, and the two resultant cells sooner or later separate. Sometimes, however, several cell divisions occur before the cells separate and thus there is formed a temporary multicellular body, but one without any physiological division of labor between the cells, because all are independent in their vital activities. Moreover, this tendency of *Protococcus* to form temporary cell groups suggests the type of development which was taken during plant evolution when the multicellular body was established. We may now turn our attention to the characteristic life processes of green plants, as exemplified by *Protococcus*.

Nutrition. *Protococcus* lives, grows, and multiplies in a moist environment, exposed to sunlight, and it is therefore in this environment that we must look for the materials with which it constructs protoplasm, and secures the energy for all its activities. Furthermore, since the organism is enclosed within a cell wall, its income and outgo must

be gases or materials in solution in order for them to pass through the wall to the living protoplasm.

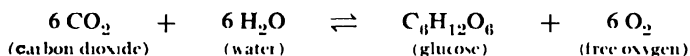
In short, *Protococcus* takes simple inorganic materials from its surroundings, such as carbon dioxide, water, and mineral salts. These are relatively stable compounds and therefore practically devoid of available energy; but, through the radiant energy of sunlight, the organism shifts and recombines the constituent elements in such a way that products rich in potential energy result. *Protococcus* exhibits the prime distinguishing characteristic of green plants: the power to construct its own foodstuffs.

The key to this power of chemical synthesis by light, PHOTOSYNTHESIS, resides in a highly complex chemical substance, called CHLOROPHYLL, which consists of two very similar but distinct pigments. Chlorophyll is segregated in plastids, special cytoplasmic bodies noted above, which give to *Protococcus* during its active phases and to the foliage of plants in general their characteristic green color. Plastids containing chlorophyll grow and divide and are known as CHLOROPLASTS. Chlorophyll arrests and transforms a small part of the energy of sunlight which reaches it, in such a way that the plant protoplasm can first employ this energy for food synthesis and later release the energy to maintain vital activities.

The first major step in the photosynthetic process is a combination of carbon with hydrogen and oxygen to form a carbohydrate. *Protococcus* secures these elements from carbon dioxide and water by a process of molecular disruption. We know that when charcoal, for instance, is burned, the carbon of the charcoal and oxygen from the air unite to form carbon dioxide, and energy in the form of light and heat is liberated. Obviously an equal amount of energy must be employed to separate the carbon and oxygen atoms associated in a carbon dioxide molecule or to separate hydrogen and oxygen in a water molecule. The kinetic energy of solar radiation, which the green plant is able to utilize in photosynthesis, is accordingly represented in the potential molecular energy which exists between free oxygen and the carbon compound, that is to say, kinetic solar energy has become transformed into potential molecular energy. It is apparent from recent studies with isotopes that the active green plant in sunlight is continually separating the hydrogen from the oxygen of the water molecules. The oxygen is liberated as free oxygen, whereas the hydrogen which has been separated from the oxygen is combined with carbon dioxide to form a

carbohydrate, the simple sugar, glucose, with a molecular formula of $C_6H_{12}O_6$.

The conventional equation for the photosynthetic reaction is:



However, the processes involved are by no means as simple as this equation implies. It appears that a relatively simple compound, probably formaldehyde (CH_2O), is first produced from carbon dioxide and water, then six molecules of this substance are finally united so that a molecule of a simple sugar, glucose, is formed. Although there is a lack of conclusive data in regard to the intermediate stages of food formation, the equation stated affords a satisfactory expression of the end result of photosynthesis.

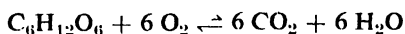
The first major step in food synthesis, the formation of the glucose molecule having been accomplished, the green plant usually transforms the sugar by the removal of a molecule of water from each glucose molecule and forms *starch* ($C_6H_{10}O_5$)_n for future use as fuel or as a basis for further synthesis.

It has been noted that the chief characteristic of proteins as compared with carbohydrates (sugars, starches) is the presence of nitrogen, and this element must be added to the carbohydrate already constructed as the next step toward protein synthesis. The green plant must employ nitrogen in simple combinations, chiefly nitrates; this is a fact of prime importance, for typically, as will appear later, animals and most colorless plants also require nitrogen but in more complex combinations. Accordingly, by the addition of nitrogen to the carbohydrate molecule, more complex nitrogenous compounds, *amino acids*, are built by green plants and these compounds in turn form the foundation for the synthesis of the immense variety of proteins. Little is known of the complex chemical processes associated with protein construction, and nothing about the actual incorporation of the proteins as an intrinsic part of the architecture of living matter, but it is evident that synthesizing *enzymes* are of basic importance. Enzymes are unique proteins which are known only as products of living protoplasm and are the activating substances (catalytic agents) for chemical transformations in which, however, they themselves take no integral part. How these enzymes are produced in the cytoplasm and how they function are highly significant problems.

At all events *Protococcus* takes the raw elements of living matter

and by the radiant energy of sunlight, which its chlorophyll traps, constructs carbohydrate, protein, protoplasm. In other words, the green plant is a synthesizing agent, building up highly complex and unstable molecular aggregates brimming over with energy received from the sun. So a green plant, whether *Protococcus* or elm, by this AUTOTROPHIC nutrition, manufactures its own food for itself as well as for the living world in general, and incidentally, as it were, continuously replenishes the available supply of free oxygen without which plants and animals could not exist.

Respiration. As already stated, protoplasm is always at work—to live is to work—and this requires the expenditure of energy: the same energy that chlorophyll has secured for the plant and stored away in its food. Therefore the food must be burned, that is, oxidized, in order to release the energy, and for this process the plant must have available a supply of free oxygen. *Protococcus* obtains this oxygen from the environment and also from that liberated through photosynthesis. The process involved in releasing this energy may be represented by the equation:



This, it will be noted, is the reverse of the equation for photosynthesis. The intake of free oxygen by a cell and the outgo of carbon dioxide and water, the chief products of combustion, together constitute RESPIRATION. This is essentially the securing of energy from food, involving the release of carbon dioxide and the intake of oxygen. And this interchange of gases between the living matter and its surroundings is characteristic not only of *Protococcus* and all green plants, but of animals and all living things. Plants respire just as truly as animals, though the more active life and complex bodies of most animals require an elaborate respiratory apparatus in order that an adequate respiratory interchange may be maintained with the necessary rapidity.

The green plant may be regarded as a chemical machine for the transformation of radiant energy from the sun into lifework; the matter and energy which enter and leave the organism obeying, to the best of our knowledge, the fundamental laws of matter and energy that govern the nonliving world.

Some idea has now been obtained of one living organism, *Protococcus*, a unicellular plant reduced to the simplest terms and provided with chlorophyll. It is also evident that this chlorophyll is the key to

the photosynthetic activity of the green plant. In other words, the expression "green plant" when employed by the biologists does not refer specifically to the color of a plant (in some cases it may appear, for example, red or brown), but to the presence of chlorophyll by virtue of which the plant is a constructive agent in nature. The typical plant, equipped for photosynthesis, has the power to manufacture its complex foodstuffs from relatively simple compounds and, in particular, to utilize nitrogen in the form of nitrates.

We turn now from the essentially constructive agents in nature to the destructive agents, from the collectors of energy to the energy dissipators, from the green plants to animals, and finally to the colorless plants which lack chlorophyll.

ANIMALS

There is probably no better introduction to the study of animal biology than that afforded by an amoeba, such as *Amoeba proteus*, a common organism of ponds, ditches, and decaying vegetable infusions. Amoebae, frequently referred to as the simplest animals, are representatives of the great group of one-celled animals, or PROTOZOA. Members of the Protozoa are found in almost every niche in nature and, like the unicellular plants, or PROTOPHYTA, are important because, although each individual is very small in size, the number of individuals is inconceivably large, and some species are harmful parasites. Collectively Protozoa produce profound changes in their environment. (Figs. 7, 13, 16; pp. 527-536.)

AMOEBA

In order to study an amoeba, it is necessary to magnify the cell one hundred times or more. This done, the animal appears as a more or less irregular mass of viscid granular material, rather slowly changing its shape and thereby moving very slowly. As a matter of fact, an amoeba is essentially a naked bit of protoplasm, without obviously specialized parts. However, careful study reveals that the organism is differentiated into cytoplasm and nucleus; it is an animal cell. (Fig. 13.)

There are no specialized locomotor organs, but now and again the clear outer layer of protoplasm, or ECYTOPLASM, flows out at one point, followed by the internal granular ENDOPLASM, so that an irregular cell projection, or PSEUDOPodium, is formed. There is no permanent mouth; food is engulfed and brought into the cytoplasm by the proto-

plasm flowing about each microscopic particle as the opportunity offers. There is no permanent digestive or excretory apparatus.

Amoeba, under favorable environmental conditions, grows rapidly and, when it has attained the size limit characteristic of the species, reproduction by cell division, BINARY FISSION, takes place, with the result that from the single parental cell there are formed two smaller individuals, complete in all respects. These daughter cells, in turn, grow and repeat the process so that within a few days the original amoeba has divided its individuality, so to speak, among a multitude of descendants. (Fig. 7.)

In summary, an amoeba performs all the essential vital functions that characterize an animal. Such being so, it is important to compare the metabolism of amoeba, the animal, with that of *Protococcus*, the green plant.

Nutrition. The food of amoeba consists chiefly of other microscopic animals and plants that it meets in its aquatic environment. Coming in contact with its prey, pseudopodia are extended by the amoeba, and soon the microscopic bit of food material is enclosed within the endoplasm of its captor. Here the food is surrounded by a droplet of fluid, to form a GASTRIC VACUOLE, into which the endoplasm secretes chemical substances containing enzymes, which soon digest the complex organic compounds rich in potential energy and in building material. Finally, this food material, which shortly before was the protoplasm of another organism, is incorporated into amoeba protoplasm; matter and energy are supplied in this way, and the animal lives and grows. (Fig. 18.)

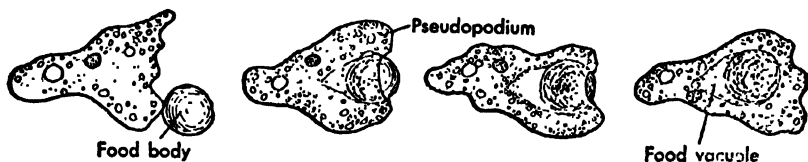


FIG. 18. Diagrams to illustrate the ingestion of a food particle by an amoeba. The drawings were made at short intervals and show contact with the food particle (*left*), the ingestion and formation of the food vacuole (*right*). (From Mavor, after Jennings. Redrawn.)

This HOLOZOIC method of obtaining food is essentially different from the autotrophic type described for *Protococcus*. In amoeba solid particles of food, tiny animals and plants, are taken into the cell, and

since the chief organic constituents of protoplasm are proteins, associated with carbohydrates and fats, it is clear that the income of the animal organism from its environment is, unlike that of the green plant, chiefly ready-made complex foodstuffs. In other words, all animals like an amoeba require relatively complex chemical compounds rich in potential energy: proteins, carbohydrates, and fats. Of these foods, proteins or their constituent amino acids are absolutely indispensable, because it is only from this source that nitrogen is available for tissue repair and growth. But the green plant, through its chlorophyll apparatus, is able to take from its environment materials largely devoid of energy and to rearrange them and endow them with potential energy received in kinetic form from sunlight. Plant tissues then use the complex foods they have formed in essentially the same way as do animal tissues.

Respiration and Excretion. The process of respiration in amoeba, as in *Protococcus*, involves the breakdown of food and protoplasm by a process of oxidation which involves the intake of free oxygen and the liberation of carbon dioxide and water. Nitrogenous wastes, such as UREA, as well as inorganic salts, are also excreted. This interchange in the Protozoa takes place over the entire surface of the animal, aided by a CONTRACTILE VACUOLE that expels fluid from the cell. So the animal, like the plant, returns to its environment various elements in simple combinations devoid or nearly devoid of available energy. We have stated that green plants are essentially constructive and animals destructive agents in nature. It is apparent, of course, that green plants are both constructive and destructive, but the constructive processes of green plants are necessary and sufficient not only for themselves but for all living things. "Plants are manufacturers of munitions which they themselves and animals explode in the never-ending battle of life." The holozoic nutrition of animals depends upon the holophytic nutrition of green plants.

Careful consideration of the income and outgo of green plants and animals shows that, although animals are dependent on plants for their complex foodstuffs, animals do not return their nitrogen to the outer world in a form simple enough to be available for green plants. For example, urea, $\text{CO}(\text{NH}_2)_2$, must be transformed into nitrates before it can be utilized by a green plant.

Furthermore, since both plants and animals eventually die, large stores of organic matter are locked up in the complex compounds of

the dead tissues. Clearly, there must be some way of completing the cycle of the elements, for otherwise life, as we know it, could not have continued long on the earth; all the essential elements would soon have been removed from circulation. This cycle is completed by the COLORLESS PLANTS; these are plants which, because chlorophyll is not present, lack the power of photosynthesis and so in most cases are dependent for food on substances more complex than green plants require, though usually not so complex as animals demand. Decay organisms find the supply for their nutritive requirements in plant and animal tissues. If they attack the dead tissues they are SAPROPHYTES. Unfortunately many of the colorless plants are PARASITES; that is, they attack the tissues of living organisms causing disease and death.

COLORLESS PLANTS

As representative of the many diverse types of colorless plants which, lacking chlorophyll, are without the power of photosynthesis, we select the vast group known as the BACTERIA. It is not practical to focus attention on one particular species of bacteria, as we have done in considering life functions in green plants and animals. Instead we shall discuss in general terms the group as a whole, referring now and then to certain species of bacteria to illustrate essential points.

BACTERIA

The wide distribution of the protozoa is exceeded by that of the bacteria. Representatives are literally found everywhere: floating with dust particles in the air, in salt and fresh water, in the water of hot springs, frozen in ice, in the upper layers of the soil, and in the bodies of plants and animals. Bacteria have received considerable attention under the names of "microbes" and "germs," owing to the fact that certain types subsist within or on the human body as parasites and bring about disturbances, chiefly chemical, which we term disease. Aside from these parasitic forms which are relatively few in number, human life and life in general on the earth could not long continue without the services of bacteria. Indeed, they have practically ruled the world since they first secured a foothold when the earth was young.

Among the bacteria are the smallest cellular organisms known. Probably one one-thousandth inch is about the average length of the rodlike bacteria, but some species are less than one fifty-thousandth inch in length and much less in breadth. None of the typical forms

comes within the range of unaided vision, and some bacteria are revealed only by the highest powers of the microscope. There is in fact room and to spare for billions of bacteria cells to live in a thimbleful of milk. The small size and similarity of structure of many of the bacteria render their study particularly difficult, and accordingly they are grouped and classified largely on the basis of chemical changes which they produce in their surroundings, rather than on the basis of structural characteristics. However, there are three chief structural types: the rodlike form, or *BACILLUS*; the spherical form, or *COCCUS*; and the spiral form, or *SPIRILLUM*. Either bacilli or cocci may be associated in linear, branching, or platelike series, or grouped together in colonies. (Fig. 19.)

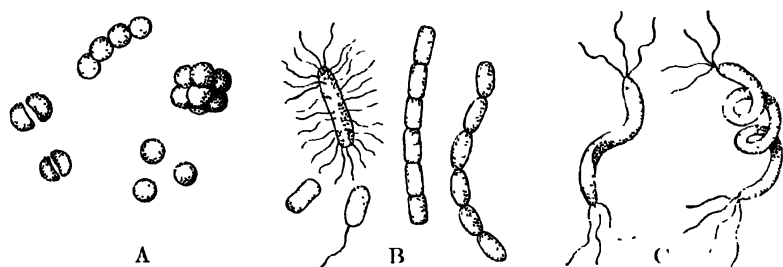


FIG. 19. Drawings to illustrate major structural types of bacteria. A, cocci; B, bacilli; C, spirilla. Note the tendency of the cells of the cocci and bacilli to adhere. Very highly magnified.

An individual bacterium is regarded as a single cell, though in most species there is no definite nucleus, the chromatin material being distributed as granules throughout the cytoplasm which is enclosed within a cell wall. Some bacteria show active movements by means of hair-like projections of the cytoplasm, the flagella, as is the case in the common spirillum of decaying vegetable infusions.

As in other unicellular organisms, reproduction is by binary fission, or cell division, which, under favorable conditions, may occur as often as every fifteen minutes. The vast multitude of cells produced in this way from a single bacterium, before long exhausts the food supply and contaminates with excretion products the medium in which they are living, so that continued growth is inhibited. In many species, under these circumstances, the protoplasm within the cell wall assumes a spherical form and secretes a protective coat about itself, and thus it enters upon a resting state. In this *SPORE* form bacteria cells can with-

stand drying, variations in temperature, and other conditions—in certain cases even strong carbolic acid—to which they would readily succumb in the active state; thereby the organisms remain alive during periods of unfavorable conditions and are ready to start active life again when the opportunity occurs. It is certainly fortunate for man that most of the parasitic species are unable to form spores, and so are destroyed when conditions are unfavorable.

CYCLE OF ELEMENTS IN NATURE

Carbon dioxide, as previously stated, is the source from which green plants derive the carbon that they synthesize to form carbohydrates, fats, and proteins. Animals directly or indirectly feed on plants, so that the ultimate source of the carbon of animals is likewise the carbon dioxide of the atmosphere. Although both plants and animals by their respiratory process are continually returning to the outer world some of this carbon as carbon dioxide, it is evident that relatively enormous amounts of carbon are nevertheless being taken out of circulation and locked up in organic compounds in the bodies of the plants and animals. For example, it has been estimated that about one-half the weight of a dried tree trunk is contributed by carbon.

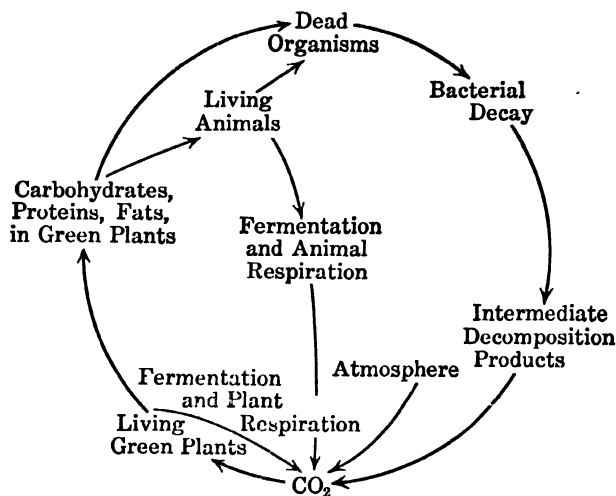


FIG. 20. A schematic representation to show the circulation in nature of the element carbon: the carbon cycle involving green plants, animals, and decay organisms.

The same general segregation is going on in regard to nitrogen and other essential elements. For instance, the green plants take nitrogen in the form of nitrates, and store it away in the proteins; and again as noted with carbon, animals get their nitrogen from plant proteins, so that the ultimate source of animal nitrogen is the same as in plants. In an essentially similar manner it is possible to trace the cycles of other chemical elements associated with protoplasm. The cycles described for carbon and nitrogen are crucial, however, and illustrate the fact that both green plants and animals are continually taking certain elements from and returning them to their environment; nevertheless the amount taken away is greater than the amount returned. (Figs. 20, 21.)

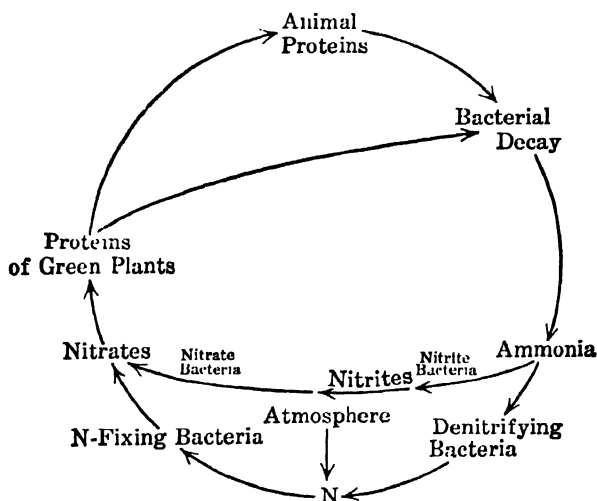


FIG. 21. A schematic representation to show the circulation in nature of the element nitrogen: the nitrogen cycle involving green plants, animals, and decay organisms.

The living agents which restore to the inorganic world the elements removed by green plants and animals are the colorless plants, such as the bacteria, molds, yeasts, etc. When an animal or plant dies, decay sets in almost immediately—a process which means that the complex chemical compounds are slowly but surely reduced to simpler and simpler substances until literally only dust remains. Although undoubtedly many of these compounds would automatically, so to speak, tend to simplify, nevertheless simplification is hastened and, in fact, chiefly

maintained by organisms of decay, such as bacteria. The decay processes, FERMENTATION and PUTREFACTION, occur through the use of enzymes which the colorless plant cells form in their cytoplasm and release into the environment. Carbohydrates and fats are transformed into carbon dioxide and water, and the proteins are reduced to carbon dioxide, water, and ammonia (NH_3) or free nitrogen. In addition the nitrogenous wastes (urea, etc.) of animals are similarly broken down. Practically all of the complex chemical reactions associated with decay are carried on by different species of bacteria in association with their essential life processes.

Most green plants take their nitrogen chiefly in the form of nitrates, and, accordingly, it is found that another type of bacteria (NITRATE BACTERIA) acts upon ammonia released by decay processes and transforms it into nitrous acid (HNO_2). After certain chemical reactions in the soil, to form potassium nitrite, ammonium nitrite, etc., still another type, the NITRATE BACTERIA, oxidizes the nitrites into nitrates, e.g., KNO_3 or NH_4NO_3 , so that again this nitrogen is in a form which is available for use by green plants.

It should be stated, however, that there is a leak from the nitrogen cycle, since some of the nitrogen in the form of ammonia or free nitrogen escapes to the atmosphere. The greatest loss is caused by a group of DENITRIFYING BACTERIA whose metabolic activities are largely associated with changing nitrates into gaseous nitrogen which escapes into the air and so is placed beyond the reach of green plants and animals. Fortunately, there are other types of NITROGEN-FIXING BACTERIA which recapture the nitrogen from the atmosphere and return it again to the cycle of elements in living nature. These organisms are widely distributed, some living freely in the soil and others in tiny nodules which they produce on the rootlets of certain higher plants, such as beans, clover, and alfalfa. (Fig. 22.) This accounts for the fact, long known but not understood, that the leguminous plants, when plowed under, are particularly efficient in enriching the soil. Incidentally, the relationship between the bacteria and the higher plant appears to be mutually beneficial: an example of SYMBIOSIS. It is not clear whether the bacteria fix the nitrogen under the conditions existing in the nodule, or whether the higher plant fixes the nitrogen in the presence of the bacteria, or whether both share equally in the reaction. In any case, the end result is beneficial to both.

In brief, there are numerous cycles of elements in nature involving green plants and animals, and returning again the essential elements to the inorganic world through the metabolic activities of bacteria and other colorless plants. Such is the reciprocal nature of the nutritive processes of living organisms.

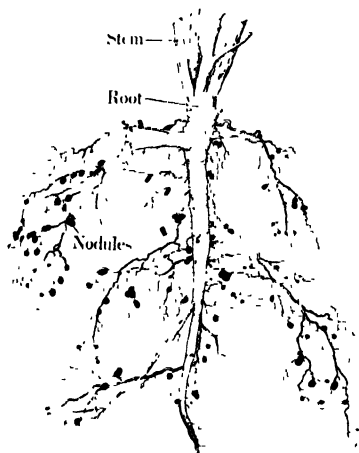


FIG. 22. Root system of a leguminous plant showing many root nodules caused by the symbiotic nitrogen-fixing bacteria. (Redrawn from Bergen and Caldwell.)

Since the chemical changes produced by the bacteria are either the direct results of, or are incidental to, the process of nutrition in these organisms, it is evident that the material taken as food by certain groups is relatively complex—for example, by those which cause the early putrefactive changes in proteins; whereas that employed by other bacteria is very simple, since they find adequate nutrition from chemical combinations less complex than those needed by green plants. Indeed, there are certain bacteria that are able to utilize carbon dioxide for the formation of foodstuffs as do green plants.

but instead of obtaining energy for the synthesis from sunlight, these autotrophic forms derive it from chemical energy liberated by the oxidation of inorganic substances in their environment. Such a process possibly represents the most primitive method of nutrition and the one from which all the other types have been derived during the evolution of life. (pp. 397-398; 521-522.)

HAY INFUSION MICROCOSM

The importance of the complex nutritional interdependence of organisms in general as well as the cosmical function of green plants—the link they supply in the circulation of the elements in nature—may be emphasized and summarized by a brief description of a hay infusion. (pp. 419-421.)

Probably nowhere is the “web of life” more conveniently or convincingly exhibited than in the kaleidoscopic sequence of events, physi-

cal, chemical, and biological, that are initiated when a few wisps of hay are added to a beaker of water. Apparently the chief components of a hay infusion are hay and water, but these merely supply the matter and energy for the interplay of various forms of life. Most of these are beyond the scope of unaided vision though chiefly responsible for the obvious changes which occur from day to day in their environment.

Ordinarily pond water, for instance, contains free oxygen and various inorganic salts in solution, and not infrequently different species of bacteria, unicellular green plants, and Protozoa. The hay soaking in the water contributes soluble salts, carbohydrates, proteins, etc. It also supplies many microscopic animals and plants which have adhered to it in dormant form and are only awaiting suitable surroundings before assuming active life again. (Fig. 23.)

A microscopical examination of an infusion when it is first made shows very few active organisms, but within a day or so, depending largely on the temperature, it reveals countless numbers of bacteria which have arisen by the reproduction of the relatively small number of

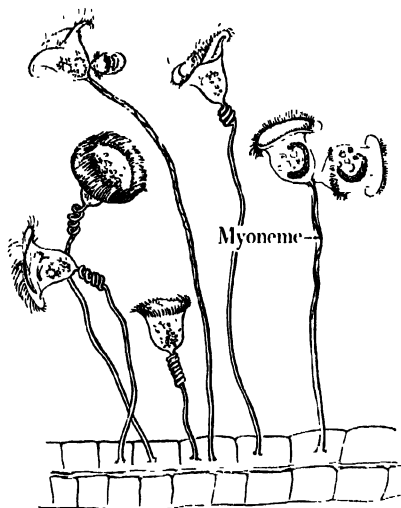


FIG. 23. The highly specialized unicellular ciliate, *Vorticella*, which is commonly found in hay infusions and other laboratory cultures. Note the process of conjugation (upper left), reproduction by binary fission (right) and the contractile stalks with the myoneme fibrils. (After Wilson, modified.)

dormant and active specimens originally present. At first the bacteria are fairly evenly distributed in the infusion, but as conditions change, largely through the chemical and physical transformations which they themselves bring about, those species which can employ oxygen in combined form (that is, in chemical compounds) find existence possible and competition less keen at the bottom of the beaker, whereas those species which are dependent upon free oxygen gather nearer the surface where the supply of oxygen is being replenished constantly from the atmosphere.

Up to this point the life of the microcosm is largely bacterial, comprising unicellular saprophytic plants which employ as food the complex decomposition products of the proteins and other substances from the hay. The process is essentially destructive and the simplified products are represented in the relatively simple excretions of the bacteria.

During bacterial ascendancy, however, another factor has been gradually intruding itself almost imperceptibly into the drama. This is the microscopic animal life which has been multiplying with increasing rapidity as conditions became more favorable, and which forthwith assumes the dominant life phase in the infusion. Among the animal forms, the first to appear are exceedingly minute flagellated Protozoa, known as monads, many species of which absorb products of organic disintegration brought about by the bacteria, while others exhibit *holozoic* nutrition, ingest solid food, including the bacteria themselves. Then tiny ciliated Protozoa, probably Colpidium and Colpoda, close relatives of Paramecium, appear in untold numbers and feed upon the bacteria. The dominance of these smaller ciliates is brought to an end after a few days by the ascendancy of larger ciliates which, though feeding to a certain extent upon the already greatly depleted bacterial population, obtain most of their food by eating the smaller ciliates. So the cycle of life continues, saprophytic forms gradually being replaced in dominance by herbivorous organisms and these in turn by carnivorous organisms. In truth, nothing lives or dies to itself. (Figs. 10, 391, 398.)

Obviously this chain of events must come to an end through the dissipation of energy brought about by the metabolic processes of the colorless plants and animals. Sooner or later the supply of potential energy stored up in the chemical compounds of the hay will have become nearly or completely exhausted, transformed into the kinetic form and expressed in the life activities of the plant and animal population.

Thus, after a few weeks, the world of the hay infusion has reached a standstill; extermination faces the population and inevitably occurs unless microscopic green plants, close relatives of Protococcus, find opportunity to develop in the energy-exhausted environment and proceed to entrap the kinetic energy of sunlight, store it up in carbohydrates and proteins, and thus restore energy in the potential form to the hay infusion.

If such occurs, the hay infusion world is a microcosm indeed. Green

plants, colorless plants, and animals gradually become reciprocally adjusted so that a self-perpetuating condition of practically stable equilibrium is established in what is termed a balanced aquarium. The rise and fall of teeming populations, made possible by the rapidly changing environmental conditions which the bringing together of hay and water initiated, is replaced by an apparently harmonious interdependence of organisms demanding different food conditions, such as we are familiar with in the world at large. The world in which life exists, the biosphere, is essentially a balanced vivarium with green plants, colorless plants, and animals maintaining their characteristic, but interdependent, metabolic activities.

CHAPTER V

The Plant Body (I)

The evidence seems to show beyond question that our present species of plants have descended by gradual evolution from simpler and fewer species which formerly existed—back, it is possible, to a single kind which thrived in remotest antiquity.

—Ganong

Nearly all stages exist between the simplest unicellular plant body, such as exhibited by *Protococcus*, and the highly complex multicellular body of the familiar flowering plants, or SEED PLANTS. A simple multicellular plant type is found among the threadlike, or filamentous, green algae, commonly called pond scums. In *Spirogyra*, a common representative of this group, the plant body consists of a series of tubular cells attached end to end. This organism may be regarded as a colony of cells, since the individual cells of a filament are essentially independent in their activities and identical in structure. Occasionally *Spirogyra* is attached instead of floating free, whereas in many other similar species, such as *Ulothrix*, the filaments are anchored by specialized cells, or HOLDFASTS. (Figs. 24, 204.)

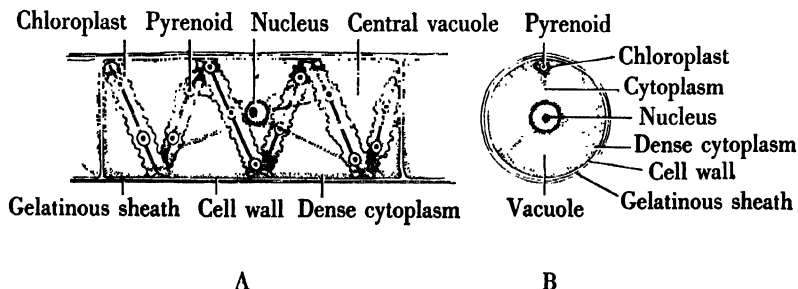


FIG. 24. Drawings of a cell of the filamentous algae, *Spirogyra*, as seen in longitudinal section (A), as seen in transverse section through nucleus (B). Highly magnified. (Redrawn from Smith and others.)

Even more common are plant bodies composed of branching filaments of cells. The branches may all be similar, or there may be a chief axis with lateral branches of different form. Frequently the branches, though still composed merely of filaments of cells placed end to end, may show, for example, much larger chloroplasts and be more active in photosynthesis. Even in so simple a plant, cellular differentiation and physiological division of labor are evident.

The next specialization in plant structure relates to the character of growth. Whereas in simple unbranched filamentous plants growth takes place, as a rule, by the division of all of the cells composing it, in the branched types growth is usually restricted to one or more cells situated near the end of each filament. Depending on the character of the growth from the apical cells, various complex forms of massive branching structures arise in seaweeds as, for instance, in many of the red algae. The chloroplasts of these plants are chiefly developed in the cells on the surface; this again indicates a physiological division of labor and also suggests that many, if not all, of the modifications of the simple plant body, or THALLUS, so far considered are provisions for bringing about the most favorable exposure of the photo-synthetic apparatus to light. (Fig. 354.)

Another method of attaining the same result is found in other algae. In the common sea lettuce (*Ulva*) the thallus takes the form of a plate of cells, as a result of cell division occurring in two planes, and then the plate usually becomes thicker by division of the cells in a third plane also. Moreover, by further modifications of the thallus, the single attaching cell of the simple filamentous types is replaced in the larger algae by massive holdfasts which anchor them securely to rocks. At this stage there is no marked differentiation in the cellular components

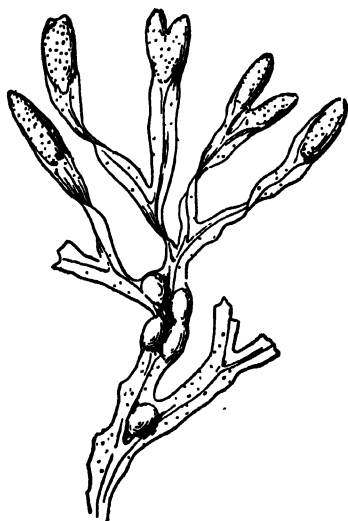


FIG. 25. The Rockweed (*Fucus*): one of the brown algae and a common seaweed. Note the ribbon-like branching filaments comprising the thallus type plant body. The swollen tips are sexual organs. (From Coulter.)

of the holdfasts, because they perform only this one function of the roots of higher forms; the absorption of water being carried on by the individual cells of the whole plant. Among the most complex seaweeds, for example in the rockweed, gulfweed, and the giant kelps, the form of the thallus is highly modified into parts which serve certain functions of root, stem, and leaf of higher plants; but even so none of the fundamental tissue differentiations, so characteristic of the higher forms, is associated with this division of labor. (Figs. 25, 26.)

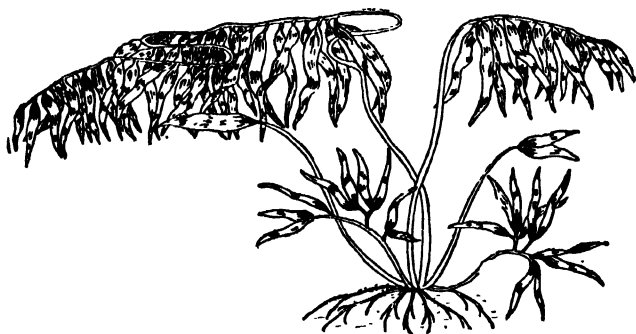


FIG. 26. The giant kelp, *Macrocystis*, a marine alga. The thallus plant exhibits distinct leaf-like and stem-like structures supported by the water, and a holdfast that anchors it to the bottom. These enormous plants may attain a length of 200 feet. (From Martin.)

All of the plants just described are ALGAE which, with the colorless plants, or FUNGI, form a major division of the plant kingdom, known as the THALLOPHYTA. A further increase in complexity of plant body beyond that of the algae is exhibited by the MOSSES and their allies, the BRYOPHYTA. In a typical moss, specialization of tissues results in the formation of a plant body composed of an upright or a creeping plant stem, which is provided with rootlike rhizoids for anchorage and absorption of materials, and leaves for photosynthesis. But there is little cellular differentiation and no vascular, or conducting, tissues; these are reserved for the VASCULAR PLANTS, or TRACHEOPHYTA, comprising the FERNS and their allies, or Pteridophytes, and the SEED PLANTS, or spermatophytes. (pp. 504-521.)

As will be explained in detail later, most plants exhibit in their life history an alternation of generations: the sexual plant, or GAMETOPHYTE, bearing sex cells, or gametes, gives rise to a nonsexual spore-

bearing plant, or SPOROPHYTE, which in turn produces a gametophyte. In plants higher than the thallophytes, these two generations are markedly different in size and structure. The sporophyte is the conspicuous and complex generation in the ferns and seed plants—the generation which is recognized by everyone as a fern or a seed plant, and, for the present, attention will be directed to this form.

PLANT STRUCTURE

The body of the sporophyte of a typical seed plant is clearly differentiated into two parts, ROOT and SHOOT. The root is an organ for attachment and for the intake of water with various materials in solution that are necessary for the life of the plant. The shoot consists of STEM and LEAVES. The stem is a supporting and conducting structure that forms the connecting link between the root and the photosynthetic tissues of the leaves. The reproductive organs that produce the spores are usually developed on highly modified leaves which in the familiar seed plants are grouped, with certain accessory structures, to form a FLOWER.

In order to obtain a mental picture of the essential working plan of the tissue distribution in these major parts of the body of a seed plant, we shall consider first an ideal vertical section of a representative of the commonest group, the DICOTYLEDONS. (Fig. 27.)

The root and shoot system together constitute a continuous body, which may be regarded as forming a narrow cylinder of cells; at the bottom is the growing point of the primary root, and at the top, the growing point of the shoot. This *primary cylinder*, in turn, is made up of a solid *central cylinder* of cells, surrounded by two hollow outer cylinders. The inner of these concentric hollow cylinders surrounds the central cylinder, and in turn is enclosed by the outer cylinder. The latter forms the outer layer of cells of the plant. These three cylinders comprise the PRIMARY TISSUE SYSTEMS.

The central cylinder, known as the STELE, runs continuously throughout root and stem. It provides the PITH, or primary axial tissue, and the VASCULAR BUNDLES. The latter include the food-conducting tissue or PHLOEM, the water-conducting tissue of XYLEM, and between them the actively growing tissue or CAMBIUM. The cambium becomes continuous with the tissues at the growing points of stem and roots, and together these embryonic tissues, called MERISTEM, may be regarded as the GROWTH SYSTEM of the plant. (Fig. 27.)

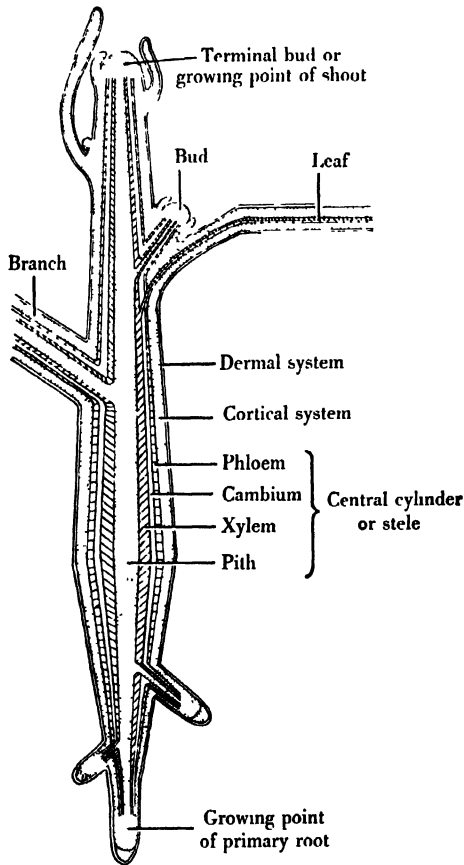


FIG. 27. Ideal vertical section of a generalized seed plant (Dicotyledon), showing the typical tissue systems. The central cylinder, or stele, comprises the pith (coarse dotted), xylem (diagonally lined), phloem (cross lines), with cambium (fine dotted) between and extending to the growing points of root and shoot. The cortical system (crosses) forms a hollow cylinder which surrounds the central cylinder and is, in turn, enclosed by the outer cylinder (double lined), of the dermal system. (From Ganong.)

The middle cylinder, immediately surrounding the solid central cylinder, comprises the CORTICAL SYSTEM which provides the chlorophyll-bearing tissue of the young stem and the CORTEX of bark and root.

The outside cylinder forms the DERMAL SYSTEM which supplies the surface tissues of the young root and also the protective EPIDERMIS covering the stem. (Fig. 28.)

The three cylinders associated in the stem extend out into each leaf, where they form the vascular tissues, the chlorophyll-bearing tissue, and the epidermis.

Bearing in mind this diagrammatic plan of the root and shoot and of their component tissue systems, we are prepared to survey some of

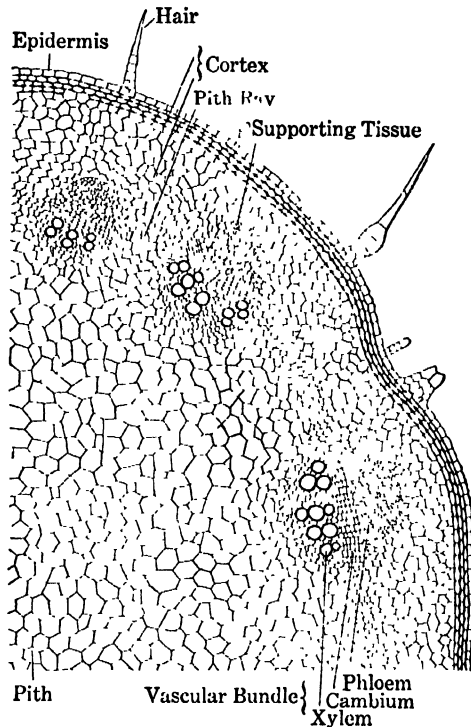


FIG. 28. Portion of a transverse section of sunflower stem. Note continuity of cambium cells between vascular bundles. (From Smith and others)

the typical forms assumed by the root, stem, and leaf, and then to analyze the tissue systems by microscopic study of transverse and longitudinal sections.

ROOTS

Roots are the plant organs which maintain direct contact with the soil. Here they anchor the plant and perform the primary functions of absorption and conduction of water and solutes to the stem. The PRI-

MARY ROOT of a young plant, a direct continuation downward from the shoot, may persist throughout the life of the plant as the **TAP ROOT** and merely give off small, lateral, secondary roots. Tap roots are common in many herbs, such as the dandelion, and in young trees. More often the primary root is entirely replaced by **SECONDARY ROOTS** which radiate and branch in all directions from the main axis of the plant until they form a complex underground structure. This may equal in size the part of the plant body that is developed above the surface by the shoot system. (Fig. 29.)

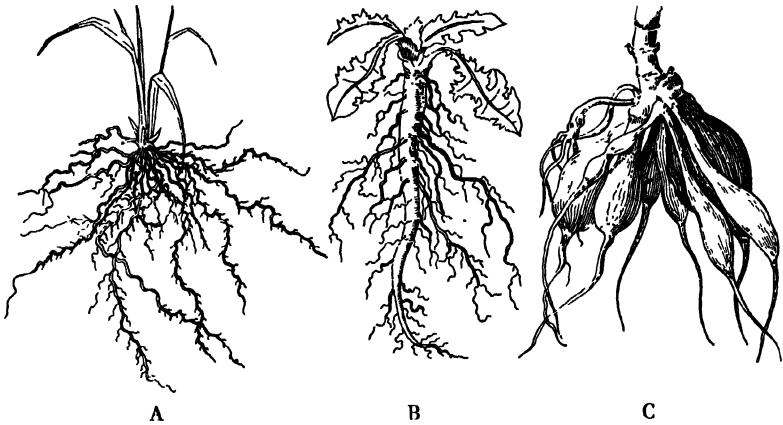


FIG. 29. Drawings of three types of roots: A, fibrous roots of a grass; B, tap root of the dandelion; C, cluster of fleshy roots of the dahlia. (After Bergen and Davis.)

In plants which live through two years (**BIENNIALS**), often the first year is spent in storing food. Sometimes storage occurs in the roots, in which case these organs are greatly enlarged to form a reservoir of material, at the expense of which during the second season the plant rapidly develops flowers and seeds. These **STORAGE ROOTS** may be tap roots as in the turnip, or lateral roots as in the dahlia, sweet potato, and white sweet clover. (Figs. 29, 30, 31.)

Although the contact of the plant with its environment through its roots is ordinarily underground, tropical plants in particular frequently develop **AERIAL ROOTS** from the stem or its branches. Roots which rise from such unusual places are called **ADVENTITIOUS ROOTS**. In certain species the aerial roots hang free in the air and absorb moisture from the atmosphere. In addition, such roots may develop chlorophyll and

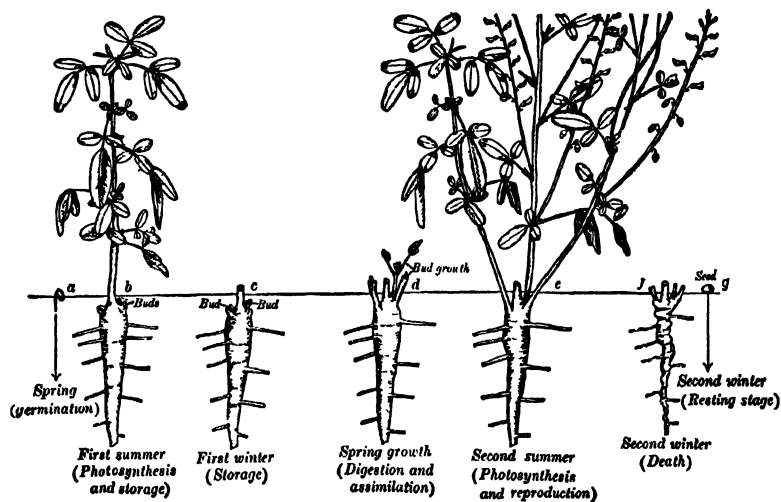


FIG. 30. The seasonal history of the white sweet clover, a biennial plant. Stages a, b, c, first year; stages d, e, f, g, second year. See Fig. 31. (From Densmore.)

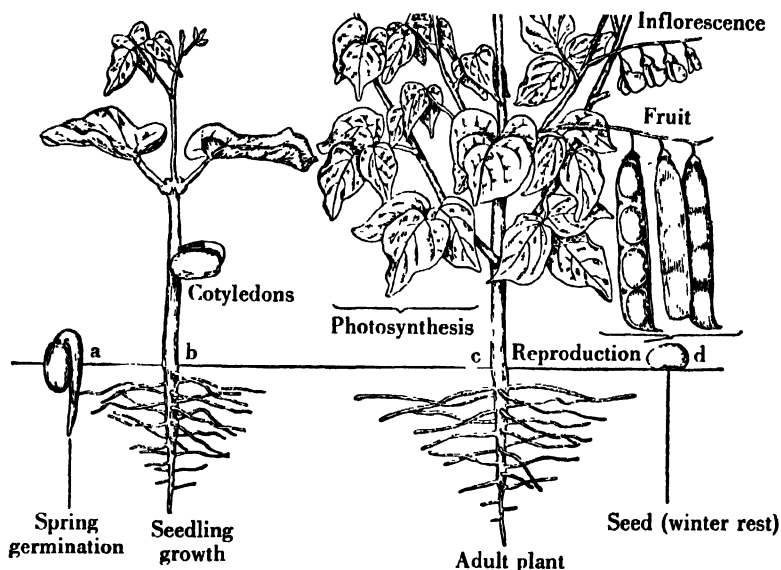


FIG. 31. Seasonal history of the bean, an annual plant. Stages a, b, c, development during growing season to form seed, stage d, which remains inactive during the winter. See Fig. 30. (From Densmore.)

so perform the characteristic function of leaves. Sometimes, as in the banyan tree, aerial roots grow from the branches down to the earth where they become attached, eventually forming secondary supports which may become stout trunks and function as stems. Comparable to these roots are the so-called PROP ROOTS of some palms and of the familiar Indian corn and the aerial CLINGING ROOTS of ivy. (Fig. 32.)

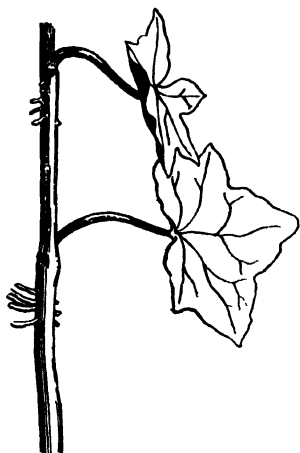


FIG. 32. English ivy, showing the aerial roots, developed from stem tissues, which enable it to cling to walls. (From Ganong.)

Many plants depend chiefly or entirely on other plants for their food materials. The roots of such PARASITIC species frequently grow into the tissues of their HOST, and become more or less modified into suckers, or HAUSTORIA. In the dodder and mistletoe, the haustoria enter the tissues of the stem of the host, while in many of the false foxgloves (*Gerardia*) they enter the tissues of the roots. And in some aquatic and parasitic plants roots are absent, their function being taken over by the stem or leaves. (Fig. 313.)

Without multiplying examples, it is clear that the part of a plant which the botanist calls a root, and which typically anchors the plant to the earth and takes water with various materials in solution from the soil, frequently is highly modified and even assumes the duties of other organs in certain plants which are adapted for special places in the economy of nature.

HISTOLOGY OF ROOTS

Microscopic examination of a root tip shows the tip to be covered with a large number of cells which form a protective ROOT CAP. These cells are gradually rubbed off as the root elongates and forces its way through the soil, and are continually replaced by new cells supplied by the GROWING POINT immediately above. The small, densely packed cells constituting the growing point represent the region of cell formation for the entire root tip, since near the center is a group of cells from which smaller cells are divided off, and these in turn absorb food materials and gradually attain the normal size. It will be recalled that

the growing point is continuous with the cambium region above, and it thus represents the growth system, or meristem, at the root tip. (Fig. 33.)

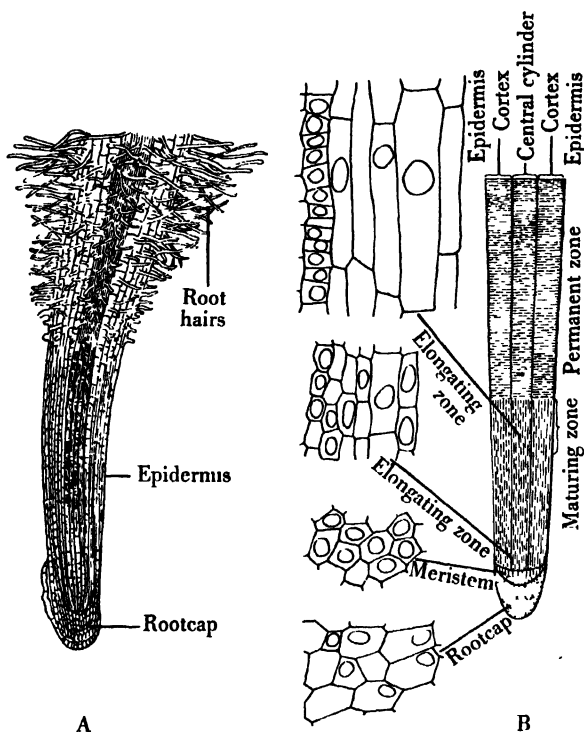


FIG. 33. Root system. A, actively growing root tip of a radish plant as viewed externally. See Fig. 35. B, section through the root tip showing differentiation of plant cells in the different zones. Diagrammatic. (After Ganong; Densmore.)

Just above the growing point is the ELONGATING ZONE which includes cells recently formed by the tip in its growth downward. In this region the cells retain their relatively thin cell walls but enlarge rapidly, especially in length, the force exerted by cell elongation forcing the root tip through the soil. The cytoplasm of these cells, by the development and fusion of large vacuoles of CELL SAP—chiefly water with sugar, salts, and various other substances in solution—soon forms a thin lining closely applied to the wall; a condition characteristic of many plant cells, in contrast with those of animals. (Fig. 34.)

As the elongating zone gradually merges above into the MATURING ZONE, there is seen on the surface the first evidence of the protective layer, or epidermis, and, just within, the cortex made up of several layers of cells. Still further toward the center of the root, the central cylinder, or stele, appears with differentiating vascular tissue.

Furthermore, conspicuous on the outer surface of the maturing zone are numerous ROOT HAIRS, each a modified epidermal cell. It has been emphasized above that the primary function of the root is the intake of water, with certain of the elements of food in solution, which forms a film about the soil particles. This function is performed almost entirely

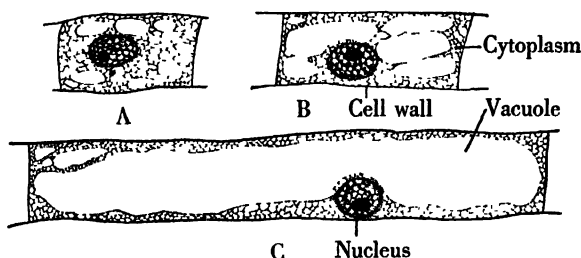


FIG. 34. Stages in development of an embryonic plant cell (A) through an intermediate stage (B) to the mature condition (C). Note particularly the development of the cell vacuole and the distribution of the cytoplasm to form a peripheral layer. Highly magnified. (From Smith and others.)

by OSMOSIS, that is by *diffusion* through the semipermeable plasma membranes of the innumerable root hairs. Accordingly cells of this type, continually dying and being replaced by new ones near the growing points of the young roots, form the vital point of contact between the root system and its environment. The root hairs exhibit the selective power of protoplasm to a remarkable degree. For illustration, red clover and barley plants when burned yield about the same proportion of mineral matter as ash. But the barley ash contains nearly twenty times as much silica as the clover, while the latter contains nearly six times as much lime as the barley. (Fig. 35.)

In the maturing zone, but particularly just above in the so-called PERMANENT ZONE, the stele shows still more cellular specialization. The young vascular bundles are differentiated into the phloem tissue, characterized by its small angular tubes; while the developing xylem, with its large vessels, has nearly obliterated the primitive ground tissue, or pith. Between the xylem and the phloem appears the developing cambium,

but this begins its characteristic growth contribution somewhat above. Indeed, as we pass upward the cellular structure becomes more and more similar to that of the stem; the older woody roots of trees and shrubs being, from the standpoint of both structure and function, essentially stems, except that leaves are not formed on roots. (Figs. 27; 33, *B.*)

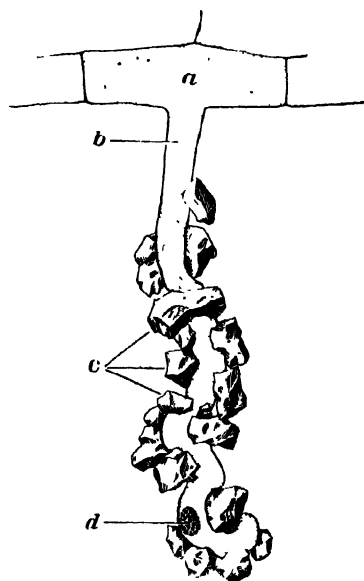


FIG. 35. Root hair showing its relation to adjoining epidermal cells of the root and to particles of the soil surrounded by a film of water. *a*, vacuole filled with cell sap; *b*, cytoplasm (dotted); *c*, soil particles; *d*, nucleus within the cytoplasm lining the cell membrane. Diagrammatic. See Fig. 52. Highly magnified.

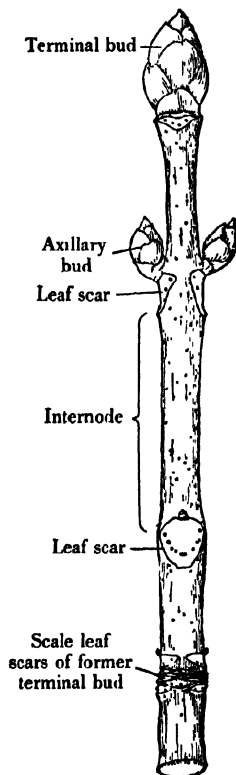


FIG. 36. A woody twig of the horse chestnut, showing terminal and axillary buds enclosed by scale leaves to form winter buds. Note the elongation of the stem during the season just finished as indicated by the scale leaf scars of former terminal bud. See Fig. 50.

STEMS

The stem is the axis of the shoot and has two primary functions: first, to support and raise the photosynthetic organs, or leaves, into a position of vantage with respect to light, and to bear the reproductive organs and their products; and, second, to act as the medium of communication between the absorbing organs, or roots, and the leaves and reproductive organs.

Stems exhibit a wide range in form and external structure. Thus in HERBS, where the shoot dies down to the ground each winter or at the completion of a life cycle, the stem is relatively slender and soft in texture, whereas in SHRUBS and TREES the stem persists throughout the life of the plant, and grows thicker annually to form a woody axis. Stems of shrubs are comparatively slender and short and usually give rise to branches near the ground, while those of trees grow stout and tall, forming a TRUNK. However, some species may be shrubs in one type of environment and trees in another.

In herbaceous stems the entire length usually bears leaves, whereas in woody stems leaves are restricted to the growth of the last few years. Indeed in DECIDUOUS trees, which lose their leaves in autumn, they are confined each summer to the current growth of the stem. The fall of the leaf is an entirely normal process; the leaf is cut off, without injury to the stem, by the development across the leaf stalk of a special layer of cells that seals the wound as the leaf falls. Leaf scars thus show the former positions of leaves. (Fig. 36.)

The points on a stem at which leaves arise are known as NODES and the portion between two nodes is an INTERNODE. The nodes are centers of active growth where BUDS, and so lateral stems, or BRANCHES, arise. The disposition of the leaves at the nodes, or PHYLLOTAXY, follows characteristic patterns that insure the minimum amount of shading. Most common is a leaf at each node in an ascending spiral about the stem, but sometimes there are two or more leaves at each node.

Buds are the specialized growing points of the stem and may be TERMINAL and so determine the elongation of the stem, or LATERAL and give rise to branches. In a BRANCH BUD there is a tiny branch with leaves ready to develop, in a FLOWER BUD there are one or more flowers, and in a MIXED BUD, both leaves and flowers. Adventitious buds may occur on roots.

Photosynthesis is carried on chiefly by leaves, but most young stems are green and so cooperate in this process, whereas in woody plants the stem surface becomes covered with **BARK**, and chlorophyll is no longer present. However, small scattered areas of more porous bark, the pores of which are termed **LENTICLES**, make possible the interchange of gases between the inner tissues of the stem and the atmosphere.

The stem, like the root, may be modified and diverted from its typical structure and take over more or less of the functions of other parts. For the purpose of propagation, creeping stems occur, such as the surface **RUNNERS** of the blackberry and strawberry, and the underground **RHIZOMES** of many sedges, grasses, and common ferns. Sometimes the stem replaces the root system to a large extent, but more often it acts as an underground reservoir in which food material is stored during the short growth period for the rapid development of the flowering shoot. This is well seen in some of the early spring plants such as the bloodroot and trillium, and reaches a maximum in the **CORM** of the crocus. (Figs. 37, 38, 48.)



FIG. 37. Propagation of the black raspberry by branches which become rooted at considerable distances from the parent plant. (From Densmore.)

Extremely arid regions are characterized by plants, such as the cacti, in which the leaves are completely suppressed to prevent rapid evaporation; leaf function in these forms is taken over by the stem, which is provided with well-developed chlorophyll-bearing tissue. Sometimes

the stem or branches may superficially resemble a leaf by being flattened or otherwise modified, as in certain cacti such as the prickly pear, the apparent leaves of the so-called smilax (*Myrsiphyllum*), and the filamentous "leaves" of asparagus. Finally, the versatility of the stem is illustrated by the THORNS of the honey locust, the twining TENDRILS of the grape, and the TUBER of the potato which is a concentrated part of a rhizome. (Figs. 38, 39, 379.)

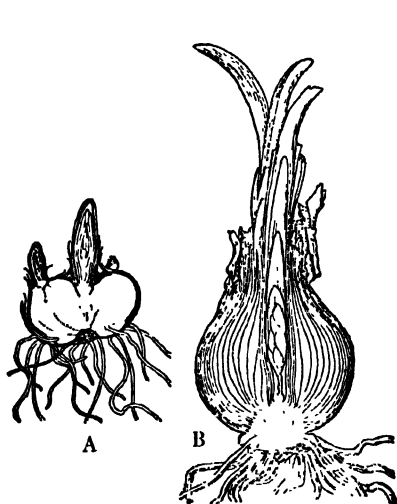


FIG. 38. Underground stem, or corm, of crocus A; underground bud, or bulb, of hyacinth B. Vertical sections. (From Smith and others.)

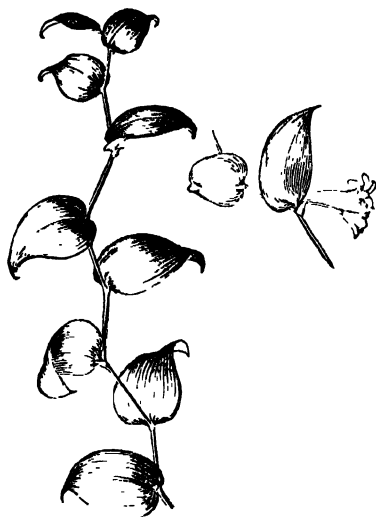


FIG. 39. Stem of *Myrsiphyllum* (left), with leaf-like structures (cladophyll). Each cladophyll develops in the axil of a leaf which persists only as a tiny projection at the base of a cladophyll. Flower stalk with two cladophylls (right).

HISTOLOGY OF STEMS

Just as cell division in the meristem tissue of the growing point of a root results in downward growth, so in the bud, at the growing point of the shoot, cell multiplication results in growth upward. In other words, from the region where root and shoot merge, the growth of the plant is in opposite directions.

The general character of the embryonic tissue is essentially the same in both the root and shoot regions, being composed of densely packed,

more or less cubical cells which are completely filled with protoplasm. At this stage the cells have not become modified for special functions by the formation of vacuoles of cell sap, or in other ways. But all the tissues of the stem are derived from cells which develop in the growing point, so that slightly below this region three areas are to be noted in which differentiations are in progress. These result in the formation of the outer cylinder (epidermis), the intermediate cylinder (cortex), and the central cylinder (stele), in which the ground tissue, or pith, is gradually surrounded by the developing vascular bundles. (Figs. 28, 40, 41.)

The vascular bundles in the stem are much the same as in older roots. The tissues of the bundles are specialized for three chief functions: the wood, or xylem, for the conduction of water; the phloem

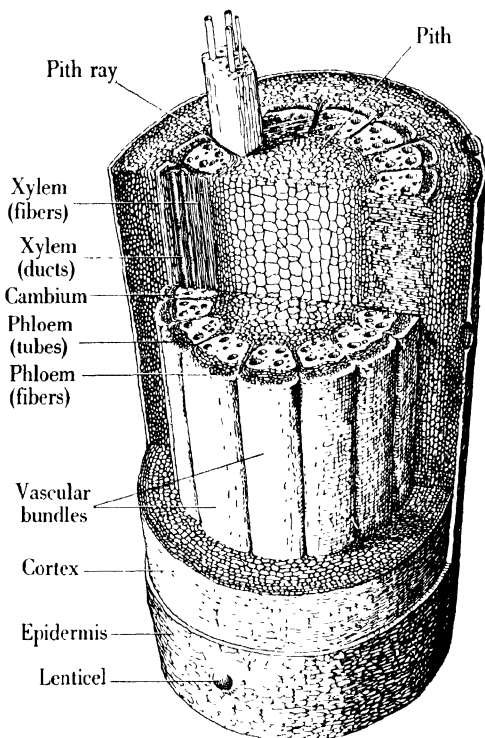


FIG. 40. Drawing of an idealized portion of the woody stem of a dicotyledonous vine. Note the regular arrangement of the vascular bundles and the other plant tissues. See also Fig. 43.

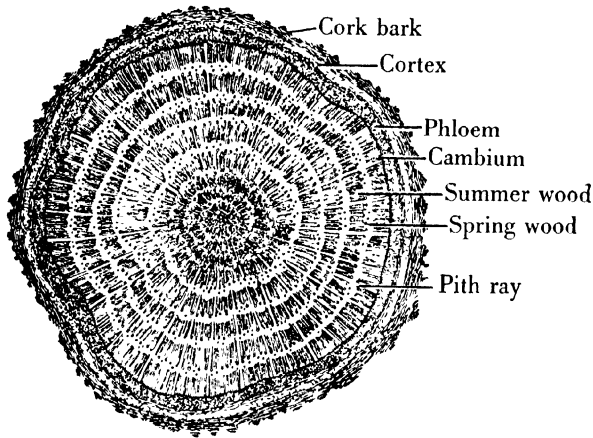


FIG. 41. Transverse section of an oak stem eight years old, as shown by the annual rings with alternating light spring wood and dark summer wood. The central darker portion of the stem is the heart wood. Diagrammatic. (From Densmore.)

for the translocation of food; and fibers in each for mechanical support. Furthermore, the cambium tissue provides for the continuous growth of the stem. The vascular bundles of stem are, of course, directly continuous with those of the root and leaf.

The disposition of the vascular bundles is quite different in the two great divisions of seed plants: the DICOTYLEDONS with two seed leaves and netted-veined leaves, and the MONOCOTYLEDONS with one seed leaf and parallel-veined leaves. Dicotyledons are much the more numerous and comprise many small plants as well as all the common trees and shrubs. The most important plants belonging to the monocotyledons are the grasses, palms, lilies, and orchids. The structure of the vascular-bundle system will first be described in a typical dicotyledonous stem. (Fig. 370.)

We have noted that the developing stem is soon differentiated into three chief regions: the epidermis, cortex, and stele. The epidermis covers the surface and consists of a single layer of cells whose outer walls are greatly thickened and impregnated in part with a waxy substance, or CUTIN, for protection and for conservation of water. Specialized pores, or STOMATA, characteristic of leaves, occur on the stems of herbs, but these are replaced by lenticels when bark is formed on woody stems.

The cortex, just within the epidermis, usually comprises two cellular layers. First there is an outer COLLENCYMA layer of cells, some of which contain chloroplasts and so perform photosynthesis; these cells typically have the angles of their cellulose walls thickened for mechanical strength in the young stem while still allowing for stretching and growth. Just beneath the collenchyma is the PARENCHYMA layer, composed of more or less generalized cells which usually develop chloroplasts in the young stem. And scattered in the parenchyma are groups of thick-walled dead cells which provide FIBERS for further rigidity. (Figs. 28, 40.)

The central cylinder of the stem, or stele, comprises two general regions: the central pith surrounded by the vascular-bundle area. The pith is composed of thin-walled cells that compose the ground tissue.

The vascular bundles, as seen in a transverse section of the stem, exhibit the general form of a broken ring about the pith. Each bundle comprises three clearly differentiated parts: the thick-walled cells of the xylem nearest the center of the stem, the thin-walled cells of the phloem situated peripherally, and one or several layers of embryonic, or meristem, cells of the cambium between the xylem and phloem. The active division of the cells of the cambium layer forms phloem cells on the outer side and xylem cells on the inner side. Thus the vascular bundles increase in size and gradually replace the intervening cells, except those that remain as the so-called PITH RAYS and serve chiefly for the conduction of materials across the stem. Eventually the cambium of the various vascular bundles may become continuous so that it forms a closed cylinder of growing tissues. Cambium activity continuously increases the diameter of the stem and hence increases its own diameter accordingly. (Fig. 40.)

The mature xylem is composed of three chief types of cells, TRACHEIDS, VESSEL CELLS, and

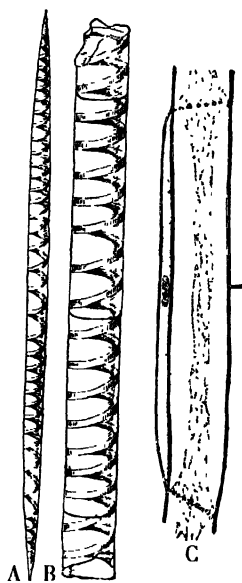


FIG. 42. Conducting tissues from a highly developed stem: A, *tracheid* and B, portion of a *vessel*, each with spirally thickened wall; C, longitudinal section of a segment (part formed from one cell) of a *sieve tube* and its *companion cell* (left). (After Smith and others.)

WOOD FIBERS, which lose their protoplasmic contents and contribute their dead cell walls to the structure of the stem. Tracheids are elongated cells with thickened walls, due to the deposition of material in a spiral band that extends the full length of the cell. Vessel cells unite end to end and by the loss of their walls at the points of contact form long ducts. Tracheids and vessels provide the chief water-conducting elements of the stem. Wood fibers are long, slender, pointed cells whose thick walls give rigidity and strength to the stem and, with the tracheids and vessels, form most of the wood of trees. (Figs. 41, 42.)

The phloem also consists of three chief types of cells, known as SIEVE TUBES, COMPANION CELLS, and PHLOEM FIBERS. The tubes are thin-walled, elongated, living cells without nuclei, the cavities of adjacent cells being in communication by tiny pores in the terminal walls, and serving primarily as food-conducting elements. The companion cells, as the name indicates, are closely associated with the sieve tubes—indeed, each is in communication by pores with its sister sieve tube cell and apparently cooperates with it. The phloem fibers afford mechanical protection for the sieve tubes.

Such is the general arrangement of the tissues of a typical dicotyledonous stem, but it will be understood, of course, that great variation

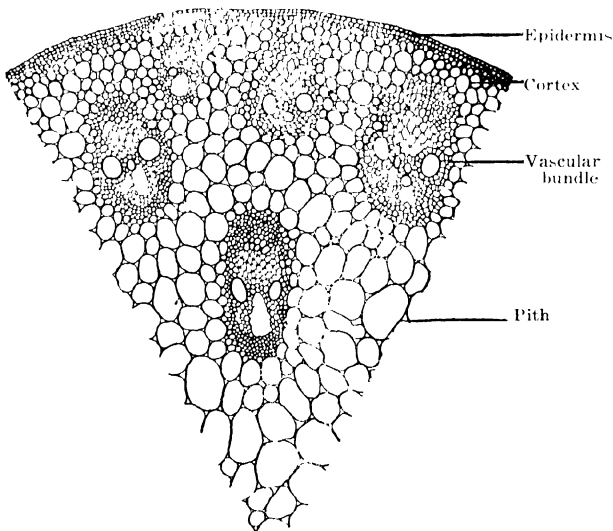


FIG. 43. Portion of a transverse section of a monocotyledonous stem. Enlarged. Diagrammatic.

in the details occurs in this immense plant group, in response to adaptations to diverse environmental conditions and modes of life.

MONOCOTYLEDONOUS STEMS differ from those of the dicotyledons chiefly in the arrangement and structure of the vascular bundles. These, instead of being disposed in a cylinder, are usually scattered throughout the stele. Sometimes, however, there are no vascular bundles in the center and the pith cells disappear, so that a hollow stem is formed, as is the case in most varieties of grasses and the bamboo. Furthermore, the vascular bundles differ from those of dicotyledons by the absence of a cambium layer. Thus both the arrangement and the structure of the vascular bundles preclude the indefinite growth in diameter of the monocotyledonous stem and are directly or indirectly responsible for many of the characteristic differences between the two great divisions of the flowering plants. (Fig. 43.)

CHAPTER VI

The Plant Body (II)

LEAVES

Leaves are lateral outgrowths from the stem, but, unlike most stems, are usually limited in growth; they attain a certain size and then stop. A branch of the stem typically arises in the axil of a leaf, or just above its point of attachment. (Fig. 39.)

Leaves and roots form the two chief points of contact between the plant and its surroundings. The fundamental functions of leaves are to expose to the sunlight the chlorophyll apparatus and to afford a surface for the interchange of gases. That work is performed by leaves is evident from the careful estimate that at least one gram of sugar per square meter of leaf surface is manufactured each hour on a bright summer day. Accordingly the principal part of a typical leaf is a broad **BLADE** which affords the optimum conditions for exposure. The blade is usually attached to the stem, or branch, by a stalk, or **PETIOLE**, which is somewhat modified at the point of union into a **LEAF BASE** from which may arise small, leaflike appendages, or **STIPULES**. When the petiole is absent, the blade of such a sessile leaf appears to arise directly from the stem.

Extending through the center of most leaves is a large **VEIN**, the **MID-RIB**, which continues in the petiole. On either side of the midrib are many smaller veins which in dicotyledons form a conspicuous network permeating the blade, and in monocotyledons run parallel to the midrib. In either case they form a complex system of tubes, continuous with the vascular bundles of the stem, for the conduction of materials and for the support of the softer tissues of the blade.

The shape of leaf blades varies very greatly, of course, in different plants. For example, the blade may be divided into lobes, which if they

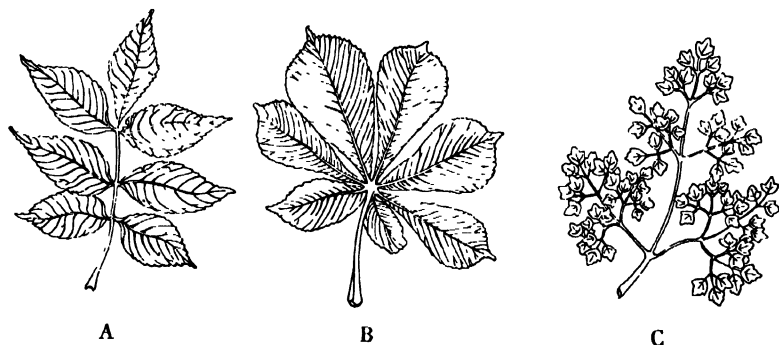


FIG. 44. Compound leaves. A, pinnately compound leaf of an ash; b, palmately compound leaf of the horse chestnut; c, four-times-divided leaf of the meadow rue. (From Smith and others.)

extend to the midrib or the base of the blade are termed **LEAFLETS** and the whole a **COMPOUND LEAF**, as in the ash, rose, and horse chestnut. Some plants have three- or four-times-divided compound leaves. (Fig. 44.)



FIG. 45. Banana plant showing support of stem by greatly elongated, claspng leaf-bases.

The leaf, like the root and stem, exhibits numerous modifications; indeed, it may assume the function of these parts. The leaf bases of the banana, for instance, grow so close together that they form the main body of the tree (Fig. 45), while hairs on the leaves of certain plants of the pineapple family absorb water and perform the functions of root hairs. The chlorophyll-bearing tissue may be nearly or completely suppressed, as in the *SCALES* which enclose *WINTER BUDS* in a protective case. These are conspicuously developed in the horse chestnut and the hickory. Or the scale leaves, in addition to affording protection, may act as reservoirs in which food materials are stored, as in the *BULB* of the hyacinth and onion. In fact, all transitions between scale leaves and typical foliage leaves may frequently be seen in an unfolding leaf bud. Still more marked departures from the usual leaf-form are the *TENDRILS* of some climbing plants such as the sweet pea, the *SPINES* of the barberry and the thistle, the *FLOATS* of the water hyacinth, and the *INSECT TRAPS* of truly carnivorous plants such as the pitcher plants and sundews which capture small living animals. (Figs. 46-47.)

Leaf modification in another direction, for reproduction, occurs in the spore-bearing structures of ferns and seed plants. In some ferns the spore cases, or *SPORANGIA*, are borne upon typical leaves, and in others

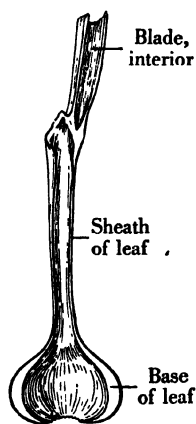


FIG. 46. Onion leaf. Longitudinal section showing hollow interior of blade, thin sheath of leaf, and thickened base of leaf. (After Sachs.)

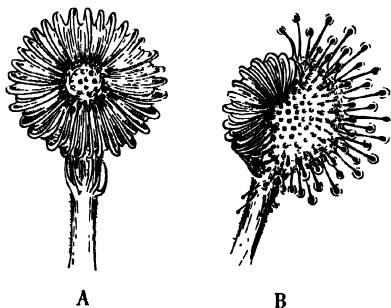


FIG. 47. Leaves of sundew during digestion of captured prey. The leaf at the left has all the tentacles closed; the leaf at the right has only half of tentacles closed over the prey.

on special leaves with the chlorophyll-bearing tissue partly or completely suppressed. Such leaves which are given over to the production of spores, as in the common sensitive fern, are known as **SPOROPHYLLS**. In the flowering plants, the flower is a group of sporophylls, known as **CARPELS** and **STAMENS**, associated in most cases with certain sterile leaf structures, termed **SEPALS** and **PETALS**, which afford protection to the sporophylls and offer attraction to insect visitors. We shall consider the structure of the flower in more detail when discussing reproduction in plants. (Figs. 48, 49.)

HISTOLOGY OF LEAVES

The embryonic cells forming the growing point, or bud, of the shoot comprise, as we have seen, the fundamentals of both stem and leaves; that is to say, stem and leaves arise together in buds. The method of their development is well seen in the buds of a common water plant, *Elodea*. Here the rounded end of the stem is composed of the characteristic embryonic tissue. The rudiment of each individual leaf is first visible on the surface as an enlarged cell, which by division and differentiation gradually develops into a flat projection of special tissues constituting the fully formed leaf. (Fig. 50.)

The fundamental structure of a typical leaf is well illustrated by a microscopic study of a vertical section. The essential tissues consist of thin, upper and lower limiting layers of cells, or epidermis, which are continuous at the edges of the blade, and thus enclose the supporting and conducting tissues consisting of vascular bundles, or veins, and the **CHLORENCYMA**, or chlorophyll-bearing cells that carry on the work of photosynthesis. (Fig. 51.)

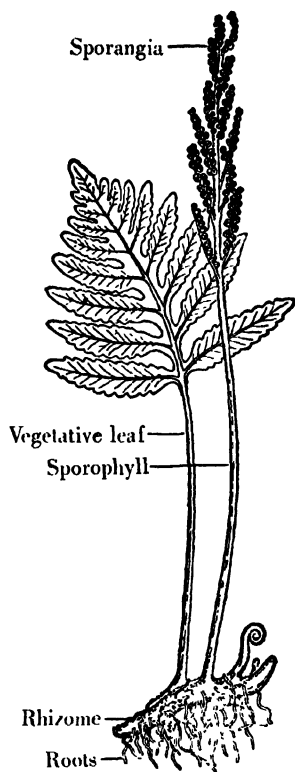


FIG. 48. The sensitive fern (*Onoclea sensibilis*), showing a vegetative leaf and a spore leaf, or sporophyll, arising from the underground stem, or rhizome. (From Bergen and Davis.)

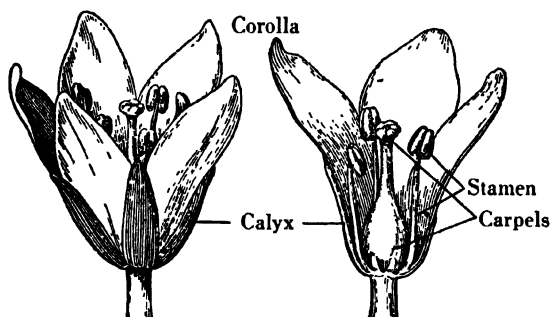


FIG. 49. The floral parts of the alpine azalea (*Loiseleuria*). Collectively the sepals constitute the calyx, and the petals form the corolla. The pistil represents several united carpels. (After Müller.)

The outer walls of the epidermal cells are usually thickened and cutinized so that they are impervious to water and gases. Accordingly the epidermis is perforated with tiny pores, or STOMATA, which lead to air spaces among the chlorenchyma cells. It is estimated that the number of stomata on the lower surface of typical leaves averages about two hundred per square millimeter. Each stoma is enclosed by two specialized epidermal cells, termed GUARD CELLS, which change the size of the opening according to varying internal and external conditions, and so regulate the rate of exchange of oxygen and carbon dioxide between the internal cells of the leaf and its surroundings, and also the exit of water vapor.

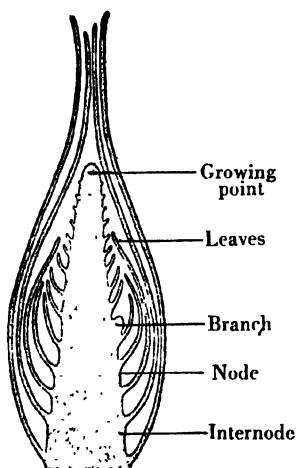


FIG. 50. Diagram of a section through a terminal naked bud of *Elodea*, showing the development of leaves and a branch (right). (From Smith and others.)

The veins, as we know, form the framework of the leaf, as well as the complex network of highways for the transportation of materials between the blade as a whole and the stem. In transverse section the larger veins usually have the form of a ring or crescent, the upper part consisting of thick-walled xylem cells for conducting water and for strength, and the lower comprising thin-walled phloem cells for the transport of food materials. The whole may be strengthened by a surrounding sheath of

cells. It is clear that veins are continuous with and possess the essential features of the vascular bundles seen in the stem, except that they lack the cambium. (Fig. 51.)

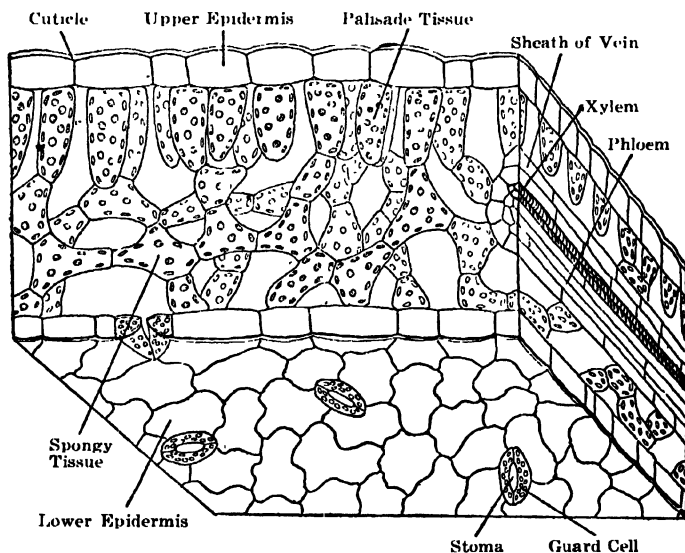


FIG. 51. Diagram of a portion of the blade of a leaf, showing the relations of the various tissues. Vertical section. (From Smith and others.)

The major functional tissues of the leaf consist of chlorenchyma cells. Immediately under the upper epidermis these cells are usually arranged in a definite layer known as the PALISADE tissue. Below this region the cells are less regularly disposed so that there are more AIR SPACES between them. The spaces in this SPONGY tissue form a practically continuous system of passages throughout the leaf and thereby facilitate the interchange of oxygen, carbon dioxide, and water vapor between the leaf cells and the outer world through the stomata. (Fig. 51.)

The cytoplasm within the thin walls of the chlorenchyma cells forms merely a lining in which are situated the nucleus and numerous specialized, disc-shaped, cytoplasmic bodies, the chloroplasts, which contain chlorophyll and therefore appear green. These are, of course, the essential agents of photosynthesis. The center of the cell is occupied by a large VACUOLE filled with cell sap. This sap is usually under pressure, which accounts for the close application of the cytoplasm to the inside of the cell wall and produces the TURGOR, characteristic not only of

these cells, but also of many other types of plant cells. The wilting of the leaves and stems of cut plants is due chiefly to the escape of water from the cell vacuoles resulting in loss of turgor, and consequently of rigidity. (Fig. 34.)

PLANT FUNCTIONS

We have now outlined the essential structure of a seed plant, with the exception of the parts modified for reproduction, which is deferred for discussion in a later chapter (XX). It is important at this point to consider the organism as a functional unit and to observe how the various cells, tissues, and organs cooperate in the nutrition of the living plant: the function of primary importance to the individual.

The essentials of nutrition were described readily in the green plant *Protococcus*, because the whole organism comprises only one cell

which directly interchanges matter and energy with its environment. (Fig. 17.) But with the establishment of the complex plant body, an organization of thousands of billions of highly specialized cells, the intricate interrelationship of the various parts to the nutrition of the whole plant becomes a highly complex problem.

The green plant takes in very simple substances and builds them up into its complex foodstuffs. In the higher plants, water in large amounts is taken in through the root hairs. Dissolved in this water are various substances, nitrates, phosphates, sulfates, etc., which supply most of the elements necessary for the construction of protoplasm. (Fig. 52.) The leaves admit carbon dioxide through the stomata. Thus the substances which are to be built up into foodstuffs typically enter at opposite

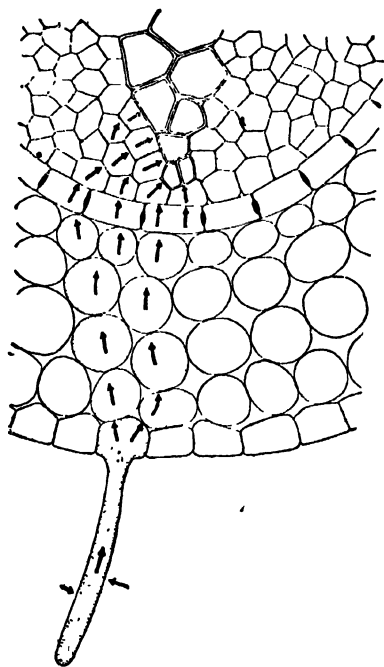


FIG. 52. Diagram of the path of water with solutes from the soil through a root hair and cortical cells of a root to the xylem. (From Smith and others.)

ends of the plant, and must be brought together in a chemical laboratory, as it were, in order that their union may be effected. Food construction takes place chiefly in the leaf, and is initiated by the chlorophyll in the chloroplasts. Accordingly we must consider the forces involved and the transportation highways, including those that carry the finished products to the various parts of the plant for their use. In general, osmotic phenomena are responsible for the movement of substances in solution in the plant body. Dissolved substances pass from cell to cell by diffusion through their plasma membranes and cell walls, each solute moving from regions of greater concentration to those of lesser concentration. (Fig. 53.)

TRANSPIRATION STREAM

The water enters the root hairs, passes to the xylem, and is usually given a start up the stem by so-called **ROOT PRESSURE**—all the result of osmosis and diffusion in the multitude of root cells. The water, having ascended through the xylem of the root, enters the corresponding region of the stem. It will be recalled that the conducting elements are tracheids and vessel cells that form a series of nonliving tubes extending up the stem to the leaves, through which they are distributed in the veins. This is the fluid-conducting highway from root to leaf. It appears that as evaporation occurs from the cells of the leaf, an osmotic “pull” draws water from adjacent cells; this compensates for the loss of fluid and in so doing starts the rise of the **SAP**. Involved in the dynamics of this rise is the interesting physical phenomenon that water when confined in tiny tubes, such as those of plant stems, possesses remarkable tensile strength—“it is as strong as wire”—and evaporation at the upper end of the water column in the leaves serves to pull up the water. This makes possible the rapid rise of water in the tubes composed of dead cells in which, of course, osmotic phenomena are absent. (Fig. 53.)

The outgo of water vapor by evaporation through the stomata of the leaves is termed **TRANSPIRATION**, and is brought about by heat energy secured both from the surrounding atmosphere and from a surplus of the energy of sunlight absorbed by the leaves during photosynthesis. In the last analysis, the energy of heat, resulting in evaporation from the leaves, is largely responsible for the movement of the column of water, or **TRANSPIRATION STREAM**, which is continually

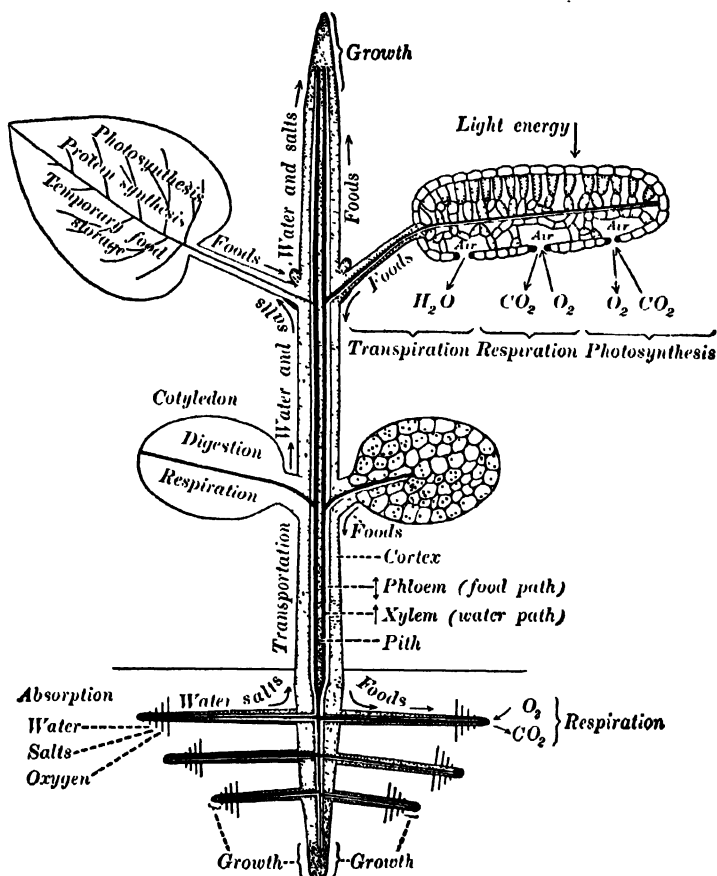


FIG. 53. Diagrammatic presentation of important physiological activities of a seed plant (bean). The first leaves (seed leaves, or cotyledons) are richly stored with food and contribute only slightly to photosynthesis. (From Densmore.)

passing through the plant—entering the root with various substances in solution, passing up the xylem, and emerging, minus the solutes, through the stomata as water vapor. The fact that much more water usually is evaporated from a forest than from an equal area of a lake affords some conception of the great importance of vegetation in returning water to the atmosphere and also in “consuming” heat energy and thus cooling the summer air. It has been estimated that for each pound of tissue constructed, the plant transpires about forty gallons of

water. Nearly two barrels of water may pass through a corn plant during the growing season; of this only about half a pint is used in photosynthesis and some two quarts are stored in the mature plant.

TRANSLOCATION

The supply of carbon which the plant needs is obtained from carbon dioxide which enters the leaves through the stomata. The water, containing various salts in solution, which has been taken in by the roots, meets the carbon dioxide in the chlorenchyma cells. As we know, through the radiant energy of light a complicated series of chemical reactions is initiated by which carbon, oxygen, and hydrogen are united to form a sugar. In this process, free oxygen is evolved which may be used in respiration or liberated through the stomata. Part of the sugar thus formed is directly utilized by the plant as fuel, and part is employed as the basis for the manufacture of proteins and the living protoplasm itself by the addition of nitrogen and various other chemical elements. (Fig. 30.)

Therefore the leaves are special organs in which certain materials of the inorganic world are assembled and arranged in new chemical compounds so that these can be utilized as building material for the plant body and as sources of energy for carrying on the vital functions. In other words, the new compounds are the food of the plant and, incidentally, food for the rest of the living world.

In every case the food built up in the leaves must be distributed, or **TRANSLOCATED**, to the organism as a whole. This occurs largely by diffusion and therefore insoluble food must be rendered soluble, **DIGESTED**, by specific organic catalyzers, or enzymes, that induce or accelerate the process of chemical simplification. Then the material passes to the smallest vessels and then on to larger and larger veins which finally lead to the stem.

In the stem, the routes taken by the food depend upon the immediate needs of the plant. Food may pass either up or down through the conducting vessels, or sieve tubes, formed by elongated living cells in the phloem, or some may be transferred to the xylem to afford materials for rapidly growing parts. When growth is not active, most of the food passes downward through the phloem in order that it may be stored, chiefly as starch, in stem and root. In brief, all the living cells of the plant directly or indirectly draw upon the supply of food trans-

located through the phloem, so we may look upon the phloem as primarily a food-distributing system from the leaf, just as we have seen that the xylem is the system for carrying water and solutes from root to leaf.

The dynamics of translocation from leaf to shoot and root through the phloem again involves chiefly the movement of solutes from regions of greater to those of lower concentration. If sugar is needed at a growing point, more flows automatically to that point. Or, if sugar is removed for storage as starch, more sugar solution flows in. However, the plant is not entirely at the mercy of osmosis and diffusion. The cellular mechanism is highly sensitive. It coordinates these phenomena, in ways as yet largely unknown, for the welfare of the organism as a whole.

FOOD UTILIZATION

The food which the plant has constructed and transported to the various parts of its body must be employed by the individual cells in supplying the material and energy for their life processes. When the food stream reaches them, the cells select the various materials essential for their individual life, and in addition those which they require for the performance of their particular part in the economy of the whole. They may use the foods as received or elaborate from them by enzyme action the specific proteins, carbohydrates, or fats needed. But doing this requires work, and work means expenditure of energy—the same energy of sunlight which was stored in the food during its construction by the chlorenchyma cells. In order to release this energy *RESPIRATION* must occur. Carbohydrates, fats, and proteins must be oxidized, that is, burned; and consequently free oxygen must be transmitted throughout the plant to the various cells, and carbon dioxide carried away. This is effected by an intercellular system of air spaces which ramifies throughout the plant and communicates with the surrounding atmosphere chiefly by way of the stomata, but also to some extent through the lenticels opening through the epidermis of the stem. (Fig. 40.)

IRRITABILITY AND ADAPTATION

Finally, it is important not to lose sight of the unity of the organism as a whole which results from the cooperation of the various cellular

elements comprising the plant body. The plant not only is adapted but is adaptable to its environment, both living and lifeless. The protoplasm responds to stimuli through its inherent power of irritability just as truly, though not so actively or so complexly, as do animals with a nervous system. The response is a change in either structure or function, or in both, and usually is due to growth, so it appears chiefly in young, developing parts. However, the so-called "sleep movements" of some plants such as the well-known sensitive plant, *Mimosa*, are the result of rapid changes in the turgor of special cells. (Fig. 54.)

Some stimuli initiating growth responses apparently arise within the plant, such as those which induce a constant rotation of the tips of developing stems; but most stimuli are due to environmental changes, notably light, gravity, pressure, moisture, temperature, and various chemical substances.

The most obvious responses, because immediate, are growth movements in a direction that is determined by the direction of the stimulus; these are termed **TROPISMS**. We are familiar with specific reactions to light, or **PHOTOTROPISM**, in which the root is negatively phototropic (grows away from the source of light) and the shoot is positively phototropic (grows toward the light). Conversely, the response to gravity, or **GEOTROPISM**, of the root is positive and that of the shoot is negative. Chemical substances, of course, have many and varied influences on growth and in some cases apparently determine its direction. **CHEMOTROPISM** is exhibited in the growth of the pollen tube down the stigma of the flower, to be described later. Furthermore, responses to mechanical stimuli, such as pressure, or **THIGMOTROPISM**, are well shown by the tendrils of climbing plants and the turgor reaction of the sensitive plant already mentioned. Roots, in particular, exhibit **HYDROTROPISM** in their growth through the soil toward water. (Fig. 55.)

In brief, the plant is not static either as an individual or as a species. To live, a plant must react to its environment. Most of these reactions

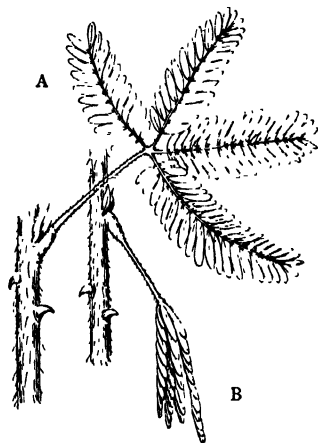


FIG. 54. Sensitive plant, *Mimosa pudica*, showing A, leaf in typical position and B, after mechanical stimulation.

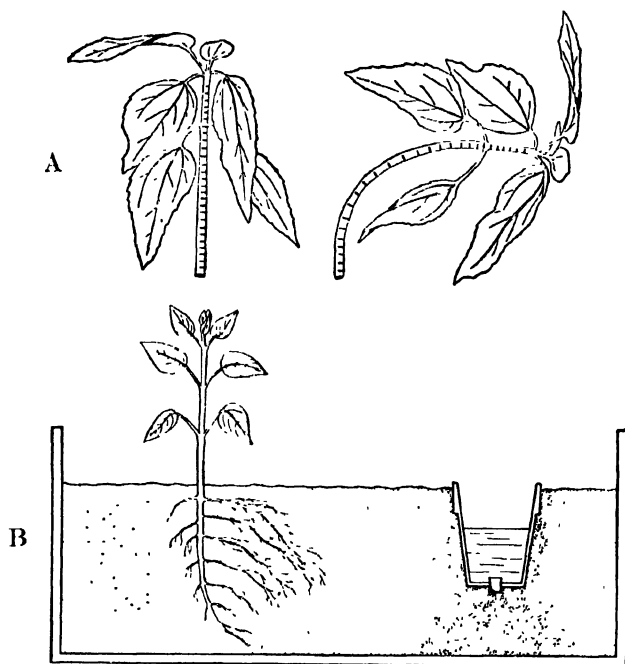


FIG. 55. A, Phototropism. Left, part of a sunflower plant with its stem marked at equal intervals. Right, the same plant after exposure to a one-sided illumination. Bending occurs in the region of elongation. B, Hydrotropism. Section of a box containing sand, with a plant and a porous flower pot containing water. The unequal water content of the soil on different sides of the plant affects both the form and the direction of growth of the roots. (From Smith and others.)

are growth responses, which frequently are brought about through the action of special chemical substances, or **HORMONES**, that are distributed hither and yon through the plant under the influence of various stimuli.

In fact there is a system of hormones whereby growth and other processes in one part of the body are both stimulated and controlled from other regions. For instance, certain hormones, the **AUXINS**, that promote root growth, are formed in the tips of the growing shoots and in mature leaves. The latter also manufacture other hormones that influence the growth of young leaves, and still others which determine the development of flowers. The phototropic reactions of seedlings are brought about by auxins which induce an elongation of cells that are

in the dark and consequently cause a bending of the whole toward the light. Again, so-called wound hormones stimulate cell division and hence promote the development of a protective layer over the surface of

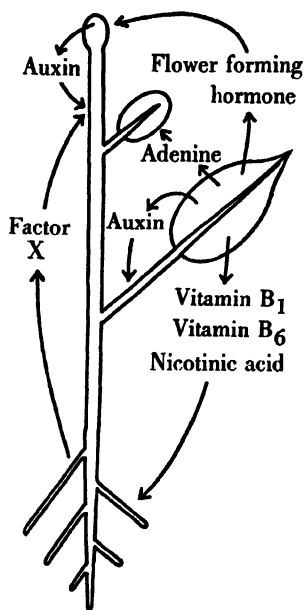


FIG. 56. Some hormone and hormone-like chemical interrelationships between the organs of a plant. Arrows extend from point of origin of a specific substance to where it is translocated for use. In upward sequence are shown: root, mature leaf and stem, growing leaf and stem, and apical bud. "The plant is a true democracy, one for all and all for one." Continuing investigations in this field are producing results of great economic importance. (From Went.)

wounds. Furthermore biochemists recently have been able to synthesize artificially some growth-promoting substances, with the result that it is now possible to induce greatly accelerated growth and to control certain processes, such as the induction of roots on cuttings otherwise nonrooting, the prevention of abnormal dropping of young fruit, and so on. (Fig. 56.) Finally, it is important to note that plant hormones may act as vitamins in animal metabolism: another important example of the chemical interrelationship of all life.

We have now surveyed the structure and functions of a typical higher plant as a whole and, in particular, have indicated how the organism is specialized for the chief function which primarily concerns the individual: the function of nutrition, or the transformation of matter and energy into life and work. However, the duration of the existence of an individual is relatively limited, and it is obvious that some provision must exist for the continuation of the race. In other words, new individuals must be formed. Reproduction, a universal function of living organisms, is essential for the maintenance of the species rather than of the individual, and will be extensively considered in later chapters (XVI-XXI).

CHAPTER VII

The Animal Body: Invertebrate (I)

Animals are always attempting the next to the impossible and achieving it.
—Goeche

The most obvious characteristic which distinguishes animals from plants is the power of locomotion which most animals possess. This criterion, however, fails among some of the primitive unicellular types; for example, *Sphaerella*, a green unicellular plant, swims as actively as a unicellular animal. Moreover, among multicellular animals there are many permanently attached forms, such as the typical stages of the sponges, hydroids, barnacles, etc. Although, then, the power of locomotion is not a universal diagnostic character of animals as compared with plants—this, as has been explained, being chiefly a matter of metabolism—it is a fact that the great dissimilarity between the bodies of multicellular plants and those of animals is a direct or indirect result of the loss by plants and the development by animals of the primitive power of locomotion possessed by most unicellular organisms. (Fig. 205.)

At the basis of this difference is probably the fact that plants, in general, manufacture their food from readily available materials whereas most animals must actively seek the complex foodstuffs they require. Therefore early in the evolution of plants comparatively rigid cell walls of cellulose were established, which directed the development of the body along relatively 'fixed lines. On the contrary, animal cells, unhampered by the limitations imposed by rigid confining walls, were free to respond in more ways to environmental conditions, and this freedom made possible the extremely diverse forms of mobile bodies characteristic of the animal world. (Figs. 10, 205, 399, 402.)

THE CHIEF GROUPS OF ANIMALS

The animal kingdom may be divided, from the standpoint of cellular organization, into two groups: the unicellular animals, or **PROTOZA**,

comprising about twenty thousand known species, nearly all of which are microscopic, such as amoeba, Paramecium, and their allies; and multicellular forms, or METAZOA. The latter division includes animals ranging in size from those so small that hundreds can sport in a drop of water, to the giant whales of today and the dinosaurs of the geologic past. (Figs. 459, 472.)

Considered from another standpoint, all animals may be divided into two groups known as INVERTEBRATES and VERTEBRATES. The former group, frequently referred to as the lower animals, comprises nearly a million known species and exhibits an enormous variety of form and complexity of structure, ranging from the Protozoa and sponges to the mollusks, crustaceans, and insects. On the contrary, the vertebrates, or higher animals, form a relatively homogeneous group of about seventy thousand species, including the fishes, amphibians, reptiles, birds, and mammals.

The highly complicated and varied organization of animals makes it impossible to present a concise and adequate plan of a typical animal body; it is therefore necessary to choose one group as the basis for study, and then to compare with this, in so far as comparisons are possible without confusion, some of the most significant variations presented by other groups. The group of vertebrates is naturally selected for chief consideration, because its relative homogeneity renders it the most available, and because man is a vertebrate. However, even before attention is focused on the vertebrates, it is necessary to form a background by the study of the morphological and physiological principles exhibited among the invertebrates, particularly in certain basic types, such as the unicellular Paramecium and the metazoon types exemplified by the hydra, earthworm, and crayfish.

PARAMECIUM

Unicellular animals, the Protozoa, constitute the most primitive phylum of the animal kingdom and represent, it is believed, the stock from which the vast array of multicellular animals, or Metazoa, have been derived. It is therefore important to study in some detail two representative protozoa, such as amoeba and paramecium. Since an amoeba has already been considered in the discussion of the metabolism of animals, one of the several species of so-called slipper animalcules, *Paramecium caudatum*, found the world over in ponds, ditches, and decaying vegetable infusions, is selected as an example of an

obviously specialized protozoan. Incidentally, paramecia have probably been more intensively investigated by biologists than have any other animals except fruit flies, frogs, and man himself. (Fig. 57.)

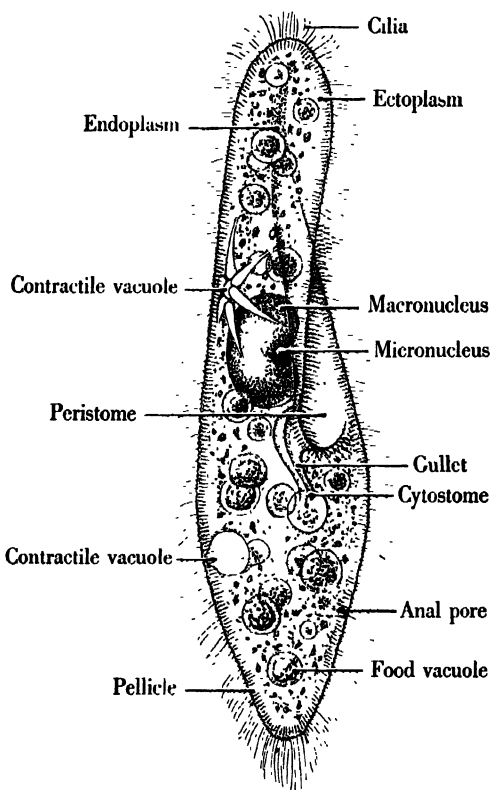


FIG. 57. *Paramecium caudatum*. Diagrammatic. Highly magnified. (After Buchanan.)

Paramecium is a giant among the Protozoa, being just visible to the naked eye as a whitish speck if the water in which it is swimming is properly illuminated. When considerably magnified it appears as a more or less slipper-shaped or, better, cigar-shaped body. The anterior end is somewhat more blunt than the posterior end, with the greatest width behind the middle of the body. Extending from the anterior end, obliquely backward and to the right, is a depression or groove, the PERISTOME, which terminates in a mouth opening, just posterior to the

middle of the body, and is followed by the gullet which leads still further backward and downward into the central endoplasm. Obviously the depression forming the peristome, or what is regarded as the ventral surface, makes the animal somewhat asymmetrical. A transverse section through the body is circular except in the region of the peristome where it is crescent-shaped.

The surface of *Paramecium* is covered with a definite PELLICIE, and just beneath this is a layer of ectoplasm which encloses the granular and more fluid endoplasm forming the bulk of the body. The pellicle and ectoplasm maintain the definite form of the animal but allow a considerable flexibility, which is evident when, for instance, the body is squeezed as it swims between objects in its path.

Under high magnification the pellicle proves to be sculptured into longitudinal rows of hexagonal depressions bounded by ridges. From the middle of each depression a tiny protoplasmic thread, or cilium, protrudes whose base lies in the ectoplasm beneath. The myriads of cilia form a nearly uniform coat over the entire animal, and their coordinated oarlike movements provide for locomotion, and for feeding the organism by wafting a food-laden current of water down the peristome through the mouth and into the gullet. The distribution and differential beating of the cilia and the asymmetry of the body cause the animal to rotate on its long axis and to progress in a spiral course as it bores its way through the water. (Fig. 58.)

In addition, *Paramecium* shows considerable versatility in its behavior. Although it has no specialized sense organs, the whole surface of the body responds to various kinds of stimuli. Throughout the ectoplasm there are highly complex networks of supporting and conductive fibers some of which are in direct relation with

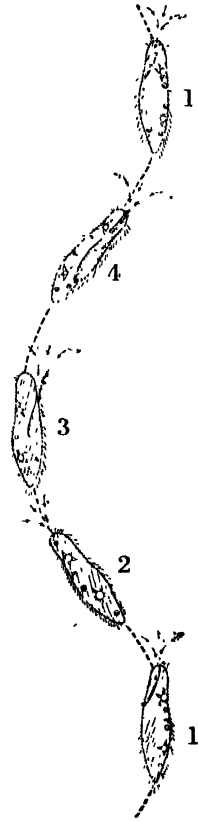


FIG. 58. Diagrams to show the rotation on the long axis, and the spiral path of *Paramecium*. 1-4, successive positions assumed. The dotted areas with small arrows represent the currents of water drawn from in front. (From Jennings.)

the bases of the cilia. The conductive fibers focus at one point, the **MOTORIUM**, near the gullet, and constitute the **NEUROMOTOR SYSTEM** which is believed to coordinate the activities of the cell. The animal when stimulated usually responds with an **AVOIDING REACTION** which consists of backing off, turning toward the aboral side, and then moving forward. In this way the animal tries various directions at random until, perchance, the stimulus is avoided; then it proceeds on its way. (Fig. 59.)

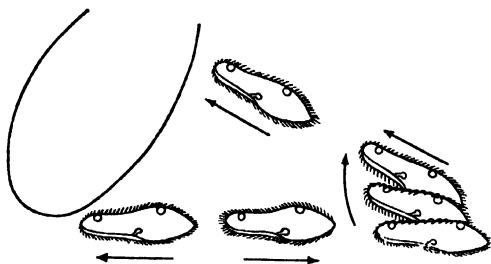


FIG. 59. Diagram to show the avoiding reaction of *Paramecium*. A solid object or other source of stimulation is shown at the left. Arrows indicate successive positions taken by the animal. The rotation on its long axis is not indicated. (From Jennings.)

Evenly distributed in the peripheral cytoplasm, just beneath and perpendicular to the pellicle, are innumerable spindle-shaped bodies, known as **TRICHOCYSTS**. Various kinds of stimulation incite their discharge from the body as relatively long, slender rods. The mechanism of expulsion and transformation of the trichocysts is not known, and their function is in doubt though it is assumed to be related to defense. (Fig. 60.)

Paramecium is provided with two **CONTRACTILE VACUOLES**, one toward either end of the body, which contract rhythmically. Each forms part of a system consisting of a circle of radiating collecting canals which empty their contents at one point to form a definitive, but temporary, contractile vacuole which expels its contents through a pore to the outside. The contractions of the vacuoles serve chiefly to eliminate excess water from the protoplasm, but probably various waste products of metabolism are carried along so that an excretory function is also served. However, excretion in general as well as the respiratory interchange is maintained all over the surface of the body through the pellicle.

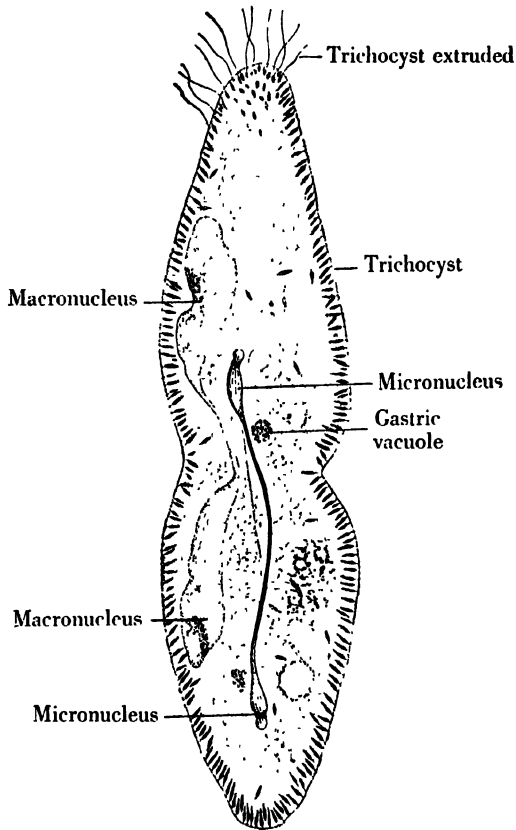


FIG. 60. *Paramecium caudatum* in process of reproduction by cell division (binary fission). Longitudinal section of stained preparation, highly magnified. (From Calkins.)

More deeply in the cell, in the endoplasm, the vacuoles that carry food are usually the most conspicuous objects in the living animal. These GASTRIC VACUOLES arise as droplets of fluid surrounding the food, chiefly bacteria, that has entered the mouth by the activity of the peristomal cilia. Each gastric vacuole in succession is carried from the gullet along a fairly definite course through the cell by endoplasmic currents. As a gastric vacuole progresses, enzymes are secreted into it, digestion and absorption occur, and finally the residue is passed out of the body at one point, the ANAL PORE. (Fig. 57.)

The nuclear material in *Paramecium*, instead of forming a single

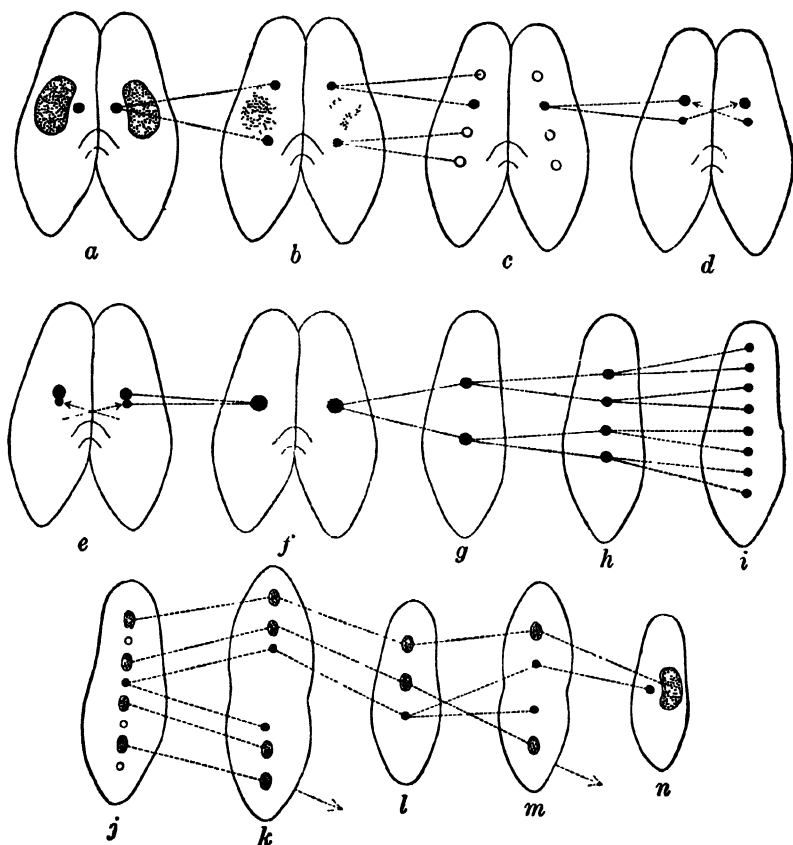


FIG. 61. *Paramecium caudatum*. Diagrams to illustrate conjugation. *a*, pair of conjugants. *b*, in each conjugant the macronucleus breaks down and the micronucleus divides. *c*, each micronucleus divides again, and three of the four micronuclei in each conjugant break down. *d*, each micronucleus divides into two nuclei of unequal size; the smaller is the migratory nucleus and the larger the stationary nucleus. *e*, the migratory nucleus of each conjugant moves into the other member of the pair. *f*, the migratory nucleus fuses with the stationary nucleus in each conjugant, and then the conjugants separate; only one of the ex-conjugants is shown in the following figures. *g*, the fusion nucleus (synkaryon) divides into two micronuclei. *h*, each of these two then divides, and a further division produces eight micronuclei as shown in stage *i*. *j*, four micronuclei enlarge to form macronuclei and three micronuclei degenerate. *k*, the single macronucleus divides, and now the ex-conjugant divides by binary fission to form two daughter cells, each with two macronuclei and one micronucleus. *l*. Another division produces two daughter cells, each with the normal macronucleus and micronucleus, as shown in *n*. The final result, then, is four small animals from each ex-conjugant. These grow to full size and asexual reproduction by binary fission continues until conjugation occurs again. (After Hegner.)

body as in most cells, is distributed in two parts, a relatively large MACRONUCLEUS and a small MICRONUCLEUS, both imbedded in the endoplasm. The former functions chiefly in the general activities of the cell, whereas the latter is largely devoted to reproduction. This segregation of the nuclear material into separate bodies is characteristic of all the ciliated Protozoa, or Ciliata, though the number of micronuclei varies. Other common species of *Paramecium*, such as *P. aurelia* and *P. calkinsi*, have two micronuclei. (Figs. 10, 57.)

Reproduction in *Paramecium* involves the division of the cell into two daughter cells, so that the parent cell loses its individuality. In this process of binary fission both of the nuclei as well as the cell body divide, and complicated processes of dedifferentiation, regeneration, and growth occur to produce two daughter cells that soon are complete replicas of the parent. (Fig. 60.) Under proper conditions of food and temperature, *Paramecium* divides about two or three times every day and so it is not long before the descendants are legion. This can continue indefinitely if the environment remains favorable; but periodically, without interrupting the sequence of divisions, an internal nuclear reorganization occurs either by AUTOGAMY or by ENDOMIXIS. Both processes involve the destruction of the macronucleus and its replacement by a new macronucleus of micronuclear origin, but in autogamy self-fertilization occurs to produce a synkaryon.

Sexual reproduction in *Paramecium* typically consists in the temporary union, or CONJUGATION, of two animals, usually from different strains, or MATING TYPES, so that cross-fertilization results. (Fig. 61.) The oral surfaces of the conjugants fuse, and thus a path is formed for the exchange of gametic nuclei of micronuclear origin. The gametic nuclei then unite to form a synkaryon in each animal. After this mutual fertilization the conjugants separate and from the synkaryon there is gradu-

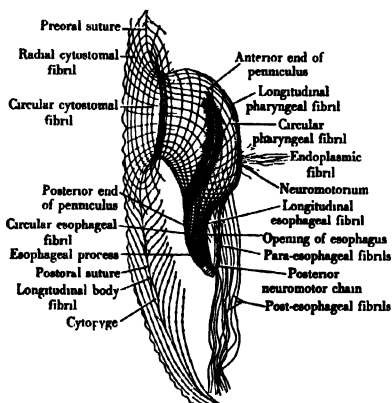


FIG. 62. Diagram of the neuromotor system in the region of the peristome and gullet of *Paramecium multimicronucleatum*, to afford an idea of the intracellular complexity attained in the cytoplasm of some protozoa. Very highly magnified. (After Lund.)

ally established, by division and transformation, the typical micronuclear and macronuclear apparatus of the species.

From the study of *Paramecium* it is evident that the unicellular plan affords opportunity for great complexity of structure and function. And *Paramecium* is fairly representative of the Protozoa that have made the most, so to speak, of the possibilities afforded by a single cell. For further advance, recourse must be had to combinations of many cells. Such, indeed, are the bodies of all the higher animals, or Metazoa. (Fig. 62.)

HYDRA

In discussing the development of multicellular animals it was stated that the dividing egg typically forms a blastula which becomes transformed into the gastrula stage. (p. 17.) The gastrula is essentially a sac composed of two layers of cells: an outer, or ectoderm, and an inner, or endoderm, layer. Although this simple gastrula form is not found in mature animals, those composing the phylum COELENTERATA are built on the general plan of a two-layered sac. This diploplastic condition is well exhibited in the various species of hydra, which are almost microscopic, fresh-water animals commonly found attached to submerged vegetation or stones in brooks and ponds. (Fig. 63.)

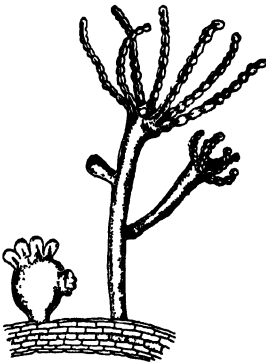


FIG. 63. Hydra. Two individuals with buds. The one to the left is contracted; the other is expanded. Magnified. (After Pfurtscheller. Redrawn.)

The body of hydra somewhat resembles a long narrow sac, the flat, closed end constituting the BASAL DISC, and the conical open end, the HYPOSTOME. The opening is the MOUTH which is surrounded by a circle of five or more slender outpocketings of the body termed TENTACLES. The main axis of the body extends from the basal disc to the mouth, and every plane passing through this axis divides the body into symmetrical halves. In other words, the parts of the body are symmetrically disposed about, or radiate from, the main axis; thus hydra affords an example of RADIAL SYMMETRY. (Fig. 64.)

The body wall, including the tentacles, is composed of two distinct cell layers, ectoderm and endoderm, separated by a very thin space filled with a noncellular jellylike material, known as MESOGLEA, se-

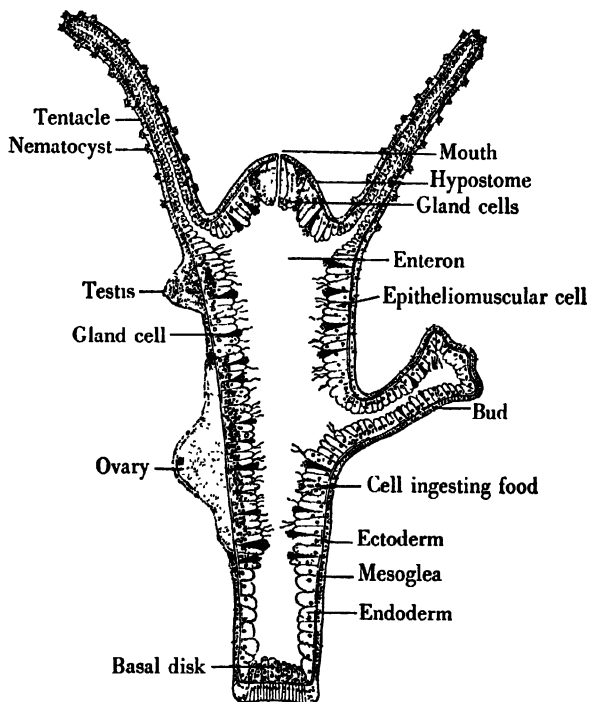


FIG. 64. Hydra. Drawing of a longitudinal section to show internal structure. Magnified. (After Kepner and Miller.)

creted by the cells of both ectoderm and endoderm. The entire surface, except the basal disc, is covered with a thin, transparent, noncellular covering. Hydra thus illustrates a very simple type of metazoan structure in which but two primary tissues exist, such specializations as are necessary for the performance of the essential life functions being confined to the various cells that compose these layers. Many of the cells of the endoderm which line the ENTERON are concerned with the digestion of solid food taken in through the mouth, while the cells of the ectoderm are variously modified for protection and the other relations of the individual to its surroundings, as well as for reproduction. (Figs. 65, 66.)

The ectoderm comprises several major types of cells. The elongated EPITHELIOMUSCULAR CELLS have broad bases with contractile fibrils which, together with those of certain cells of the endoderm, are responsible for the animal's remarkable powers of expansion and con-

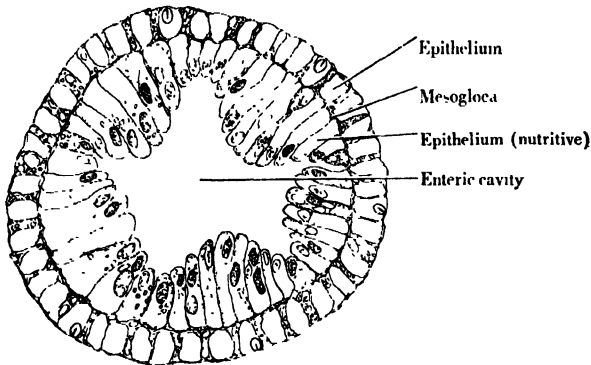


FIG. 65. Hydra. Drawing of a transverse section to show internal structure. Magnified.

traction. The **SENSORY CELLS** act as external receptors of stimuli, and the **NERVE CELLS** form a sort of net for the conduction of nerve impulses. Between the bases of the epitheliomuscular cells are wedged **INTERSTITIAL CELLS** that give rise to **GERM CELLS** and to **CNIDOBLAST CELLS**. The latter form stinging capsules, or **NEMATOCYSTS**, which are widely distributed over the surface but are most numerous on the tentacles. Each of the four kinds of nematocysts encloses a coiled tube that is ejected when the nematocyst explodes under proper stimulation, and new nematocysts are continually being developed to replace those expended. That they are effective weapons is evident from the fact that tiny animals may be quickly paralyzed and killed by a poison injected by the tubes of the nematocysts. (Fig. 67.)

The ectoderm of the basal disc is without nematocysts and functions chiefly for attachment and for locomotion which is effected by a sort of gliding. It also secretes mucus, and a gas bubble within the

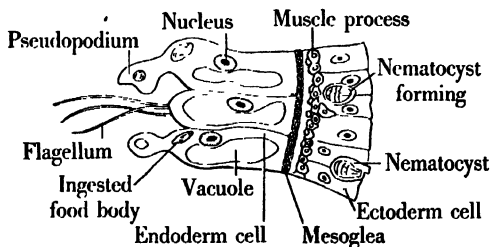


FIG. 66. Hydra. Drawing of transverse section of body wall to show cellular differentiation. Diagrammatic. Highly magnified. (After Parker.)

mucus may serve to buoy the animal to the surface of the water. But the disc is not the sole agency in locomotion. Sometimes the animal attaches itself alternately by basal disc and by tentacles and tumbles along; at other times it "walks" inverted on its tentacles.

The endoderm forms considerably more than half of the body wall and consists of several types of cells. These are elongated epitheliomuscular cells, with broad bases, which both function in digestion and contraction; small GLANDULAR CELLS that are secretory in function; still smaller interstitial cells situated at the bases of the larger types of cells; and finally, NERVE CELLS. (Fig. 66.)

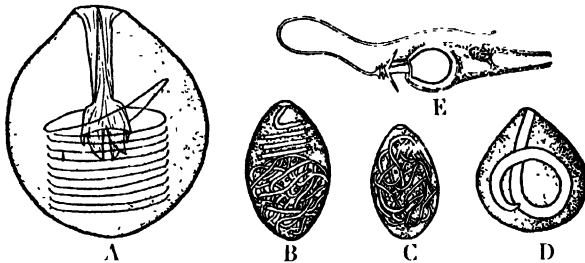


FIG. 67. Hydra. Types of stinging cells, or nematocysts. A, *Penetrant*; B, *Streptoline penetrant*; C, *Stereoline glutinant*; D, *Volvent*; E, *Exploded nematocyst*. (X 3300.) (From Hegner. A-D, after Papenfus; E, after Schneider.)

A hydra attached by its basal disc, with body and tentacles fully extended, commands a relatively large area. Protozoa, tiny crustaceans, etc., that come in contact with the nematocysts in the tentacles are paralyzed and held, and then conveyed by the tentacles to the mouth which expands and engulfs them. Once within the enteron the glandular cells of the endoderm secrete enzymes that are churned about with the food by contractions of the body and by vibratile flagella that project into the enteron from many of the cells. The digested material is then absorbed by endoderm cells. Furthermore, particles of food are engulfed by these cells and digested intracellularly. Waste material is ejected through the mouth.

Most species of hydra are grayish in color but exceptions are the two cosmopolitan species: the brown hydra, *Pelmatohydra oligactis*, and the green hydra, *Chlorohydra viridissima*. The latter is green because innumerable unicellular algae, *Chlorella vulgaris*, have an abode within the endoderm cells: a mutually beneficial symbiotic relationship. (pp. 424-425.)

Reproduction in hydra is both *asexual* and *sexual*. Now and again outpocketings, or *BUDS*, grow from the body wall, gradually develop into tiny embryos, and then are freed as new individuals. Sometimes hydra undergoes transverse or longitudinal fission but probably only as a sequel to atypical conditions. The processes involved in such asexual reproduction are not very different from those involved in the replacement, or *REGENERATION*, of parts lost by mutilations—a power possessed to a very high degree by hydra. (Figs. 63, 64.)

Most species are *DIOECIOUS*, the sexes being separate; but some are *HERMAPHRODITIC*, each individual producing both eggs and sperm. The testis and ovary are temporary conical elevations of the ectoderm within which the gametes are formed from interstitial cells: a multitude of sperm in the testis and a single egg in the ovary. The sperm are set free into the water, and after one fertilizes a ripe egg protruding from the ovary, the zygote passes through the early embryological stages and then is liberated and develops into a young animal. (Fig. 68.)

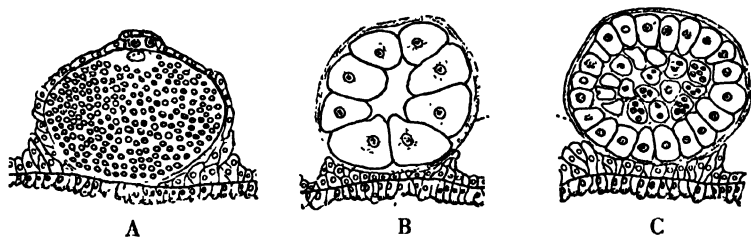


FIG. 68. Hydra. Section of the ovary showing egg in three stages of development: A, *mature egg* with egg nucleus and two polar bodies (*above*); B, *blastula* stage; C, *gastrula* stage (early). Highly magnified. (From Hegner, after Tannreuther.)

Hydra affords an example of one of the simplest multicellular animals. The *primary tissues*, ectoderm and endoderm, are not specialized during development as *secondary tissues* (muscular tissue, nervous tissue, etc.) for one essential function or another; the continuous life processes are adequately provided for by the specialization of isolated cells or small groups of cells within the ectoderm and endoderm. (pp. 541-548.)

EARTHWORM

The bodies of all animals more complex than the coelenterates are built of three primary tissue layers which, as development of the individual continues, give rise to the secondary tissues and thereby form a

relatively complex body. This third primary tissue, the mesoderm, typically is developed, as we have described earlier, from the endoderm and comes to occupy the position held by the mesoglea of hydra, that is, between the ectoderm and the endoderm. (Fig. 178.)

The development of the mesoderm is largely the key to the advance in body organization of higher animals, because it makes possible a radical change in plan that involves the establishment of a body cavity, or COELOM, in which are located many of the chief organs. Accordingly the coelenterates, since they lack the coelom, are often referred to as ACOELOMATES, whereas higher animals, since typically they possess a coelom, are known as COELOMATES. The difference in structure can best be made clear by considering the anatomy of a somewhat higher invertebrate, such as one of the many species of earthworms, members of the phylum Annelida. (pp. 554-557.)

BODY PLAN

Whereas the hydra-body is essentially a sac composed of two layers of cells surrounding the enteric cavity, the body of the earthworm is built on the plan of a tube within a tube, the outer tube forming the BODY WALL, and the inner, the wall of the digestive tract, or ALIMENTARY CANAL. The walls of these tubes merge into each other at both ends, and thus together they enclose a space, the coelom. The alimentary canal opens to the exterior at both ends, forming the MOUTH and ANUS. (Fig. 69.)

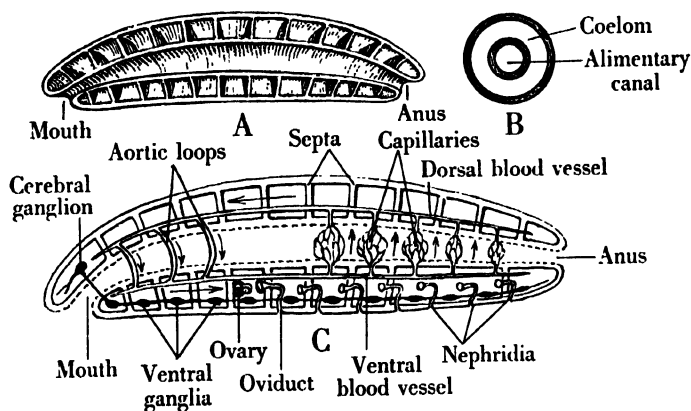


FIG. 69. Diagrams of the general body plan of the earthworm. A and C, longitudinal sections; B, transverse section. (From Sedgwick and Wilson.)

The coelom of the earthworm is divided by a large number of transverse partitions, the SEPTA, which extend from the inner surface of the body wall to the outer surface of the alimentary canal. The result is that the worm's body cavity is not a continuous space running from one end of the animal to the other, but consists of a linear series of chambers through the center of which runs the alimentary canal. The limits of these chambers are indicated on the outside of the worm by a series of grooves which encircle the body wall. In short, the body is made up of a series of essentially similar units known as SEGMENTS, and is a simple example of SEGMENTATION, which affords further opportunities for division of labor between the various parts of the body. It is a characteristic structural feature expressed in varying degree in nearly all higher animals.

Many of the chief parts, or organs, of the earthworm are symmetrically arranged with respect to the long axis of the body which extends from mouth to anus, so there may be passed through the main axis a single plane that divides the body into symmetrical halves, each of which is a "mirror image" of the other. The main axis, therefore, extends from the mouth (ANTERIOR END) to the anus (POSTERIOR END), and the plane that divides the body into right and left sides passes through the upper (DORSAL) and lower (VENTRAL) side: the body exhibits BILATERAL SYMMETRY—a characteristic plan of higher animals. (Fig. 72.)

TISSUES AND ORGANS

Definitive organs are highly developed in the earthworm, and these demand a much greater differentiation of tissues than occurs in hydra where local modifications of ectoderm and endoderm serve the purposes of its relatively simple organization. Accordingly in the earthworm and in all higher forms the mesoderm is added to the two primary cell layers, and from these three there is developed a great variety of special tissues. It is convenient to distinguish six main groups of tissues: epithelial, supporting, muscular, nervous, vascular, and germinal. (Fig. 11.)

The importance of EPITHELIAL TISSUES is evident from the fact that the body is covered and lined with these cellular membranes which form the areas of contact between the organism and its environment. For example, food before it is really inside the body must pass through the epithelium lining the digestive tract, and before it can do that it

must be digested by enzymes secreted by epithelial cells. Furthermore, the waste products of metabolism must pass from the body through epithelial membranes. Specialization for secretion and excretion leads to GLAND formation. Glands may be unicellular and scattered here and there in the surface of the cellular membrane, or they may be grouped at certain points of vantage. Just as often, however, many cells combine to form multicellular glands, which sink, as it were, below the surface as simple or complex tubes or sacs of secreting cells, and thus amplify many fold the effective surface within a given space. And finally, specialized epithelial cells form important elements of sense organs, the outposts of the nervous system. (Figs. 70, 71.)

Obviously the larger and more complex the organism, the greater is the necessity for sustaining and binding material; therefore, as

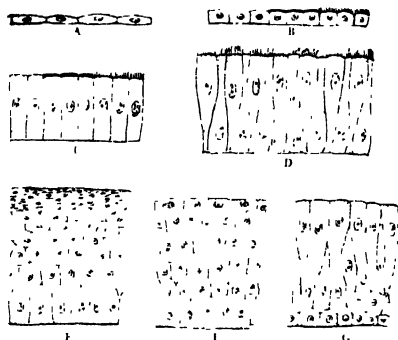
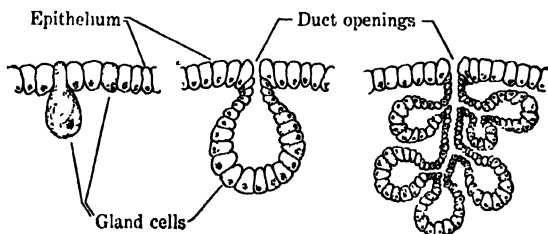


FIG. 70. Epithelial tissues. A, one-layered flat epithelium; B, one-layered cubical epithelium, three cells with cuticle and three with cilia; C, cylindrical epithelium, three cells with cuticle and three with cilia; D, ciliated epithelium; E, many-layered epithelium; F, transitional epithelium; G, stratified epithelium. (From Walter.)



the animal scale is ascended, there is found, in general, an increase in SUPPORTING TISSUE. Whereas in epithelia the cells themselves form the major part of the tissue, in supporting tissues it is direct or indirect products of the cells, known as intercellular material, or matrix.

FIG. 71. Diagrams of glands with ducts (exocrine): specialized epithelial cells which elaborate specific substances and secrete them for the use of the organism: unicellular gland (*left*); multicellular glands, simple (*center*), compound (*right*).

that gives character to the tissue. Thus the function of **CONNECTIVE TISSUE** is performed chiefly by intercellular bundles of fibers, and the same condition is true for the cartilage and bone forming the internal skeletons of higher animals.

MUSCULAR TISSUE is responsible for the power of motion and locomotion characteristic of most animals, and also for the necessary movements performed by the internal organs in carrying on the various life processes. Muscle cells have in a highly developed and specialized form a fundamental property of all protoplasm, contractility, which they exhibit by shortening and broadening when stimulated by impulses coming chiefly through the nervous system. A muscle is a cooperating group of muscle cells, bound together by connective tissue elements and richly supplied with blood vessels and nerves. (Figs. 11, 72, 87, 88.)

All protoplasm is irritable, that is, it responds to stimuli, but obviously the larger and more complex the body becomes, the more necessary it is that stimuli be available to its various parts and that the actions and reactions of its component cells be instantly coordinated so that the parts act as a whole, as an organism. This function is performed by **NERVOUS TISSUE**, which receives stimuli and transmits nerve impulses when stimulated. (Figs. 72, 73.)

One seldom thinks of **BLOOD**, **LYMPH**, and **TISSUE FLUID** that transport materials in the body, as tissues, but in truth they must be re-

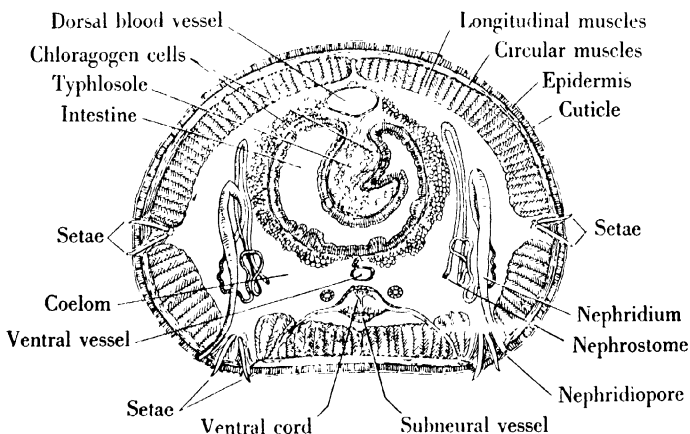


FIG. 72. Earthworm. Transverse section through the middle region of the body.

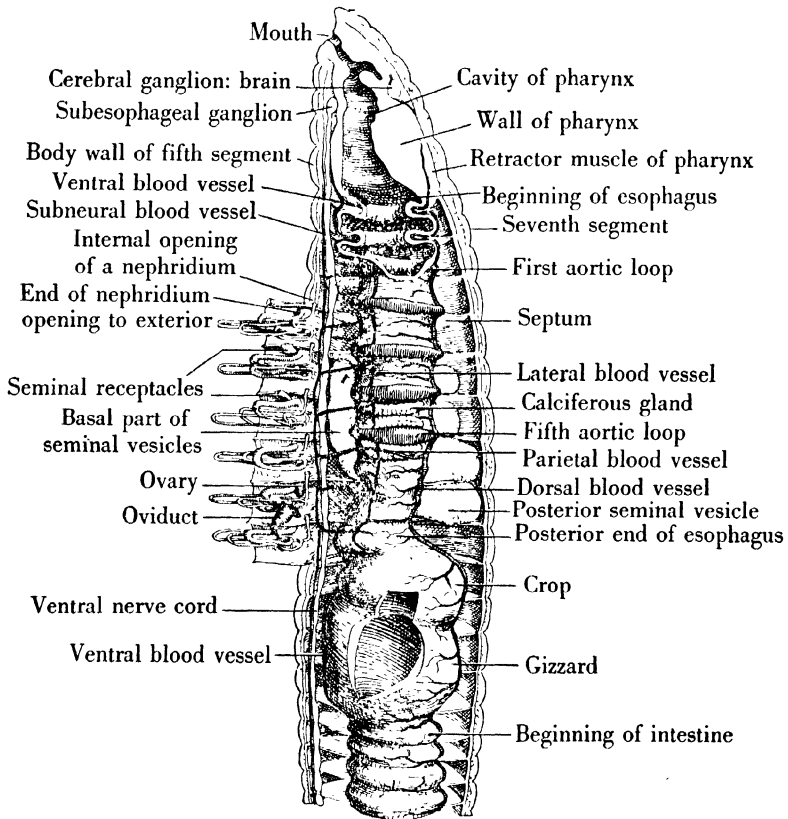


FIG. 73. Earthworm. Drawing of a dissection, lateral view of the anterior end, from the left side, segments I-XXIV. (Modified, after Linville and Kelly.)

garded as a **VASCULAR TISSUE** in which the living cells are suspended in a fluid matrix, the **PLASMA**. The vascular tissues minister to, and are in intimate contact with, every tissue and cell of the organism. Finally, within the body—though perhaps not of the body—is the **GERMINAL TISSUE** destined to effect the propagation of the race through reproduction.

It is clear that the earthworm and higher animals show great advances over the two-layer body plan exhibited by hydra. The more complex body plan involves the cooperation of various tissues to form organs, and the cooperation of organs to form **ORGAN SYSTEMS**, each of which has major importance in the economy of the whole.

CHAPTER VIII

The Animal Body: Invertebrate (II)

ORGAN SYSTEMS: EARTHWORM

The organ systems of the earthworm and all higher animals may be classified as follows: the INTEGUMENTARY and SUPPORTING SYSTEMS, which constitute the covering and the framework of the individual; the ALIMENTARY, CIRCULATORY, RESPIRATORY, and EXCRETORY SYSTEMS, which directly or indirectly are concerned with nutrition; the NERVOUS SYSTEM, which in cooperation with the various SENSE ORGANS, the MUSCULAR SYSTEM, etc., coordinates the various parts of the individual and also orients the whole with respect to its environment; and, finally, the REPRODUCTIVE SYSTEM, which makes possible the continuation of the race. The fundamental life processes for which these systems provide must be carried on by all animals, and the chief differences in the structure of animals, from the lowest to the highest, reflect the means adopted to serve these essential functions under different conditions imposed by the environment and mode of life.

ORGANIZATION OF THE EARTHWORM

The body of an earthworm may be described as a long cylindrical tube with terminal openings, the mouth and anus. The surface is covered by a secreted transparent cuticle perforated by numerous tiny pores for respiration and the release of secretions; also by a series of DORSAL PORES opening into the body cavity, and by the openings of the excretory and reproductive systems. Furthermore, four pairs of very small, chitinous bristles, or SETAE, protrude through the ventral and lateral surfaces of nearly every segment. (Fig. 72.)

Immediately under the cuticle is a layer of cells which constitutes

the outermost cellular layer, or EPIDERMIS. Beneath this is a layer of CIRCULAR MUSCLE, and then one of LONGITUDINAL MUSCLE, and finally the PERITONEAL EPITHELIUM which lines the body cavity. Thus the integumentary and supporting systems of the earthworm consist of the skin, or epidermis, and layers of muscle; a true skeleton, such as occurs in higher animals, is not in evidence.

ALIMENTARY SYSTEM

Dissection of an earthworm reveals, within and extending the entire length of the body, an inner muscular tube, the ALIMENTARY CANAL. The space between it and the body wall is the coelom, which is divided transversely by thin membranes, or septa, into a series of compartments, or segments. Indeed the septa essentially suspend the alimentary canal in the coelom, which is filled with a colorless COELOMIC FLUID that is irregularly forced about from one segment to another as the worm contracts. The wall of the canal, in general, consists of an outer peritoneal epithelium of so-called CHLORAGOGEN CELLS, and this layer forms the intestinal portion of the coelomic lining. Internal to this is a thin layer of longitudinal muscles, then a similar one of circular muscles, and finally a layer of ciliated nutritive epithelium, endodermal in origin, which lines the lumen of the canal.

The alimentary canal is a straight tube that shows various specializations for extracting and digesting the food, which consists of particles of organic matter, chiefly pieces of leaves and humus in general. Food particles are moved through the mouth into the BUCCAL POUCH and passed to the muscular PHARYNX. After the addition of secretions from the PHARYNGEAL GLANDS, the food traverses the long, narrow ESOPHAGUS, where CALCIFEROUS GLANDS contribute an acid-neutralizing secretion. Then the food enters the CROP where it is temporarily stored until passed to the GIZZARD to be rolled and squeezed into small fragments. And now the ingested material is ready to go on to the INTESTINE proper, where digestion and absorption chiefly occur. To increase the surface area for these functions there is a deep glandular infolding of the dorsal wall of the intestine that extends its entire length and is known as the TYPHLOSOLE. (Figs. 72, 73.)

The process of digestion does not differ fundamentally from that in higher animals to be considered later. The food runs the gantlet of a series of chemical substances, chiefly enzymes, which reduce complex molecules of the food to simpler ones that can be absorbed and so

actually taken into the body. The waste indigestible materials, or **FECES**, are egested through the anus as the so-called castings, frequently seen on the surface of ground inhabited by worms.

CIRCULATORY SYSTEM

For the distribution of material to the various parts of the body of the earthworm, a circulatory system is required. This system comprises a series of tubes, or **VESSELS**, in which is circulated a fluid tissue, the blood. Blood is composed of a liquid plasma, red in color owing to a dissolved pigment, and of suspended colorless **BLOOD CELLS**. In vertebrates the closely related respiratory pigment, hemoglobin, is in the blood cells and not in the plasma. (Fig. 74.)

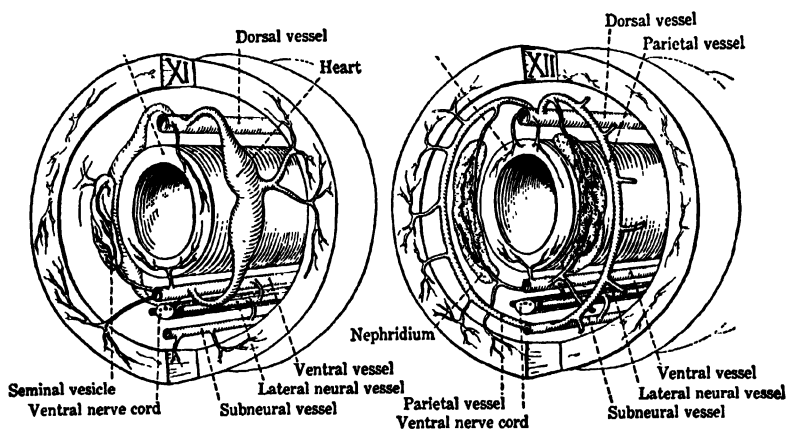


FIG. 74. Earthworm. Diagrams of the circulatory system in segments XI and XII. Transverse sections. (From Hegner.)

The blood vessels consist chiefly of five relatively large longitudinal trunks, one of which runs just above and nearly the entire length of the alimentary canal. This **DORSAL VESSEL** induces the blood flow by waves of contractions, or **PERISTALSIS**, of its muscular walls. The successive waves pass forward and force the blood before them until the five pairs of **AORTIC LOOPS**, or so-called hearts, are reached. Here the blood is similarly forced through the loops into the **VENTRAL VESSEL** which is just beneath the alimentary canal. In the ventral vessel some of the blood proceeds anteriorly and some posteriorly, and in both cases eventually through smaller and smaller vessels, or **CAPILLARIES**, until it reaches the body wall and various organs. The return current is by

the LATERAL-NEURAL VESSELS and by the SUBNEURAL VESSEL and then up to the dorsal vessel by the PARIETAL VESSELS. Thus the blood *circulates*, carrying food and oxygen to the tissues, and waste materials, including carbon dioxide, away; and so it functions not only in nutrition but also in respiration and excretion.

RESPIRATORY SYSTEM

The relatively simple body and inactive life of the earthworm render unnecessary an elaborate respiratory system such as is present in many higher animals. Accordingly this system consists merely of a network of capillaries which permeate to the surface of the body wall and there allow the blood to exchange carbon dioxide for oxygen through the moist membrane.

EXCRETORY SYSTEM

Most of the waste products of metabolism leave the body by a series of tiny coiled tubes, the NEPHRIDIA, one pair being present in nearly every segment. A nephridium is a ciliated tube with an open funnel in one segment and the major portion of the coiled tube in the next posterior segment, where it leads out of the body by a NEPHRIDIOPORE on the ventral surface. Ciliary action draws solid particles from the coelomic fluid into the tube to be passed out through the pore, while gland cells in the coiled portion remove waste products from the blood to be similarly disposed of. (Fig. 73.)

NERVOUS SYSTEM

Coordination of the activities of the individual, both external and internal, is the function of the nervous system and sense organs. The chief nervous center of the earthworm is a bilobed mass of tissue, the brain or CEREBRAL GANGLION, lying on the dorsal surface of the pharynx. From each lobe there passes ventrally a CIRCUMESOPHAGEAL COMMISSURE which merges into the SUBESOPHAGEAL GANGLION just beneath the pharynx. From this ganglion the VENTRAL NERVE CORD (actually two closely united cords) extends in the midventral line to the posterior end of the worm. (Fig. 80.)

In each segment, except the first three, the cord enlarges into a ganglion from which arise three pairs of nerves. The latter are either EFFERENT or AFFERENT NERVES. Efferent nerves consist of MOTOR NERVE FIBERS which are delicate prolongations of nerve cells, or

NEURONS, in the ganglia, and carry motor nerve impulses to the muscles, glands, and other organs. Afferent or SENSORY NERVE FIBERS arise from SENSORY CELLS, or RECEPTORS, chiefly on the surface of the body, and carry sensory nerve impulses to the ventral nerve cord which, in turn, may relay them to the brain. Or the sensory impulse may be immediately transformed in the nerve cord into a motor impulse and pass by motor fibers to a muscle or other EFFECTOR. In this event a simple REFLEX ARC is established and a reflex action occurs. The groups of sensory cells constitute the simple SENSE ORGANS of the worm which enable it to respond to light, contact, and other stimuli. (Figs. 69, 72, 73, 142, 143.)

REPRODUCTIVE SYSTEM

The earthworm is hermaphroditic since both male and female reproductive organs are present in each individual. The male system consists of two pairs of TESTES, a pair of SPERM DUCTS leading to the surface, and three pairs of SEMINAL VESICLES. The female system comprises a pair of OVARIES, a pair of OVIDUCTS which start as an open funnel in one segment and then enlarge into an egg sac in the next posterior segment before opening to the exterior, and finally, two pairs of SEMINAL RECEPTACLES. (Figs. 69, 73.)

Cross-fertilization occurs because, during copulation, sperm from each individual pass into the seminal receptacles of the other where they are stored until egg-laying occurs. Then the enlarged glandular CLITELLUM on the body surface, which also aids in holding the animals in copulation, secretes a circular tube which, as it is moved forward, receives eggs and sperm. Soon this cocoon is passed off the anterior end of the worm, and then it closes to form the capsule in which the fertilized eggs develop into tiny worms. The detailed consideration of earthworm embryology and development is deferred until later (Chap. XIX).

CRAYFISH

Bearing in mind the general plan of the body of the earthworm, we may next consider the main principle underlying the changes in this plan which give rise to many of the diverse forms among the higher animals. This principle is chiefly a specialization of the individual segments so that the body, instead of consisting of a large number of essentially similar segments, is formed of a complex series of them, many of which are quite different from the rest. Furthermore, by the partial

or complete fusion of two or more segments and the suppression of segmentation, definite regions of the body are differentiated. These changes are well illustrated by members of the immense phylum ARTHROPODA, or "jointed-foot" invertebrates, such as lobsters, insects, and spiders.

The body of a primitive arthropod differs from that of the earth-worm chiefly in the reduction of the number of segments and the development of paired jointed APPENDAGES as outgrowths from the body in each segment. From such a primitive type all the multitude of diverse forms of arthropod bodies can be derived. (Fig. 75.) For in-

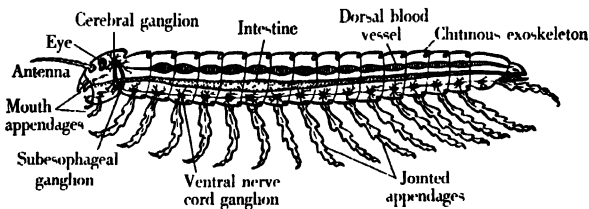


FIG. 75. Diagram of the structure of an idealized primitive arthropod in which very little specialization of the segments has occurred. (After Schmeil.)

stance, in the fresh-water crayfish, which is essentially like the larger marine lobster, the body consists of twenty-one segments, but by the union and differentiation of certain segments, the body is divided into three more or less distinct regions: head, thorax, and abdomen.

Furthermore, the primitive locomotor appendages of the respective segments are modified into organs for the performance of widely different functions: those of the head, as sensory organs, jaws, etc.; those of the thorax, as organs for grasping, offense, defense, and walking; and those of the abdomen for swimming, etc. Thus change in structure has gone on hand in hand with change in function so that, although there is no obvious resemblance between the jaws of the crayfish and the legs employed for swimming, nevertheless a study of their development shows beyond doubt that they owe their origin to modifications of one primary type. Accordingly the various appendages of the crayfish are said to be HOMOLOGOUS, and to exhibit SERIAL HOMOLOGY, signifying a fundamental similarity of structure based on descent from a common antecedent form. One of the tasks of the division of biology known as COMPARATIVE ANATOMY is to determine the homologous

parts of animals or of plants and to study the adaptive changes associated with change of function. (Fig. 76.)

The principle of specialization and fusion of the segments of the higher arthropods results also in profound modifications of the internal organs. In the first place, the partitions between the various segments in the earthworm have disappeared in the crayfish. Again, the alimentary canal of the earthworm is a nearly straight tube extending through the body, with relatively slight modifications in certain seg-

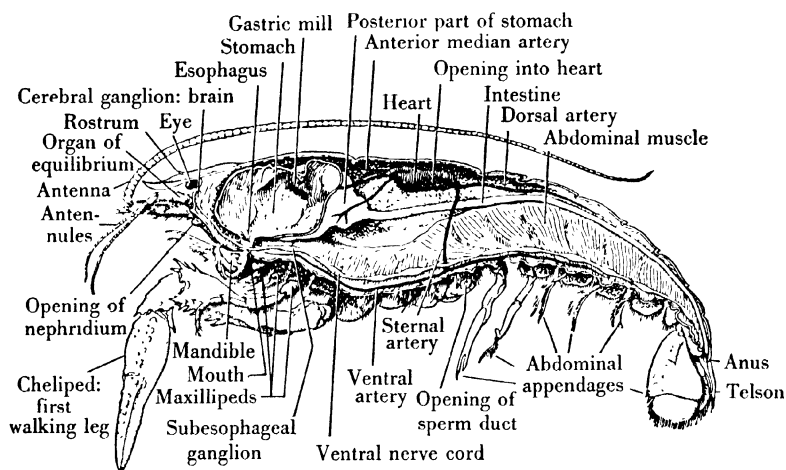


FIG. 76. Crayfish, *Cambarus affinis*. Dissection, lateral view.

ments for the elaboration of the food material as it passes along from mouth to anus; whereas in the crayfish there is an accentuation of such modified regions, and the development of large outpocketings, or glands, which are specialized for the formation of chemical substances to digest the food.

The nervous system will serve as a final illustration. In both the earthworm and the crayfish the nervous system exhibits the same general plan, but certain modifications have been brought about in the latter animal by the uniting of segments in the region of the head and thorax. This process has resulted in the fusion of the segmental ganglia into larger ganglionic masses. For example, the cerebral ganglion of the crayfish comprises the primitive ganglia of the segments which have united to form the head. (Figs. 77, 80.)

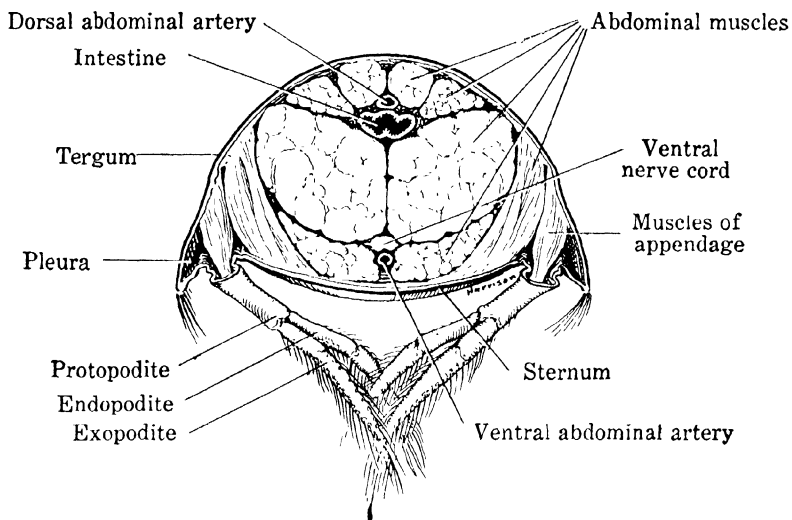


FIG. 77. Crayfish. Transverse section of the fifth abdominal segment.

This completes our synoptic view of the chief contrasting features of the earthworm and crayfish as types. More specific consideration may now be given to structure and function in the crayfish.

ORGANIZATION OF THE CRAYFISH

The entire body of the crayfish is covered with a nonliving secreted EXOSKELETON, composed of a chitinous CUTICLE impregnated with lime. The exoskeleton is extremely resistant, except at the joints to allow movement, and since it cannot continue to enlarge as the animal increases in size, it must be shed periodically and a new shell secreted: a process known as MOLTING, or ECDYSIS.

The body is segmented, but this is not everywhere apparent because there is a rigid anterior portion, or CEPHALOTHORAX, covered dorsally and laterally by a shieldlike CARAPACE. Across the carapace runs a groove which demarks the head region from the thorax. An anterior, pointed extension of the carapace, called the ROSTRUM, is just above the pair of stalked eyes. The cephalothorax is composed of six head segments and eight thoracic segments, and posterior to it is the abdomen of seven movable segments. An extension, or TELSON, of the terminal abdominal segments bears the anus. (Fig. 76.)

A typical segment of the abdomen comprises externally a dorsal

plate or TERGUM, lateral plates or PLEURA, and a ventral transverse bar or STERNUM. Every segment bears a pair of jointed appendages; each pair as already emphasized, is a variant of a common, primitive type consisting of a basal segment, or PROPODITE, which bears two branches, an outer EXOPODITE and an inner ENDOPODITE. In certain cases the modifications result in appendages which are FOLIACEOUS, as the second maxillae; or BIRAMOUS, as the swimmerets on the abdomen; or UNIRAMOUS, as the walking legs. (Figs. 77, 78.)

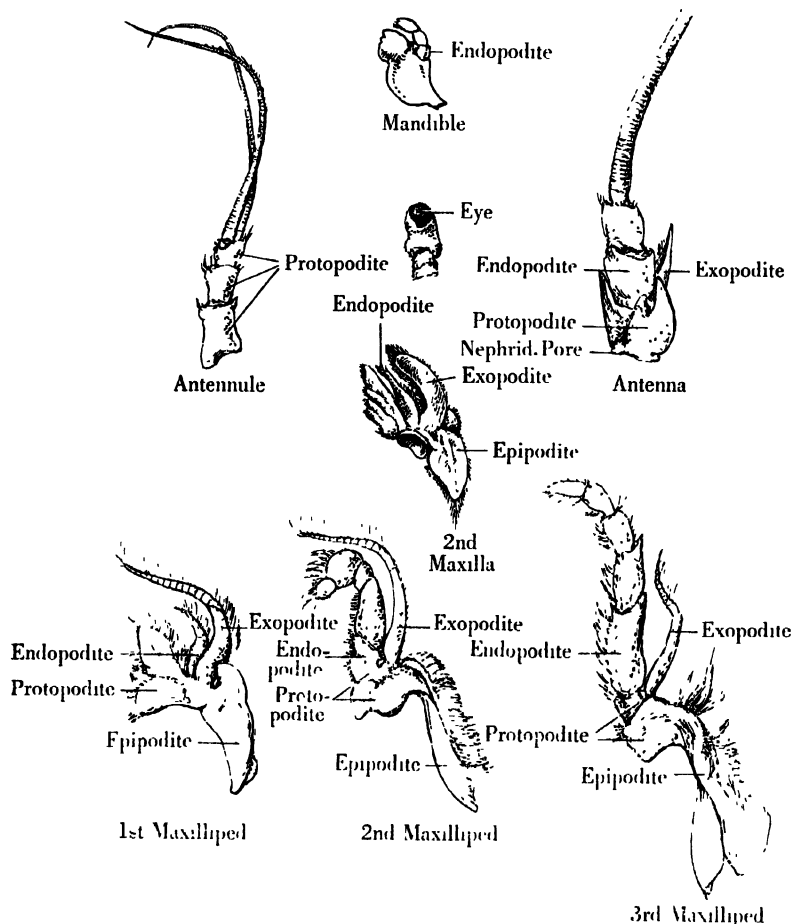


FIG. 78 Modified biramous appendages of a crayfish. Protopodite, endopodite, and exopodite are homologous throughout the series. (After Kerr. Redrawn.)

The coelom of the crayfish, in comparison with that of the earthworm, is very greatly reduced, the conspicuous spaces, or SINUSES, between the organs in the body being filled with blood and so constituting a HEMOCOEL. A large part of the body cavity is filled with muscle tissue. The largest muscles are in the abdomen to flex and extend this region, but other large muscles are in the thorax and the pincers, or CHELIPEDS, while smaller ones move the other appendages, etc. The rigid segmental arrangement of the internal organs of the earthworm is largely absent in the crayfish, though still obvious in the structure of the nervous system. (Figs. 76, 79.)

ALIMENTARY SYSTEM

The mouth is situated on the ventral surface of the head, just between the jaws, or MANDIBLES, and leads into the initial part of the alimentary canal, or esophagus. From here the food, consisting largely of living and dead animal tissues which have been manipulated by the mandibles and other appendages about the mouth, is passed to the stomach for further treatment. In the anterior, or CARDIAC CHAMBER of the stomach there is a group of chitinous bodies, known as the GASTRIC MILL, which, moved by powerful muscles, grind the food. Sometimes there are also present two hard bodies, or GASTROLITHS, that probably represent stored calcareous material for use in forming the exoskeleton during ecdysis.

The ground-up food is forced through a STRAINER to the PYLORIC CHAMBER of the stomach into which open the HEPATIC DUCTS that deliver the secretions from two large DIGESTIVE GLANDS, the so-called liver. After this combined mechanical and chemical treatment the products of digestion are absorbed and the residue then carried through the long, straight intestine to the anus. (Fig. 76.)

CIRCULATORY SYSTEM

The absorbed food passes to the circulatory system, which consists of a heart, a series of blood vessels, and a number of sinuses, all containing blood. The latter is a nearly colorless fluid containing the respiratory pigment and numerous amoeboid blood cells. The heart is a muscular-walled sac suspended in the PERICARDIAL SINUS in the median dorsal part of the thorax. Blood in the sinus enters the heart through six valvular apertures, or OSTIA. (Figs. 76, 79.)

Five arteries arise from the anterior part of the heart. They are the

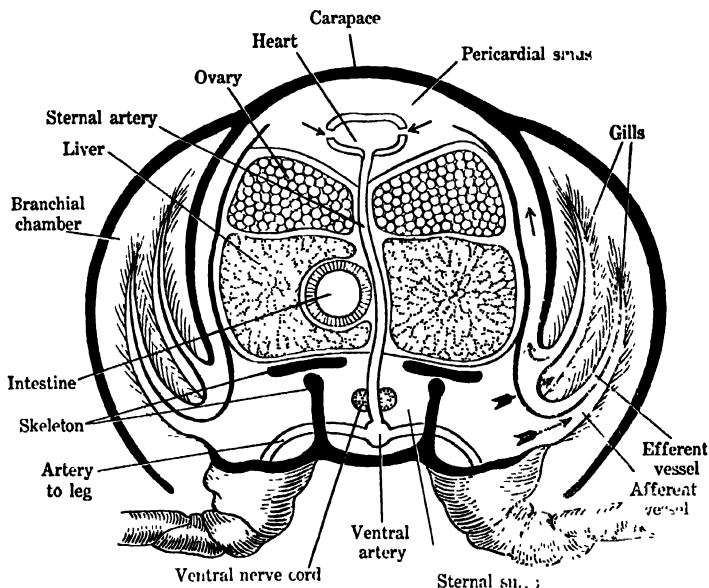


FIG. 79. Crayfish. Transverse section of the thorax showing the gills and some of the internal organs. Diagrammatic. (After Hegner.)

ANTERIOR MEDIAN ARTERY passing forward above the stomach and supplying the cardiac part of the stomach, the esophagus, and head; two ANTENNARY ARTERIES, one on either side of the anterior median artery, passing forward and downward and by branches supplying part of the stomach, antennae, excretory organs, muscles, etc.; and two HEPATIC ARTERIES arising below the antennary arteries and proceeding to the digestive glands. Proceeding posteriorly from the ventral part of the heart is the DORSAL ARTERY which supplies the upper part of the abdomen, while a branch gives rise to the STERNAL ARTERY leading downward and passing between the nerve cords connecting certain ganglia. Here, below the nervous system, it forms the VENTRAL ARTERY supplying this region.

Under the impetus of the rhythmical contractions of the heart, the blood circulates throughout this series of arteries which finally terminate as capillaries in the tissues. Here the blood escapes from the vessels into small tissue spaces and sooner or later reaches the large STERNAL SINUS from which it passes through the respiratory organs. From thence it returns to the heart by way of the BRANCHIOCARDIAC SINUSES and the PERICARDIAL SINUS.

RESPIRATORY SYSTEM

Delicate, fingerlike outpocketings of the body wall, or **GILLS**, effect a large exposure of blood-bearing tissue to the surrounding water so that the respiratory interchange may be effected. The gills are arranged in two rows, near the bases of certain appendages, in the **BRANCHIAL CHAMBER** which is beneath the pleura of the carapace. A current of water bathes the gills, chiefly by the activity of the platelike exopodite of the **SECOND MAXILLA**: the so-called **bailer**, or **SCAPHOGNATHITE**. (Figs. 78, 79.)

EXCRETORY SYSTEM

The excretory organs of the crayfish comprise a single pair of **GREEN GLANDS**, which are possibly related to the annelidan nephridia. Each is composed of a glandular portion and a thin-walled bladder with a short duct opening on the surface on the basal segment of each **ANTENNA**. (Fig. 76.)

NERVOUS SYSTEM

The general plan of the nervous system, as already stated, is similar to that of the earthworm. The cerebral ganglion is larger and sends nerves to the eyes, antennules, and antennae. Circumesophageal commissures from the brain pass ventrally to a relatively large subesophageal ganglion formed by the fusion of the ventral ganglia of several segments. It supplies nerves to the **MANDIBLES**, **MAXILLAE**, and first and second **MAXILLIPEDS**. Smaller ganglia of the ventral cord occur in each of the posterior segments and supply the surrounding regions. In addition, the crayfish is provided with a complex of nerves arising from the brain and commissures to supply the walls of the stomach. (Figs. 76, 80.)

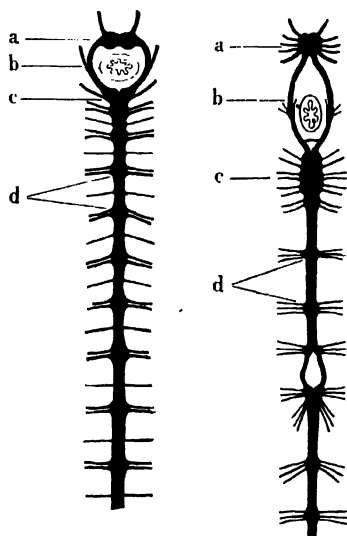


FIG. 80. Diagrams of the anterior portion of the central nervous system of an earthworm (*left*) and a crayfish (*right*). a, brain (cerebral, or supra-esophageal, ganglion); b, nerve commissures encircling the pharynx (shown in section); c, subesophageal ganglion; d, ganglia of the ventral nerve cord, with nerves emerging.

SENSE ORGANS

The chief receptors of the crayfish are a pair of highly complex eyes. Each eye is on the tip of a movable stalk on either side of the head, and consists of more than two thousand long, slender visual units, or **OMMATIDIA**, whose four-sided outer tips appear, as **FACETS**, through the transparent **CORNEA** covering the surface. Such a **COMPOUND EYE** produces **MOSAIC VISION**, the image resulting from as many points of light as there are ommatidia. This type of eye apparently is well suited to detect motion because changes in position of a comparatively large object will affect all the ommatidia. (Fig. 81.)

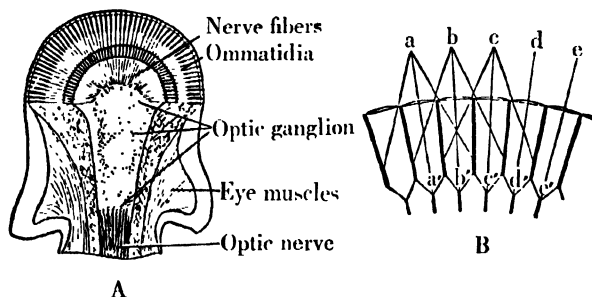


FIG. 81. Crayfish. A, eye in longitudinal section; B, diagram of part of a compound eye showing how rays of light are absorbed by the pigment surrounding the ommatidia and only those rays that pass through the center such as a-a', b-b', etc., reach the nerve fibers (below). (From Hegner, after Borradaile and Potts, and Lubbock.)

The crayfish is provided with **STATOCYSTS**, one in the basal segment of each antennule, which are organs of equilibration and perhaps may function also as auditory organs. Each is a chitinous sac enclosing some two hundred sensory hairs and a number of sand grains, or **STATOLITHS**. The contact of the latter with the hairs, changing by gravity as the animal moves, determines the orientation, or equilibrium, of the body. If iron filings are substituted for sand grains, the animal's equilibrium can be upset by a magnet!

In addition to eyes and statocysts the crayfish has receptors for other stimuli. Thus the entire body responds to touch, though plumed **TACTILE HAIRS** on certain of the appendages are especially sensitive. Similarly, receptors for the so-called **CHEMICAL SENSE**, which probably includes both taste and smell, are widely distributed.

REPRODUCTIVE SYSTEM

Unlike the earthworm, the crayfish is dioecious, each individual being either male or female. The male organs consist of a testis, just beneath the pericardial sinus, and two long, coiled sperm ducts that lead from the testis to the surface through the GENITAL PORES on the protopodites of the fifth pair of walking legs. The ovary of the female is similar in size and position, the oviducts opening through a pore on the protopodites of the third pair of walking legs. The sperm are transferred at copulation to a seminal receptacle on the ventral surface of the abdomen of the female, where they are available to fertilize the eggs when laid some months later. The fertilized eggs are attached to the appendages of the abdomen and there proceed to develop until as free-swimming larvae they are able to shift for themselves.

REGENERATION

Hydra and the earthworm have the power of regeneration so highly developed that it is essentially a method of asexual reproduction. In the crayfish, the power is much more limited, though the various appendages, including the eyes, are replaced when lost. Sometimes, however, the new appendage differs in structure and function from the original. Furthermore each of the walking legs is provided with a special breaking point near its base where the muscles contract to prevent loss of blood when a leg is severed. Or an injured leg may be discarded at this point by the action of certain muscles—a process called AUTOTOMY. In either case regeneration occurs at the stump.

Hydra, earthworm, and crayfish have now been described, chiefly to afford a background for an understanding of vertebrate structure and function. It will be recalled that hydra exhibits radial symmetry and the basic two-layered condition which is a transient phase in the early development of higher forms. The earthworm illustrates bilateral symmetry, the addition of the mesoderm, an alimentary canal opening to the exterior by an anterior mouth and a posterior anus, segmentation, coelom, definite tissues, organs, and organ systems. The crayfish shows, in relatively simple form, certain general structural changes, based upon the modification of the earthworm type. These changes involve the specialization of various regions of the body, in-

cluding the development of jointed appendages, essential to the fulfillment of more complex life conditions.

It should be emphasized, however, that these three types have been selected from the groups of invertebrates to illustrate several fundamental structural principles, but that there are other invertebrate groups exhibiting body plans which, superficially at least, depart very widely from the types described. However, it is believed that these forms, which will be considered in a later chapter (XXXII), do not break the general evolutionary relationships of the invertebrates as a whole.

CHAPTER IX

The Animal Body: Vertebrate

If we contemplate the method of Nature, we see that everywhere vast results are brought about by accumulating minute actions.

—*Spencer*

The vertebrates include the fishes, amphibians, reptiles, birds, and mammals and form one of the most clearly defined divisions of the animal kingdom. Together with a few very primitive forms, such as *Amphioxus*, they constitute the culminating phylum of the animal world, the *Chordata*. There is, in fact, less diversity in structure among the vertebrates as a group than is found, for example, in the one subdivision of the Arthropoda, the Crustacea, of which the crayfish, as described in the previous chapter, is a member. Accordingly we shall confine our attention largely to a description of the structure and physiology of an "ideal vertebrate," and mention incidentally some of the chief modifications of general significance which appear in the different groups, and especially in man. (Fig. 442; Chap. XXXIII.)

BODY PLAN

The body of an "ideal vertebrate" is more or less cylindrical in form, and is essentially bilaterally symmetrical with respect to a plane passed vertically through the main axis which extends from the anterior to the posterior end. Three regions of the body may be distinguished: head, trunk, and tail. Frequently there is a short neck between the head and trunk. (Figs. 82, 83.)

The head forms the anterior end and contains the brain, eyes, ears, and nostrils, or ANTERIOR NARES, as well as the mouth and throat, or PHARYNX. On either side of the head, behind the mouth, is a series of openings, or GILL SLITS, leading into the pharynx; these, however, in air-breathing vertebrates disappear before the adult condition is attained.

The trunk forms the body proper and contains the coelom and the major part of the alimentary canal leading posteriorly to the exterior by the anus, as well as the chief circulatory, excretory, and reproductive organs.

In most aquatic vertebrates the trunk very gradually merges into a large muscular **TAIL**, the region posterior to the coelom and anus. Thus the vertebrate tail is a unique structure, since the tail of invertebrates terminates with a segment bearing the anus. In many terrestrial vertebrates the tail has practically become an inconsequential unpaired appendage.

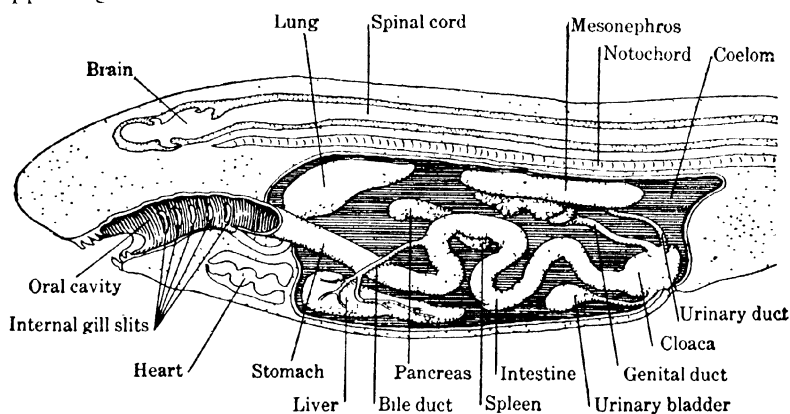


FIG. 82. Body plan of a vertebrate. Longitudinal section. Diagrammatic.

The vertebrate coelom comprises two chief parts: a large **ABDOMINAL CHAMBER** and a small anterior chamber. The latter constitutes the **PERICARDIAL CHAMBER** in fishes but in higher forms it is divided into two parts, one (pericardial) enclosing the heart and the other (pleural) investing the lungs. The lining membrane of the coelom, known as the **PERITONEUM**, forms the innermost layer of the body wall, covers the organs, and in certain regions forms broad folds, or **MESENTERIES**, in which the organs are suspended. In the mammals the organs of the chest, or **THORAX**, are separated from those of the abdomen by a transverse muscular partition, the **DIAPHRAGM**. (Figs. 98-100.)

In aquatic vertebrates extensions from the trunk and tail form median fins. Paired fins, developed from the trunk, comprise the **PECTORAL** fins, situated near the junction of head and trunk, and the **PELVIC** fins, in a position just lateral to the anus. The pectoral and pelvic fins, or the forelimbs and hindlimbs which replace them in all forms above

the fishes, are the only lateral appendages typically found in vertebrates.

SKIN

The surface of the body that comes in direct contact with the environment is covered by an integument, or skin, which, though primarily protective and sensory in function, takes part to a greater or lesser degree in respiration, excretion, secretion, and absorption. The skin varies considerably in thickness over different parts of the body, and is thinnest over the exposed part of the eyeball. Scales, feathers, claws,

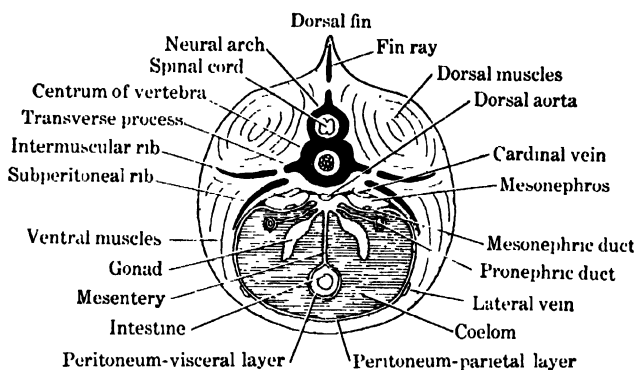


FIG. 83. Body plan of a vertebrate. Transverse section. Diagrammatic.

horns, hoofs, nails, teeth, etc., are derivatives of the skin. Unlike the simple skin of invertebrates, that of vertebrates is formed of two chief layers: an outer epithelial tissue, the EPIDERMIS, derived from the ectoderm; and an inner DERMIS derived from the mesoderm of the embryo. (Fig. 84.)

The outer epidermis always consists of several layers of cells, the lower, known as the MALPIGHIAN LAYER, comprising actively dividing cells, and these gradually are moved up to produce the superficial layers of flattened, horny, dead cells. This layer is thus not directly converted into the cuticle as is the case, for example, in the arthropods. The outermost dead cells are constantly sloughed off individually, or in groups when the human skin "peels" after sunburn or when a snake "sheds its skin." As a rule, blood vessels do not permeate the epidermis, which in part accounts for the fact that a former Malpighian cell becomes more and more "dead" the farther it is pushed toward the surface.

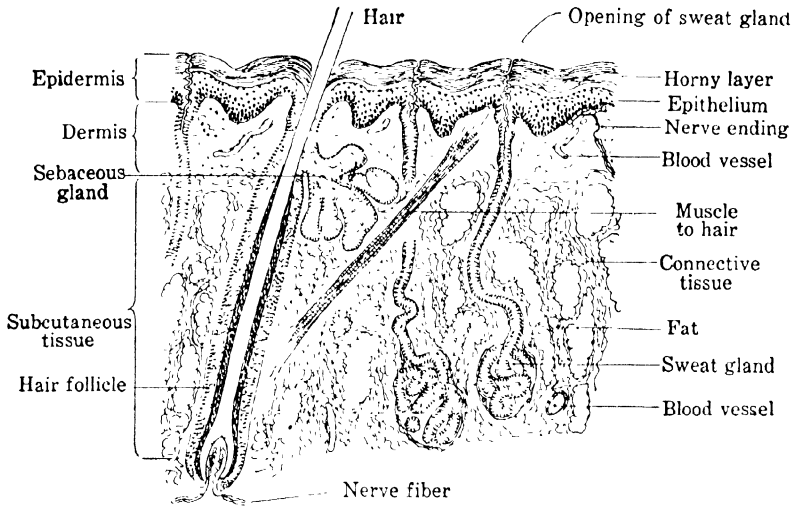


FIG. 84. Human skin. Vertical section highly magnified.

The dermis is the characteristic part of the vertebrate skin and comprises a felted meshwork of connective tissue fibers and cells which underlies the relatively thin epidermis. Within this meshwork are embedded blood and lymph vessels, pigment cells, sense organs, nerve endings, muscle fibers, sweat and sebaceous glands, hairs, deposits of fats, etc. The innermost region of the dermis is transitional with the subcutaneous tissue where fat cells are usually more abundant and the weave of the connective tissue fibers is looser. Some of the fibers interlace with those in the sheaths of the underlying muscles and so aid in anchoring the skin.

Perhaps the most interesting among the derivatives of the skin are teeth, which occur in nearly all vertebrates except modern birds, and are homologous throughout the series. It is clear that originally they were **PLACOID SCALES**, such as occur in the skin of present-day sharks (Fig. 85) and have become modified in form and function in and around the mouth. Both placoid scales and teeth consist of a basis of **DENTINE**, the so-called ivory, formed by the dermis and overlaid, in part, by **ENAMEL** from the epidermis. A typical mammalian tooth consists of the **ROOT** surrounded by cement and embedded in a socket in the jaw, and the **NECK** which is transitional to the **CROWN** that protrudes above the gums. Inside the tooth is the pulp cavity which is

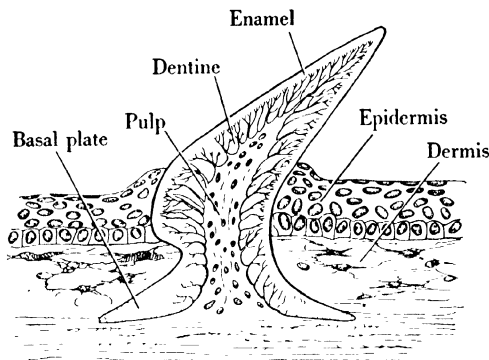


FIG. 85. Placoid scale projecting through epidermis of skin. Longitudinal section. (After Kerr.)

supplied with nerves and blood vessels originating from the tissues below. (Fig. 86.)

The teeth of fishes, reptiles, and amphibians are usually all similar in form, but in mammals there are usually four kinds in each jaw. In most mammals, including man, two sets of teeth are developed: the first, deciduous or milk teeth, and the second, permanent. In human dentition, the first set comprises ten teeth in each jaw—four incisors, two canine, and four molars; and the second set, sixteen in each jaw—four incisors, two canine, four premolars, and six molars.

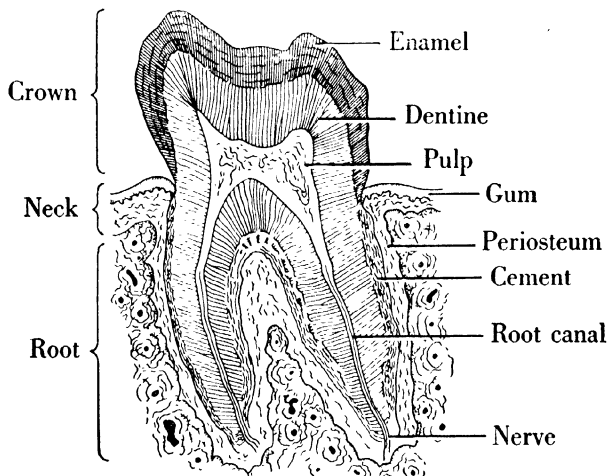


FIG. 86. Human tooth. Vertical section.

MUSCLES

The body wall proper, just beneath the skin, is chiefly composed of muscular tissue, commonly spoken of as flesh, which varies in thickness in different parts of the body. In the mid-dorsal region it surrounds the brain and spinal cord and the axial supporting structure, or notochord, while ventrally it forms the wall of the coelom. In the lower vertebrates and in the embryonic stages of higher forms the muscular layer is composed of segments known as MYOTOMES. But in the adult stage of advanced vertebrates this evidence of segmentation largely disappears, and the muscular tissue for the most part assumes the form of highly complex longitudinal bands, extensions from which extend into the paired appendages. (Figs. 83, 87, 88.)

Muscles, such as those attached to the bones, in which contraction can be brought about at will are termed VOLUNTARY muscles, whereas those which effect most of the movements of the viscera are known as INVOLUNTARY muscles. From the standpoint of microscopic structure, muscle tissues are of three kinds. Voluntary muscles consist of STRIATED muscle cells, or fibers, and involuntary muscles, except those of the heart, are composed of SMOOTH muscle cells. The cells of the heart, known as CARDIAC muscle cells, resemble somewhat in structure those of voluntary muscles. Smooth and cardiac muscle cells are associated with other tissues in the organs and organ systems, whereas the striated muscle cells typically form definite organs which are usually thought of collectively as "the muscular system." (Figs. 6, 12.)

A voluntary muscle consists of a large number of striated muscle fibers extending lengthwise and held by connective tissue in bundles, or FASCICULI. These, in turn, are grouped in larger bundles, and these in still larger aggregations, the muscles. The connective tissue sheath which encloses the whole muscle is essentially continuous as a TENDON with a similar sheath covering a bone, so that muscle and bone become a working unit. Blood vessels and nerve fibers permeate the tissue to supply each muscle cell.

SKELETON

The shape of the vertebrate body is maintained by a system of supporting and protecting structures, termed the SKELETON. Although various outgrowths of the skin, such as scales, feathers, and hair, form a part of the skeletal system known as the EXOSKELETON, which is com-

parable to the protective coverings of the invertebrates, it is the bony **ENDOSKELETON** which is characteristic of the higher animals. This living internal skeleton, largely mesodermal in origin, exhibits such great diversity and complexity that its study, known as **OSTEOLOGY**, forms an important subdivision of comparative anatomy.

In the lower fishes the endoskeleton is composed of a firm elastic tissue, **CARTILAGE** or gristle, but from the higher fishes to man most of the cartilage becomes **OSSIFIED**, that is, transformed into **BONE**. The human skeleton consists of about two hundred separate bones, but the number varies at different periods of life, because some bones which at first are separate later become fused.

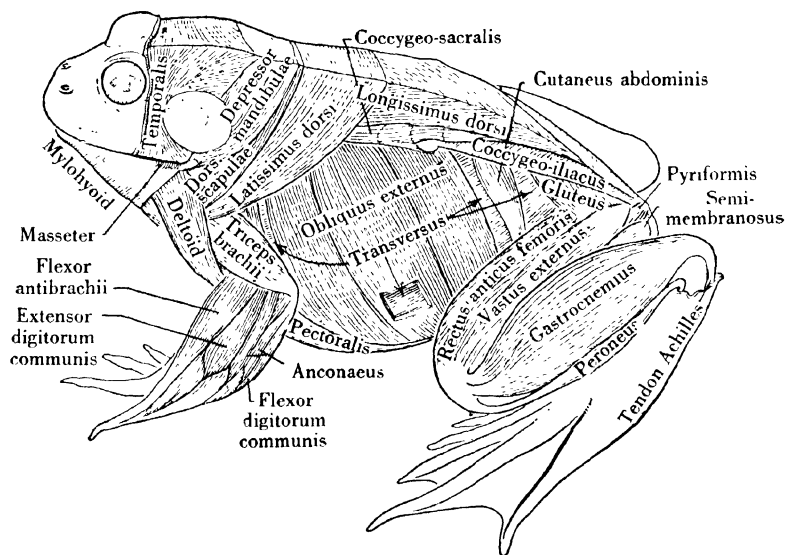


FIG. 87. Muscles of the frog as seen from the left side. Diagrammatic. (after Storer.)

While it is true that the bones constitute the main supporting framework of the body, they are entirely inadequate to knit together the organism into a working unit. We find therefore various kinds of soft connective tissue interwoven between the integral parts of the body. These tissues form sheaths about most of the organs and also supply the connecting links between muscle and muscle, muscle and bone (**TENDONS**), and bone and bone (**LIGAMENTS**).

Supporting tissues, of which bone, cartilage, and connective tissue form the chief groups, are characterized by the development of large amounts of resistant nonliving material in or between the component cells themselves, the character of the tissue being determined chiefly by the nature of this matrix. Thus connective tissues are of several kinds depending chiefly upon the nature of the intercellular fibers which largely obscure the cells themselves. In some cases WHITE fibers are loosely arranged, and in others closely matted; or they may be arranged in bundles. Where elasticity is necessary, ELASTIC fibers are interspersed with the white fibers, or even replace them almost entirely. (Fig. 12.)

Cartilage cells lie in spaces, or LACUNAE, in the matrix. In HYALINE cartilage the matrix is clear and translucent, usually without fibers; in

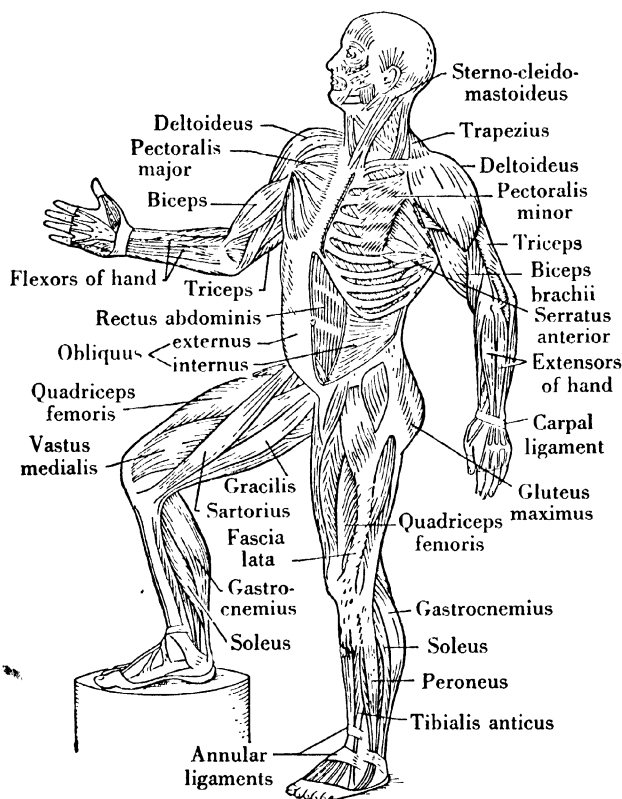


FIG. 88. Chief muscles of the human body as seen from ventral and lateral aspects. Diagrammatic. (After Storer.)

ELASTIC cartilage there are elastic fibers embedded in the matrix; and in FIBROCARILAGE interwoven bundles of white fibers largely take the place of the hyaline matrix. (Fig. 12.)

Most bones are preformed in cartilage. Certain specialized cells replace the cartilaginous scaffolding in the course of a complex series of events including the deposition of lime salts, which give the matrix the characteristic rigidity of bone. The living bone cells lie in spaces,

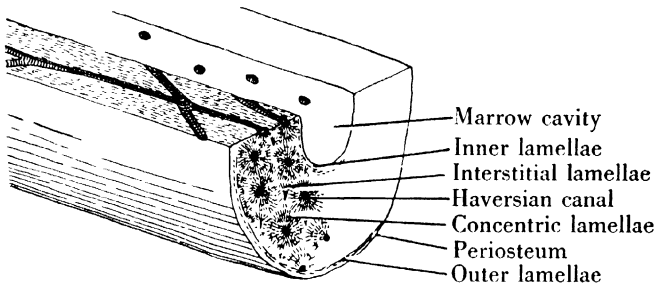


FIG. 89. Bone structure as seen in longitudinal and transverse sections. Diagrammatic. (After Walter. Redrawn.)

the lacunae, in the matrix and are arranged in concentric circles, or LAMELLAE, about a central cavity, the HAVERSIAN CANAL. Tiny tubes, or CANALICULI, keep the cells in communication with each other and with the Haversian canals through which blood and lymph vessels and nerves reach them, chiefly from the central MARROW CAVITY. Thus a structure, at once rigid and modifiable, results. (Figs. 12, 89.)

The primitive axis of the skeleton consists of a cylindrical cord or

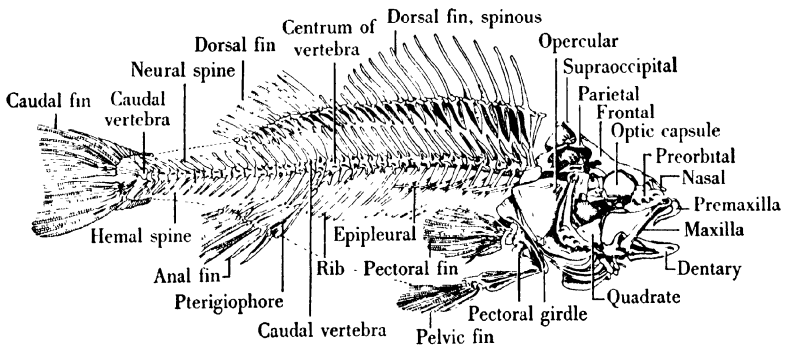


FIG. 90. Skeleton of a bony fish, the perch. Drawn from a laboratory specimen.

rod of cells, the notochord, which lies in the mid-dorsal line of the body wall just below the brain and spinal cord and above the coelom. (Fig. 91.) In most vertebrates, however, the notochord in its original form

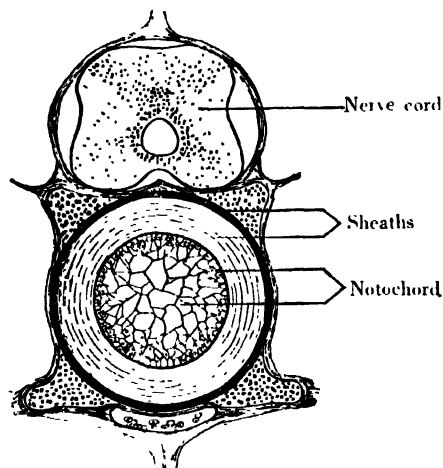


FIG. 91. Nerve cord, notochord and coverings as seen in a young dogfish. Transverse section, enlarged. Diagrammatic. (From Walter. Redrawn.)

is only a temporary structure, being partially or completely replaced during later development by a linear series of cartilaginous or bony elements, known as VERTEBRAE, which form the VERTEBRAL COLUMN, or backbone. This is one of the most characteristic structures of vertebrates as compared with invertebrates, or backboneless animals. In adult man there are twenty-six vertebrae: seven cervical, twelve thoracic, five lumbar, one sacral, and one caudal, each of the last two comprising five fused vertebrae that form the SACRUM and COCCYX, respectively. Sometimes there are rudiments of as many as eight tail, or caudal, vertebrae in the human embryo. (Figs. 82, 83.)

A typical vertebra of the higher animals consists of a basal portion, the CENTRUM, which supports a NEURAL ARCH; together these parts form a ring of bone about the spinal cord. From various parts of the vertebra PROCESSES typically develop for movable articulation with neighboring vertebrae, for the attachment of muscles, etc. Between each centrum of the vertebrae of birds and mammals is an elastic cushion of fibrocartilage (INTERVERTEBRAL DISC) to absorb shock. (Fig. 92.)

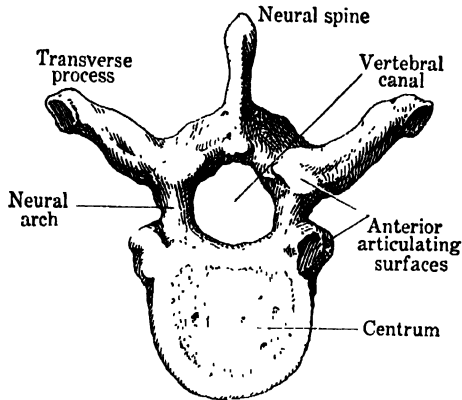


FIG. 92. Human vertebra (tenth thoracic). End view drawn from laboratory specimen.

In most vertebrates, RIBS are attached to the transverse processes of certain vertebrae. There are twelve pairs of ribs in the human body. The ribs extend outward and downward within the body wall, and in terrestrial forms usually are attached in the midventral line to the breast bone, or STERNUM, and knit together the "thoracic basket" into a unit for the anchorage of the anterior limbs. In the adult of most vertebrates, the centra of the vertebrae occupy the position formerly held by the notochord; while above, the neural arches form the VERTEBRAL CANAL encircling and protecting the spinal cord; and below, the transverse processes, ribs, and sternum surround the anterior portion of the coelom. (Figs. 92, 96.)

The vertebrate head, containing the anterior openings of the alimentary canal and respiratory passages and also the brain and chief sense organs, is protected in the lower fishes by a cartilaginous case, and in higher animals by a bony case, or SKULL, which articulates with the first vertebra of the backbone. Attached to the skull are JAWS, which serve as supporting structures for the mouth. The human skull is the most complex part of the skeleton. It is actually composed of two parts of diverse origin that supplement each other and, during development, fuse into one.

The skull and vertebral column form the main SKELETAL AXIS from which is suspended the APPENDICULAR skeleton, or bony framework of the paired appendages (FINS or LIMBS) and their supporting structures (GIRDLES). The appendicular skeleton is simple in the anterior

(pectoral) and posterior (pelvic) paired fins of fishes, which act as paddles; but when these are modified into paired limbs for progression on land, the mechanical problems involve the development of complex limb skeletons to support the body, and to act as levers for the movement of the limb muscles in locomotion. In response to this need, there is developed an elaborate series of bones which in all cases, however greatly modified in adaptation to different environments and modes of life, may be referred to a common plan. This is known as the **PENTADACTYL LIMB**, in reference to the five digits (**FINGERS** and **TOES**) in which it usually terminates.

The limbs are attached directly or indirectly to the vertebral column by two groups of bones that form the **PECTORAL** and **PELVIC GIRDLES**. The comparative anatomy of the girdles shows that each, basically, is composed of three bones on either side of the body, the three meeting at a common point, like a tripod. These bones are the **SCAPULA** (shoulder blade), the **PROCORACOID**, and the **CORACOID** in the pectoral girdle, and the **ILIUM**, **PUBIS**, and **ISCHIUM** in the pelvic girdle. Incidentally, in the higher vertebrates a new bone, the **CLAVICLE** (collar bone) is added and, in mammals, including man, this bone replaces the procoracoid. The pectoral girdle is attached dorsally to the vertebral column merely by ligaments and muscles, and the same relation holds ventrally

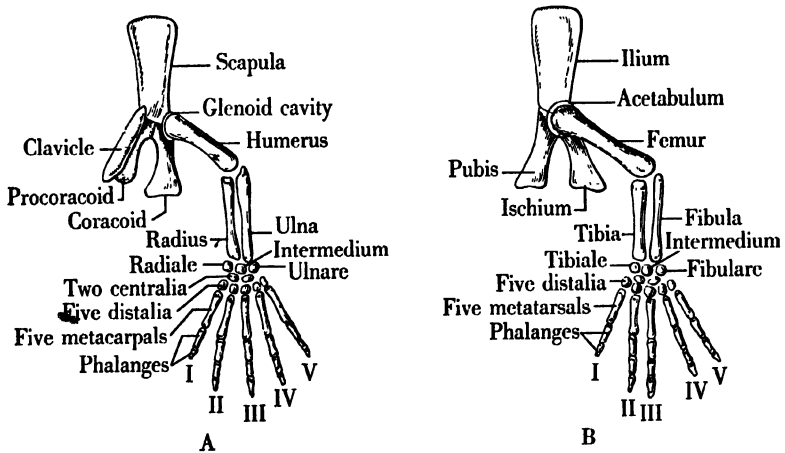


FIG. 93. Diagrams to illustrate the general plan of the vertebrate limbs. A, forelimb and pectoral girdle; B, hindlimb and pelvic girdle. (After Parker and Haswell. Redrawn.)

with the thoracic basket, except that in certain forms, such as man, the girdle is united with the sternum. The pelvic girdle, however, is more firmly united with the vertebral column by an actual bone fusion. Indeed, frequently, as in man, the component bones firmly unite with each other and with the fused sacral vertebrae (sacrum) to form the PELVIS. This difference in the method of attachment of the two girdles gives greater range of mobility to the pectoral limbs and firmer support to the pelvic limbs, which usually bear more than their share of the body weight. (Figs. 93-96.)

The three girdle bones of each limb are homologous with those of the other: the scapula with the ilium, the clavicle with the pubis,

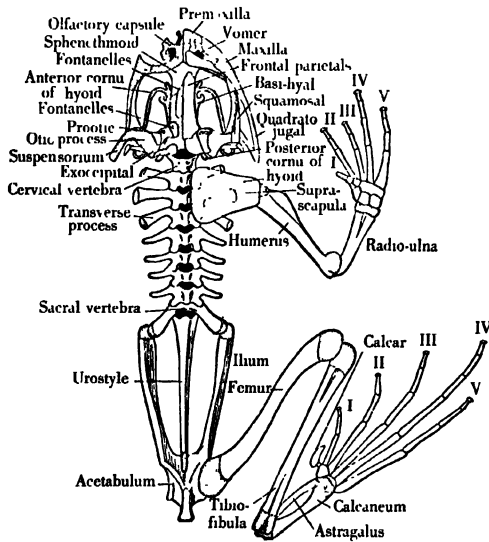


FIG. 94. Skeleton of the frog. Dorsal aspect; the left half of the shoulder girdle and the left fore- and hindlimbs are removed, as also are the membrane bones on the left side of the skull. Permanently cartilaginous parts dotted. (After Howes, slightly altered.)

and the coracoid with the ischium. Furthermore, the HUMERUS, the ULNA, and the RADIUS of the forelimb are homologous respectively with the FEMUR, the FIBULA, and the TIBIA of the hindlimb. Similarly, the CARPALS, METACARPALS, and PHALANGES of the hand are homologous with the TARSALS, METATARSALS, and PHALANGES of the foot. This basic similarity is an example of SERIAL HOMOLOGY, as in the crayfish.

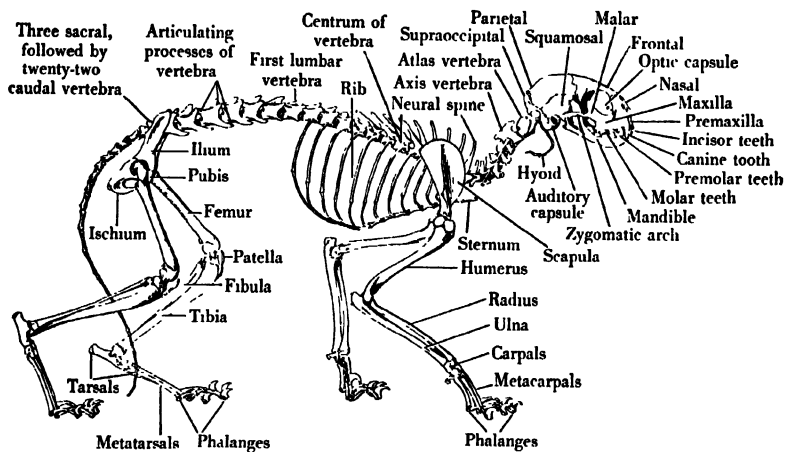


FIG. 95. Skeleton of the cat. Drawing from the right side to show chief bones of axial and appendicular divisions.

Again, the homology of the limb bones of an individual extends to those of all vertebrates. The bones in the wing of a bird or bat, in the flipper of a seal or whale, and in the foreleg of a cat or horse are homologous with those in the human arm. Thus, for the most part, "old structures are used in a new way to fashion a fresh unity." (Fig. 260.)

THE HUMAN BODY

Considering specifically the structural features of the human body, we find that the outstanding characters are largely associated with man's erect posture. It is true that the body is not perfectly adapted to its upright position, but this is more than compensated for by the complete division of labor between the upper and lower limbs; this differentiation liberated the forelimbs from contributing to locomotion and gave the opportunity for the pentadactyl plan to attain its highest development in the human hand. With its completely opposable thumb, the hand is directly or indirectly responsible for more of man's unique characters than is usually realized. The hand is an efficient grasping organ—a battery of tools that makes possible the use of artificial tools which, in a way, may be regarded as accessory organs, devised by the brain and appropriated or discarded at will. (Fig. 97.)

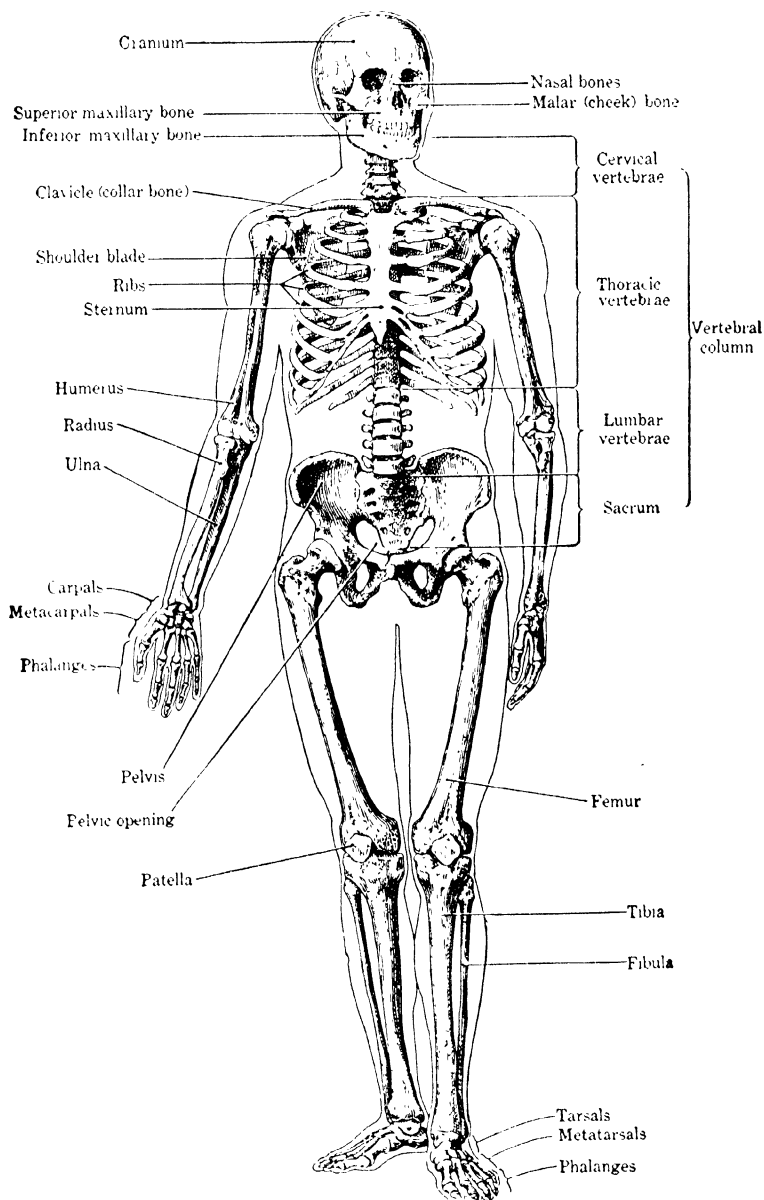


FIG. 96. Human skeleton, drawn from laboratory specimen.

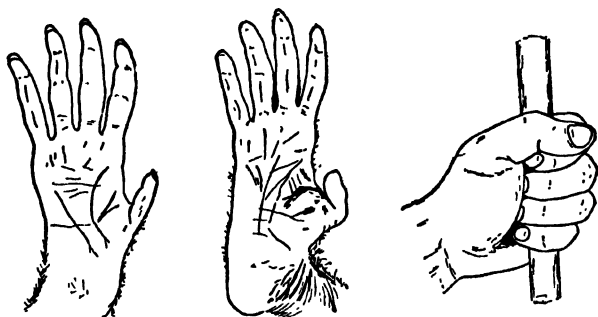


FIG. 97. Hand and foot of an Orangutan (*left*) in comparison with the human hand, with its completely opposable thumb. (From Walter.)

The hand is also a delicate sense organ, since touch is "the great confirmatory sense" underlying many of our sensory experiences with the world about us. "Tactile fingers are continually learning." Indeed, it is upon a basis of conscious and subconscious tactile sensations that much of the superstructure of the higher mental processes is reared. It seems clear that the erect posture and the facile hand have contributed very largely to the supremacy of the brain and thus to man's outstanding position above the beasts. (Figs. 96, 137.)

DISTINCTIVE VERTEBRATE CHARACTERS

In concluding this general survey of the structure of the vertebrate body, we may emphasize three characters which are of prime importance in distinguishing this class of animals.

In the first place, whereas the skeletal structures of invertebrates typically consist, as in the crayfish, of an exoskeleton of hard, nonliving materials deposited on the surface of the body, the chief function of which is protection, the vertebrate skeleton is primarily a living endoskeleton. It is an organic part of the organism which, although it affords protection for delicate parts, provides adequately for support and supplies muscle levers, and in this way makes practicable the relatively large bodies of the higher animals. The notochord is at once the foundation and axis of the vertebrate internal skeleton and either persists throughout life as such, or endures simply long enough to function as a scaffolding about which the vertebral column is built. It is in recognition of the prime importance of the notochord that the vertebrates and the associated groups are known as Chordates. (Fig. 441.)

In the second place, it will be recalled that the central nervous system of the earthworm and crayfish consists of a nerve cord extending through the body cavity below the digestive tract, except at the anterior end where the cord encircles the pharynx to form a dorsal brain. The position of the vertebrate brain is similar, though the spinal cord is not a solid cord but a nerve tube which lies in the vertebral canal embedded in the muscles of the body wall dorsal to the digestive tract and outside the coelom.

The third fundamental characteristic is a series of perforations or gill slits through the pharynx and body wall. In the lower vertebrates the gills provide an exit for the current of water entering by the mouth, and, being richly supplied with blood, afford the chief means of respiratory interchange between the animal and the surrounding medium. In the higher forms the gills are present merely during a transient phase in the development of the individual, since the function of aërating the blood is taken over by the lungs. (Figs. 82, 112, 273.)

In addition to the above basic chordate characters there are, of course, others common to the vertebrates: in particular these are bilateral symmetry, segmentation, the coelom, red blood cells, the skull, paired appendages, and a postanal projection, the tail.

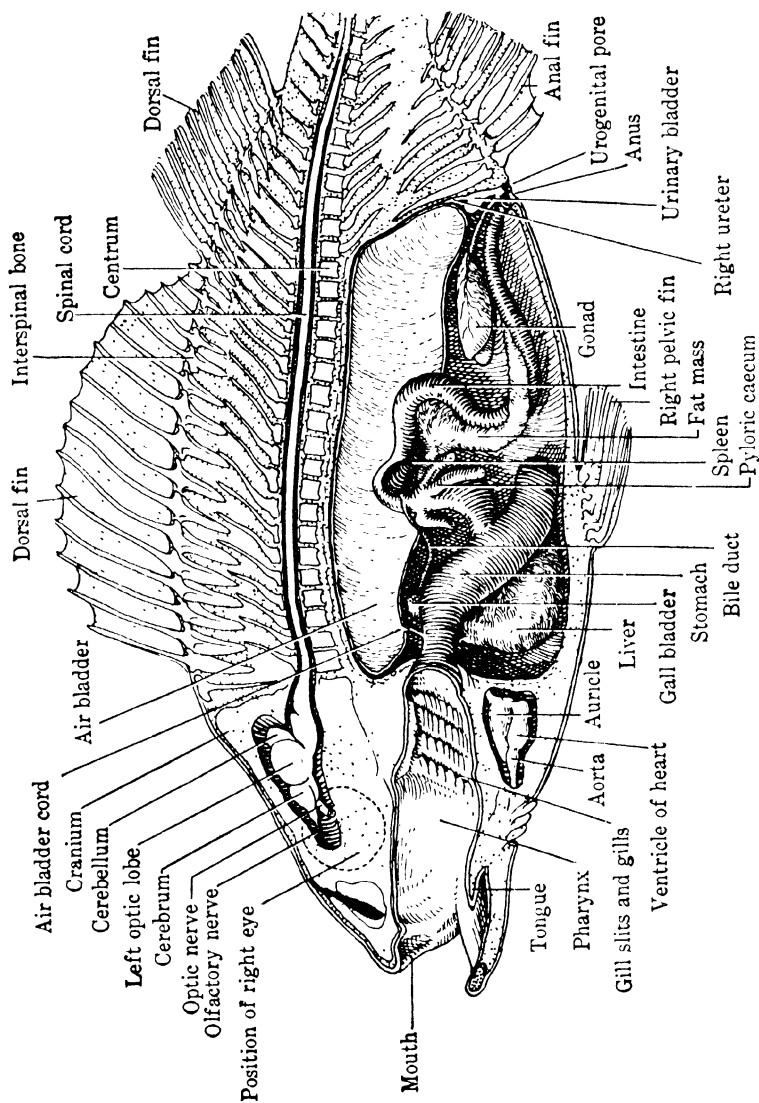


FIG. 98. Dissection of a bony fish, *Perca flavescens*, the Yellow Perch, showing the internal structures as seen from the left side.

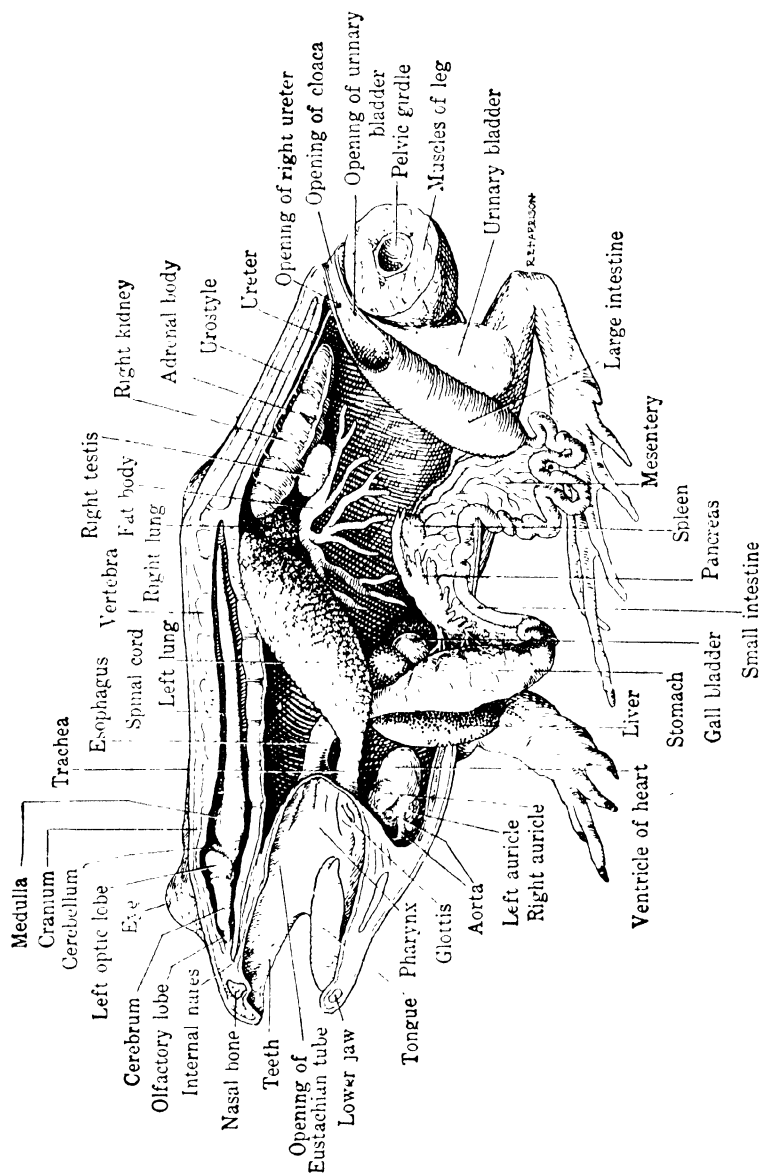


FIG. 99. Dissection of an amphibian, the frog, *Rana clamitans*.

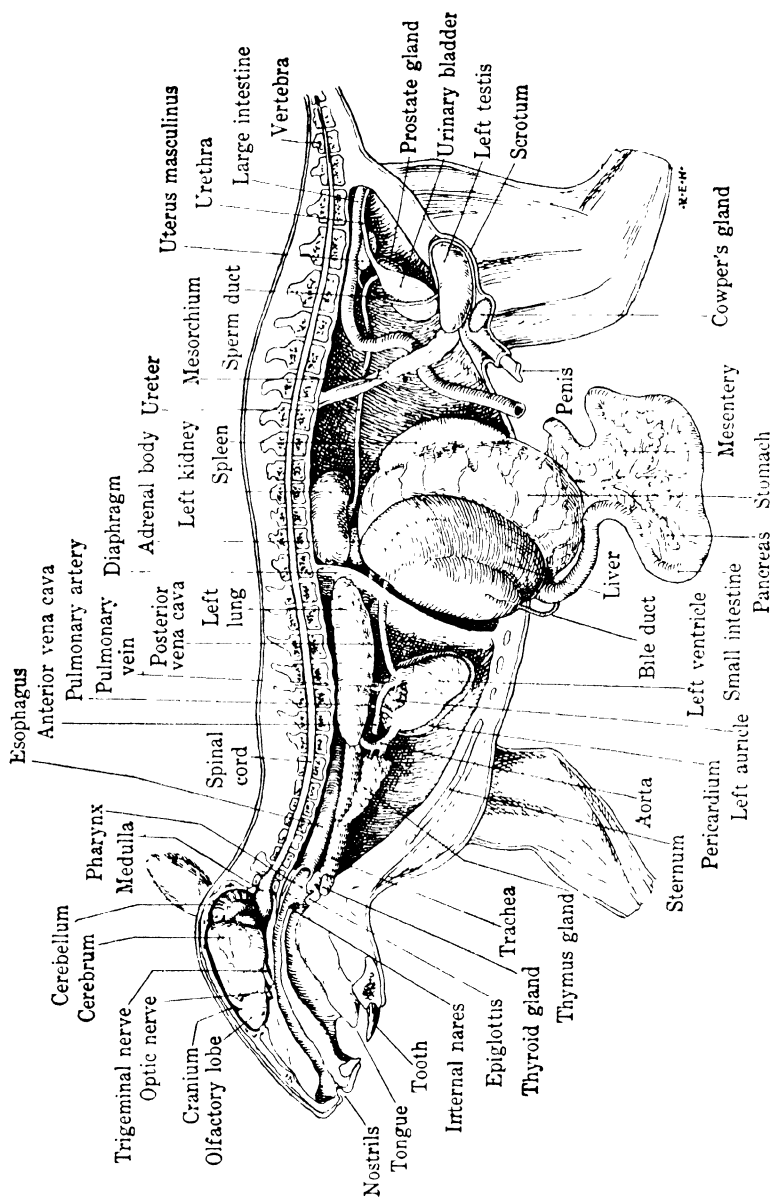


FIG. 100. Dissection of a mammal, the gray squirrel, *Sciurus carolinensis*. (Modified, after Linville and Kelly.)

CHAPTER X

Nutrition

It is a great satisfaction for me to know when regaling on my humble fare that I am putting in motion the most beautiful machinery with which we have any acquaintance

-- *Dickens*

Among the single-celled animals, as noted earlier in amoeba, nutrition is reduced to its simplest terms. The food material enters the cell and is acted upon by digestive substances formed by the nearby protoplasm; the food is chemically changed, or digested, so that it becomes available for the use of the cell. In the hydra a special layer of cells, developed from the endoderm, is primarily devoted to digestion. Some of these nutritive cells actually engulf small particles of food and digest them within the cell (INTRACELLULAR DIGESTION), but the major part of digestion occurs in the enteric cavity by intercellular secretions from the cells. Digestion of the latter type (EXTRACELLULAR) is characteristic of the earthworm and all higher animals. (Figs. 18, 64, 72.)

We have considered the form and supporting structures of the body wall of a typical vertebrate—the outer tube which surrounds and contains the viscera—and it will be recalled that enclosed by this tube, just as in the case of the earthworm and crayfish, a second or inner tube, the digestive tract, or alimentary canal, extends from mouth to anus. (Figs. 69, 82.)

The alimentary canal is essentially a tubular chemical laboratory which passes the food from one part to another by muscular activity. Each of these regions, in turn, supplies specific reagents, both for changing the food into a soluble form so that it can pass through the walls and be distributed to all the cells of the organism, and also for making it suitable for use by these cells. The complex food materials which enter the human mouth run the gauntlet of a whole series of digestive fluids.

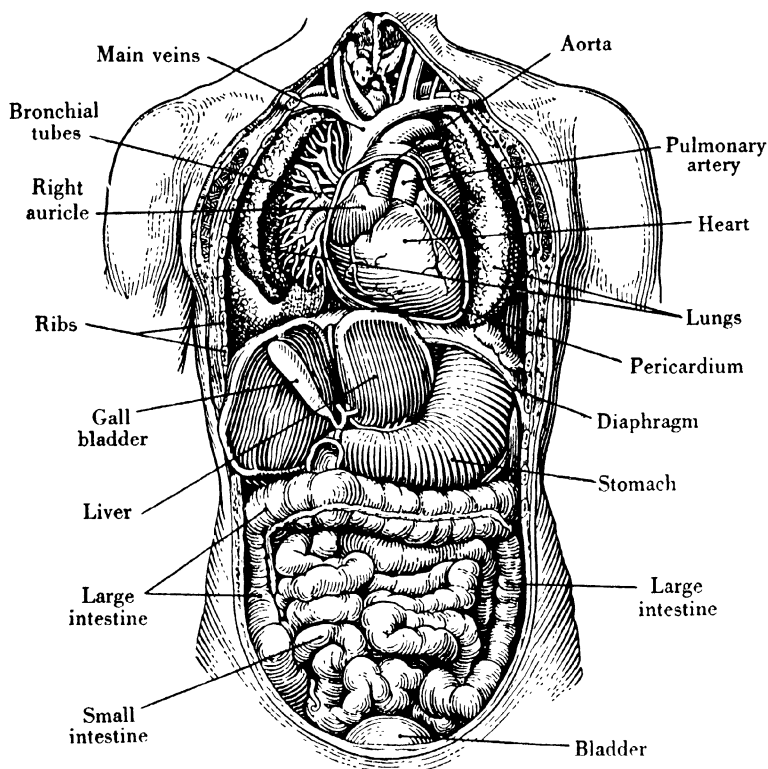


FIG. 101. Dissection of the human body. Ventral aspect. Diagrammatic. (From Peabody and Hunt.)

Although the various kinds of food eaten by animals differ widely in their chemical composition, nevertheless the process of digestion is basically similar in nearly every case: it is a process of **HYDROLYSIS**. This is a chemical reaction in which a molecule of the substance to be digested combines with a molecule of water to form a new compound. Then this splits into two or more simpler molecules. By repeated hydrolyses, exceedingly complex food substances are changed to relatively simple ones. Hydrolyses are brought about through the activities of special catalytic agents, the ferments, or **ENZYMES**, a special enzyme for each kind of chemical reaction being supplied by the alimentary canal or its derivatives. Moreover, the diverse digestive enzymes, carrying out chemical simplification of various foodstuffs, finally produce,

by hydrolysis, just a few relatively simple substances: AMINO ACIDS from proteins, FATTY ACIDS and GLYCEROL from fats, and SIMPLE SUGARS from more complex carbohydrates. (Figs. 101, 102.)

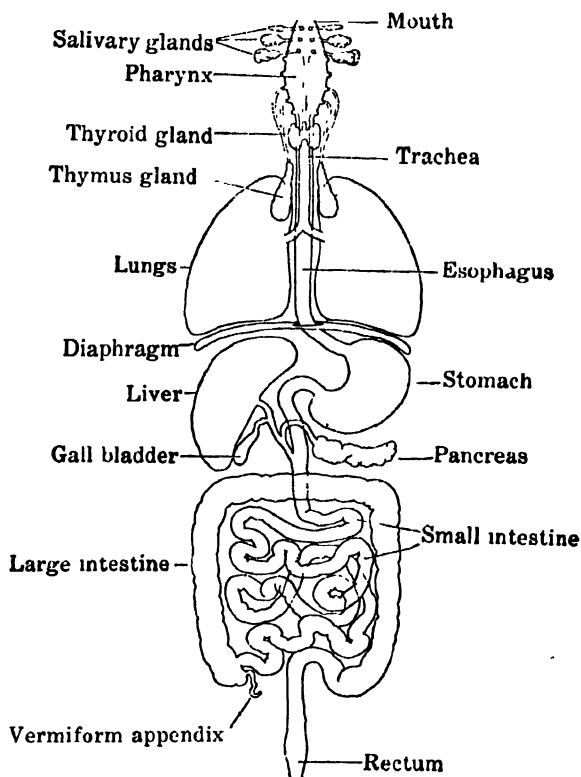


FIG. 102. Diagram of the human alimentary canal and its derivatives, including salivary glands, thyroid, thymus, lungs, liver, and pancreas.

The wall of the alimentary canal consists of several cellular layers: a lining epithelium, a connective tissue layer, two muscular layers, and an outer peritoneal epithelium. The nutritive epithelium which lines the alimentary canal and its several glandular derivatives is the digestive tract proper in the sense that it is of basic functional importance in secreting the digestive fluids and in absorbing the products of digestion. The other layers perform accessory functions such as support, conduction of blood vessels and nerves, and peristaltic movements of the canal. (Fig. 103.)

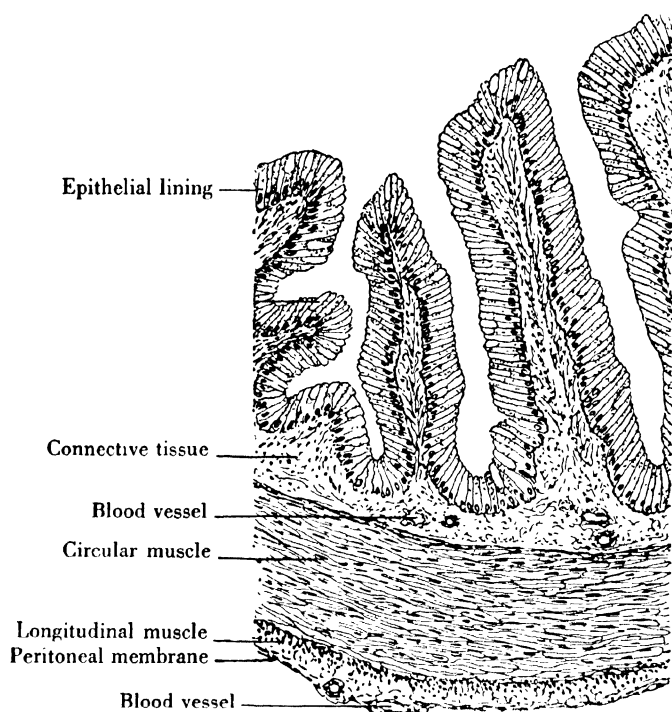


FIG. 103. Portion of a transverse section of the small intestine of the frog as seen in a permanent preparation. Somewhat diagrammatic and enlarged.

MOUTH AND THROAT

The anterior entrance to the alimentary canal is the mouth, a transverse aperture in the head that leads into the mouth chamber, or **BUCCAL CAVITY**, supported by the jaws. The buccal cavity gradually merges into the throat, or **PHARYNX**, which in the vertebrates acts as a passage both for the food and the respiratory gases. The respiratory current of water in aquatic forms soon passes to the exterior by a series of perforations, the **GILL SLITS**, through the pharynx and body wall; in higher forms the respiratory current of air enters the **LUNGS**. On the other hand, in all vertebrates the preparation of the food for its passage through the alimentary canal starts in the buccal cavity. (Figs. 102, 112.)

The human buccal cavity is lined with a membrane, continuous at the lips with the outer skin, which is provided with unicellular **MUCOUS GLANDS** that secrete **MUCIN**. This secretion together with that from

three pairs of large SALIVARY GLANDS constitutes the SALIVA, which moistens and cements the food so that it may be readily moved by the TONGUE for mastication by the teeth and then passed on toward the esophagus. Furthermore, saliva contributes to the digestion of starches by two enzymes, PTYALIN and MALTASE. However, only a small portion of the starch is digested during the rapid passage of food through the mouth region, and the activity of the enzymes probably ceases after the food has been subjected to the acid environment of the stomach. (Fig. 107.)

ESOPHAGUS AND STOMACH

The mouthful of food, masticated, moistened, and with the starch partially digested, is rolled by the tongue and passed along the pharynx into the esophagus. Henceforth it is beyond voluntary recovery, because it is pushed along by involuntary rhythmical contractions, PERISTALSIS, of the wall of the digestive tract. The ESOPHAGUS is a muscular tube which extends through the thorax and rapidly delivers the food without further digestion to the STOMACH.

The stomach, the first stopping place of food that has been swallowed, is a muscular sac situated just posterior to the diaphragm in mammals. In common with most of the viscera, the stomach is sus-

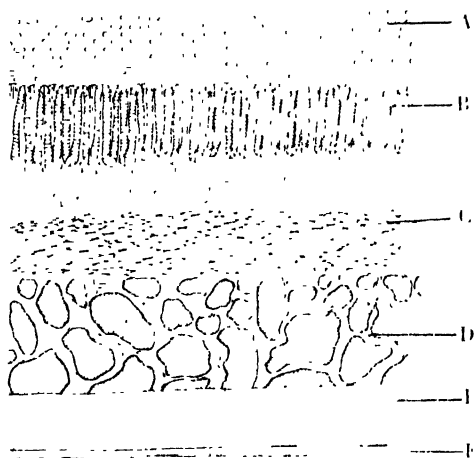


FIG. 104. Vertical section through the wall of human stomach. Diagrammatic. A, inner surface with openings of gastric glands; B, gastric glands; C, submucosa; D, E, muscle layers; F, outer surface serosa. (After Peabody and Hunt. Redrawn.)

pended in the abdominal cavity by a broad membranous fold, or *mesentery*, which is continuous with the peritoneal membrane lining the cavity. Within the tissues of the mesentery, blood vessels, nerves, etc., pass to the stomach. (Figs. 100, 104.)

In the stomach the work of the digestive tract progresses by the action of specific digestive enzymes contained in the *GASTRIC JUICE*, which is secreted by innumerable *GASTRIC GLANDS*. These glands are tiny pits in the stomach wall lined with special glandular cells. (Fig. 104.) Human gastric juice is a complex fluid comprising over 99 per cent water and containing hydrochloric acid (HCl), a protein-splitting enzyme (*PEPSIN*) which has a milk-curdling activity similar to *RENNIN*, common salt (NaCl), and mucus. This array of substances softens the food mass, gives it an acid reaction, and simplifies the various proteins. In the course of a few hours, with the assistance of the slow churning movements of the stomach wall, the ingested food is transformed into *CHYME*, which gradually passes through the *PYLORIC VALVE* into the intestine. Apparently little or no absorption of food materials occurs in the stomach.

SMALL INTESTINE

The human intestine is a much coiled tube, about twenty-six feet in length, that extends from the stomach to the anus. In the upper part, known as the *SMALL INTESTINE*, the most radical changes in the food

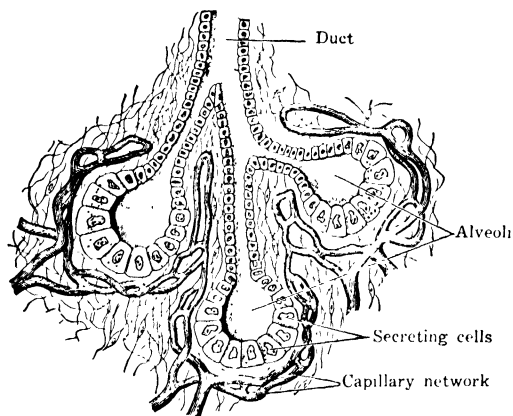


FIG. 105. Diagram of a gland (compound with duct, exocrine) in section, together with the surrounding tissues. Highly magnified. (From Hough and Sedgwick.)

take place, so that digestion is essentially completed; here also most of the products of digestion pass through the intestinal walls into the body proper, by the process of absorption. Accordingly various kinds of glands are found to elaborate and secrete the digestive fluids. Some of these are unicellular or simple multicellular tubular glands embedded in the intestinal wall; others are highly complex and far removed from the intestine into which they pour their products through long ducts. But, as we know, even in the latter case the glands are really derivatives of the intestine—cellular areas sunk, as it were, below the membrane to which they really belong—because they arise during development as outpocketings of its wall, the ducts being the sole remaining connection with the point of origin. (Fig. 105.)

Liver. The largest gland in the body, the LIVER, releases its secretions into ducts which unite to form a single BILE DUCT. This empties the secretions into the upper part of the small intestine. The product of the liver, termed BILE, which is constantly formed (about 1000 cc per day in man) but may be temporarily stored in the GALL BLADDER, is a

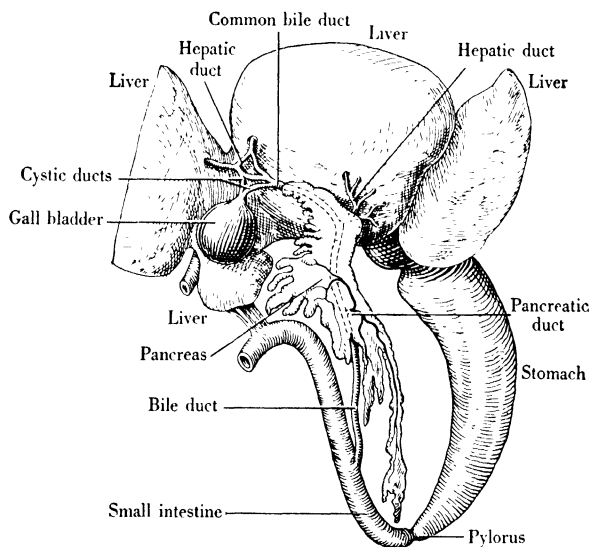


FIG. 106. Liver and pancreas of the frog, showing their ducts. Lobes of liver turned forward. The cystic ducts unite with hepatic ducts and finally lead into the common bile duct. The latter passes through the pancreas, receives further hepatic ducts and the pancreatic duct and leaves the pancreas, opening into the upper part of small intestine (duodenum).

highly complex, alkaline mixture of substances. Some of them, the bile pigments, etc., are excretions on their way out of the body through the intestines, while others are secretions which contribute to digestion by cooperating with an enzyme from another gland, the pancreas. Thus bile salts aid in the emulsification of fats and the absorption of fatty acids. (Fig. 106.)

Incidentally, it should be emphasized that the liver is perhaps the most versatile organ in the body. Among its functions, in addition to those of a digestive gland, may be mentioned its action in protein and carbohydrate metabolism; the storage of various substances, including vitamins, necessary for the body; the regulation, in part, of the fluid balance of the body; the formation of substances necessary for blood clotting; and the removal from the blood of toxic substances absorbed from the intestine.

Pancreas. The PANCREAS may be regarded as the chief digestive gland in the vertebrate body though it also performs additional func-

<i>Location</i>	<i>Secretions</i>	<i>Enzymes</i>	<i>Substances Changed</i>	<i>Intermediate Products</i>	<i>Products Ready for Absorption</i>
Mouth	Saliva	Ptyalin Maltase	Starch Maltose	Maltose	Simple sugars
Stomach	Gastric juice	Pepsin Rennin	Proteins	Proteoses Peptones Casein	
Small intestine	Pancreatic juice	Trypsin group	Proteins Proteoses Peptones	Polypeptides Dipeptides	Amino acids
		Amylase	Starch	Maltose	
		Lipase	Fats		Fatty acids Glycerol
	Intestinal juice	Frepsin group	Polypeptides Dipeptides		Amino acids
		Maltase Invertase Lactase	Maltose Cane sugar Lactose		Simple sugars

FIG. 107. Table showing the chief chemical activities in the alimentary canal.

tions. It lies posterior to the stomach in man, and each day secretes into the small intestine, through the bile duct into which the pancreatic duct opens, about 1200 cc of strongly alkaline PANCREATIC JUICE. This contains several types of enzymes, the TRYPSIN group acting on proteins, AMYLASE on starches, and LIPASE on fats. (Figs. 106, 107.)

Food that has been subjected to the enzymes of the upper digestive tract is now attacked by the pancreatic juice. But this is not all; the process of progressive chemical simplification of the food is carried on by the secretions of innumerable minute glands embedded in the intestinal wall. This so-called INTESTINAL JUICE supplies several enzymes, the TREPSIN group to hydrolize proteins and protein products to simple peptides and free amino acids, and the other enzymes to convert complex sugars into simple sugars. As in the stomach, digestion is facilitated by muscular contractions of the intestinal wall. There are slow swayings of entire loops of the intestine, there are local "segmentation" contractions, and finally there are peristaltic waves that pass the material along for absorption or elimination.

One naturally wonders how it is that the living tissues of the digestive tract, and especially of the glands themselves, withstand the digestive activities of their own enzymes, because the stomach or intestine of an animal killed during active digestion will begin self-digestion. A partial explanation of immunity during life appears to be that the enzymes are not in an active form while they are within the glands, but are later chemically changed by specific enzyme-activating substances, coenzymes, etc., that they meet in the digestive tract when food is actually present.

Absorption. The purpose of digestion is, first, to make the food soluble so that it may enter the body proper, that is, pass through the epithelium lining the digestive tract wall; and, second, to put it into a chemical form that can be used by the cells. The passage into the body, or ABSORPTION, occurs chiefly in the small intestine, the walls of which are lined with millions of

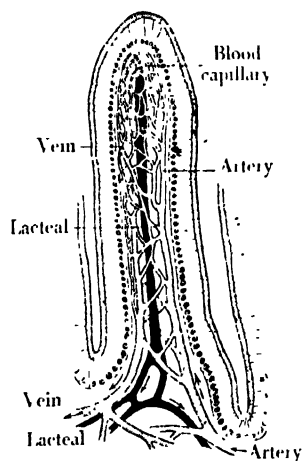


FIG. 108. Diagram of a section through one of the villi as found in the lining of the small intestine. Highly magnified. (After Peabody and Hunt.)

minute projections, the **VILLI**, which bring tiny vessels into intimate contact with the absorptive membrane while greatly increasing the effective absorptive surface. Apparently absorption is not merely the result of simple physical processes, such as diffusion and osmosis, but is largely the function of the actual living cells forming the epithelium of the villi. (Figs. 108, 149A.)

The transportation system of vessels in the villi consists of **BLOOD** vessels, which take up the absorbed products of protein and carbohydrate digestion, and **LYMPH** vessels, here called **LACTEALS**, which receive the derivatives of the fats. Both also take absorbed water and salts.

Accordingly the path through which the digested proteins and carbohydrates are transported differs from that of the fats. The blood vessels returning blood from the digestive organs finally merge to form a large vessel, the **PORTAL VEIN**, which proceeds to the liver to allow that organ to regulate certain of the blood constituents—in particular to store up sugar, in the form of **GLYCOGEN**, after a meal and later dole it out to the blood as conditions demand. On the other hand, the lacteals merge into larger and larger lymph vessels and finally into the **THORACIC DUCT** which empties into the blood vascular system, the fats being switched, as it were, around the liver so that they do not directly enter the blood supply to that organ. (Fig. 109.)

With this general statement of distribution in mind, the important products of protein digestion may be further considered. As we know, these products, mainly if not entirely amino acids, are absorbed by the intestinal wall without appreciable change, and enter the blood. The amino acids are removed from the blood stream by the various tissues of the body and are accumulated in the tissue fluid. From this temporary storage the cells select certain of the amino acids for the maintenance and growth of new tissue. In this synthesis a certain assortment of some fifteen or more amino acids may be required, and since the protein molecules are assembled from hundreds or thousands of amino acid molecules according to an unvarying pattern, it appears that these gigantic molecules are synthesized under the control of specific protein-organizing enzymes that are themselves proteins. Furthermore, these enzymes must have the ability to synthesize replicas of their own structural pattern, that is, to multiply in suitable surroundings.

The amino acids absorbed in the blood, in excess of the require-

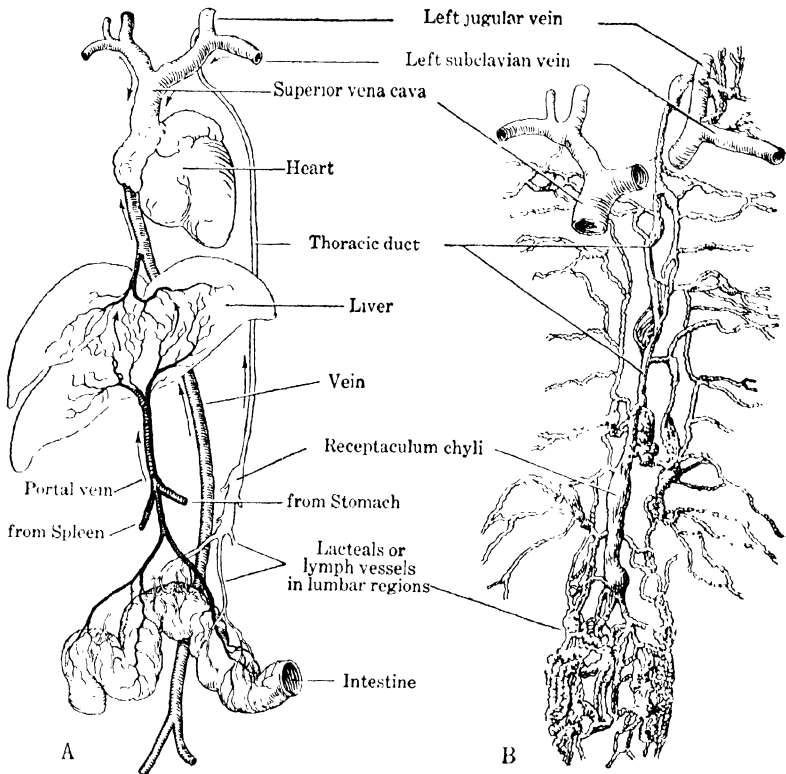


FIG. 109. A, diagram to show the paths of absorbed food from the human digestive tract: proteins and carbohydrates through the veins; fats through the lymphatic vessels. B, diagram showing distribution of the chief lymphatic vessels in the human body.

ments for maintenance and growth, undergo deamination, and the nitrogen is excreted in the urine in various forms, mainly as urea in mammals, amphibians, and fishes, and as uric acid in birds and reptiles. The nonnitrogenous residues may serve as fuel for the animal organism, or may be stored either as glycogen or fat. Other excess acids are important in metabolic processes, in detoxication reactions, and as forerunners of physiologically important animal products.

LARGE INTESTINE

During the passage of food through the small intestine, digestion is practically completed and absorption has progressed far. The remain-

der is transferred through the ileo-caecal valve into the LARGE INTESTINE, or COLON, where the enzymes already present continue their digestive activity and the products are absorbed. The activities of bacteria are more evident than in the small intestine and bring about various chemical changes, apparently of no positive benefit and largely incidental to

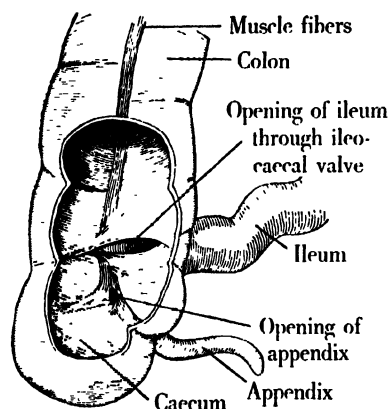


FIG. 110. Diagram showing ileo-caecal valve at junction of small and large intestines. (After Williams.)

the slow passage of the residue, except in the case of certain strictly herbivorous animals, such as the cow, where the bacteria make possible the use of cellulose. Water, which up to this point has been necessary to keep the materials fluid to facilitate digestion, is now gradually absorbed. Then the useless undigested materials, or FECES, are released to the exterior either through a terminal cavity, the *cloaca*, into which also open the urogenital ducts, or directly out through the anus as in most mammals.

FOOD USE

Digestion, absorption, and distribution completed, the actual food supplying matter and energy is at the disposal of the various cells for carrying on the essential metabolic processes. Since the daily energy output of the average man not engaged in heavy physical labor is about 3000 calories, and the energy yield per gram for proteins and carbohydrates is about 4.1 calories, and for fats about 9.3 calories, it is not difficult to determine from these fuel values how much of each food-stuff is required to supply the necessary energy.

Of course, provision must also be made for tissue maintenance, and this draws upon the proteins with their nitrogen constituent. In general it may be said that, since carbohydrates and fats adequately supply the energy demands, protein consumption apparently need not greatly exceed the nitrogen required for tissue maintenance. However, excess protein derivatives, the amino acids, are, in part at least, put to good use. Reaching the liver by the portal vein, the amino groups are removed and the deaminized amino acids converted into glycogen, so-

called animal starch. Thus this highly important function of the liver makes it possible for the body to use protein to supply energy for the body when it is not needed to build tissue.

VITAMINS

The tissues also require small amounts of certain accessory food substances, the **VITAMINS**, which, except for vitamin D, are usually present in sufficient quantity in a normal mixed diet. If they are not, so-called "hidden hunger" results. Vitamins are organic substances, not related chemically to one another, that do not supply energy or structural material, and do not act as typical enzymes, but are necessary for cell metabolism. Their exact mode of action is not yet determined, and in some cases their exact chemical constitution is unknown. At present at least six vitamins are recognized as of outstanding importance.

VITAMIN A, the growth-promoting vitamin, is essential for developmental processes, in particular for glandular structures, and so has a profound effect on the vigor and general health of the body, including resistance to infections. It is chemically closely related to the yellow pigment, carotene, and is widely distributed in foods. Important sources are butter, cream, egg yolk, liver, cod-liver oil, leafy vegetables, and carrots.

VITAMIN B₁, the antineuritic vitamin, called **THIAMINE**, has a special relation to the metabolism of nerves, and its deficiency is associated with a loss of appetite, certain types of neuritis, and in extreme cases the disease known as **BERIBERI** which involves, among other symptoms, paralysis. Excellent sources for thiamine are whole-grain cereals, leafy vegetables, fruit, nuts, yeast, and liver.

VITAMIN B COMPLEX, so-called, includes several other vitamins that are intimately associated with thiamine, notably **STACHIN** and **RIBOFLAVIN**. Inadequate amounts of niacin result in growth deficiencies and the disease called **PELLAGRA**, characteristic symptoms being brown pigmentation of the skin, nervous disorders, and digestive disturbances. The last may also be evidence of riboflavin deficiency. The sources of these vitamins are, in general, the same as for thiamine.

VITAMIN C, the antiscorbutic vitamin, or **ASCORBIC ACID**, when included in adequate amounts in the diet prevents **SCURVY**, a disease evidenced by hemorrhagic conditions of the skin, teeth, gums, and joints, and leading, if not arrested, to progressive weakness and death. Vitamin

C is abundant in most fresh foods, especially vegetables and fruit. Oranges, lemons, and tomatoes are ready sources.

VITAMIN D, the antirachitic vitamin, regulates chiefly the concentration of calcium and phosphorus in the blood and the process of calcification of the bones and teeth. Deficiency of this vitamin results in the disease known as RICKETS, characterized by various skeletal deformities. Although it is not generally distributed in significant amounts in our usual foods, rich sources are available in oil from the liver of the cod and halibut. Moreover, the action of ultraviolet rays on certain sterols produces the vitamin, so that exposure of the human body to sunlight, within reasonable limits, is beneficial.

VITAMIN E, the antisterility vitamin, has been studied particularly in rats, where it has been found to affect the reproductive functions, insufficient amounts resulting in sterility. It is widely distributed in foods.

VITAMIN K, the antihemorrhagic vitamin is associated with blood clotting. A deficiency of this vitamin markedly delays the formation of the clot and may result in hemorrhages.

It should be noted that a good diet, which includes an abundant supply of vitamins, promotes intellectual keenness as measured by psychological tests. There seems no doubt that dullness can often be traced in part to a nutritional lack, so there is more than the obvious meaning to the adage, "Food makes the man."

ACCESSORY GLANDS

It is important to note certain accessories of the alimentary canal which lose all direct connection with it as development proceeds. These are really glands that have carried the process of outpocketing from the digestive tract to the breaking point, as it were, and have become DUCTLESS GLANDS. Such, for instance, are the THYROID and THYMUS glands near the anterior end of the esophagus. The human thymus regresses during childhood and is of doubtful function, but the thyroid delivers its important product directly into the blood stream. Such secretions are called INTERNAL OR ENDOCRINE SECRETIONS. We shall have occasion later to discuss the coordinating functions performed by HORMONES secreted by ductless glands and other endocrine organs. At the moment it may be remarked that the pancreas is stimulated to secrete its digestive enzymes by a hormone, known as SECRETIN, brought to it by the blood. When food enters the small in-

testine from the stomach, secretin is liberated into the blood by special gland cells in the wall of the small intestine. (Figs. 102, 116, 118.)

Certainly, at first glance, the complicated digestive system of the vertebrate may seem to have little in common with that of the earthworm, but as a matter of fact the fundamental plan of organization is the same. The differences are chiefly the result of an increase in the working area of the alimentary canal. This increase affords greater secretive and absorptive surface, a larger variety and amount of digestive substances, and also a prolonged length of time during which the food is subjected to treatment. This development has been effected by folds and elevations of the inner surface of the alimentary tract; by outpushings of limited areas of the tube to form large glands, which in most cases contribute their products to their point of origin through ducts; and by increasing the length of the inner tube as compared with the outer tube (body wall)—an adaptation that results in throwing the intestine into various convolutions within the body cavity. In this way some of the complex nutritional demands of the higher animals are satisfied.

CHAPTER XI

Respiration

The living body is the theatre of many chemical and physical operations in line with those of the inorganic domain.

—Thomson

As has been stated earlier, the essential factor of respiration is an interchange of gases between protoplasm and the environment: an intake of free oxygen for combustion, and an outgo of the waste products, chiefly carbon dioxide and water. In the unicellular organisms, such as *Protococcus* and *amoeba*, and in simple multicellular animals like *hydra*, this is a relatively direct process since an elaborate mechanism is not necessary to facilitate the interchange. But with the establishment of a highly differentiated multicellular body, fewer and fewer cells are in immediate contact with the aerating medium and so various provisions are necessary to transfer the gases to and from the outer world and the individual cells themselves. (Figs. 10, 13, 17.)

In all forms the *SKIN* functions to some extent in respiration; in the earthworm, in fact, it acts as the chief respiratory membrane since a profuse supply of blood vessels to the moist surface of the body effects a sufficiently rapid gaseous interchange for the relatively inactive life of the organism. The crayfish meets the problem of respiration by delicate outpocketings of the body wall to form the *GILLS*; this arrangement provides a method of bathing a large area of the respiratory membrane in the respiratory medium, the surrounding water. Insects, however, instead of bringing the blood to the surface, develop a network of tubes, the *TRACHEAE*, which ramify throughout the body tissues and conduct air directly to the cells. (Figs. 79, 111.)

Among all the vertebrates, as has been indicated, the anterior end of the digestive tract functions as a common food and respiratory passage. In fishes, the respiratory water current which enters the mouth makes its exit by way of the gill pouches and gill slits; the lining of

the pouches, outpocketings of the lining of the alimentary canal, functions as the respiratory membrane. (Fig. 112.)

In the air-breathing vertebrates there are the added problems of protecting and keeping moist the greatly increased respiratory surface which their more active metabolism, that is, their proportionally greater energy requirements, demands. The respiratory membrane must be kept moist because even in terrestrial animals the process re-

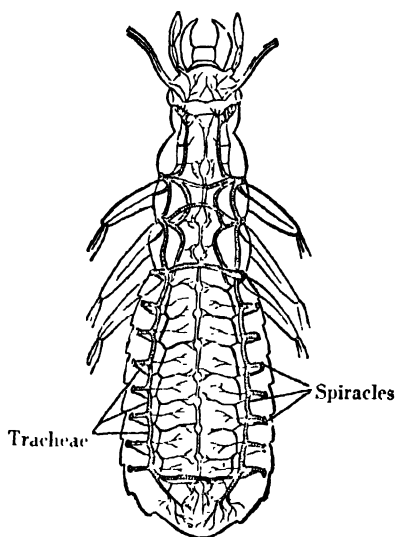


FIG. 111. Tracheal system of an insect (After Kolbe)

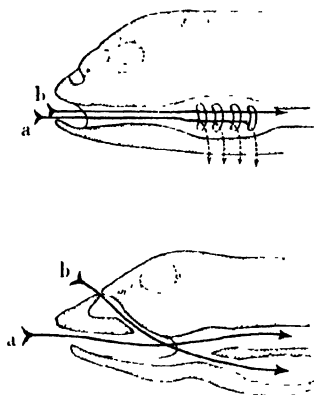


FIG. 112. Diagram of a vertical section through the head region of a fish (*above*) and higher vertebrate (*below*) to show paths of the respiratory currents (a) and food (b).

mains essentially aquatic. Diffusion of oxygen and carbon dioxide takes place through a watery film covering the respiratory membrane. In terrestrial vertebrates the gill slits persist merely as transient embryonic reminders of evolutionary history, and the function of the gill pouches is taken over by a huge, moist, membranous outpocketing of the ventral wall of the pharynx into the anterior portion of the body cavity, forming the LUNGS. Thus, even in man, the respiratory membrane that lines the lungs is, from the standpoint of development, a specialized part of the epithelium of the alimentary canal. Furthermore, the establishment of lungs entails, in turn, a complex respiratory

mechanism so that the air within them may be renewed at frequent intervals. The operation of this mechanism is often called **EXTERNAL RESPIRATION**, in contrast with **INTERNAL RESPIRATION**, which is the actual cell respiration.

LUNGS

In the human respiratory exchange, air enters through the nostrils (**ANTERIOR NARES**) and passes along the nasal passages and out the **POSTERIOR NARES** into the lower part of the pharynx. Air may also enter through the mouth. From the pharynx the air passes over the **EPIGLOTTIS**, and through the slitlike **GLOTTIS** into the **LARYNX**, the so-called Adam's apple, and then down the windpipe, or **TRACHEA**. Within the larynx are the **VOCAL CORDS** which vibrate in response to air currents. The tension of the cords and the amplitude of their vibrations are responsible for the characteristics of the voice. The mouth, pharynx, and nasal cavities act as resonating chambers. (Fig. 113.)

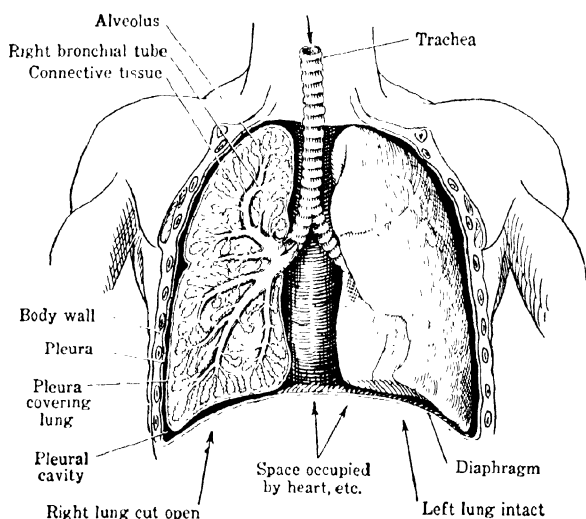


FIG. 113. Diagram of a section through the chest region in man, showing the lungs and thoracic cavity.

As the lower end of the trachea enters the chest, or thorax, it divides into right and left branches, the **BRONCHI**, which in turn branch into numerous **BRONCHIAL TUBES** within the lungs, each essentially a bag of elastic, spongy tissue. Here the bronchial tubes divide into smaller

and again smaller branches, until finally they form microscopic twigs, each ending in one or more tiny air sacs, the ALVEOLI. In the human lungs there are many thousands of alveoli, every one in direct communication with the air. Furthermore, the walls of each alveolus are profusely supplied with capillaries through which flows blood sent by the heart and soon to return to the heart for distribution to every part of the body. It is while the blood is in the capillaries of the alveoli that it gives up to the air in the alveoli the carbon dioxide, water, and heat taken from the tissues, and at the same time receives oxygen. This exchange is effected through the delicate walls of the capillaries and alveoli. The alveoli are really the effective surface of the lungs. (Fig. 113.)

RESPIRATORY MECHANISM

In order for the lungs to function in respiration, the air within them must be periodically renewed, and this rhythmical process of INSPIRATION and EXPIRATION is what one usually refers to as breathing. The complex mechanism involved and its method of operation may be briefly outlined.

The lungs of mammals are cone-shaped, elastic sacs suspended in an airtight cavity, the thorax, which can be enlarged by raising the ribs and lowering the diaphragm: a muscular partition between the thoracic and abdominal cavities. The sole entrance to the lungs is through the trachea, and accordingly an atmospheric pressure of approximately fifteen pounds to the square inch is exerted down through the trachea on the inner walls of the lungs to keep them constantly in close contact with the walls of the thoracic cavity; otherwise there would be a vacuum between the lungs and the thoracic wall. Therefore, when the thoracic cavity is enlarged by contraction of the muscles of the ribs and diaphragm, the elastic lungs expand in maintaining contact with its walls, and inspiration takes place; when the thoracic cavity is decreased, by relaxation of the same muscles, expiration occurs. The lungs have an entirely passive part in the process. Of course, if through injury or operation (pneumothorax) the chest wall is punctured, then the lung tissues will probably be exposed to higher external pressure, and they will collapse. (Figs. 114, 115.)

Since the rhythmical respiratory movements are due to the contractions of muscles, it follows that stimuli reach the muscles from the nervous system, because muscles, excepting those of the heart, do not

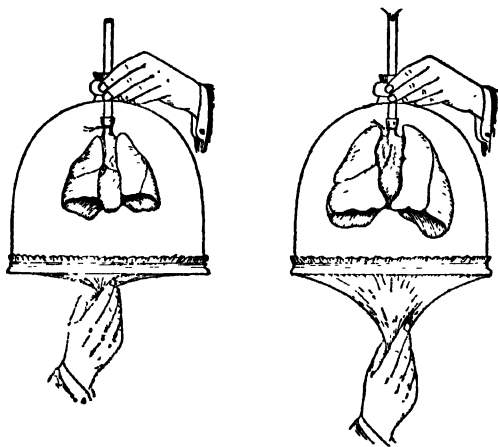


FIG. 114. Diagrams to illustrate the mechanism of diaphragm breathing. The lungs of a mammal are enclosed in a bell-jar. As the rubber membrane below (representing the diaphragm) is pulled down, thus enlarging the cavity, air enters through the tube above (trachea) and expands the lungs. (From Conn and Budington, after Tigerstedt.)

contract automatically. Nerve impulses arise in the RESPIRATORY CENTER in the lower part of the brain, just before it merges into the spinal cord, and travel along nerves to the muscles involved. Although the respiratory center is essentially automatic, the carbon dioxide content of the blood reaching the center determines the rate of the respiratory movements which it induces, even a slight increase in carbon dioxide resulting in a marked acceleration. Moreover there are nerves from

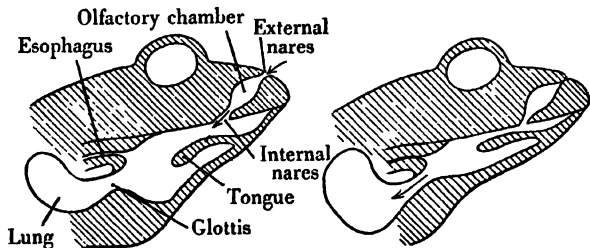


FIG. 115. Diagrams to illustrate respiratory movements of the frog. At left, the external nares are open and air enters the mouth cavity. At right, the external nares are closed and the floor of the mouth cavity raised, forcing air into the lungs, as indicated by arrow. Note that absence of a diaphragm and air-tight thoracic cavity necessitates a different mechanism from that used in mammals. (From Hegner.)

the lungs which carry nerve impulses that also contribute to the control of breathing, apparently by holding in check the activities of the center itself.

Indeed, the center can be influenced by stimuli from nearly any part of the body: witness the effect on breathing of a cold plunge. Although the action of the center is chiefly involuntary, since we breathe when we are asleep, obviously it can be controlled to a considerable extent by the will, for we can hold our breath for some time by sending impulses to the respiratory center to inhibit its discharge. If this center is destroyed or if the nerves carrying impulses to the muscles of chest and diaphragm are severed, respiratory movements immediately and permanently cease.

RESPIRATORY INTERCHANGE

The respiratory mechanism has attained its objective when air and blood are brought into such close relationship in the lungs that gaseous interchange can occur and heat be transferred. Inhaled air varies very widely in temperature but in our homes is perhaps most frequently about 20° C (68° F). Exhaled air is about 36° C (97° F), or nearly the same as that of the human body. Thus under usual circumstances the exhaled air is warmer than when it entered the lungs; the blood has lost heat. Again, the amount of water in the inhaled air is variable being low on a dry day and high on a wet day; but the exhaled air is practically saturated with water vapor; the blood has lost water. Furthermore, the inhaled air contains merely a trace of carbon dioxide, but when it leaves the lungs it bears a little more than 4 per cent; the blood has given up carbon dioxide. Finally, air entering the lungs contains approximately 21 per cent oxygen, but when exhaled contains only about 16 per cent; the blood has received oxygen. In short, the blood by its traffic with the air in the lungs gives up heat, moisture, and carbon dioxide, and takes up oxygen.

One naturally is interested to know how the blood while passing through the lungs acquires the oxygen—the element demanded by every cell in its life processes. At least two phenomena are involved. In the first place, the air contains a considerable amount of free oxygen under relatively high tension, and therefore oxygen passes into the liquid plasma of the blood where the oxygen conditions are just opposite. It follows the physical laws of the diffusion of gases through permeable membranes, the walls of the alveoli and the capillaries. There-

upon most of the oxygen is appropriated by the red blood cells, of which there are many trillions in the human body. They carry a complex chemical substance, HEMOGLOBIN, which has a high chemical affinity for free oxygen; it is oxygenated to form an unstable chemical compound, OXYHEMOGLOBIN. Accordingly the red blood cells leave the lungs with the oxygen affinity of the hemoglobin satisfied and return to the heart to be distributed throughout the body.

The oxygen is delivered to the tissue cells, through the mediation of the tissue fluid, by the capillaries in the tissues where the oxygen supply is low—just the opposite of the condition in the lungs—because the various tissue cells use the oxygen nearly as rapidly as it is received. So the red cells give up most of their oxygen, that is oxyhemoglobin is reduced to hemoglobin, and the blood receives in exchange, as it were, carbon dioxide (because the CO_2 supply is lower in the blood) and also water and heat resulting from oxidation processes in the tissue cells. Nearly half of the carbon dioxide is carried by the red blood cells and the rest by the blood plasma, chiefly in the form of an alkaline bicarbonate, which means in essence that the CO_2 is neutralized during its passage in order to prevent serious changes in the slightly alkaline condition (p H 7.3) of the blood.

And now the blood, after its passage (lasting about two seconds) through the capillaries, returns to the heart, whence it is sent to the lungs so that it can transfer carbon dioxide, water, and heat to the air in the alveoli. The carbon dioxide passes to the air largely because it is more concentrated in the blood than in the alveolar air. The respiratory cycle is now complete.

It should be noted that the blood does not release all of its carbon dioxide in the lungs nor all of its oxygen in the tissues. Considerable amounts of both gases are essential. Moreover, under ordinary living conditions, ventilation is unnecessary for maintaining the proper purity of the air in a room. There is no danger of jeopardizing health or comfort by a slight reduction of available oxygen or increase of carbon dioxide or by the accumulation of expired “poisons.” The most important factors are the temperature and moisture of the air.

Such, in brief, is the elaborate apparatus maintained in the higher animals and man to provide for the new conditions associated with the location of many of the body cells further and further from the source of oxygen, and also to satisfy the increasing demand for oxygen-securing facilities as the life processes increase in vigor. We shall

later consider the attendant changes in the blood vessels; now it is necessary only to be sure that the mechanism does not obscure its object. One must not forget that, although one ordinarily thinks of the movements involved in the renewal of the air in the lungs as respiration, respiration actually is neither inspiration nor expiration, nor the interchange of gases between blood and air or between blood and tissue cells. The essential feature of respiration is the same here as it is in unicellular plants and animals: it is the process by which the protoplasm of each and every living cell secures energy from food by combustion, a process which involves the appropriation of oxygen and the liberation of carbon dioxide. All else, though necessary, is accessory.

CHAPTER XII

Secretion

Nature is more subtle than any argument.—*Francis Bacon*

Glands with ducts (exocrine glands) are widely distributed throughout the human body, notably in the skin and alimentary canal as previously studied in association with these and various other organ systems.

Ductless glands (endocrine glands) are concerned with the synthesis and secretion of several specific substances. Such glands really constitute a secretory system whose products (hormones) are released directly into the blood stream. The hormones are removed from the blood for specific essential functions in various organs and tissues as will now be described.

Since a primary attribute of protoplasm is irritability, it is not strange that the cells of an organism mutually influence each other's activities and that reciprocal interrelationships have been established during evolutionary history. The various cells, tissues, organs, and organ systems of animals, invertebrate and vertebrate, are unified into an organism largely by the ENDOCRINE SYSTEM, which maintains a chemical regulation among its various parts. This is made possible by the facilities for distribution afforded by the circulatory system, and also by the NERVOUS SYSTEM which provides a central station with facilities for instantaneous intercommunication between all parts of the body.

Only with the increase in knowledge of the general problem of metabolism was the far-reaching significance of the chemical control and integration of bodily processes gradually brought to the fore. Although one may properly think of the various chemical regulators, or HORMONES, as forming a coordinating system, in so far as their collective action has such a result, in the present stage of our knowledge it is possible to do little more than cite the specific action of individual

hormones as examples of the general method of chemical regulation which their study, ENDOCRINOLOGY, is revealing. It will be recalled that similar chemical agents occur where they are of basic importance in plants. (Fig. 56.)

Certain hormones in vertebrates are elaborated by special secretory cells embedded in organs devoted partly to other functions, notably in the pancreas, gonads, and intestine; whereas others are formed by glandular organs devoted solely to their production, such as the thyroid, parathyroids, and pituitary. In every case the hormones are specific chemical substances which are liberated into the circulatory system for transport to the place where they are to exert their influence. Since these glandular cells secrete their products directly into the blood or lymph, they are known as **DUCTLESS GLANDS**, and their products are called **INTERNAL SECRETIONS**. (Fig. 116.)

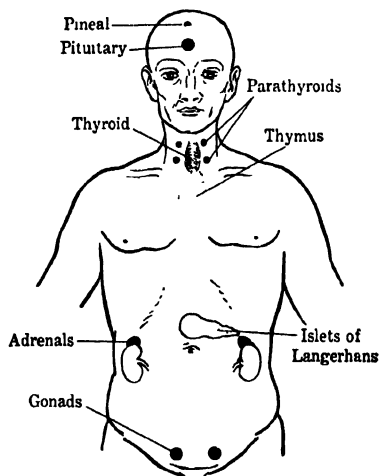


FIG. 116. Approximate positions of the endocrine glands in man.

PANCREAS AND INTESTINE

Groups of special gland cells in the pancreas, called **ISLETS OF LANGERHANS**, secrete the hormone, chemically isolated as **INSULIN**, which enables the body to oxidize dextrose, to store glycogen in the liver, and in general to maintain essential carbohydrate metabolism. (Figs. 102, 106, 117.)

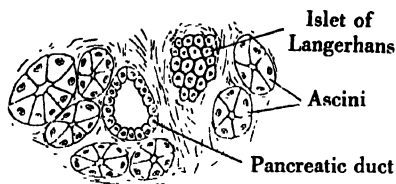


FIG. 117. Section of pancreas tissue, showing one of the islets of Langerhans, for the endocrine secretion of insulin. Exocrine glands (ascini) which secrete pancreatic juice are also shown. (From Kimber, Gray, and Stackpole.)

DIABETES has long been known to be the result of a deficiency in pancreatic function leading to the incoordination of the chemical processes by which the body utilizes carbohydrates to supply energy. Evidence of the disease is

chiefly an increase in the sugar content of the blood and the presence of sugar in the urine. The tissues cannot use the sugar and must in part use proteins and fats for energy. A close approach to the normal metabolic condition can be attained, however, by giving the patient insulin secured from the pancreas of sheep or other animals. This insulin takes the place of that which the diabetic pancreas fails to provide, and so restores normal metabolism to many afflicted with diabetes.

Some of the nutritive cells lining the small intestine secrete hormones, in particular, one known as **SECRETIN**. The acidity of the chyme (the food coming from the stomach) stimulates these cells to secrete the hormone, which then passes by the blood stream to the pancreas and stimulates this gland to liberate its digestive enzymes.

GONADS

Certain tissues in the male and female reproductive organs exert various endocrinal effects. This is evidenced, in particular, by the effect of castration on the development of secondary sexual characters. (Fig. 195; p. 272.)

The male sex hormone, **TESTOSTERONE**, is secreted by cells between

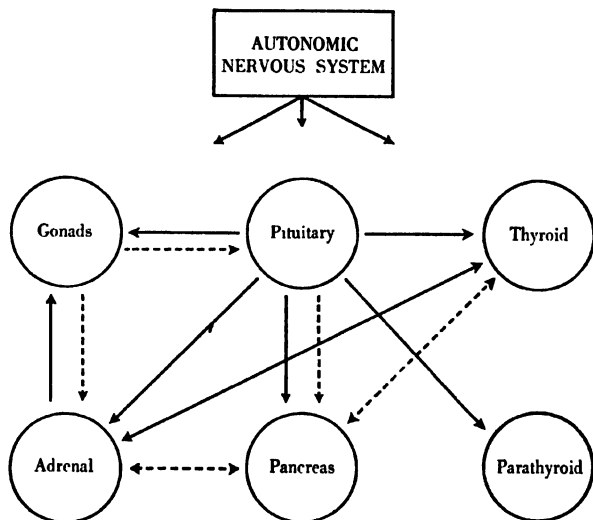


FIG. 118. Diagram to illustrate some of the chief lines of interplay between endocrine glands of the vertebrate. Stimulation is indicated by solid lines ———, inhibitory action by broken lines - - - -

the tubules that produce sperm. When injected in castrated animals it corrects the deficiencies caused by testis removal. Hormones from the pituitary gland are necessary for the normal development of the testes.

Several hormones are secreted by ovarian tissue. One, known as **ESTRIN**, is apparently produced in the egg follicles. It is associated with the development of secondary sex characters and certain uterine changes, including those of the menstrual cycle. Another hormone, called **LUTEIN**, is secreted by the **CORPUS LUTEUM** which fills the follicle when the egg has been liberated. This hormone inhibits ovulation, stimulates the growth of the uterus, sensitizes it for the implantation of the embryo, and induces other changes in the uterus during pregnancy. The development of the ovary itself is dependent, as is the testis, upon a hormone from the pituitary gland. It is becoming increasingly clear that the sex functions and the behavior of the higher animals are to a considerable extent associated with a complex of hormonal interrelationships. (Fig. 118.)

THYROID

Attention may now be turned to glands devoted solely to the secretion of hormones. First may be considered the thyroid, which arises as an outgrowth from the digestive tract in the neck region but soon loses all connection with its point of origin and becomes a ductless gland. (Figs. 102, 119.)

The general effect of the thyroid hormone, **THYROXINE**, on metabolism is a regulation of the rate of oxidation in the body to meet changing physiological demands. An excess of thyroxine induces such vigorous fuel consumption that no surplus remains in the body to be stored as fat, while a deficiency in the glandular secretion results in a tendency toward fat formation. The administration of thyroid extract or thyroxine is often an efficient, though dangerous, means of reducing fat by increasing the oxidative processes of the body. A defi-

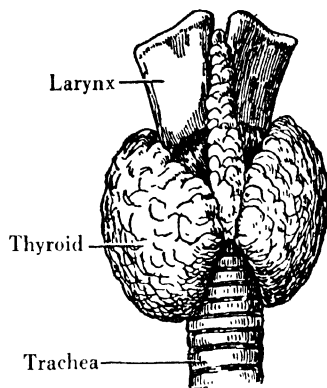


FIG. 119. Thyroid gland and adjacent structures. Viewed from front. Diagrammatic. (From Stiles.)

ciency of the hormone during adult life frequently results in a pathological condition called MYXEDEMA. Children in whom the development of the thyroid is suppressed become dwarfish idiots known as CRETINS, whereas overdevelopment of the gland induces increased nervous activity and mental disorders. The feeding of thyroid extract prevents or retards the development of cretinism and cures myxedema. A surgical removal of part of the gland may cure the nervous instability and other symptoms due to an excessive amount of the hormone. GOITER is a pathological enlargement of the thyroid caused by a deficiency of iodine, which is needed to manufacture the iodine-containing thyroxine.

PARATHYROIDS

The PARATHYROIDs, usually four in number, are small glands closely associated with the thyroid but performing a distinct function, the regulation of the calcium-phosphorus balance in the blood, by a hormone known as PARATHYRIN. Removal of the glands is followed by a sharp decrease in calcium, which results in convulsions, tetany, and death, unless controlled by the injection of the parathyroid hormone. (Fig. 116.)

ADRENALS

The ADRENAL GLANDS, one situated in close proximity to each of the kidneys, are endocrine organs of high significance. The inner portion (MEDULLA) of these glands forms

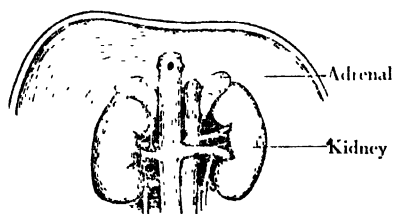


FIG. 120. Diagram to show position of the adrenals and kidneys of man. (From Stiles.)

a very important hormone, known as EPINEPHRIN, or ADRENALIN, which is released into the blood when the adrenal glands are stimulated by the nervous system. Epinephrin has its most marked effect when muscular exertion is at a premium: it accelerates heart action, stimulates the liver to release its stored glycogen, retards the

activities of the alimentary canal, dilates the eyes, etc. It appears to act as a chemical whip which makes various organs respond quickly in the general mobilization of the body. (Figs. 120, 181.)

A group of ADRENAL CORTICAL hormones, six of which have been isolated, exercise a regulating influence on carbohydrate metabolism. Destruction of the adrenal cortex, which secretes these substances, is followed by muscular weakness, convulsions, and other symptoms characteristic of the rare ADDISON'S DISEASE. Administration of CORTIN, an extract that contains several adrenal cortical hormones, relieves the symptoms.

Among the compounds recently isolated from the adrenal cortex, one, successfully synthesized in 1946, is proving remarkably effective in alleviating the pain and crippling of rheumatoid arthritis and related diseases. This substance, now known as *cortisone*, is still under experimental development and supplies for general use are limited.

PITUITARY

The pituitary gland, or hypophysis, is sometimes referred to as "the master gland" because of the wide range of its hormonal influence. It comprises two small lobes of diverse origin: the anterior lobe arises from the roof of the pharynx, and the posterior lobe from the infundibulum on the ventral surface of the brain. (Fig. 121.)

The anterior pituitary supplies at least ten hormones, many of which exert specific control over other endocrine organs or over the production of other hormones. Representative examples may be cited:

The SOMATROPIC hormone controls growth and development. A deficiency during the growing period results in DWARFISM, and an excess in GIGANTISM. In adult life an excess of the hormone produces ACROMEGALY, a condition characterized by abnormal enlargement of the bones, particularly of the face, hands, and feet.

PROLACTIN exerts a controlling effect on the development of the male and female gametes, in particular on the ovarian follicles and therefore on their own hormonal influences.

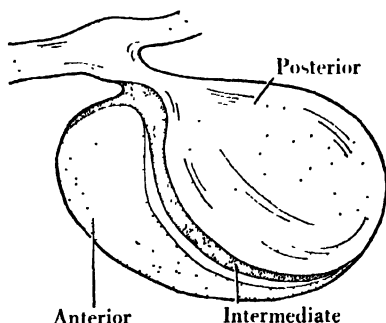


FIG. 121. Diagram of a section through the human pituitary gland. The anterior lobe is endodermal in origin, whereas the posterior lobe is ectodermal. (From Fasten.)

PROLACTIN initiates and maintains lactation after the mammary glands have matured under the influence of other hormones.

The ADRENOTROPIC hormone regulates the development of the adrenal cortex and the production of its hormone.

The PANCREATOTROPIC hormone is associated with the control of the islets of Langerhans and the regulation of insulin production.

The THYROTROPIC hormone regulates the secretion of thyroxine from the thyroid gland.

The DIABETOGENIC hormone has a regulative action toward insulin in the control of blood sugar, perhaps by acting on nerve centers which influence carbohydrate metabolism.

Hormonal substances derived from the posterior lobe of the pituitary gland affect blood pressure, kidney function, and the contractility of smooth muscle. Whether these hormones are secreted into the blood under normal conditions is uncertain. The presence of the posterior lobe apparently is not essential for health. (Figs. 118, 121, 144.)

PINEAL BODY

A small cone-shaped outgrowth of the dorsal surface of the mid-brain, known as the pineal body, apparently is the remnant of a median eye which was present in some fossil forms and appears in one genus of living lizards. Over three centuries ago Descartes referred to it as "the seat of the soul." Now it is generally accorded an endocrinal function, but neither the nature of the secretion nor its effects are clear. (Figs. 144, 145.)

THYMUS

The thymus gland usually consists of two lobes joined across the front of the neck. In man it reaches its greatest development the second year of life, remains essentially unchanged until puberty, and then decreases markedly in size. The hormone of the thymus, sometimes called THYMOCRESCIN, has been claimed to accelerate cell growth and division and therefore to influence the growth rate during early life. (Fig. 102.)

This very brief review of the endocrine system is sufficient to indicate the importance of hormones and their interrelationships in the economy of the organism. It may well be that each and every tissue liberates specific chemical substances that are hormonelike in action.

When one considers also the influence of stimuli from the nervous system on the complex of the endocrine glands, in particular on the pituitary, the maze of action and interaction that integrates the organs into an organism seems astounding. (Fig. 118; p. 216.)

The almost uncanny potency of some of these chemical agents is evidenced, for example, by the fact that as little as one milligram of thyroxine is sufficient to induce a 2 per cent increase in the total oxidation of the resting human body. The amount of this hormone required by the body during a whole year is probably about 2½ grams, while that in use at any one time is approximately 0.2 gram. "But this pinch of material spells all the difference between complete imbecility and normal health." So close is the "physiological sympathy of the parts in the commonwealth of the body, that it is perhaps justifiable to regard the mind as a function of the whole organism"—a thought that must give pause not only to the biologist but also to the psychologist and the sociologist.

CHAPTER XIII

Excretion

The mathematically accurate end-reaction of a chain of known and unknown causes and effects.

—*Noves*

Provision for eliminating from the organism the waste products of metabolism is no less important than those for supplying the materials and energy by which the vital processes are maintained. In many of the unicellular organisms the whole surface of the cell functions as

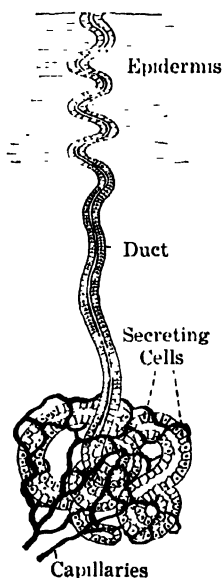


FIG. 122. Diagram of a sweat gland, with secreting cells and duct. Highly magnified.

an excretory organ, but it will be recalled that even in some of these animals, such as amoeba and paramecium, contractile vacuoles are active in the removal of useless metabolic products. Furthermore, in all but a few of the lowest Metazoa there are highly specialized organs for excretion. In the vertebrates, the kidneys and the gills or the lungs are devoted largely to excretion; in addition the skin and liver act in subsidiary capacities. Each excretory organ receives a profuse blood supply from which it removes the waste products that are to leave the body as an excretion. (Figs. 10; 13, 122.)

There is an essential distinction between an excretion, which represents chemical waste from the vital processes, and the material that is egested from the animal digestive tract as feces. The latter consists almost entirely of an indigestible residue which was taken in with the food but which has not directly contributed to the metabolic processes of the organism.

though some of the material may have acted temporarily in an accessory capacity. Accordingly the digestive tract is not included in the list of excretory organs. It will be recalled, however, that certain waste products formed by the liver cells are released via the alimentary canal.

The nature and amount of waste materials eliminated by the excretory organs are, of course, determined by what is brought to them by the blood, and this amount, in final analysis, is dependent upon the food—the fuel that has been burned—and the disintegration of protoplasm from the metabolic processes associated with the wear and tear of life. Carbohydrates and fats yield carbon dioxide and water; proteins yield in addition UREA, URIC ACID, CREATININE, AMMONIA, etc., the products of nitrogenous metabolism. Various inorganic salts are also excreted.

GILLS AND LUNGS

We have already discussed the elimination of carbon dioxide by the gills and the lungs in the discussion of respiration. Here the cells of the respiratory membranes have an excretory function that is essentially passive, since the carbon dioxide, which is under higher tension in the blood than in the water or air, follows the physical laws of diffusion of gases and passes from the blood. In addition to carbon dioxide, a large amount of water and heat is lost from the blood of homothermal animals, the amount depending on the moisture and temperature of the air entering the lungs. When the air is exhaled, its temperature is very nearly that of the body, and it is saturated with water vapor. About one-third of the water excreted by the human body is released from the lungs. (Fig. 113.)

SKIN

The skin of some of the lower vertebrates, for instance the frog, is an essential excretory organ, because more carbon dioxide is eliminated through the skin than through the lungs; but in most of the higher forms, including man, excretion by the skin is confined to the SWEAT GLANDS. About two million of these simple tubular glands, having a total length of several miles, open through pores on the surface of the human body. The sweat glands take from the blood, in addition to large quantities of water, traces of nitrogenous waste or urea, fatty acids, and inorganic salts, chiefly sodium chloride; these substances form a residue on the surface of the skin when the PERSPIRATION evap-

orates. However, most of the water thus released may be regarded as a secretion rather than an excretion because, being employed in regulating the body temperature, it is of use to the body. It is a fact familiar to everyone that the evaporation of perspiration accelerates the loss of heat by the skin. The skin is also provided with **SEBACEOUS GLANDS**, which commonly open at the base of hairs and there release a true secretion—a lubricant for hair and skin, and a conserver of body heat. (Figs. 84, 122.)

LIVER

The liver, in addition to its other functions, aids greatly in excretion. It removes miscellaneous nitrogenous wastes from the blood and converts them into urea. Then the liver secretes the urea into the blood to be removed later by the kidneys and passed from the body in the **URINE**. Other waste products collected from the blood by the hepatic cells form a part of the bile which reaches the intestine by the bile duct for elimination in the feces. (Fig. 101.)

KIDNEYS

The kidneys are two bean-shaped bodies which, in cooperation with the liver, constitute the chief excretory organs of vertebrates. Structurally they may be described as compound tubular glands. Any serious interference with kidney activity rapidly leads to a poisoning of the body tissues with accumulated waste products. However, the removal of wastes is but one aspect of essential kidney function; these organs

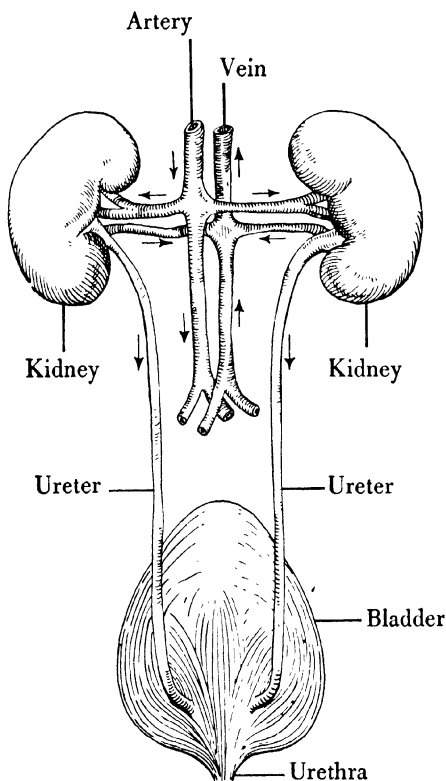


FIG. 123. Diagram showing main structural features of the human urinary system, as seen from dorsal aspect.

also act as a blood regulator to maintain a proper balance of the normal chemical constituents of the blood plasma. (Fig. 123.)

The functional units of a kidney consist of several million tiny **RENAL TUBULES**. Each tubule begins in the **CORTEX** of the kidney as a cup-shaped enlargement, known as a **BOWMAN'S CAPSULE**, which surrounds a tuft of capillaries, or **GLOMERULUS**, connected with the renal artery. The tubules continue from the capsule by an intricate course through the **MEDULLARY REGION** of the kidney to open at the tip of a **PYRAMID**. In the medullary region the tubules are enmeshed in capillaries extending from the glomerulus. Thus each renal tubule has two regions supplied with capillaries: the capsule and the tubular region. (Fig. 124.)

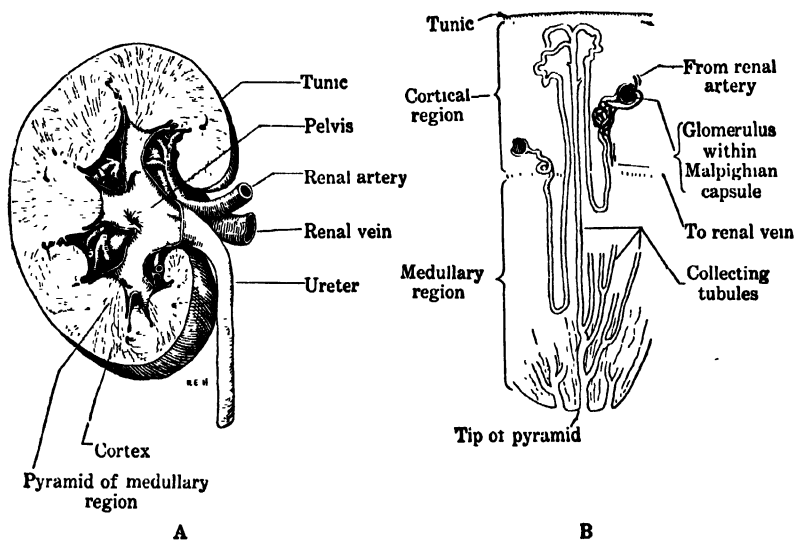


FIG. 124. Human kidney. A, longitudinal section through center of kidney. B, diagram of the course of the tubules in the kidney. The cortex is the region in which the tubules come into functional association with the capillaries. Tubules extend through the medullary region to open on the tips of the pyramids.

As the blood passes through the glomerulus, water, sugar, various salts, urea, etc., filter from the capillaries and pass down the tubule, during which much of the water, all the sugar, and other substances are reabsorbed, the absorption being selective and regulated by the immediate needs of the tissues. The residue, urine, reaches the end of

the tubule, passes through an opening on a pyramid in the PELVIS of the kidney, and so proceeds on its way down the URITER and eventually out of the body. About 90 per cent of the nitrogenous waste is eliminated from the human body in the form of urea. (Figs. 98-100.)

URINE

The excretion of the kidneys, known as urine, is a highly complex, variable, watery solution of organic and inorganic substances which flows continuously from the kidneys through the ureters to the URINARY BLADDER. Here it is stored temporarily until passed to the exterior through the URETHRA. Since urine contains nearly all the normal products of katabolism, as well as the majority of abnormal substances that may enter or be formed by the organism, one of the best indications of the general metabolic condition of the human body is afforded by a chemical and microscopical analysis of the urine. For example, in Bright's disease protein appears in the urine; in diabetes, excess sugar and water are found; and in gout, uric acid is present in abnormal quantity. The interpretation of the urinalysis is always of importance, because the urine rapidly reflects normal changes in the physiological condition as well as abnormal changes; even the nervous tension associated with a medical examination may be evidenced by the presence of glucose in the urine.

The amount of urine excreted depends upon many factors. Under normal conditions, with a given intake of water, the volume of urine varies chiefly with the temperature and moisture of the atmosphere. For instance, when the atmosphere is hot and dry, a relatively large amount of water is released through the skin as perspiration, and relatively less water departs via the kidneys. Accordingly the intake of water must be greater in order to provide for normal removal of the waste products of metabolism through the kidneys. One is likely to think of the kidneys as essentially passive organs that merely drain materials from the blood. But, as a matter of fact, the kidney tissues are active; a milligram of kidney tissue apparently consumes more oxygen per unit of time than the same weight of tissue from a beating heart.

EVOLUTION OF THE KIDNEYS

Aside from their functional importance, the kidneys are of considerable interest to the comparative anatomist because of their complicated

evolutionary history throughout the vertebrate series. Indeed the renal tubules of the vertebrate kidney may be most readily interpreted by comparison with nephridia, the excretory units of the earthworm. (Figs. 72, 125.)

It will be recalled that each of these excretory organs of the earthworm is a coiled tube, or nephridium, segmentally arranged in pairs in the coelom on either side of the alimentary canal. Each nephridium begins as an open funnel in the coelom of one segment, passes through the segmental partition (septum) to the next posterior segment, and there, after coiling, continues to the ventral surface and opens to the exterior by a pore. Reduced to its simplest terms, a nephridium is a tube communicating between the coelom and the outer world, and affording a path of egress for waste materials selected from the coelomic fluid. Also the nephridia of the earthworm remove waste material from the blood as well as from the coelomic fluid, for the blood vascular system carries nitrogenous waste, inorganic salts in solution, etc., to the coiled part of the nephridial tube where special cells absorb these substances from the blood and release them into the interior of the nephridial tube to be passed out of the body.

Although the primitive segmentation of the coelom has disappeared in the vertebrates, nevertheless segmentally arranged nephridia are the basis of the essential excretory elements of the kidneys. In the lowest of the vertebrates the primitive type of kidney, or PRONEPHROS, as it is called, consists of a series of nephridia-like structures in the dorsal part of the anterior end of the coelom. These tubes, however, instead of opening independently to the exterior, discharge their products into a common tube (PRONEPHRIC DUCT) which passes the wastes to the outside. In higher animals the pronephros disappears, and its function is taken over by another series of similar excretory units which appears in the coelom posterior to the pronephros. This series constitutes the

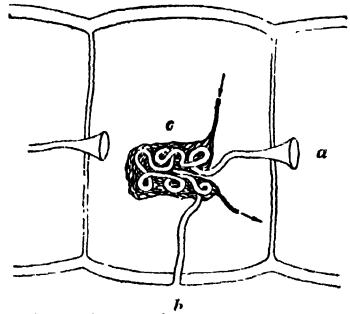


FIG. 125. Diagram to show the general structural plan of a nephridium of an earthworm, anterior end toward the right. *a*, internal opening (nephrostome) of nephridium; *b*, external opening (nephridiopore); *c*, capillary network about the coiled, glandular portion in the coelom.

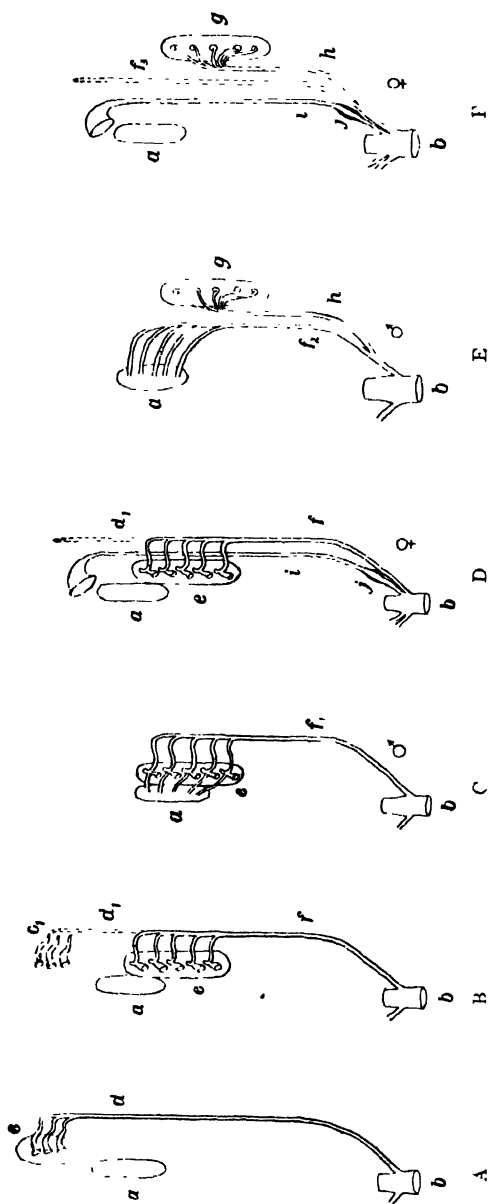


FIG. 126. Diagram of the fundamental plan of the vertebrate urogenital system. A. Pronephric system—primitive and early embryonic type in all vertebrates; functional in the frog tadpole. B. Mesonephric system—embryonic type in all vertebrates, and adult type in the lowest vertebrates (Cyclostomes). C. Mesonephric system and the male (♂) reproductive system in adult fishes and amphibians (frog). D, the same, female (♀). E. Metanephric system, in male, ovary in female; b, cloaca or terminal portion of alimentary canal; c, pronephros; c₁, the same, vestigial; d, pronephric duct; d₁, the same, vestigial; e, mesonephros; f, mesonephric duct (originally posterior portion of pronephric duct); f₁, mesonephric duct acting also as sperm duct; f₂, mesonephric duct acting solely as sperm duct; f₃, mesonephric duct, vestigial; g, metanephros; h, metanephric duct; i, oviduct; j, uterus. See Figs. 98–100.

MESONEPHROS and opens into the pronephric duct, which accordingly is now called the MESONEPHRIC DUCT. Finally, in still higher vertebrates the mesonephros of the embryo is replaced by a third urinary organ, the kidney proper (METANEPHIROS) and its special duct, the ureter. (Fig. 126.)

It is clear then that three distinct kidney systems appear in the vertebrate series, in each case by the development and grouping of nephridia-like elements into a definite organ. In this process the primitive communication of individual nephridia with the body cavity is lost, and the functions of the tubular portion increased, until, in the higher forms, all the waste products are taken directly and solely from the blood. Each of the relatively large, compact kidneys of the higher vertebrates consists essentially of an enormous number of nephridia-like elements, the renal tubules, bound together by connective tissue and covered with a protective coat. The tubules within the kidney deliver the materials taken from the blood—the urine—to the pelvis of the kidney, whence it passes down the ureter into the urinary bladder and finally to the exterior. (Fig. 124.)

Such, in broad outline, is the historical point of view from which the human kidneys are best interpreted. As a matter of fact, however, the evolutionary transformation is still further complicated by anatomical, though not physiological, relations with the reproductive system. As will be indicated later, this closely associated system now and again foists, as it were, some of its accessory responsibilities upon parts of the excretory (urinary) system, and even takes over portions and makes them integral parts of its own system when they have been permanently abandoned by the urinary system during embryonic development.

CHAPTER XIV

Circulation

I finally saw that the blood, forced by the action of the left ventricle into the arteries, was distributed to the body at large, and its several parts, in the same manner as it is sent through the lungs, impelled by the right ventricle into the pulmonary artery, and that it then passed through the veins and along the vena cava, and so round to the left ventricle . . . which motion we may be allowed to call circular.

—Harvey, 1628

The transport of materials to and from the various parts of the organism is obviously a simple problem in the Protozoa and many of the lowest Metazoa, compared with the situation in animals with deeply-hidden tissues, each and every cell of which must be served. A complex body is impossible without a complex circulatory system. The circulatory mechanism in the earthworm and crayfish has been outlined and now attention must be turned to its further development in the vertebrates. (Figs. 73, 76.)

The crucial points of contact between the higher animal and its environment, in so far as the intake of matter and energy is concerned, are the membranes which line the alimentary canal and its derivatives, the gills or lungs. Through the lining of the alimentary canal must pass all the materials which are to be built into integral parts of the organism and the fuel which is to supply the energy for the vital processes, while through the membranes of the gills or lungs must pass the oxygen to release this energy. Only when these membranes have been passed are the materials really within the body and at its disposal for distribution by the circulatory system to the individual cells of the various organs that are to use them.

In addition to carrying the fuel and the oxygen, the circulatory system must remove from the cells the waste products of metabolism and deliver them to the excretory organs, such as the lungs or kidneys, to be passed to the outside world. The circulatory system is therefore

the essential connecting link between the points of intake, utilization, and outgo of materials.

Furthermore, the circulatory system is a coordinating agent of crucial importance because it distributes hormones from the various endocrine glands to the particular tissue or organ where their regulatory influence is to be effected. It is therefore a distributing system that not only maintains a suitable environment for the myriads of cells of the body, but also, in cooperation with the nervous system, unifies the organs into an organism.

Various stages in the development of a circulatory system can be traced in the invertebrates. In some it consists merely of a single cavity or several connected cavities filled with a fluid containing various types of cells, while in others more and more of the spaces, or sinuses, are replaced by definite tubes, or **VESSELS**, for the conduction of the fluid. With the establishment of closed vessels, the contractions of various organs and the movements of the body as a whole can no longer be entirely depended on for the movement of the fluid, and accordingly, in certain regions, there is developed in the walls of the vessels a muscular layer which by rhythmic pulsation forces the fluid along. It will be recalled that in the earthworm there is the coelomic fluid within the body cavity, which is forced about by the movements of the worm and bathes most of the internal organs, and there is also a system of vessels, the vascular system, a part of which contracts rhythmically and distributes the blood to the various tissues. Again, in the crayfish the blood circulates through sinuses and vessels. (Figs. 74, 79.)

In the vertebrates circulation is effected by two systems, the **BLOOD VASCULAR** and the **LYMPHATIC** systems. The blood vascular system consists of vessels that distribute the blood, which is composed of a liquid **PLASMA** in which float various formed bodies, chiefly **RED** and **WHITE CELLS**. The lymphatic system in the lower vertebrates comprises spaces, channels, and vessels, but in the mammals, including man, it is essentially a network of vessels. It is clear that in higher animals the complex closed circulatory system has replaced the predominantly open circulatory system of lower forms. The lymphatics carry **LYMPH**, which consists of a liquid plasma with white cells. The two circulatory systems are closely associated, but since the lymphatic has a relatively passive function, it is the blood vascular system that one ordinarily refers to as the circulatory system. (Figs. 109, 127.)

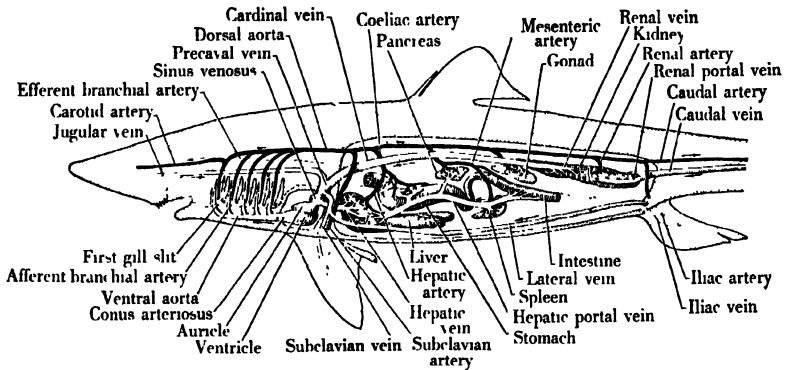


FIG. 127. Diagrammatic lateral view of the vascular system of a shark (dog-fish). Vessels carrying oxygenated blood shown in black; non-oxygenated in white. Arrows indicate direction of blood flow.

The essential elements of the closed vascular system are, first, a muscular organ for propulsion of the blood, the **HEART**, which lies near the mid-ventral line in the anterior part of the coelom; and, second, tubes that convey the blood to the heart, the **VEINS**, and away from the heart, the **ARTERIES**. The arteries divide and subdivide to form smaller and smaller arteries which finally merge into exceedingly delicate tubes, or **CAPILLARIES**, that permeate the tissues of the body. The capillaries, in turn, deliver the blood to tiny **VEINS** which pass it on through larger and larger veins to the heart. Consequently the blood, regulated by **VALVES**, flows in a circle from the heart around to the heart again, through a closed system of vessels. Indeed, in the meshes of a network of blood streams all the life of our bodies goes on. About one-twentieth of the weight of the normal human body is blood.

CIRCULATION IN THE LOWER VERTEBRATES

The heart represents that part of the vascular system in which the power of rhythmic contraction is concentrated, and it can be regarded as a blood vessel whose walls have become highly modified by an extensive development of muscular tissue. In the lowest vertebrates and in embryonic stages of higher forms the heart consists typically of two chief chambers, an **AURICLE** and a **VENTRICLE**, with muscular flaps, the valves, which allow the blood to flow in one direction only, that is, from auricle to ventricle. An enlargement, the **SINUS VENOSUS**, connects the veins (**VENOUS SYSTEM**) with the auricle, and there is frequently

another connection, the CONUS ARTERIOSUS, in a similar position at the arterial end. The heart is thus essentially a linear series of chambers. The sinus venosus and auricle function mainly as reservoirs to fill rapidly the especially muscular ventricle. The ventricle, acting as both a suction and force pump, forces the blood on to the conus arteriosus and from there to the ARTERIAL SYSTEM as a whole. For present purposes, however, the heart in the lowest vertebrates (fishes) may be considered as composed of two chambers, auricle and ventricle. (Figs. 127, 128.)

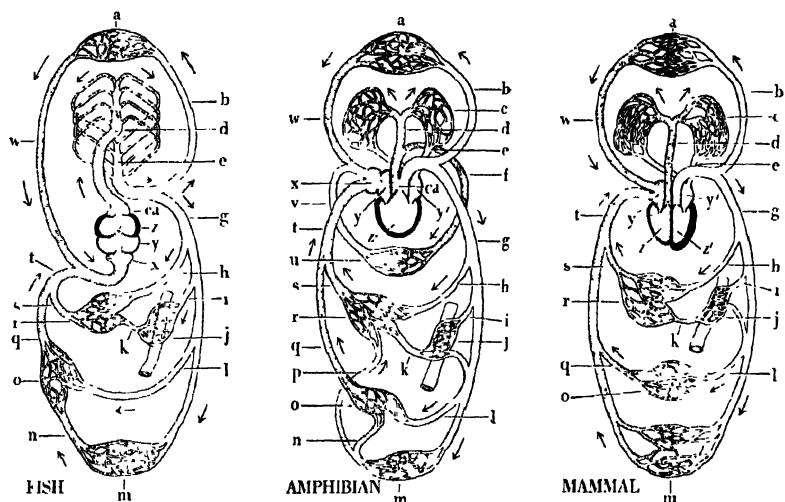


FIG. 128. Plan of the vascular system of a fish, amphibian, and mammal. Oxygenated blood, unshaded; unoxygenated blood, shaded. a, capillaries of head region; b, chief arteries leading to head region; c, capillaries of lungs; ca, conus arteriosus; d (in fish), vessel from heart dividing up into the afferent branchial arteries of gills; d (in amphibian and mammal), pulmonary artery to lungs; e (in fish), artery from gills formed by union of efferent branchial arteries (capillaries of gills, connecting afferent and efferent branchial arteries, not shown); e (in amphibian and mammal), pulmonary vein to left auricle; f, artery from ventricle to skin; g, chief artery (dorsal aorta) to posterior parts of body; h, hepatic artery to liver; i, arterial blood supply to stomach, intestine, etc.; j, capillaries of stomach, intestine, etc.; k, portal vein; l, blood supply to kidneys by renal arteries; m, capillaries of posterior extremities; n, renal portal vein; o, capillaries of the kidneys; p, abdominal vein; q, renal veins; r, capillaries of liver; s, hepatic vein; t, main venous current from posterior parts of body to heart; u, capillaries of skin; v, cutaneous vein; w, return venous current from the head region; x, sinus venosus; y, auricle in fish, right auricle in amphibian and mammal; y', left auricle; z, ventricle in fish and amphibian, right ventricle in mammal; z', left ventricle. Arrows indicate direction of blood flow.

The arterial system is the distributing system of vessels that carries the blood to all regions of the body. Soon after its origin at the heart, the body-circuit in aquatic animals is temporarily interrupted to allow blood to pass through the GILLS and exchange carbon dioxide for a supply of oxygen. To facilitate this gaseous interchange, the arteries (AFFERENT BRANCHIAL) as they enter the membranes about the gill slits break up into smaller and smaller vessels which finally are of microscopic caliber and consist of but a single layer of cells. These capillaries, in turn, merge into larger vessels (EFFERENT BRANCHIAL ARTERIES) which finally lead into the chief artery of the body, the DORSAL AORTA. This extends along the median dorsal line of the body, just below the vertebral column, and sends branches to the various organs. (Fig. 127.)

The branches of the dorsal aorta, on reaching the region which they supply with arterial blood, break up into capillaries similar to those in the gills, so that the blood can deliver essential supplies to the tissues. The blood receives in return various waste products of metabolism, including carbon dioxide and, in certain cases, absorbed food materials from the intestine, and special secretions chiefly from endocrine glands. The fine capillaries lead into veinlets and these into veins of constantly increasing caliber which sooner or later complete the circuit by returning the blood to the heart.

The return current, however, is not quite so simple as would appear from the above statement. Just as all the outgoing stream is interrupted for the respiratory interchange in the gills, so a part of the return current is continuously diverted through the liver. The veins returning blood from the digestive organs merge to form the PORTAL VEIN which proceeds to the liver, where it supplies tiny, irregular blood spaces, or SINUSOIDS, to allow the liver cells to regulate certain of the blood constituents. From the liver the blood passes into the HEPATIC VEIN which conveys it toward the heart. Thus the liver receives blood from two sources: an artery providing blood primarily for the use of the hepatic cells and the portal vein delivering blood, containing a large amount of food material, solely to receive special treatment before being sent back to the heart for distribution all over the body. This special arrangement for a venous blood supply to the liver is known as the HEPATIC PORTAL SYSTEM. (Fig. 129.)

Moreover, in vertebrates lower than the birds, the venous blood from the posterior part of the body makes a detour through the capil-

laries in the kidneys on its way back to the heart. This constitutes what is termed the **RENAL PORTAL SYSTEM**. Therefore in these animals the kidneys as well as the liver receive blood from two sources, an artery and a vein. (Fig. 129.)

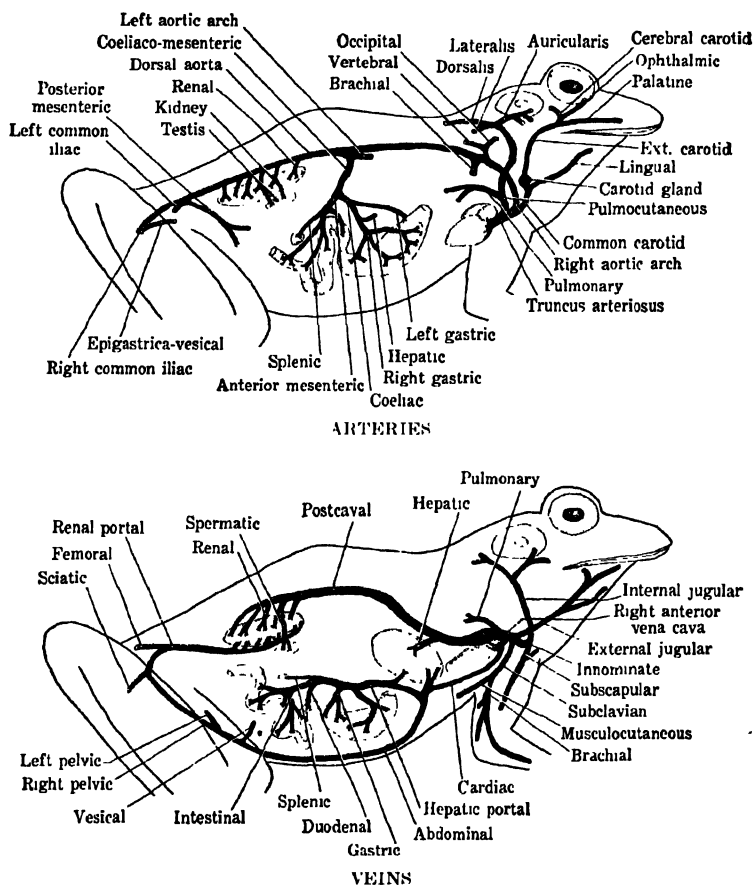


FIG. 129. Diagrams showing the chief vessels of the arterial and venous systems of the frog. (After Hegner.)

Such is the general plan of the blood vascular system of the lower vertebrates. The modifications which occur in higher forms are related chiefly to changes in the respiratory mechanism necessitated by the establishment of a permanent terrestrial mode of life, with consequent

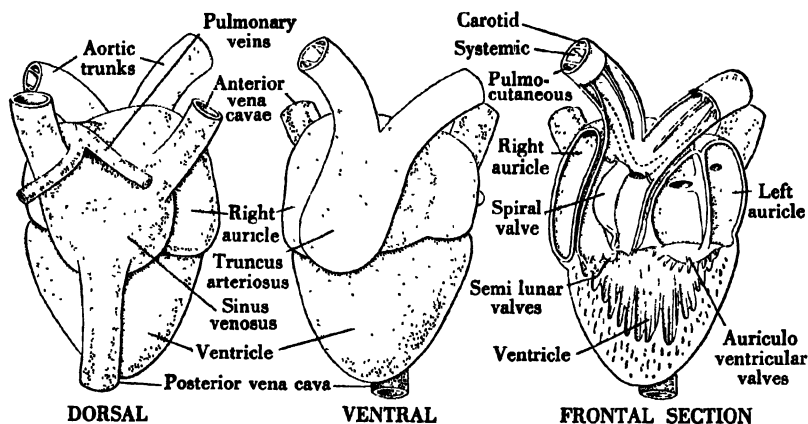


FIG. 130. Diagrams showing various aspects of the frog's heart, external and frontal section. (From Storer.)

dependence on the free oxygen of the atmosphere instead of that dissolved in the water.

CIRCULATION IN THE HIGHER VERTEBRATES

Some of the far-reaching changes that the blood vascular system undergoes as a result of the substitution of lungs for gills may now be noted. In the first place the series of paired branchial arteries, which formerly supplied the gills, no longer break up into capillaries, but instead lead directly into the dorsal aorta, and accordingly are termed

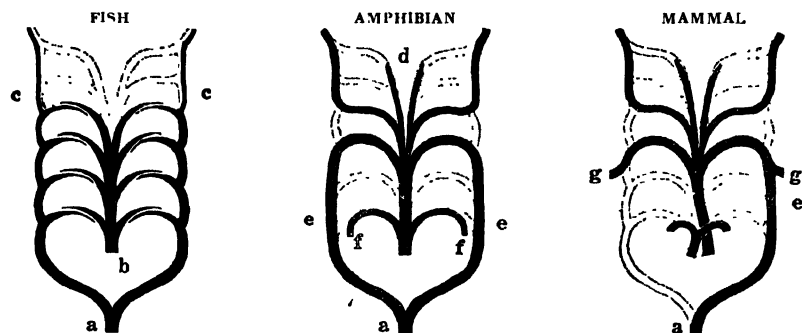


FIG. 131. Diagrams to show some of the transformations of the six pairs of primitive gill arteries (aortic arches). Dotted lines indicate portions of the arches that have disappeared. a, dorsal aorta; b, ventral artery from heart (not shown); c, internal carotids; d, external carotids; e, aortic arch; f, pulmonary arteries; g, subclavian arteries to forelimbs.

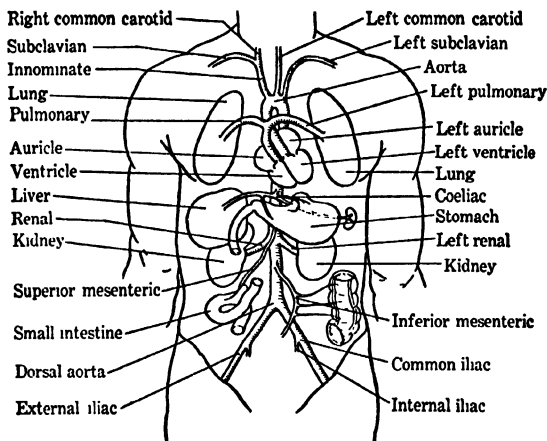
AORTIC ARCHES. Thus fishes bequeath, as it were, to higher animals a series of paired aortic arches which, though they are no longer of use in their former capacity, appear in the developmental stages. Some of the aortic arches disappear at that time and others are modified and diverted to various uses in the adult. (Fig. 131.)

For our purpose it is sufficient to emphasize that in mammals one aortic arch continues to carry blood directly from the heart to the dorsal aorta, while parts of another deliver blood from the heart to the lungs and back again to the heart. Thus there is established a second current of blood through the heart, which necessitates a median partition in both the auricle and ventricle in order to keep the two currents separate.

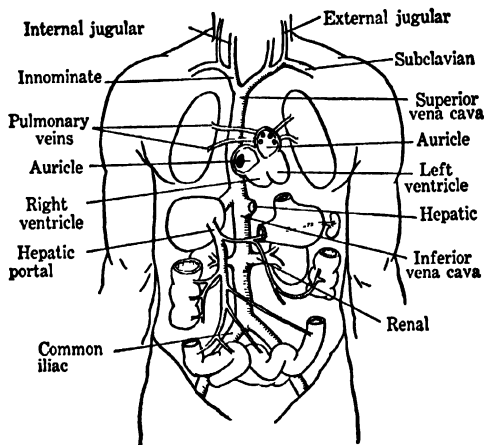
In this way there developed a four-chambered heart consisting of right and left auricles and ventricles. The **RIGHT AURICLE** receives blood from the venous system of the body and passes it through the **TRICUSPID VALVE** into the **RIGHT VENTRICLE** to be pumped through the **PULMONARY ARTERY** to the lungs. After traversing the capillaries of the lungs, the blood is returned by the **PULMONARY VEIN** to the **LEFT AURICLE**, thence through the **MITRAL VALVE** into the **LEFT VENTRICLE** which forces it into the **AORTA** and so on its way about the entire body. To all intents and purposes, the higher vertebrates have two hearts which act in unison: a right, or pulmonary, heart receiving non-aerated blood from the entire body and pumping it to the lungs, and a left, or systemic, heart receiving aerated blood from the lungs and delivering it to the entire body. Thus the blood vessels of the primitive aquatic respiratory apparatus are transformed by gradual additions and subtractions into the **PULMONARY SYSTEM** of the higher vertebrates. (Fig. 132.)

The muscular heart is, in truth, a highly efficient apparatus. Day in and day out throughout life the human heart, beating rhythmically at an average rate of 70 times per minute, does about 300,000 foot-pounds of work. This power is expended in moving the weight of the blood, in imparting to it the velocity of its motion, and in maintaining pressure in the aorta and the pulmonary artery and throughout the vascular system. The **PULSE** is the alternate expansion and contraction of a vessel, in particular an artery, due to changes in blood pressure that result from the heart beat.

The velocity of the blood is greatest when it leaves the heart and gradually diminishes until, in the capillaries of both the pulmonary and



ARTERIES



VEINS

FIG. 132. Diagrams showing the chief vessels of the arterial and venous systems of man. (From Mavor.)

systemic systems, it is reduced to a minimum. On the return trip from the capillaries through the veins to the heart, the velocity gradually increases, though blood re-enters the heart at a much lower velocity than that at which it departed. Of the 23 seconds that it takes a unit of blood to make the complete circuit in man, about two seconds are

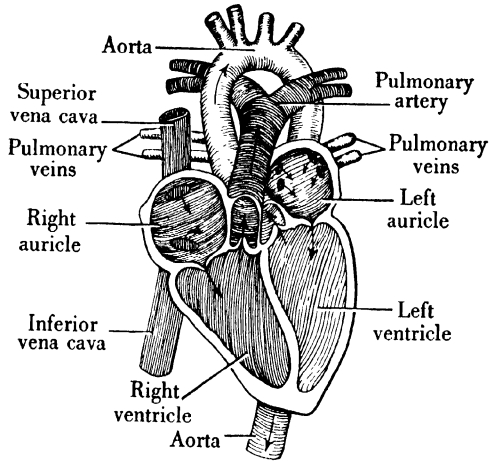


FIG. 133. Diagram showing internal structure of human heart and connecting blood vessels. The direction of blood flow is indicated by arrows.

spent in the capillaries—a relatively long time in view of the fact that the average length of the capillary path is about 0.02 inch. The chief factor underlying the change in velocity is simple. The blood, driven throughout its course by the same force, the heart beat, varies in velocity with the width of the bed through which it is flowing. Although

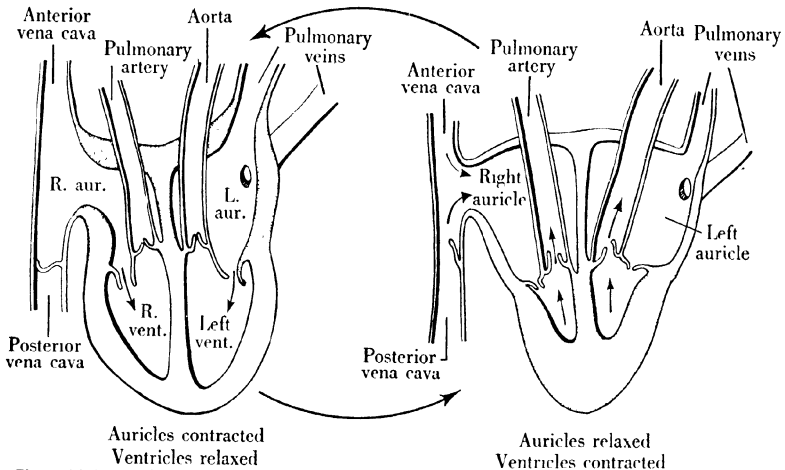


FIG. 134. Diagrams showing internal structure of the four-chambered heart in action. Arrows indicate direction of blood flow. (From Mavor after Adams. Redrawn.)

the area afforded individually by an artery or vein is greater than that provided by any single capillary, nevertheless the total area afforded by the capillary system is enormously greater than that provided by either the arterial or venous system. The total surface of the capillaries of a man has been stated to be about equal to the area of a city block.

Moreover, since a liquid in a closed system of tubes must flow from a region of high pressure to one of low pressure, the blood PRESSURE

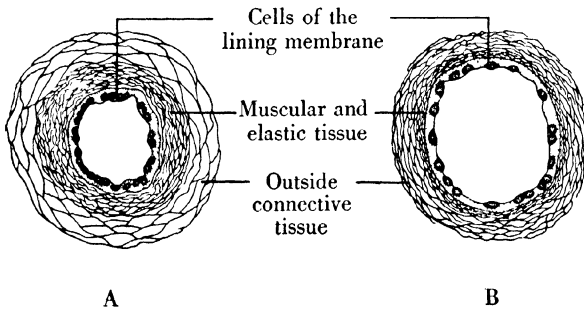


FIG. 135. Transverse section of an artery (a) and vein (B). Diagrammatic. (From Peabody and Hunt.)

continuously diminishes from heart back to heart again. Resistance to flow in the capillaries and other tiny vessels, known as PERIPHERAL RESISTANCE, is due to their small size and the great total area of their internal surface; and this accounts for the fact that pressure of the blood in the arteries is much higher than in the veins. Although the pressure in the capillaries of any region as a whole is less than that in the arteries supplying them, and greater than that in the veins which

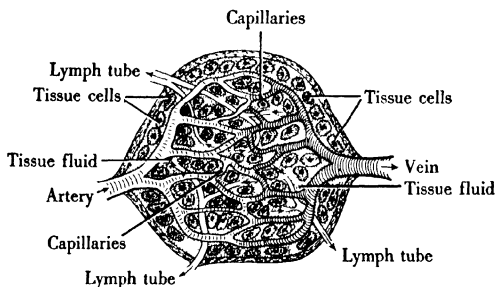


FIG. 136. Diagram of a lymph node, showing the intimate relations between capillaries, lymphatics, and tissue cells.

they supply, nevertheless the pressure in a single capillary is very low, as is demanded by its delicate wall. (Fig. 135.)

In the capillaries the blood moves very slowly under low pressure, and it is here that the blood does its work, which is to contribute to the TISSUE FLUID and interchange materials with it. All the rest of the vascular system—heart, arteries, and veins—is arranged to give the blood this major function in the capillaries. (Fig. 136.)

The tissue fluid is essentially some of the blood plasma that has passed through the walls of the capillaries, carrying along food materials, oxygen, etc., to be exchanged for the various waste products of metabolism of the cells that it bathes. Therefore there is a continuous drainage of fluid from the capillaries into intercellular spaces. Some of this tissue fluid, with waste products, etc., passes immediately into the capillaries again, but the excess passes into small LYMPH VESSELS. The filtration is, of course, from a region of higher to one of lower osmotic pressure with regard to each diffusible substance. (Fig. 137.)

Lymph is essentially excess tissue fluid or blood plasma with many white cells, chiefly LYMPHOCYTES from the lymph glands, etc. It passes through larger and larger lymphatic vessels until it is finally delivered to veins in the region of the neck, and the materials are restored to the blood. The flow of lymph from regions of high pressure in the lymphatics of the tissues to those of lower pressure where they enter the venous system is furthered by various muscular movements of the body. (Fig. 137.)

With such a marvelously complex transportation system, clearly some provision must exist for regulating the blood flow in order to meet the varying local demands of the organs of the body under dif-

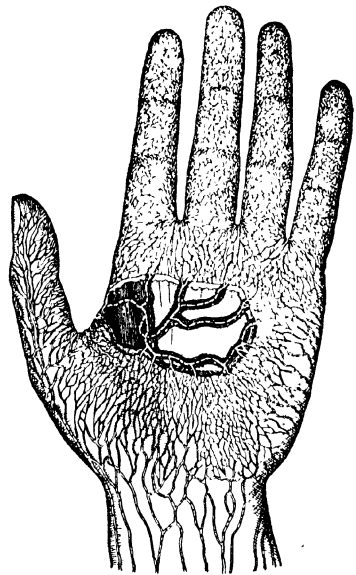


FIG. 137. The superficial lymphatic vessels and also some of the deeper lymphatics of the human hand. (From Hough and Sedgwick)

ferent physiological conditions. This is achieved chiefly by nerve impulses, conducted by a system of **VASOMOTOR NERVES**, which bring about the dilation or contraction of the smaller arteries leading to an organ. Since the total volume of blood in the body is practically constant, an extra supply to one part necessitates a slightly reduced supply for another. For instance, after a hearty meal extra blood is sent to regions where digestion is going on, leaving less for other organs—the reduced supply to the brain probably contributing to the proverbial drowsiness at such times.

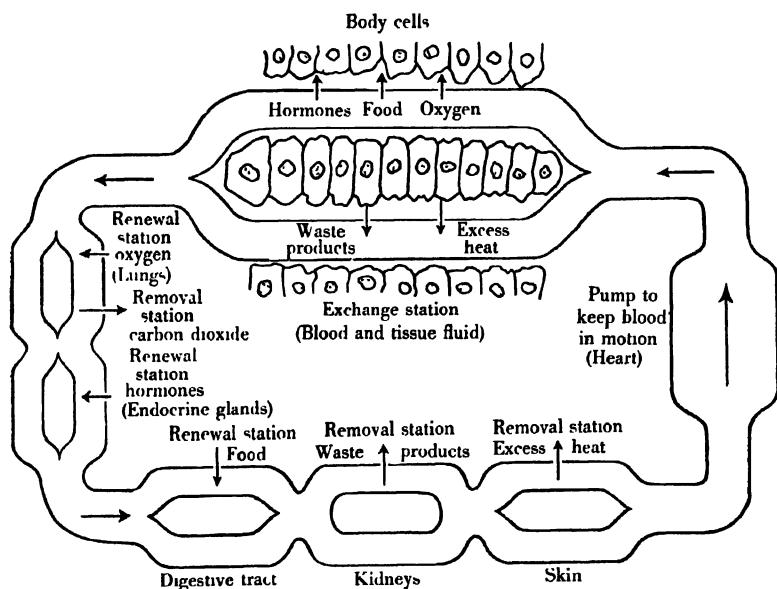


FIG. 138. Diagram illustrating how a suitable environment for the body tissues is maintained by the circulation of blood. (After Martin.)

Of course, the blood itself undergoes continuous changes during its circulation through the body as it receives or delivers food substances, secretions, and excretions. Its supply of red blood cells is replenished from the bone marrow and apparently stabilized, in part, by a vascular organ, the **SPLEEN**, situated in the abdomen behind the stomach. (Fig. 138.)

The elaborate mechanism that maintains a practically constant body temperature in homothermal animals (birds and mammals) is largely

dependent upon heat distribution, heat loss, and heat conservation by the circulatory system. When a man is at rest, a gentle stream of blood flows through the capillaries of his muscles; during violent exercise, however, a great torrent, impelled by increased heart action, delivers food and oxygen and carries away waste products and heat. This superfluous heat is carried by the blood to the lungs and skin for elimination. The skin becomes flushed by the distension of its blood vessels and heat is radiated, aided always by perspiration. In this situation the body is losing heat, but we "feel warm" because the sense organs that make us aware of temperature are situated in the skin. We "feel cold" when blood is withdrawn from the skin to the internal organs and heat is being conserved. This makes clear the paradox that one is likely to "feel warm when catching cold."

So much for the paths and duties of the blood and lymph that circulate through the body. Just enough has been described, perhaps, to emphasize that hand in hand with increase in size and complexity of the animal body there goes an elaboration of the transportation system. Gradually this system has been transformed to meet the new demands made upon it, and so it leaves in higher animals evidence of their origin.

CHAPTER XV

Nervous System

It seems that Nature, after elaborating mechanisms to meet particular vicissitudes, has lumped all other vicissitudes into one and made a means of meeting them all.

—Mathews

The basic need of the animal organism for an instantaneous correlation of diverse parts of its body and also for the adjustment of the whole animal to its surroundings is supplied by the **NERVOUS SYSTEM**, a complicated arrangement of cellular elements in which irritability, conduction, and coordinated control are highly developed. The study of the nervous system constitutes the science of **NEUROLOGY**.

Even in some unicellular organisms certain portions of the protoplasm are especially differentiated for receiving and conducting stimuli, and others for responding to such stimuli by contractions of the whole

cell or parts of it. Indeed, *Paramecium* and other ciliates possess a **NEUROMOTOR SYSTEM** that apparently consists of a coordinating center, or **MOTORIUM**, from which conductile paths extend through the cell to the cilia, etc. But it is in the lower Metazoa, such as hydra and its allies, that one finds the establishment of definite **NERVE CELLS**, some specialized for receiving stimuli and others for conducting the excitation to cells specialized for contracting (muscle cells), etc. Thus a simple **RECEPTOR-EFFECTOR** system arises which may be regarded as the basis for the development of the elaborate **NEUROMUSCULAR MECHANISM** of higher forms. (Figs. 62, 139-141.)

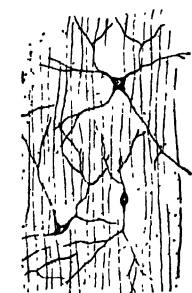


FIG. 139. Branching nerve cells in the epithelium of hydra. The parallel lines represent muscle fibers. Highly magnified. (After Schneider.)

The structural elements of the nervous system in all animals are nerve cells, known as **NEURONS**.

In the lower animals the neurons are associated so as to form NERVE NETS which surround and permeate the tissues that they stimulate to action. (Fig. 139.) In more highly developed animals the net arrangement is relegated to the control of relatively minor functions, whereas the main nervous system consists of numerous neurons arranged in groups, or GANGLIA, and prolongation of the neurons, or NERVE FIBERS,

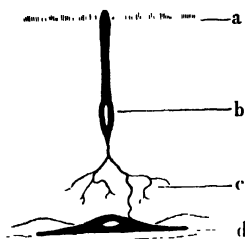


FIG. 140. Diagram of a simple type of receptor-effector system found in some hydra-like animals. It comprises receptors (b), or sense cells, reaching to the body surface (a), with basal nerve net (c) connecting with muscle cells (d). (Slightly modified, after Parker.)

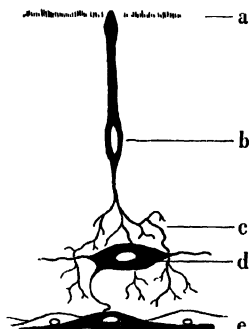


FIG. 141. Diagram of a more complex type of receptor-effector system, found in some hydra-like animals. It comprises, in addition to the receptor (b) with nerve net (c) and the muscle cells (e), another nerve (ganglion) cell (d) interpolated in the nerve net. (a) body surface. (From Parker.)

bound together into cables, the NERVES. The neurons, embedded in protective sheaths of connective tissue in the ganglia, are in physiological continuity, or SYNAPSE, one with another, but each neuron remains structurally distinct. (Figs. 142, 143, 148.)

CENTRAL NERVOUS SYSTEM

It will be recalled that the first great differentiation during the development of a multicellular animal establishes an outer ectoderm and inner endoderm, and thus separates the functions of protection and general reaction to the environment from that of nutrition. It is natural therefore that the ectoderm should have become the seat of those specializations which evolved into the nervous system and sense organs. Such is the case in all forms from the lowest to the highest, so that the

development and comparative anatomy of the nervous system of vertebrates, in particular, afford evidence of the genetic continuity of the whole series.

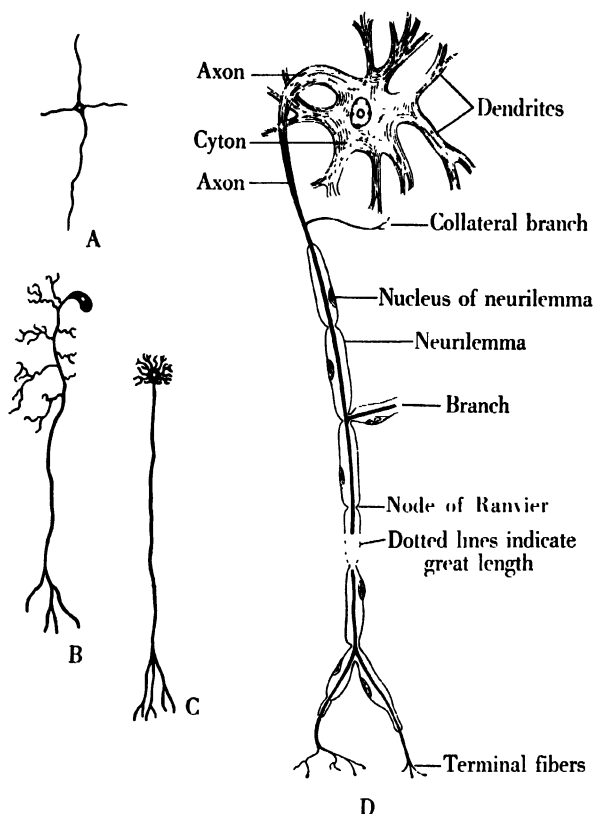


FIG. 142. Neurons. Diagrams showing stages in the differentiation of nerve cells. A, primitive neuron from the nerve net of hydra-like animals; B, motor neuron of the earthworm; C, D, primary motor neurons of a vertebrate. (D from Kimber, Gray and Stackpole.)

In the development of a vertebrate, the first indication of the nervous system is a flattened area, the **NEURAL PLATE**, in the ectoderm along the dorsal surface; this soon becomes converted into a tube by the apposition and, finally, the fusion of its edges. The **NEURAL TUBE** then becomes separated from the surface ectoderm and sinks below it, and in time forms the **CENTRAL NERVOUS SYSTEM** consisting of the **BRAIN**

and SPINAL CORD. As development proceeds, outgrowths from the central nervous system establish the CRANIOSPINAL and the AUTONOMIC systems, so that structurally as well as physiologically the whole nervous system represents a unit—a single organ, as it were, which secondarily becomes closely identified here and there with sense organ, muscle, or gland, as the case may be.

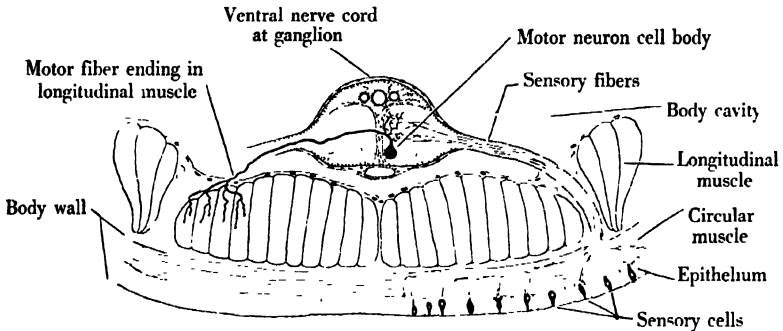


FIG. 143. Diagram of primary sensory and motor neurons of the ventral nerve cord of an earthworm, showing their connections with the skin and the muscles to form a simple reflex arc. Highly magnified. See Fig. 72.

The first marked structural modifications in the developing central nervous system of vertebrates are two constrictions of the enlarged anterior end of the neural tube, which establish the three primary brain vesicles: FOREBRAIN, MIDBRAIN, and HINDBRAIN. Thus very early in embryonic development, the anterior end of the neural tube is molded into the brain, leaving the posterior part to become the spinal cord. (Fig. 144.)

The three-vesicle brain now becomes transformed into a five-vesicle organ by a hollow outpocketing from the anterior end of the forebrain and a dorsal outpocketing from the hindbrain. In the lowest vertebrates the brain throughout life consists essentially of these divisions, known as TELENCEPHALON, DIENCEPHALON, MIDBRAIN, CEREBELLUM, and MEDULLA OBLONGATA, the last merging into the spinal cord. The telencephalon usually gives rise to a pair of CEREBRAL HEMISPHERES which, in higher forms, are destined gradually to overshadow in size and significance all the other parts of the brain. Finally, the development of a pair of OLFACTORY LOBES from the telencephalon—or its

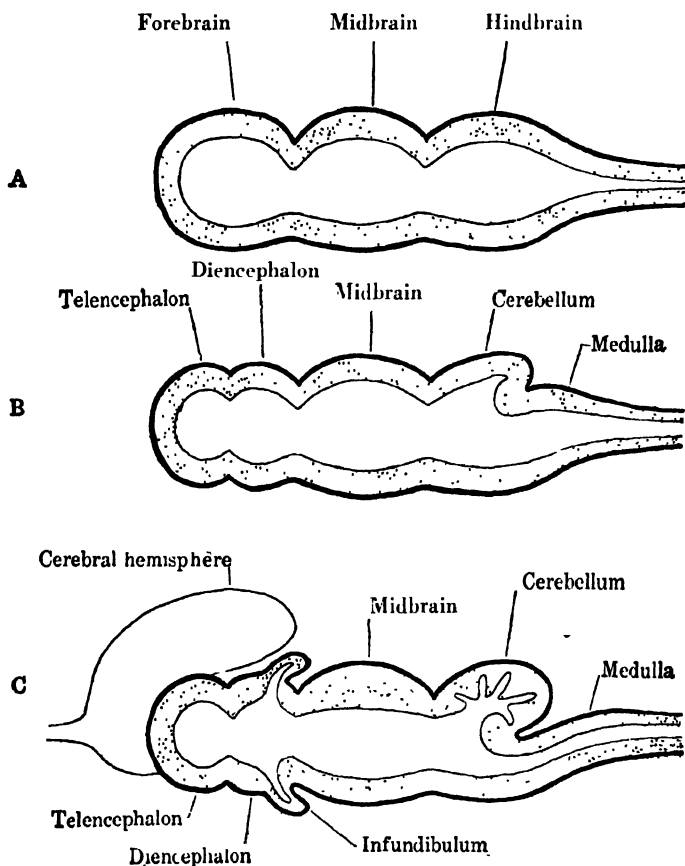


FIG. 144. Diagrams to illustrate the general method of transformation of the anterior end of the vertebrate neural tube to form the highly complex brain. Median vertical sections.

derivatives, the cerebral hemispheres—completes the establishment of the chief brain regions.

The further changes which transform this more or less linear series of vesicles into the increasingly complex and compact brain of higher forms are due to bendings, or **FLEXURES**, and to unequal thickenings and outgrowths of the chamber walls. Thus the upper and lower surfaces of the diencephalon give rise to the **PINEAL BODY** and the **INFUNDIBULUM** respectively, while from similar regions of the midbrain are developed the **OPTIC LOBES** and **CRURA CEREBRI**. Hand in hand with

these changes the primary cavities of the chambers undergo a gradual restriction, but there persists at least a remnant of the original tubular cavity, which is continuous with that of the spinal cord. (Fig. 145.)

The cerebral hemispheres, or **CEREBRUM**, constitute by far the largest

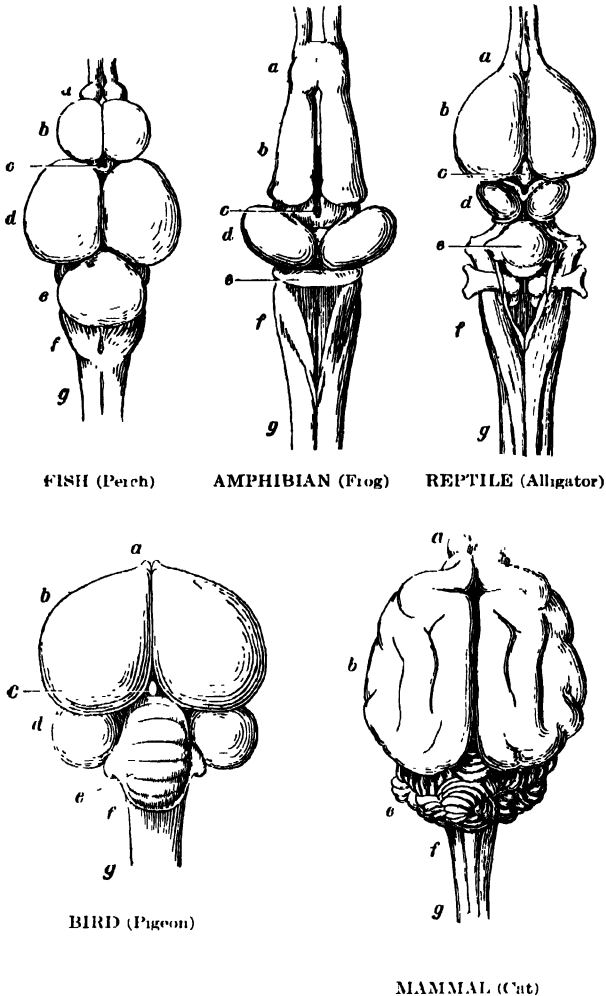


FIG. 145. Diagrams of the dorsal surface of the brain of five vertebrate types to show the relative development of the various regions. *a*, olfactory lobes; *b*, cerebral hemisphere; *c*, pineal body; *d*, optic lobes; *e*, cerebellum; *f*, medulla; *g*, spinal cord.

and most important part of the human brain, for they are the center of perceiving, thinking, voluntary motion, and even consciousness—the seat of the higher mental life in general. These primary activities are performed by neurons, the cell bodies of which are located in the CORTEX, the outer layer of GRAY MATTER, while their nerve fibers extend deeper to form the inner WHITE MATTER. These fibers transmit nerve impulses to and from the cell bodies in the cortex.

Next in importance is the cerebellum which, of course, also consists primarily of neurons. The functions of the cerebellar neurons are subsidiary to those of the cerebrum since initiative resides in the cerebrum, but messages from the cerebral hemispheres are coordinated by the cerebellum on their way to various parts of the body. For example, one may consciously extend an arm, but the various compensating movements of other parts of the body that are necessary to maintain equilibrium are controlled by the cerebellum. Such adjustments are discriminating but not conscious.

In the medulla, nerve fibers are in the ascendancy since all nerve impulses to and from the cerebrum, cerebellum, and spinal cord are transmitted through this region. Large bundles of fibers, CRURA CEREBRI, extend from the medulla to the cerebrum. Nerve cells also are prominent in the medulla: some of them, however, form functional groups, centers of action for regulating the respiratory and circulatory organs, known as the RESPIRATORY CENTER, VASOMOTOR CENTER, etc.

CRANIOSPINAL SYSTEM

The brain and spinal cord are, as we know, protected and isolated by a cartilaginous or bony case formed by the skull and the neural arches of the vertebrae which are embedded in the muscles forming the dorsal part of the body wall. The only paths of nervous communication between the central nervous system and the rest of the organism and its surroundings are the paired series of nerves, the CRANIAL and SPINAL NERVES. These arise at fairly regular intervals from one end of the brain and cord to the other, and leave through openings in the skull and between the vertebrae to constitute the CRANIOSPINAL SYSTEM. (Figs. 146, 147.)

The primitive segmental condition of the vertebrate body is usually considered to be well exhibited in the arrangement of the cranial and spinal nerves, and it is believed that the origin of the cranial nerves from the brain affords a partial index to the primary series of segments

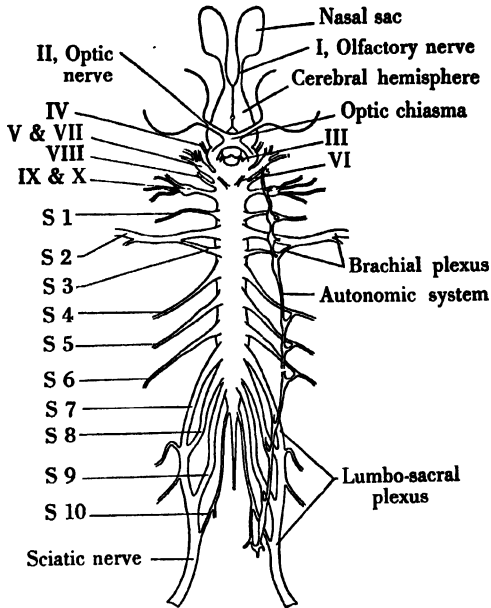


FIG. 146. Diagram showing ventral view of the central nervous system of the frog, showing the origins of the cranial and spinal nerves, and the autonomic system of one side. I-X, the ten cranial nerves; S 1-S 10, the ten spinal nerves. (After Mavor.)

merged to form the vertebrate head. Conditions as they exist at the present time can perhaps be most readily understood by imagining a simple, ancestral, segmented wormlike animal in which the dorsal neural tube gives off a pair of nerves to each segment of the body. As the result of a gradual shifting forward, union, and finally complete fusion of certain segments near the anterior end, there is formed a head region with its brain, battery of sense organs, and skull, more or less distinct from a trunk region with its spinal cord, vertebral column, paired limbs, etc. This **CEPHALIZATION** involves a corresponding shifting and modification of the primitive condition of the paired nerves, especially since the innervation of a group of cells in normal development is apparently rarely changed, a nerve following the part which it originally supplied through many transformations and even migrations.

If this point of view is accepted, the cranial and spinal nerves are, historically considered, homologous structures. But the former, synchro-

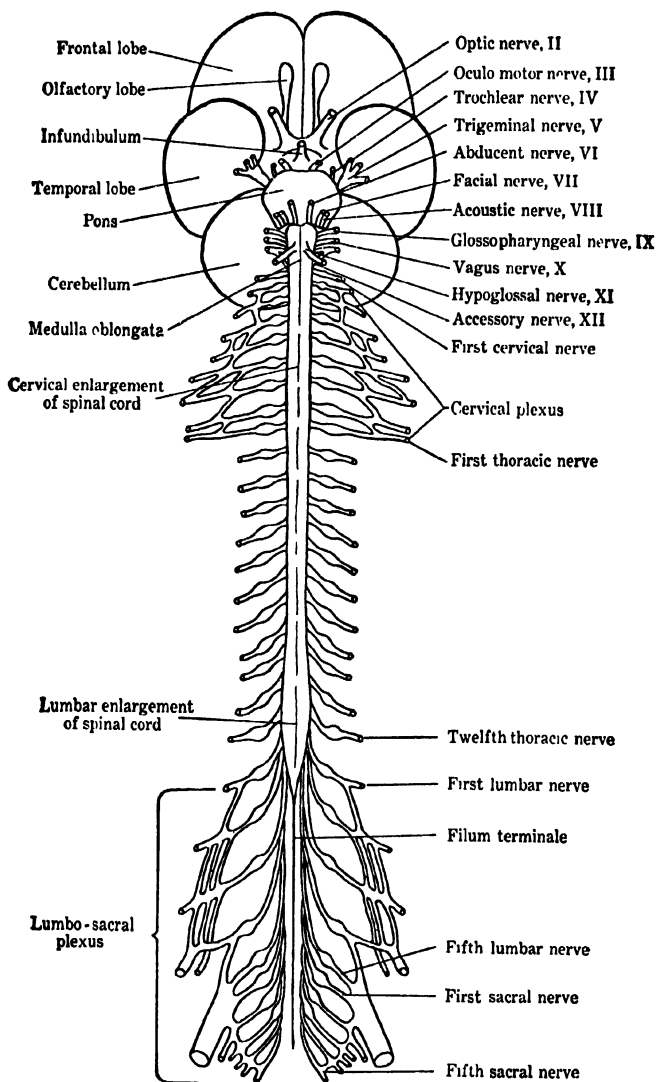


FIG. 147. Ventral view of the central nervous system of man, showing the origins of the cranial and spinal nerves and the nerve plexuses. The term cervical plexus is used to include the cervical plexus proper, composed of the first four cervical nerves, and the brachial plexus which includes the last four cervical nerves and the first thoracic nerve; the term lumbo-sacral plexus is used to include the lumbar plexus, composed of the first four lumbar nerves, and the sacral plexus which includes the fifth lumbar, the sacral, and the coccygeal nerves. The autonomic system is not shown. (From Mavor.)

nously with the changes in the head region, have departed somewhat widely from their ancestral condition and have even been augmented by nerves of diverse origin. The spinal nerves, on the other hand, continue to issue from the cord at about equal intervals and in segmental arrangement as indicated by muscle segments and skeletal structures, although those of certain regions unite in the body cavity to form groups, or PLEXUSES, to afford an adequate nerve supply to the appendages. (Fig. 147.)

From the standpoint of function the nerves are of three classes: SENSORY, MOTOR, and MIXED. Sensory nerves are the paths over which afferent impulses due to stimuli are conducted to the cord and brain, while motor nerves are the paths for efferent impulses from the brain and cord to muscle cells, gland cells, etc. The great majority of nerves are mixed, however, and contain both sensory and motor fibers, thus affording paths for afferent and efferent impulses. (Fig. 148.)

The nature of a nerve impulse has not been determined, although it is clear that both chemical and electrical changes are associated with its conduction through a nerve fiber. The nerve impulse is transmitted across the synapse by means of chemical substances that are liberated from the nerve endings. Thus the nervous system incites specific chemical actions.

It is important to note that a nerve is actually a bundle of nerve fibers, the fibers themselves being prolongations of nerve cells, the cell bodies of which are usually in groups, or ganglia. Moreover, a nerve impulse is not transmitted by a nerve as a whole, but by one component cell process, a nerve fiber, that is, by way of a definite cell path through the nerve. The same is also true in the cord and the brain, which differ from nerves largely in that they comprise more cell processes and also the cell bodies themselves. In other words, the brain and cord comprise the elements of both ganglia and nerves.

A mixed nerve conducts impulses both to and from the central organ because it contains both sensory and motor cell paths, that is, both sensory and motor fibers. The cranial and spinal nerves are primarily mixed nerves, because typically they arise by two roots from the central organ, the DORSAL ROOT containing only sensory (afferent) fibers and the VENTRAL ROOT only motor (efferent) fibers. This condition is preserved by the spinal nerves of higher forms, since each arises by two roots. But some of the cranial nerves, in response to the

profound modifications that have been brought in the head region, are either solely sensory, such as those devoted to the sense of smell, to vision, and to hearing, or only motor, such as the three pairs innervating the muscles that move the eye.

Many nerve impulses set up by sensory stimuli are, in part, shunted directly from sensory to motor nerve paths in the spinal cord itself. One removes his finger from the pinpoint before he is conscious of the prick. These so-called REFLEX ARCS bring about the multitude of REFLEXES which relieve the brain of much unnecessary labor, and are the basis of the behavior of animals. Many reflexes apparently are inher-

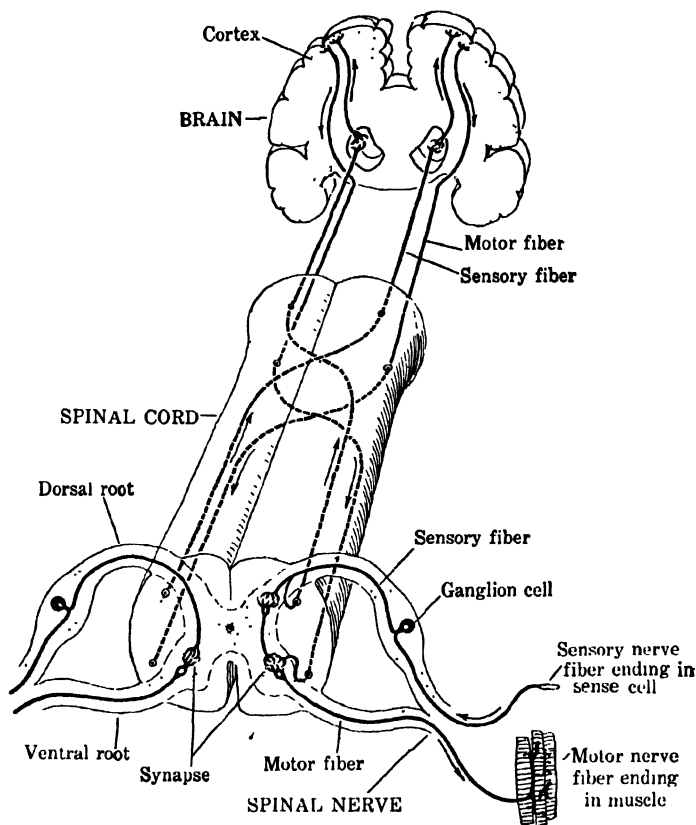


FIG. 148. Diagram of the paths of sensory and motor nerve fibers. A reflex arc from sense cell, via spinal cord, to striated muscle tissue is shown at lower right.

ited, but others, known as **CONDITIONED REFLEXES**, are established as the result of experience. (Fig. 148.)

AUTONOMIC SYSTEM

So far consideration has been given to the central nervous system (the brain and spinal cord) and to its lines of communication with the body as a whole (the cranial and spinal nerves). This **craniospinal system**, however, gives rise to a highly complex auxiliary series of ganglia and nerves through which nerve impulses from the central system regulate practically all of the functions of the body that are not under voluntary control, such as those of the circulatory system and alimentary canal. This auxiliary nervous system, the **AUTONOMIC SYSTEM** in the vertebrates comprises two parts, the **SYMPATHETIC** and the **PARASYMPATHETIC**.

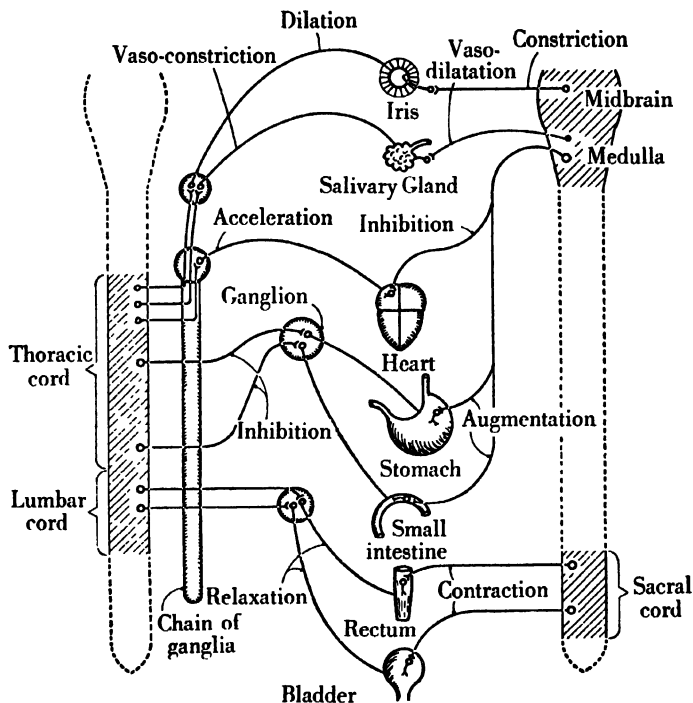


FIG. 149. Autonomic Nervous System. Sympathetic fibers from spinal cord shown at the left. Parasympathetic fibers from brain and sacral region of cord at right. Note that each organ has double innervation—antagonistic in functional reaction. (Carlson and Johnson.)

PATHETIC divisions. In general, these two divisions are mutually antagonistic and exert opposite effects upon the action of an organ. The fibers of the sympathetic division arise from the cord and consist essentially of a double nerve chain and ganglia, situated in the body cavity just ventral to the vertebral column; from here branches arise to innervate the nearby organs. The fibers of the parasympathetic arise from the mid-brain, the hindbrain, and the sacral region of the cord and proceed to ganglia in various organs. (Figs. 149, 149A.)

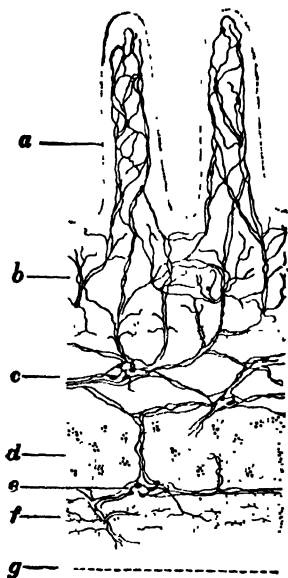


FIG. 149 A. Diagram of section of vertebrate intestinal wall to show its intrinsic nervous organization which brings about the intestinal movement. The two autonomic plexuses consist essentially of simple neurons arranged as nerve nets. *a*, food absorbing surface of the intestine; *b*, mucosa layer; *c*, plexus of neurons (submucosa); *d*, circular muscle; *e*, plexus of neurons (myenteric); *f*, longitudinal muscle; *g*, serous layer. See Fig. 108. (From Parker, after Lewis.)

Such, in essence, is the distribution throughout the body of the nervous system which, although it arises as an infolding of the ectoderm and therefore is primarily external, comes to be internal and so chiefly dependent upon more or less isolated groups of sensory cells for the reception of stimuli. Some of these, termed **EXTERNAL RECEPTORS**, remain at the surface to receive stimuli from the outer world, while others, known as **INTERNAL RECEPTORS**, are situated within the body for the reception of stimuli arising there. The external receptors are what one ordinarily thinks of as sense organs. But whatever the source of the stimulus or the location of the sense organ, all sensations are experienced and interpreted in the brain. This fact is somewhat obscured by our habit of projecting sensations to the part stimulated. "It is in the brain that the poppy is red, that the apple is odorous, that the skylark sings."

SENSE ORGANS

Although among some of the Protozoa certain regions of the cell are specialized so that they are more sensitive to one or another kind of stimulation, the great majority show no trace of sense organs. Nevertheless all forms, in common with all

protoplasm, possess the power of receiving evidence of and responding to environmental changes. Thus amoeba and *Paramecium* react to mechanical, thermal, chemical, and electrical stimulation; the entire surface of the cell is sensitive to stimuli, and the excitations are conducted from one part to another essentially by the protoplasm as a whole, aided in *Paramecium* and its allies by the neuromotor system. (Fig. 62.)

In certain invertebrates, such as hydra and the earthworm, the entire surface of the body is still depended upon as a receiving organ for all kinds of stimuli, and only simple sense cells are developed. In the majority of animals, however, although all the cells, of course, retain their power of irritability, environmental changes exert their influence chiefly upon complex receptors which are specialized to respond to particular forms of energy. The energy of heat or light, for example, is transformed by appropriate mechanisms into the energy of a nerve impulse. The sense organs thus constitute the outposts of the nervous system. (Figs. 150, 151.)

Since knowledge of the outside world is necessarily gained solely through the data afforded by our sense organs, it follows that we judge the capacity of the sense organs of other animals largely by comparing them with our own. This is a safe procedure only in the case of sense organs that more or less correspond in structure to those which we possess. In the crayfish, for example, there are complex sense organs which, without doubt, are eyes, and others which are ears, or at least perform one of the functions of our ears, equilibration; moreover, some of the head appendages are particularly adapted to receive sensations of touch. The senses of smell and taste are probably present also, but here one is on less sure ground. It is, indeed, almost certain that environmental changes which are without effect on the sense organs of the human body, and so have no recog-

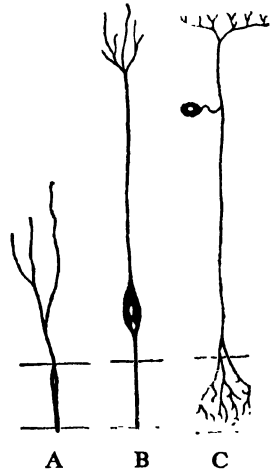


FIG. 150. Diagrams of stages in the differentiation of sensory cells. A, primitive sensory neuron of hydra-like animals; B, sensory neuron of a mollusk; C, primary sensory neuron of a vertebrate. In each case the sensory surface is represented below, and therefore the nerve impulse passes upward. (From Parker.)

nizable function in the experience of man, may stimulate receptors in lower organisms. But human ingenuity has in certain cases devised apparatus to overcome man's limitations: witness the telephone, radar, and television. (Figs. 76, 437.)

The simplest form of sense organ in vertebrates is a single epithelial cell for the reception of stimuli, connected with a nerve fiber for the conduction of the nerve impulse to a sensory center. Usually, however, many associated cells are arranged to respond and are aided by accessory structures for intensifying the stimulus, protection, etc., so that the whole forms a highly complex sense organ.

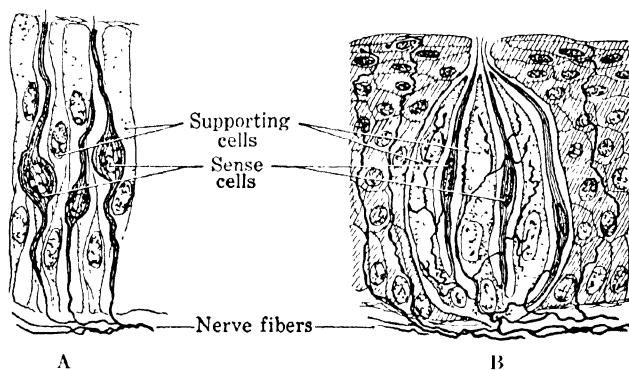


FIG. 151. A, cells of olfactory epithelium from human nose. B, cells of a taste bud in epithelium of tongue. The sensory cells terminate externally in hair-like processes which are activated by the chemical stimuli that produce odor or taste. Diagrammatic.

CUTANEOUS AND INTERNAL SENSES

Among the vertebrates, practically the entire surface of the body is found to constitute a sense organ, because the skin is permeated with a network of sensory nerves. Certain regions are supplied with special PRESSURE RECEPTORS which may take the form of a regular system of sense organs, such as the LATERAL LINE ORGANS of fishes and amphibians, or of groups of TACTILE CORPUSCLES as in man. In addition to pressure receptors, most of the surface of the human body is provided with PAIN, HEAT, and COLD SENSE SPOTS, arranged either singly or in clusters. Thus it has been estimated that there are nearly four million pain spots and about sixteen thousand heat spots.

The tissues within the body, such as the muscles, are also provided with sensory nerves. Muscular sensibility, hunger, and thirst are examples of these internal senses.

SENSE OF TASTE

In the higher vertebrates the sense of taste is restricted to the cavity of the mouth, particularly to the upper surface of the tongue, where receptors, the TASTE BUDS, are in communication with the brain by two of the cranial nerves; but in some fishes similar organs are scattered quite generally over the surface of the body. In man taste sensations are numerous but apparently are the result of combinations of four fundamental sensations—sweet, bitter, acid, and salt—and also sensations of smell. (Fig. 151, *B*.)

SENSE OF SMELL

Special sense organs of smell, the OLFACTORY CELLS, reside in the membrane lining a pair of invaginations at the anterior end of the head, termed OLFACTORY POUCHES. The cells are in communication with the brain by the olfactory nerves, the first pair of cranial nerves. The pouches are relatively simple sacs in the lower vertebrates, but in the air-breathing forms, and especially in the mammals, the walls of the pouches are thrown into folds, ridges, and secondary pouches. This is necessitated by the concentration of the olfactory surface to the air passages in the upper part of the nose which lead through the posterior nares to the pharynx. However, the human olfactory apparatus has been reduced somewhat from the complexity attained in the lower mammals, as is attested not only by its structure in the adult but also by transient remnants in the human embryo. (Fig. 151, *A*.)

THE EAR

The ear, or organ of hearing and equilibration, arises as a depression of the ectoderm of the head. In all vertebrates above the lower fishes, it loses its connection with the exterior and forms the INNER EAR, or LABYRINTH. This becomes divided into two chief parts, the SACCULUS and the UTRICULUS, from which are developed three SEMI-CIRCULAR CANALS, one in each plane of space. The sacculus is largely devoted to the reception of vibrations of the surrounding medium, that is, to hearing in the usual sense of the word. Accordingly the

sacculus becomes progressively differentiated as we ascend the vertebrate scale, a complex derivative in the mammalian ear being the COCHLEA. (Figs. 152, 153.)

The utricle and the semicircular canals provide for sensations of equilibrium, or orientation of the body in space, and show far less change through the vertebrate series. It is probable that equilibrium is the chief function of the entire labyrinth in fishes, as it is of the so-

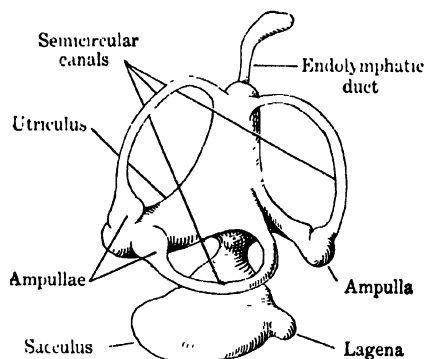


FIG. 152. Diagram of the left membranous labyrinth of a lower vertebrate, showing the saccule, utricle, and the three semicircular canals. The lagena is a derivative of the saccule which becomes the cochlea in higher vertebrates. Sensory cells are located in ampullae.

called auditory organs of many invertebrates, such as the crayfish. With the progressive specialization of the labyrinth, the essential sensory cells, which are in communication with the brain by the eighth cranial (AUDITORY) nerve, become limited to a few definite areas. These sensory cells are provided with auditory hairs which project into the cavity of the labyrinth and so are stimulated by movements of the fluid within it.

The ears of fishes lie immediately below the skull roof where they are readily accessible to vibrations transmitted

by the water. But with the substitution of air for water as the surrounding medium, there arises the necessity of a more delicate method for conducting and also for collecting and augmenting the sound waves. The result is that, in ascending the vertebrate series, we find the ear proper receding farther and farther below the surface.

Between the inner ear and the surface of the head, there is added a simple resonating chamber provided with a vibrating membrane, the TYMPANUM or EARDRUM, situated just under the skin. This arrangement is improved by the development of a bony transmitting mechanism between the tympanic membrane and the inner ear. In forms lower than the mammals, this consists of a single bone, but in mammals two more bones are added by being diverted from their earlier function of articulating the jaws with the skull. These three bones, the

MALLEUS, INCUS, and STAPES, are the smallest in the body. Articulating together as a system of levers, they increase the effective vibratory stroke of sound waves impinging on the eardrum.

Finally, the resonating (tympanic) chamber recedes farther below the surface and becomes the MIDDLE EAR, to which sound waves are conducted through a tubular passage, the OUTER EAR. In some forms,

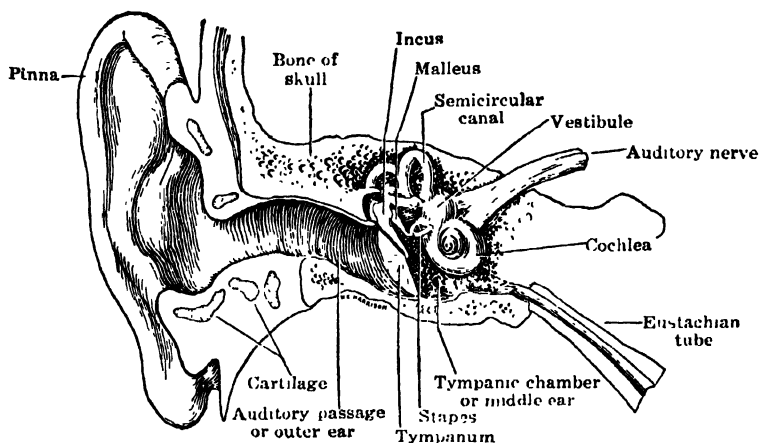


FIG. 153. Front view of a vertical section of the human ear, right side. Note the transmitting mechanism of tympanum (ear drum) and three bones: malleus, incus, and stapes. Somewhat idealized.

including man, the outer ear is provided with an external funnel-like expansion, the PINNA. Apparently much is accomplished by accumulating minute changes during the ages. (Fig. 153.)

THE EYE

The organs of sight are the most complex sense organs of animals and reach a very high degree of specialization even in some of the invertebrates. Among these species the essential sensory tissue (RETINA) of the eye usually arises by the invagination of a limited area of ectoderm, the cells of which become differentiated for receiving the photic stimuli that produce nerve impulses to be transmitted to the central nervous system. Among vertebrates the sensory cells are also of ectodermic origin, but only secondarily so, since the OPTIC VESICLES arise as outpocketings directly from the sides of the dienkephalon. (Fig. 154.)

A retina alone, such as exists in some of the lower invertebrates, can afford no visual sensations other than light and darkness, and perhaps in some cases the ability to distinguish light of one color from that of another. In order that not merely degrees of intensity of light may be perceived, but rather that objects may be seen, many of the higher invertebrates have developed various kinds of complicated apparatus for bringing the rays from a given point in space to a focus at one point on the retina. These culminate, on the one hand, in the compound eye of the arthropods, and on the other, in the "camera"

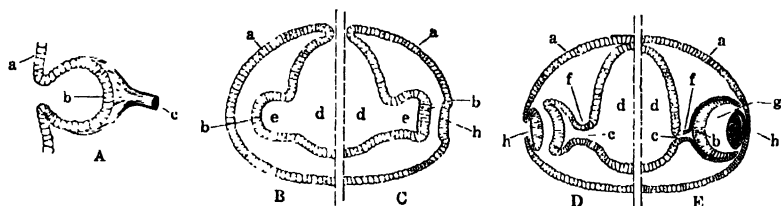


FIG. 154. Diagrams illustrating the method of formation of the eye of an invertebrate (A) and a vertebrate (B, C, D, E—successive stages). Note that the opposite surface of the retinal cells is exposed to the light rays in the vertebrate as compared with the invertebrate eye. a, ectoderm; b, retinal area; c, future position of optic nerve; d, cavity of the diencephalon of brain; e, optic vesicle; f, stalk of optic vesicle, later replaced by the optic nerve; g, vitreous chamber within optic cup; h, developing lens.

eye of certain mollusks such as the squid. In the latter case the mechanism is very much like that found in the vertebrates; but since it occurs in mollusks, which cannot be considered in the direct evolutionary line of the vertebrates, it affords an example of similar responses of different organisms to similar needs, resulting in *analogous* structures. (Figs. 155, 425.)

The wall of the vertebrate eye, or **EYEBALL**, is a more or less hollow sphere which can be rotated by six relatively large muscles. The anterior exposed part of the eyeball consists of two transparent layers: the delicate **CONJUNCTIVA**, continuous with the inner lining of the eyelid, and the rigid **CORNEA** beneath. The sides and posterior part are also composed of two layers: the outer **SCLEROTIC** coat and the inner **CHOROID** coat. Suspended within the eyeball is the **LENS**, which divides the cavity into two chief parts; the area posterior to the lens, known as the **VITREOUS CHAMBER**, is partly lined by the retina, whose nerve cells supply the nerve fibers forming the **OPTIC NERVE** (second cranial).

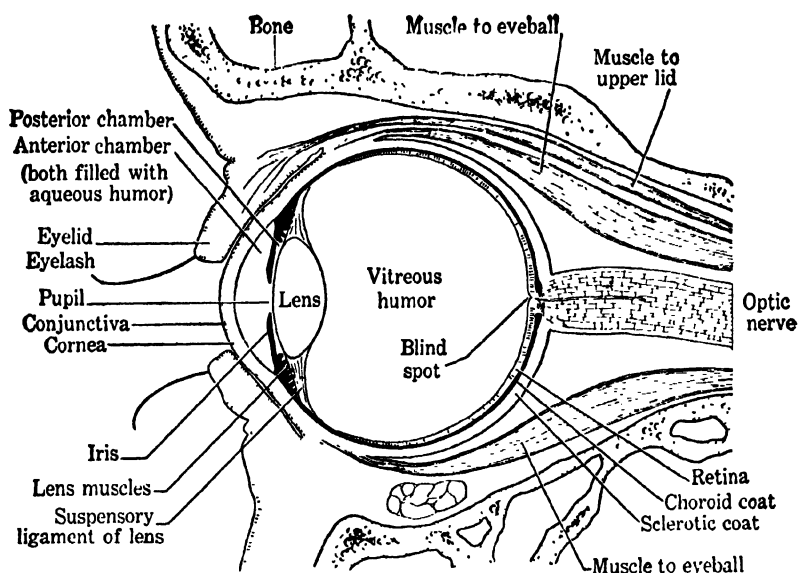


FIG. 155. Vertical section of the human eye and associated structures. Diagrammatic.

The vertebrate eye is an optical apparatus that may be compared roughly with a camera, but a camera is focused by altering the distance between the lens and the film, whereas the eye of most vertebrates, except the fishes, is focused by changing the curvature of the lens. This accommodation of the eye for near and distant objects is made possible by the elasticity of the lens and by the tension exerted on it by the elastic choroid coat and the CILIARY MUSCLES. (Fig. 156.)

Light waves passing through the conjunctiva, cornea, and an opening (PUPIL) in a regulating diaphragm (IRIS) traverse the lens and are focused on the retina. The retina typically contains two kinds of sensory cells, or light receptors, the RODS and CONES. The rods are concerned with vision in dim light, and are especially sensitive to the perception of movement, whereas the cones subserve vision in relatively bright light and also color vision. Some nocturnal animals, such as rats and bats, have retinas with only rods, and many strictly diurnal animals, such as certain reptiles, have pure cone retinas. In the human retina there are about 130 million rods and about seven million cones, the cones being concentrated in the center of the retina, where vision is most acute.

Both rods and cones transmit their excitation through the optic nerve, whence it is relayed to the cerebral cortex of the brain. The brain itself interprets the nerve impulses and composes ("sees") the picture. How this is done is not known. (Fig. 157.)

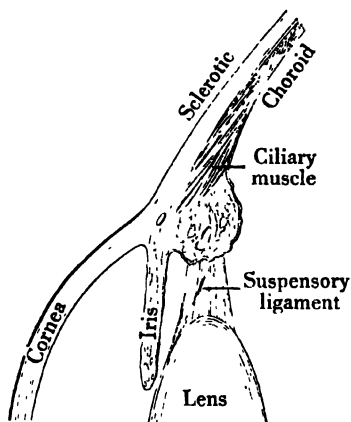


FIG. 156. Diagram of a vertical section through the ciliary region of the eye, showing the structures concerned in accommodation. When the ciliary muscles contract, tension on the lens is relaxed and it assumes a more spherical shape, is thereby strengthened for close vision. (From Hough and Sedgwick.)

It is not strange that such an elaborate apparatus as the human eye should rarely, if ever, be perfect. Structural and functional variations from the norm are of several types, any one of which may be present, and often there is a combination of two or more such deviations. A common visual defect is *MYOPIA* (nearsightedness), a condition in which the rays from distant objects are brought to a focus *in front of* the retina so that the image *on* the retina is blurred, and only relatively near objects can be sharply focused. *HYPEROPIA* (farsightedness) is the opposite condition, in which light rays are brought to a focus *behind* the retina, so that in this case, too, vision is blurred. *ASTIGMATISM* is a defect in which the surface of the cornea is curved un-

equally in different meridians so that light rays in various meridians are refracted in different amounts and therefore cannot all be focused on the plane of the retina. With advancing years *PRESBYOPIA* often makes a gradual appearance, when the lens becomes sufficiently inflexible so that it no longer responds adequately to the ciliary muscle and cannot bring near objects to a focus on the retina.

Imperfections also occur in the structure of the muscles which hold the eye in its socket and control its movements. Frequently there is a difference in length or strength in one or more pairs of the muscles so that the eyes turn inward, outward, or one above the other. Since binocular vision is possible only when the images in the two eyes fall on corresponding points of the two retinas, strain is placed on the muscles in an instinctive effort to align the eyes properly.

A broad survey of the sense organs of vertebrates from the lowest to the highest impresses one with the fact that, taken by and large, the improvements, though considerable, are not so marked as might be expected in view of the great development of the nervous system, particularly the brain. The brain increases enormously in volume and

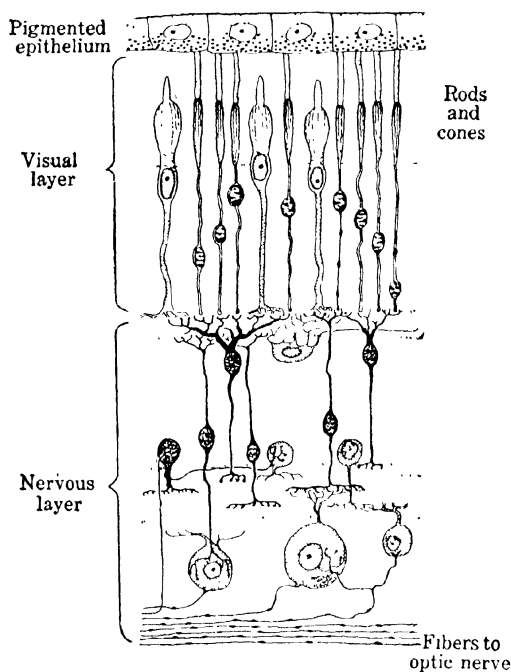


FIG. 157. Diagram of a vertical section of the vertebrate retina (human). The pigmented epithelium is the retinal layer farthest from the vitreous chamber, and in contact with the choroid coat. Light rays pass through the nervous layer to the visual layer. The resulting visual stimuli retrace the route, and pass over the connecting fibers to the optic nerve.

complexity from fish to man. In many fishes it seems to be little more than a slight modification of the anterior end of the spinal cord; and in the frog the brain and cord weigh about the same. But the human brain weighs about three pounds, nearly fifty times as much as the cord, and comprises many billions of nerve cells. However, it reveals no structure that is not present in the gorilla or chimpanzee; rather it exhibits merely, so to say, greater size with proportionately larger

cerebral hemispheres, which contribute more than four-fifths of its total weight. It seems that the *anatomical* basis of the difference in mental power between man and ape consists essentially in the presence of a larger number of neurons in the human cerebral cortex, making possible a far more detailed registration and more intricate integration of nerve impulses.

Apparently one must look to the general influence of the sensory stimuli themselves for the underlying factors in the development of the brain during its evolutionary history—the brain, in turn, being enabled to make more out of the same stimuli and so create in man the higher mental life which he enjoys. It is, perhaps, an appalling thought that all human mental states are represented by the few thimblefuls of cells constituting the cerebral cortex.

THE ORGANISM AS A WHOLE

On the basis of the synoptic view just taken of the methods of correlation in the animal body, certain principles may now be emphasized.

In the first place it is evident that an organism as a whole is greater than the sum of its parts. The body is functionally a unit. Furthermore, this unit is adaptable: it is plastic within considerable limits. Removal of any part changes to some extent the behavior of other parts and so of the whole. Removal of one portion of the nervous system, for example, affects other parts of this system and also induces changes in other organs dependent upon the nervous system for their normal functioning. Again, the various endocrine glands are largely interdependent so that any alteration in the activities of one gland may alter the activities of others. And, of course, the endocrinal and the nervous systems mutually influence each other. (Fig. 118.)

Another aspect of the coordination problem is exemplified by various so-called COMPENSATORY MECHANISMS. For instance, compensation for the removal of part of an organ may be met in several ways: by regeneration of the remnant or by increased activity of the remaining part of an organ so that normal equilibrium is restored, as when one kidney is removed and the other assumes its functions; or by some other organ taking upon itself the function of the lost organ, as when the stomach is removed and the remainder of the alimentary canal takes over many of its functions.

All these examples of regulatory phenomena involving compensation are correlated with the general maintenance of a so-called steady

state, or HOMEOSTASIS, in the body. The internal environment is maintained in a relatively constant condition by a complex series of mechanisms such as those for preventing marked changes in the volume or composition of the blood, in the temperature of the body, in the normal sugar and salt content of the blood, and so on. Probably in every case both nervous and endocrinal influences are involved. These regulatory mechanisms provide a FACTOR OF SAFETY because, for instance, a considerable part of the pancreas or of the lungs may be removed with little apparent change in the ability of the body to carry out its functions. Truly, as the Psalmist says, man is "fearfully and wonderfully made."

CHAPTER XVI

Reproduction and Cell Division

Owing to the imperfection of language the offspring is termed a new animal, but is in truth a branch or elongation of the parent.

—*Erasmus Darwin*

Since so far as is known all life arises from pre-existing life and has done so since matter first assumed the living state, it apparently follows that the stream of life is continuous from the remote geological past to the present and that all organisms living today have an ancient pedigree. It is to the establishment of this statement, as the reasonable conclusion from the data accumulated during many years, that from now on our attention is somewhat more particularly directed. It is necessary first of all to consider in some detail the relation of parent to offspring as exhibited by reproduction in present-day forms.

CELL DIVISION

The power of producing new individuals specifically similar to the parent is, as has been seen, one of the more important characteristics of living organisms in contrast with lifeless matter. Furthermore, it has been observed that reproduction is based on cell division. This is quite evident in unicellular plants and animals, but by no means so obvious in higher organisms where, as we know, special gonads and highly complex accessory organs are developed to serve the reproductive function.

It is now in order to describe in some detail the complicated internal processes involved in each typical cell division, known as MITOSIS. This subject was deferred, when considering the multicellular organism, since the reader was not in a position to appreciate the full significance of this amazing behavior. (Fig. 158.)

Reduced to its simplest terms, a typical resting cell, that is one which is not undergoing division, consists of a mass of CYTOPLASM surround-

MALLEUS, INCUS, and STAPES, are the smallest in the body. Articulating together as a system of levers, they increase the effective vibratory stroke of sound waves impinging on the eardrum.

Finally, the resonating (tympanic) chamber recedes farther below the surface and becomes the MIDDLE EAR, to which sound waves are conducted through a tubular passage, the OUTER EAR. In some forms,

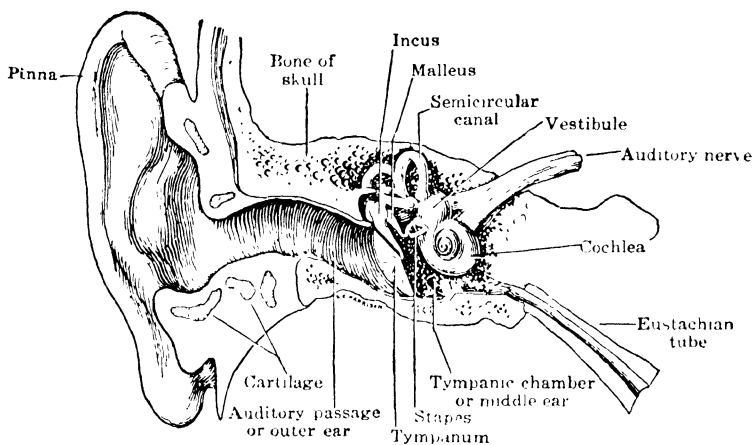


FIG. 153. Front view of a vertical section of the human ear, right side. Note the transmitting mechanism of tympanum (ear drum) and three bones: malleus, incus, and stapes. Somewhat idealized.

including man, the outer ear is provided with an external funnel-like expansion, the PINNA. Apparently much is accomplished by accumulating minute changes during the ages. (Fig. 153.)

THE EYE

The organs of sight are the most complex sense organs of animals and reach a very high degree of specialization even in some of the invertebrates. Among these species the essential sensory tissue (RETINA) of the eye usually arises by the invagination of a limited area of ectoderm, the cells of which become differentiated for receiving the photic stimuli that produce nerve impulses to be transmitted to the central nervous system. Among vertebrates the sensory cells are also of ectodermic origin, but only secondarily so, since the OPTIC VESICLES arise as outpocketings directly from the sides of the dien-cephalon. (Fig. 154.)

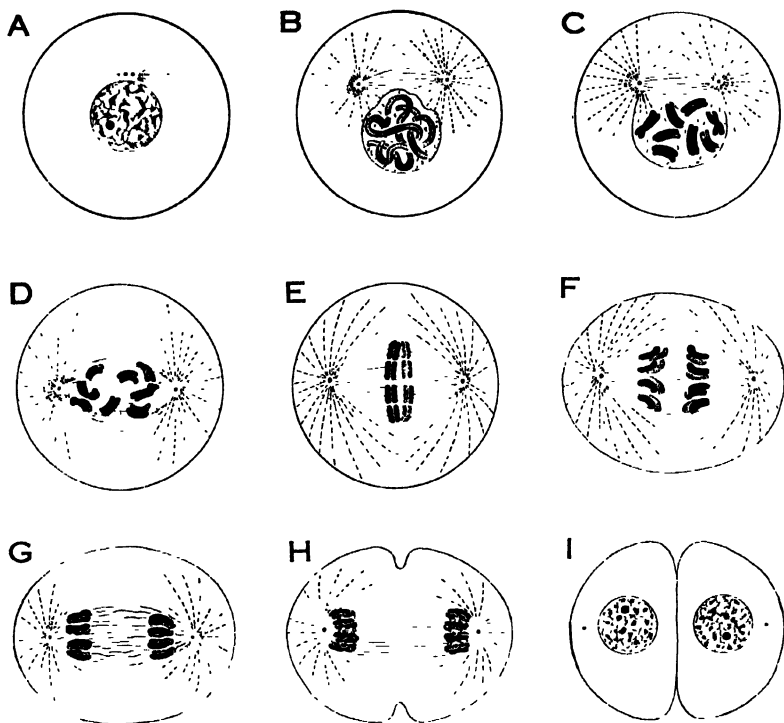


FIG. 159. Typical stages of mitosis in the body cells (somatic) in which the chromosome number is assumed to be eight. A, prophase (start): chromatin still exhibiting net-like appearance, centrosome divided and surrounded by aster; B, prophase (early): chromosomes visible as long split threads of chromatin, centrosomes moving apart and spindle arising between; C and D, prophases (later): nuclear membrane disappearing, chromosomes shorter and thicker; E and F, metaphase and anaphase (early): chromosomes arranged in equatorial plate and each separating into two along the longitudinal split; G, anaphase (later): a set of eight chromosomes approaching each aster; H, telophase: gradual loss of visibility of distinct chromosomes, asters and spindle disappearing, division of cytoplasm beginning; I, mitosis completed, two cells.

At the beginning of the **PROPHASE**, or earlier, the centrosome divides to form two bodies, and each becomes surrounded by what appears to be a halo (**ASTER**) of radiating fibers. The centrosomes and asters now proceed to move apart, take up positions at opposite sides of the nucleus, and, as the nuclear membrane disappears, there arises between them the **CENTRAL SPINDLE** which is composed of fibers in direct relation to the chromatin elements of the nucleus. While these changes

are going on, the chromatin is not inactive. The chromatin, originally appearing as a meshwork of long tangled threads, now becomes visibly resolved into a number of split threads of chromatin, termed **CHROMOSOMES**, which by concentrating and coiling gradually become shorter and thicker and so distinctly individual. The number of chromosomes varies greatly in different species, but is typically an even number and the same for all the cells of a given species.

When the chromosomes have assumed a visibly definite form, the preliminary events which constitute the prophase of mitosis merge into those of the **METAPHASE**. The chromosomes become arranged in a plane at right angles to the long axis of the central spindle, midway between the two centrosomes, to form the **EQUATORIAL PLATE**. (Fig. 159, *A-E*.)

And now the stage is set for what is apparently the climax of mitosis, designated the **ANAPHASE**. Each of the chromosomes separates into two parts, along the line of the longitudinal split already evident, in such a manner that each of the thousands of chromatin granules which make up a chromosome is equally divided. Two sets of similar daughter chromosomes are thus formed, and then one set moves to each end of the spindle. In this way each centrosome becomes associated with one set of daughter chromosomes. (Fig. 159, *F-G*.)

The last stage, or **TELOPHASE**, is one of nuclear reconstruction and division of the cytoplasm. The chromosomes become indistinct as they elongate to form the tangled meshwork of the chromatin in the nucleus of each daughter cell; a nuclear membrane arises, and the nucleus again assumes the form of a definite spherical body characteristic of the resting cell. It must be emphasized, however, that although the chromosomes usually disappear from view as definitive entities in the resting nucleus, nevertheless the individuality of each persists and the same chromosomes emerge from the nuclear complex at the next division period. (Fig. 159, *H-I*.)

Simultaneously with these nuclear changes, and before the spindle and asters—the machinery of mitosis—disappear, the division of the cytoplasm is initiated as indicated by an indentation of the cell wall, encircling the cell at the equator. This becomes deeper as it gradually extends through the cytoplasm in the same plane which the equatorial plate formerly occupied, until the cytoplasm is cut into two separate masses, each containing one of the daughter nuclei and centrosomes. In this way one cell has merged its individuality into two daughter cells

by mitotic division. Cell division—reproduction—has occurred, but the underlying physicochemical processes involved are unknown.

What is the main thought that one carries away from this brief view of a phenomenon that is going on in various cells of our own bodies continuously? Surely it is clear that whereas the mitotic process results in essentially a general division of the cytoplasm, the chromatin material is rearranged and distributed in a manner which makes it possible for each cell to receive a very definite share. Each daughter cell receives the same number of chromosomes, although in many cases there may be a great difference in the size of the resulting cells. Exactness of chromatin distribution appears to be the primary object of mitosis.

The significance of the nicety of chromatin distribution lies in the fact that not only are the various chromosomes qualitatively different but also each chromosome is qualitatively different from one end to the other. In each chromosome are longitudinally arranged threads with granules, or CHROMOMERES, distributed along them. This linear differentiation represents the sequence of GENES, the determiners of characters which are transferred from cell to cell. And since cell division is reproduction, the chromosomes are the chief agents in the transmission of characters from parent to offspring in inheritance. We shall consider these important problems in the later discussion of heredity.

METHODS OF REPRODUCTION

It will be recalled that in *Protococcus* and amoeba, for example, the nucleus and cytoplasm divide into two parts, so that by cell division, here called BINARY FISSION, the identity of the parent organism is merged into the two new cells. Simple as this seems, fission actually involves considerably more than the halving of the original cell, because each half must *reorganize* into a complete new individual with all parts characteristic of the parent. This is more obvious in some of the highly specialized Protozoa, such as *Paramecium* and *Euplotes*. (Figs. 10, 160.)

Among some unicellular plants and animals, notably in the group of Protozoa known as the Sporozoa, the parent cell, instead of merely forming two cells by binary fission, becomes resolved into many cells by a series of practically simultaneous divisions known as MULTIPLE FISSION, or SPORULATION. This is usually preceded by growth of the parent cell and its enclosure in a protective covering, or CYST, which

ruptures to liberate the spores. Other unicellular forms, such as the yeasts—colorless plants chiefly responsible for alcoholic fermentation—exhibit a modified type of fission in which the parent cell develops one or several outgrowths, or BUDS, that gradually assume the characteristic adult form and sooner or later become detached as complete similar individuals. (Figs. 283, 314.)

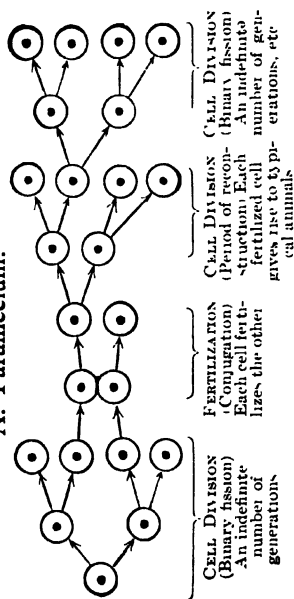
In a considerable number of instances, however, the cells arising by multiple fission or budding remain closely associated or organically connected so that they form a COLONY. In some colonial organisms the component cells are all alike and each retains its individuality, while in others certain cells are more or less restricted in their functions, so that a physiological division of labor is established which involves the shifting of individuality from the cells to the colony as a whole. This specialization is exhibited chiefly with regard to reproduction and reaches its highest expression among colonial PROTISTA (Protozoa and Protophyta) as in *Volvox*, where among about ten thousand cells, a relatively few are specialized for reproduction and the rest are somatic. Some of the reproductive cells (germ cells) divide to form a group which is set free as a miniature colony, but in certain cases some germ cells become transformed into male gametes and others into female gametes. After fertilization of the eggs, usually by sperm from another colony, the zygotes develop into new colonies which eventually are liberated from the parent colony. (Figs. 8, 9.)

As has been previously suggested, the physiological division of labor in the colonial Protista, involving, as it does, a segregation of reproductive from somatic structures, affords a logical transition from the unicellular condition to that characteristic of the multicellular forms. From one point of view these may be considered highly complex colonies of cells in which specialization, no longer confined merely to demarking germinal and somatic regions, has transformed the latter into a complex of tissues and organs, the body (SOMA) of the indi-

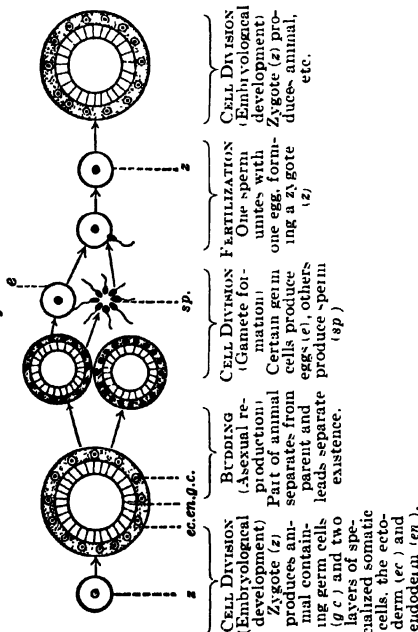


FIG. 160. Division of a highly specialized ciliate, *Euplotes harpa*. The daughter cells are about to separate. Highly magnified. (From Wallengren.)

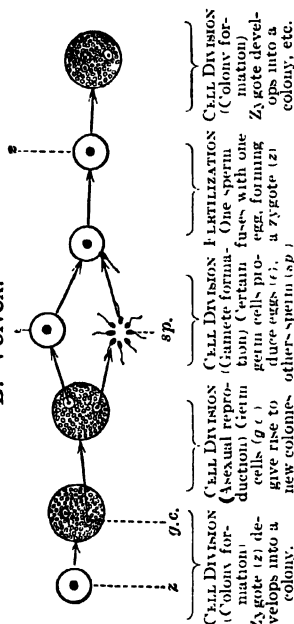
A. Paramecium.



C. Hydra.



B. Volvox.



D. Earthworm.

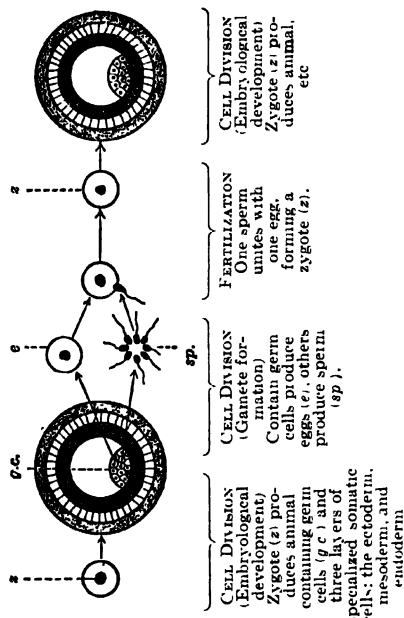


Fig. 161. Diagrams to illustrate the general reproductive cell cycle in A, a unicellular organism (*Paramecium*); B, a colony of cells (*Volvox*); C, a simple metazoan (*Hydra*); and D, a more complex metazoan (*Earthworm*). (Modified, from Hegner.)

vidual, whereas the germinal tissue (GERM) is confined to the essential reproductive organs.

It is customary, therefore, to draw a more or less sharp distinction between the soma and germ, and to consider the soma to be the individual which harbors, as it were, the germ destined to continue the race. This theory of GERMINAL CONTINUITY, chiefly associated with the name of Weismann, recognizes that the germ contains living material which has come down in unbroken continuity ever since the origin of life and which is destined to persist in some form as long as life itself. On the contrary, the soma may be said to arise anew in each generation as a derivative or offshoot of the germ, and, after serving for a while as the vehicle of the germ, to pass the germ on at reproduction, and then die. "A hen is only an egg's way of making

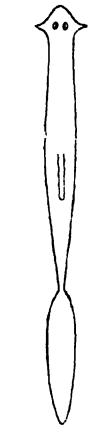


FIG. 163.
Diagram showing a flatworm, *Planaria*, in the process of fission. (From Child.)

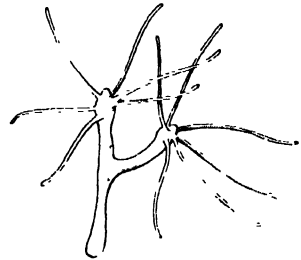


FIG. 162. Hydra reproducing asexually by fission. (From Koelitz.)

another egg." The germinal continuity concept has altered the attitude of biologists toward certain fundamental questions in heredity and evolution, as will be apparent when these subjects have been considered. (Figs. 161, 169, 227, 510.)

Though Volvox and other colonial forms afford a glimpse of the conditions which probably prevailed when the evolutionary bridge from unicellular to multicellular organisms was crossed, the varied methods of reproduction of the multicellular forms by no means indicate the early establishment of a hard and fast boundary between soma and germ. The conception of special germ cells early set aside, as it were, from the somatic cells must not be taken too literally. (Figs. 162, 163, 166.)

As we know, many kinds of plants reproduce normally by fragmentation, each of the pieces REGENERATING the whole, and essentially the same is true of some of the lower animals which reproduce by fission, budding, etc. Again, most plants and many animals regenerate parts by mutilations of one sort or another. Among plants, pieces of the root, stem, or, in special cases, of the

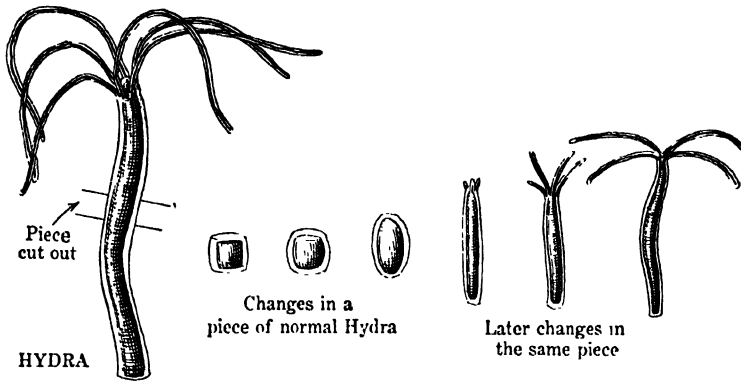


FIG. 164. Regeneration in hydra.

leaf may give rise to individuals complete in every respect.

Until the middle of the eighteenth century this power of regeneration was considered a property peculiar to plants, and soon after hydra was discovered experiments were made to determine whether the organism was a plant or an animal. Specimens were cut into several pieces and it was found that each piece developed into a complete

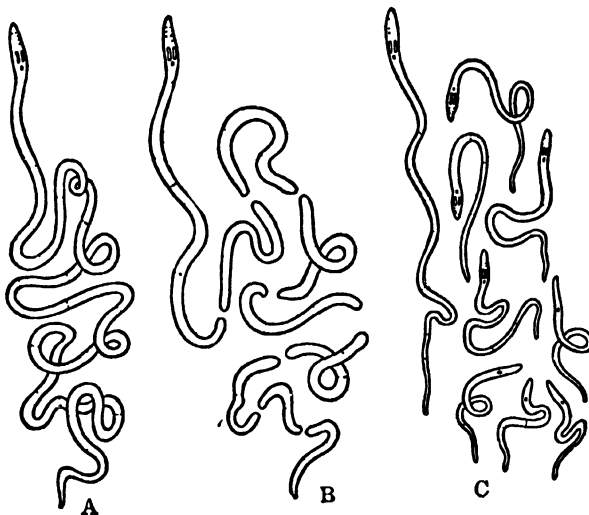


FIG. 165. Reproduction of a flatworm, *Lineus socialis*, by fission. A, mature worm; B, same, in nine parts; C, regeneration of each part resulting in a normal but smaller worm. (From Coe.)

hydra. This result, from the ideas of the time, should have led to the conclusion that hydra is a plant, but additional characteristics were observed which outweighed all other considerations. Accordingly hydra was recognized as an animal with the power of replacing lost parts. (Fig. 164.)

Since the classic work on hydra, the power of regeneration has come to be recognized as a fundamental property of all animals. It is exhibited to the greatest degree among the lower animals, and in the higher vertebrates it is confined chiefly to wound healing and to the replacement of cells which especially suffer from wear and tear, such as those forming the outer layers of the skin. Regeneration is one phase of a fundamental property of protoplasm, namely growth, whether it consists in restoring a part of a *Paramecium*, transforming a bit of a flatworm into a complete animal, or replacing half of an earthworm, the head of a snail, the claw of a crayfish, or the leg of a salamander. But associated with growth in the regenerative procedure there are complex processes of simplification (dedifferentiation) of tissues and organs, and later a rebuilding (differentiation) in order that a part may become a normally organized whole. Witness certain marine flatworms

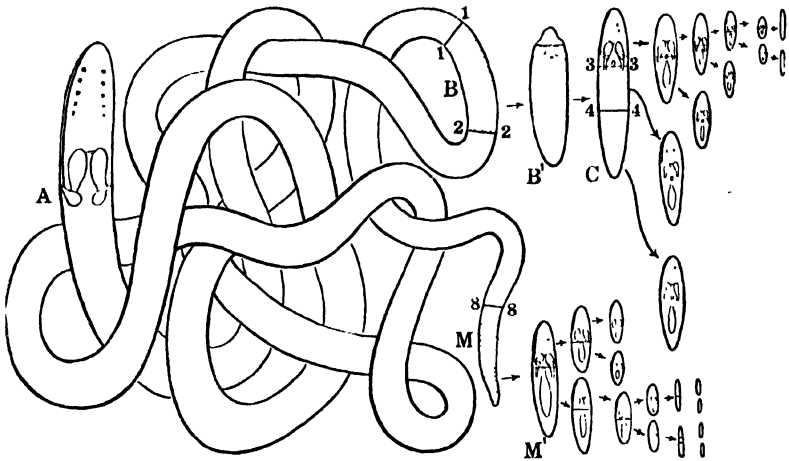


FIG. 166. Regeneration in a flatworm, *Linus socialis*. A, normal worm; B, B', section cut from body and its appearance after twelve days; C, same after thirty days, cut in planes 3-3 and 4-4. Successive cuttings and regenerations indicated by arrows. M, M', similar experiments and results on posterior end of body. (From Coe.)

that can be cut down to less than one two-hundred-thousandth of their original size and still become miniature worms like the original. (Figs. 165, 166.)

The experimental study of regeneration phenomena has opened up a new vista of the regulatory powers of living things from protozoon to vertebrate and from egg to adult, and has afforded a means of approach to some fundamental biological problems. Moreover, it has a practical value. The surgeon now knows more about the regeneration of tissues in general and of nerves in particular in wound healing, and the oysterman knows, or should know, that his attempt to destroy starfish by tearing them up and throwing the pieces overboard may serve merely to increase this enemy of the oyster. Indeed, the starfish *Linkia* is able to regenerate a complete organism from an arm segment only one-thirtieth part of the original animal. In general, however, animal tissues are much more highly specialized than those of plants. (Figs. 167, 168, 428.)

The power possessed by fragments of distinctively somatic tissue in many lower animals and plants to form a complete organism, includ-

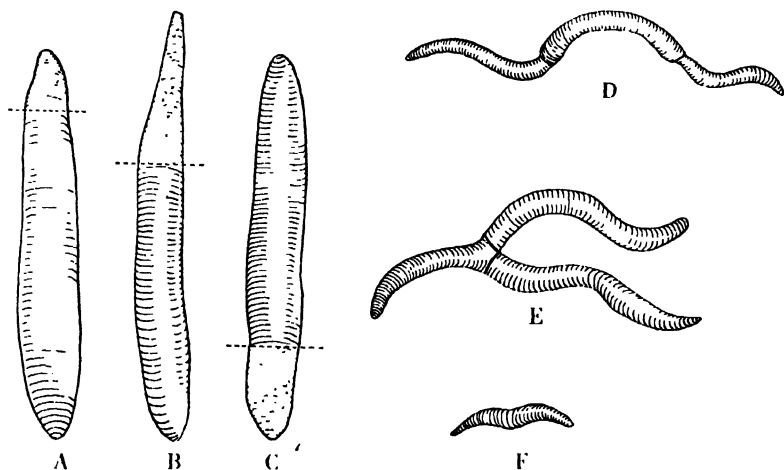


FIG. 167. Regeneration and grafting in the earthworm. A, regeneration of removed anterior segments by the posterior piece. B, regeneration of posterior segments by the posterior part, so that the worm has a tail at either end. C, regeneration of removed posterior end by the anterior piece. D, three pieces grafted together to make a long worm; E, two pieces grafted to form a worm with two tails; F, short anterior and posterior pieces grafted together. Regenerated portions are dotted. (From Morgan.)

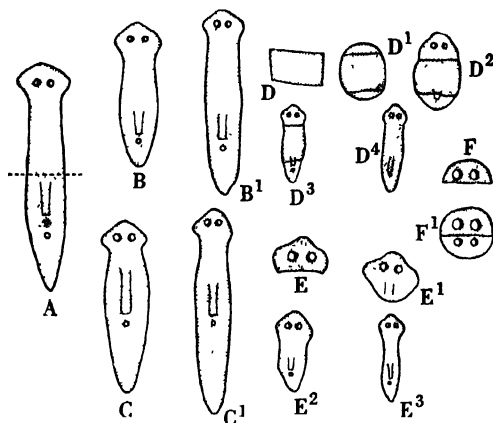


FIG. 168. Regeneration of a flatworm, *Planaria maculata*. A, normal worm; cut across at line indicated. B, B¹, and C, C¹, regeneration of anterior and posterior parts of A to form complete worms. D, piece cut from a worm; D¹, D², D³, D⁴, successive stages in the regeneration of D. E, head from which rest of animal has been cut off. E¹, E², E³, successive stages in the regeneration by E of a complete body. F, similar experiment to E, but a new head in reversed position is regenerated instead of a body, F¹. See Fig. 409. (From Morgan.)

ing the reproductive organs and germ cells, indicates that we must postulate a supply of potential germ material residing in the somatic tissue, which can restore the definitive germ cells when they are lost. At first glance this may seem to be a farfetched effort to save an idea, but it is a fact that there is a continuity from one generation to the next of the nuclear complex (GERM PLASM), whether the germ cells are set aside early in individual development, or later by the transformation of relatively undifferentiated somatic cells.

CHAPTER XVII

Reproduction and Germ Cell Formation

Where order in variety we see
And where, though all things differ, all agree.
—Pope

Reproduction, as noted in the previous chapter, is in the final analysis cell division, whether it occurs by binary fission in unicellular forms, such as *Protococcus* and *Amoeba*, or by the release from a multicellular organism of cells equipped to go through a complex series of changes by which the cells rapidly become transformed into an individual similar to the parent. In most animals reproduction is instigated by sexual phenomena involving the fusion of two germ cells, the male and female gametes, to form the fertilized egg, or zygote. Indeed, sex is fundamentally a physiological difference between gametes which, however, usually so profoundly influences the body structures that we recognize the individual as male or female. (Figs. 176, 207; pp. 245-247.)

ORIGIN OF THE GERM CELLS

Disregarding for the time being the actual origin of the germ cells in the animal body, there are special organs in the Metazoa in which the germ cells reside and undergo changes preparatory to their liberation. Such reproductive organs, or GONADS, ordinarily contain germ cells of one sex only, and are either ovaries in the female or testes in the male.

In many of the simpler animals, the gonads are merely temporary structures that appear during certain seasons of the year when conditions favor sexual reproduction. In some species the same individual produces both eggs and sperm, in which case the organism is termed a hermaphrodite. It will be recalled that hermaphroditism is frequently the condition in hydra where the testis and ovary develop as groups of ectoderm cells that in one case give rise to many sperm and in the other

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to a single egg. There is no complicated apparatus for sexual reproduction in hydra; merely now and again the temporary development of the gonads. (Fig. 64.)

The complex bodies of most animals, however, include more or less permanent gonads, as well as means for transferring the gametes directly or indirectly to the exterior. This is brought about by the fact that in coelomate animals the gonads are located, not on the outside of the body, but in the body cavity. In the earthworm, which also is hermaphroditic, the testes and ovaries are permanent organs attached to the partitions between certain segments. The germinal cells are set free in the coelom where they are taken up by sperm ducts or oviducts and carried to the outside. (Figs. 69, C; 73.)

Throughout all the chief vertebrate groups the sexes are distinct, although in rare instances hermaphroditic individuals occur. The definitive primordial germ cells first appear as localized areas of the epithelium lining the coelom, on either side of the vertebral column. As the germ cells develop they become associated with connective tissue, blood vessels, and nerves and form the paired gonads. In the most primitive vertebrates a condition less complex than in the earthworm is found, for both male and female gametes merely break out of the gonads and find their way to the exterior by a pair of minute abdominal pores. In higher forms, however, special sperm ducts and oviducts are developed in close relationship with the urinary system. (Fig. 82.)

In some aquatic and most terrestrial vertebrates fertilization occurs while the eggs are still within the oviducts; the copulatory organ transferring the sperm directly to the terminal portion of the ducts through which they make their way up to meet the descending eggs. After fertilization the zygote may soon pass to the exterior, usually, as in the case of the familiar hen's egg, after being wrapped up in nutritive and protective coats secreted about it during its passage down the oviduct. Or, as is the case rarely among lower forms and the rule among all mammals except the monotremes, the zygote on reaching the lower part of the oviduct becomes attached to the wall of an enlargement of the oviduct or of a chamber formed by the union of the two oviducts, called the UTERUS. Here the embryo proceeds far along in development before birth occurs. (Figs. 176, 181, 196.)

Among the vertebrates, as previously described, the germ cells reside during adult life in definite organs, the ovaries and testes, and upon these cells the power of reproduction of the individual is solely

dependent. It seems clear, however, that the primary germ cells do not arise originally in the specific tissues which during development form the ovaries and testes. Just when the germ cells are first segregated in the vertebrate body is uncertain, but it seems to occur very early in embryonic life, perhaps during the early cleavage of the egg as is the case in certain invertebrates. Then by shiftings of the tissues during growth, and possibly also by amoeboid movements of the germ cells themselves, they finally reach definite positions in the epithelium lining the dorsal wall of the coelom which becomes a part of the gonads. (Fig. 169.)

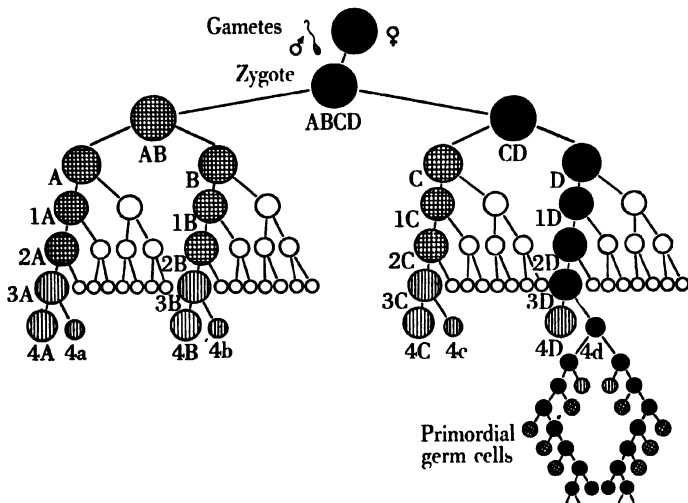


FIG. 169. Diagram of the lineage of the body cells and germ cells in a worm or mollusk. Lineage of germ cells shown in black, of ectoderm in white, and of endoderm and mesoderm in shaded circles. (From Conklin.)

With regard to the fate of the PRIMORDIAL GERM CELLS, once they have reached testis or ovary, we are on surer ground and can trace with considerable exactness their divisions and transformations which give rise to the sperm and eggs. In the first place the primordial germ cells undergo repeated divisions in the testis and ovary so that they produce a large number of embryonic germ cells, known as SPERMATOGONIA and OÖGONIA respectively.

The ovary of an adult female frog contains oögonia in various stages of development. The eggs for release at the next breeding season are the largest cells; those of intermediate size represent approximately

those of the following year; and many smaller cells are seen as oögonia from which the eggs of later years will arise. Furthermore there are other cells that form a matrix of supporting and nutritive tissue (FOLLICLE CELLS, etc.) in which the germ cells are embedded. The mammalian ovary presents a similar picture, except that since fewer eggs are produced at each breeding period, the supply of oögonia is not so large. Nevertheless, even in the human ovary there are potentially many thousands of eggs. The testis shows a similar condition, but since so many more sperm than eggs are produced, the spermatogonia divide much more actively. (Figs. 170, 181.)

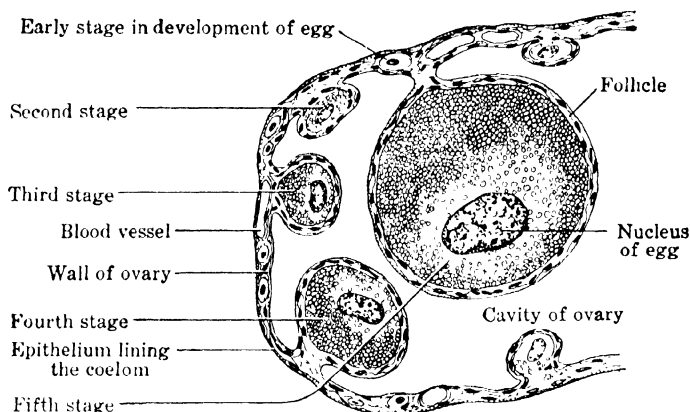


FIG. 170. Diagrammatic section through a lobe of the ovary of a frog, showing several stages in egg development. Magnified.

It is clear that the spermatogonia and oögonia in the gonads, together with all the cells forming the body proper, are direct descendants by mitotic cell division from the fertilized egg which gave rise to the individual organism. This, as has just been noted, is equally true of the chromosomes, and therefore every cell of the animal body has the same number of chromosomes as the fertilized egg. Furthermore, since fertilization always consists in the fusion of two gametes—a fusion of nucleus with nucleus and cytoplasm with cytoplasm to form a zygote—one of two things must happen. Either the zygote, which is one cell reconstructed from two gametes, must have double the chromosome number, that is, a set contributed by both egg and sperm; or some method must exist by which the chromosomes of the gametes are

reduced in number to one-half that characteristic of the somatic cells.

The maturation (**GAMETOGENESIS**) of the germ cells of animals involves two cell divisions by which each spermatogonium gives rise to four sperm, and each oögonium to one functional egg and three tiny, abortive cells known as **POLAR BODIES**, each germ cell having one-half the number of chromosomes of the somatic cells and of the germ cells previous to this point in their development. Consequently these two **MATURATION DIVISIONS**, involving **MEIOSIS**, must be examined in some detail if we are to appreciate the nicety of the process by which the chromosome number is reduced one-half without impairing the chromatin heritage from cell to cell. First the origin of the sperm, or **SPERMATOGENESIS**, will be described, and then the fundamentally similar origin of the egg, or **OÖGENESIS**.

SPERMATOGENESIS

Each **SPERMATOGONIUM** with the diploid number of chromosomes characteristic of the body cells of the species, proceeds to increase in size preparatory to the first meiotic mitosis and is designated a **PRIMARY SPERMATOCYTE**. At the close of this growth period, when the cell is in process of division, the chromosomes join in pairs, that is, undergo **SYNAPSIS**. Then the chromosomes of each pair split lengthwise so that each synaptic pair now forms a synaptic group of four chromosomes known as a **TETRAD**. The tetrads are then arranged in the equator of the spindle exactly as the single chromosomes are in ordinary mitosis. (Fig. 159, *E*.) But in the early anaphase each tetrad separates into two **DYADS** each consisting of two chromosomes, so that one dyad of each tetrad passes to each pole of the spindle and so to the arising daughter cells, or **SECONDARY SPERMATOCYTES**. (Fig. 171.)

Now the second and final meiotic division takes place by the division of the two secondary spermatocytes. In each the dyads are arranged in the equator of the spindle and then, as cell division proceeds, one chromosome of each dyad passes to each of the two daughter cells, or **SPERMATIDS**.

In this way, by two meiotic divisions, there arise from each spermatogonium four spermatids. But since only *one* chromosomal division takes place during these *two* cell divisions (in the other, synaptic mates are disjoined), the chromosome number in the spermatids is one-half that in the spermatogonia and in the body cells. The spermatids gradually are transformed into sperm and therefore each spermatogonium

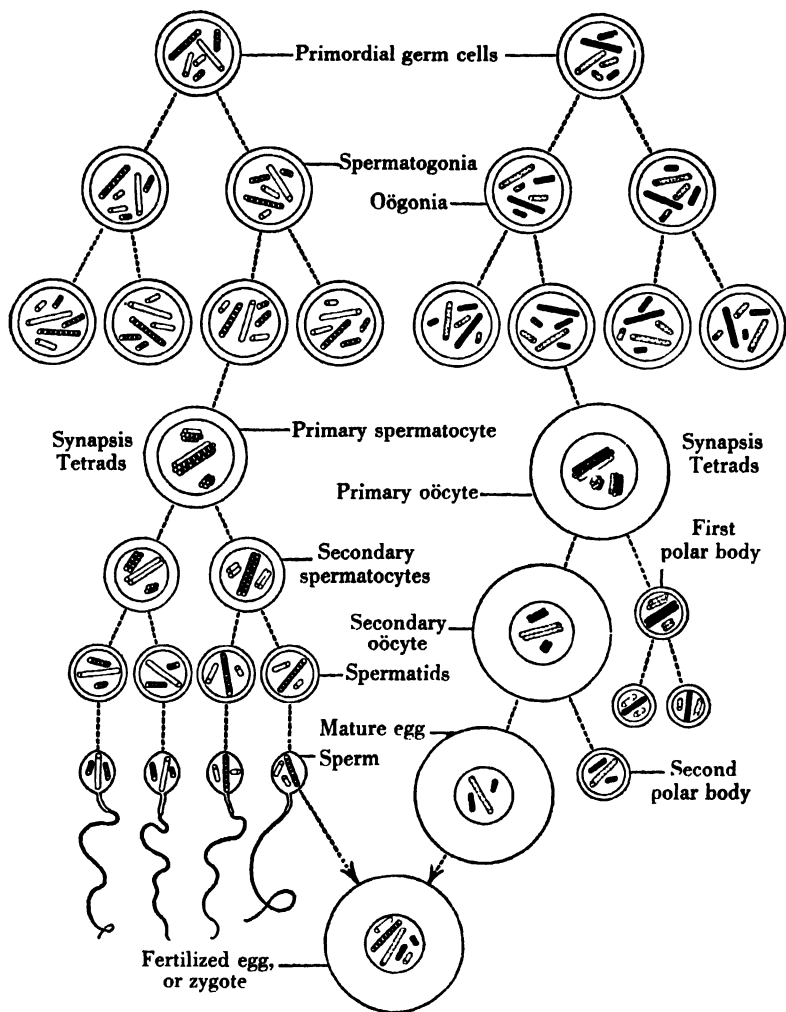


FIG. 171. Diagrams showing the maturation of sperm and egg (gametogenesis) in an animal as described on p. 234: male at left, female at right. The diploid number of chromosomes is assumed to be six. Homologous chromosomes have the same length. Homologous chromosomes, from different parents, are distinguished by shading. (After Hegner.)

gonium with the diploid number of chromosomes gives rise to four sperm each with the haploid number. Chromosome REDUCTION is accomplished. (Fig. 172.)

In brief, the meiotic divisions distribute the four component chromosomes of a tetrad to separate cells so that at the conclusion of meiosis each of the four resulting cells has a haploid set of chromosomes composed of a longitudinal half of one member of each of the original synaptic mates. Reduction thus involves the SEGREGATION of synaptic mates into gametes.

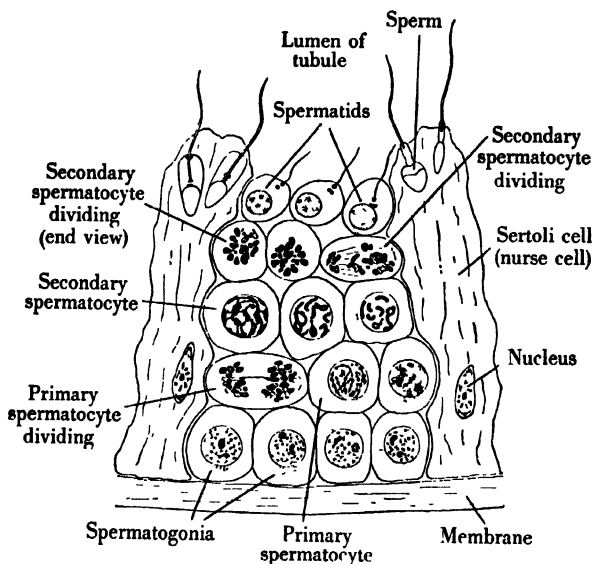


FIG. 172. Spermatogenesis. Vertical section through wall of sperm tubule in testis showing male germ in various stages of development. Diagrammatic. (After Mavor.)

OÖGENESIS

The maturation of the egg, as already intimated, follows the same plan as that of the sperm, and the reduction of the chromosomes is the same. Such modifications as occur are related to the fact that the egg is always a relatively large, passive cell stored with nutritive materials for use during the developmental process, while the sperm is among the smallest of cells—essentially a nucleus surrounded with a delicate envelope of cytoplasm. Accordingly it is only necessary to emphasize that the growth period of egg formation, during which the OÖGONIUM becomes transformed into the PRIMARY OÖCYTE, is characterized by a much greater increase in size than is the case in the corresponding

period in spermatogenesis, and that the following two maturation divisions involve very unequal divisions of the cytoplasm. Thus one SECONDARY OÖCYTE is very large and the other is a tiny cell termed the first POLAR BODY. (Figs. 171, 173.)

Moreover, the large secondary oöcyte and first polar body now divide again; the former gives rise to a large cell, the mature EGG, and a tiny SECOND POLAR BODY, while the first polar body divides equally

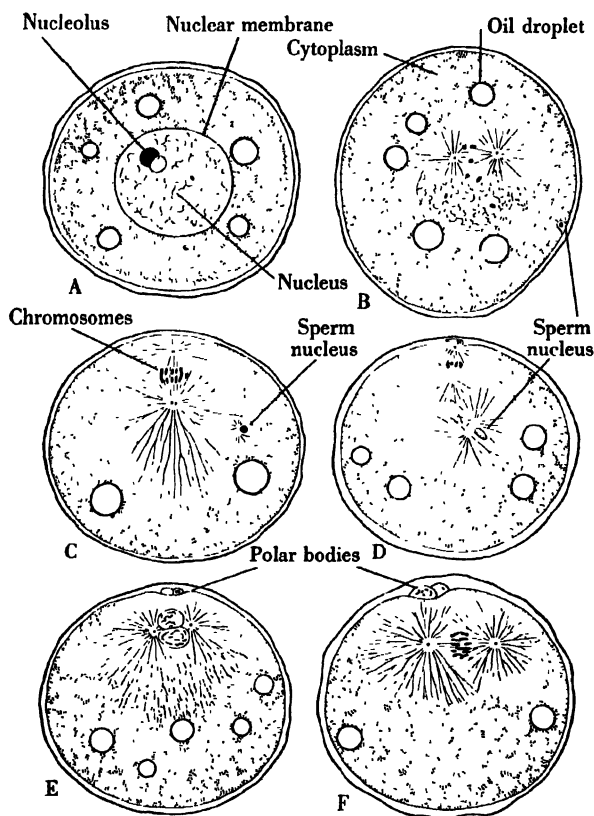


FIG. 173. Maturation and fertilization of the egg of the sandworm, *Nereis*. A, egg (oöcyte) before start of maturation; B, first polar body spindle forming, sperm just entering; C, first polar body spindle established; D, first polar body formed, second polar body spindle near; spindle with sperm nucleus; E, second polar body formed, union of egg and sperm nucleus; F, spindle for first division of fertilized egg. Note that in *Nereis*, as in many other animals, maturation of the egg is deferred until the time of fertilization. (From Wilson.)

to form two polar bodies. In this way arise the four cells, comparable to the four sperm in spermatogenesis, each with the haploid number of chromosomes. But only one of these, the egg, functions as a gamete. The three polar bodies, although possessing a similar chromosome complex, are sacrificed in providing one cell, the egg, with its increased cytoplasmic equipment. The diminutive polar bodies soon degenerate and disappear.

Such is the outline of the essentials of spermatogenesis and oögenesis in animals: processes which involve a modification of ordinary somatic mitosis so as to give each gamete half the somatic number of chromosomes characteristic of the species. It is clear that this is not merely a mass reduction of chromatin material, but is a separation and exact *segregation* after synapsis of definite chromatin entities, the chromosomes, so that each of the gametes receives the reduced number carrying one complete set of genes. And it should be emphasized that the basic phenomena of meiosis are found throughout the animal and plant kingdoms wherever sexual reproduction occurs.

THE CHROMOSOME CYCLE

The *germ cell cycle* has now been described from the fertilized egg through the germ plasm in the adult and back to the gamete again, but before proceeding to consider the details of the fusion of egg and sperm—the fertilization process—it may clarify matters to glance back to the chromosome condition in the fertilized egg at the *beginning* of the cycle that has just been considered.

Obviously the fertilized egg (zygote) contained two groups of chromosomes, one of which belonged to the egg and therefore may be termed **MATERNAL**, and one which was derived from the sperm and hence is **PATERNAL**. When the zygote divided by mitosis to form the body and germ, every cell received two groups of chromosomes directly derived from these two original groups in the zygote. It logically follows, and all observations indicate, that each and every body cell actually has two complete sets (diploid number) of chromosomes, and the same is true of the germ cells until maturation. Then, at synapsis, corresponding (homologous) maternal and paternal chromosomes pair, and after the maturation divisions each gamete has a single complete set of chromosomes (haploid number) from each pair. (Figs. 171, 174.)

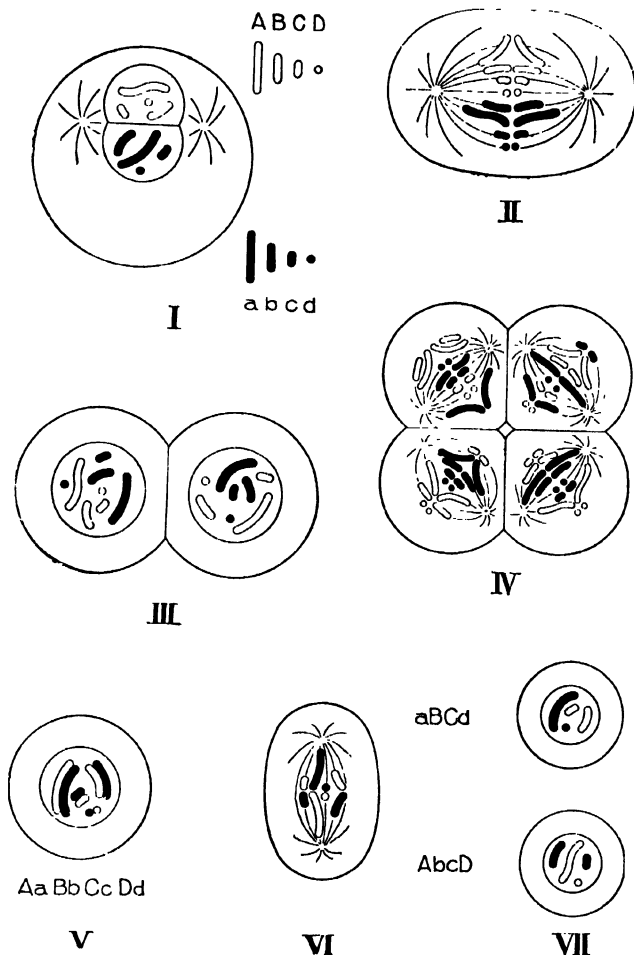


FIG. 174. Diagrams showing the chromosome cycle of an animal. Somatic (diploid) chromosome number assumed to be eight. Paternal chromosomes (from sperm) = A B C D; maternal (from egg) = a b c d. I, union of nuclei of gametes, each with the haploid number of chromosomes, in the zygote at fertilization to give the diploid number of chromosomes. II, III, IV, somatic divisions or divisions of germ cells before maturation (diploid number of chromosomes). V, synapsis in primary spermatocyte or primary oocyte, involving pairing of homologous paternal and maternal chromosomes to give the haploid number of paired chromosomes. (Tetrad formation at this stage not shown in figure.) VI, a maturation division—separation of chromosome pairs into single chromosomes again. VII, two gametes, with the haploid number of chromosomes; there are 14 more possible combinations of the chromosomes, or types of gametes, which are not shown. See Figs. 171, 243. (After Wilson, slightly modified.)

Chromosome reduction has now been emphasized as the main result of the complicated maturation phenomena. The question next arises: Is this chromatin distributed so that all the gametes receive the same heritage?

As already stated, the evidence clearly shows that the chromosomes differ qualitatively one from another, and also that the various parts of each chromosome are qualitatively distinct. And further that these qualitative differences are the physical basis of inheritance—the determiners (genes) of characters which will be realized in the individual or the race to which the cell containing them contributes. Such being the case, the chromosomal complex of each of the nuclei which arises after synapsis—the nuclei of the gametes—depends on how the various chromosomes happen to be distributed during the two meiotic divisions. As a matter of fact, all the chromosomal combinations occur that are mathematically possible with the available number of chromosomes in a given species, but with one limitation: every cell must receive a derivative of one member of each synaptic pair of chromosomes, so that each and every gamete receives a complete haploid group of chromosomes, but rarely the same group (maternal or paternal) which existed before maturation. For example, if the somatic (diploid) number of chromosomes is eight, sixteen different types of gametes are possible. In man with 48 somatic chromosomes, and after synapsis 24 pairs of paternal and maternal chromosomes, there are 2^{24} , or about seventeen million possible types of gametes in each sex; and since these combine at random at fertilization, the possible number of different types of zygotes from one parental pair mounts far up in the trillions from chromosomal combinations alone. No wonder the children of a family differ! (Fig. 246.)

In a way, therefore, fertilization is not consummated, so far as its influence on the race is concerned, until the maturation of the gametes in the new generation to which it has given rise. We shall defer until later the consideration of the significance of these facts in BIPARENTAL inheritance, and merely emphasize again that the continuity of life implies not only the continuity of cells but also continuity of their nuclear elements, the chromosomes and the genes.

CHAPTER XVIII

Reproduction and Fertilization

The entire organism may be compared to a web of which the warp is derived from the female and the woof from the male.

—Huxley

Now that we are familiar with the method of gamete formation and its contribution to the continuity of life, it is in order to consider some important details of the structure of the gametes themselves, and the significance of the complex series of phenomena that they initiate at fertilization. The biological importance of fertilization in the life of the individual organism and the race has aroused the interest of philosophers and scientists since the time of Aristotle, but it is only within the past half century that at least a partial answer has been forthcoming from a critical analysis of the gametes and their product, the zygote.

GAMETES: EGG AND SPERM

The gametes, while exhibiting in certain cases peculiar adaptations to special conditions, are remarkably similar in general structure throughout the animal series. In general the egg is a relatively large, passive, food-laden cell and the sperm a minute, active, flagellated cell. (Figs. 175, 314.)

The egg is subject to much more variation in size and general appearance than the sperm, for after fertilization it must be adapted to meet the special conditions of development peculiar to the species. In fact, the actual size of the egg in animals is determined chiefly by whether the developing embryo is in the main dependent upon food stored in the cytoplasm of the egg itself, or upon some outside source, such as the sea water in which it floats, or the tissues of the parent. The first condition is illustrated by a bird's egg, in which the large central YOLK is the egg cell proper, hugely distended by stored food and sur-

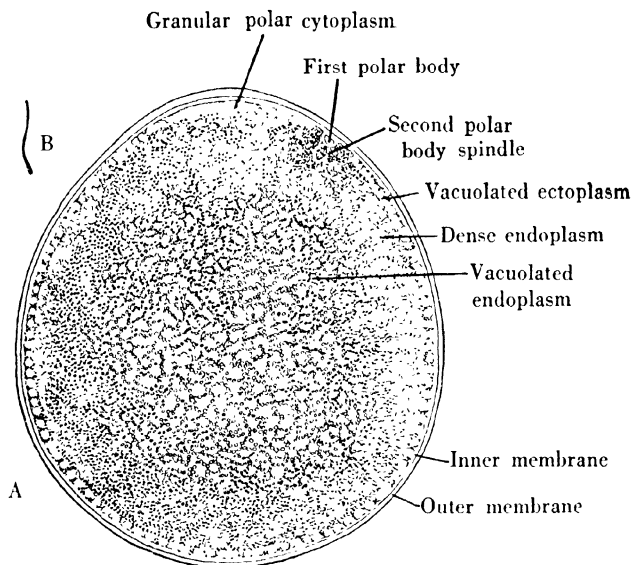


FIG. 175. Egg (A) and sperm (B) of a primitive vertebrate, the lamprey (*Petromyzon marinus*, Fig. 446). They are drawn to scale to show the great difference in size and other structural features between active sperm and large, food-laden, inactive egg. Highly magnified. (From Kellicott, after Herfort.)

rounded by nutritive and protective envelopes. These coverings are the white of the egg, shell membranes, and shell which are formed by secretion from cells in the walls of the oviduct during the passage of the egg to the exterior. On the contrary, the eggs of mammals, for instance of the rabbit and man, are very small—the human egg being about $1/175$ inch in diameter—since their essentially parasitic method of development in the uterus renders superfluous the storage of food material in the egg cytoplasm. (Figs. 176, 177, 193.)

With the specialization of the egg along lines which render it non-motile, it has devolved upon the sperm to assume the function of seeking out the egg for fertilization. A sperm does this in most cases by active lashing of its tail, or flagellum. This necessitates a fluid medium so that the sperm can swim, and such is provided by the environment of the organism or, in most higher animals where fertilization takes place within the oviduct, by special fluids secreted for the purpose.

A question of much interest is how the actual contact of the gametes

is brought about. In many instances meeting is undoubtedly merely by chance, the random swimming of the sperm sooner or later bringing them in contact with a nearby egg. In other cases movements of the sperm indicate a definite attraction by the egg. Thus the sperm of certain mosses seem to approach the egg under the influence of secreted chemicals, and those of some of the lower animals apparently are attracted by substances liberated by the egg at maturation. In all such instances there can be but little doubt that stimulation of the sperm by specific substances is a factor in bringing the gametes together and is a

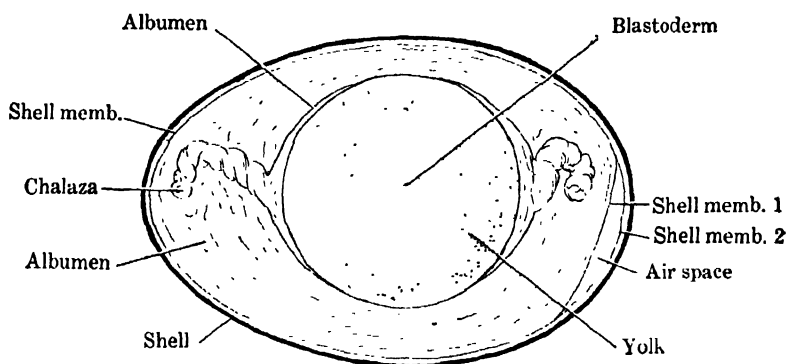


FIG. 176. Diagram showing internal structure of hen's egg, before incubation. See Fig. 192.

chemical link between egg and sperm in normal fertilization. This is an example of **CHEMOTROPISM**: a reaction of considerable importance especially in the behavior of many kinds of free-living cells.

UNION OF GAMETES

Once a sperm has come into functional contact with an egg, it initiates a chain of events which constitutes fertilization. As might be expected, the variations in details are legion, but they do not obscure the main facts. The first reaction on the part of the egg is to prevent the entrance of other sperm and thereby to ensure a free field for the operations of the first arrival. Frequently a jellylike layer is formed about the egg, or if a membrane is already present this may be rendered impermeable by instant surface changes. In cases where the egg is surrounded originally by a dense and resistant wall, the tiny opening provided for the entrance of a sperm is closed. However, the accessory

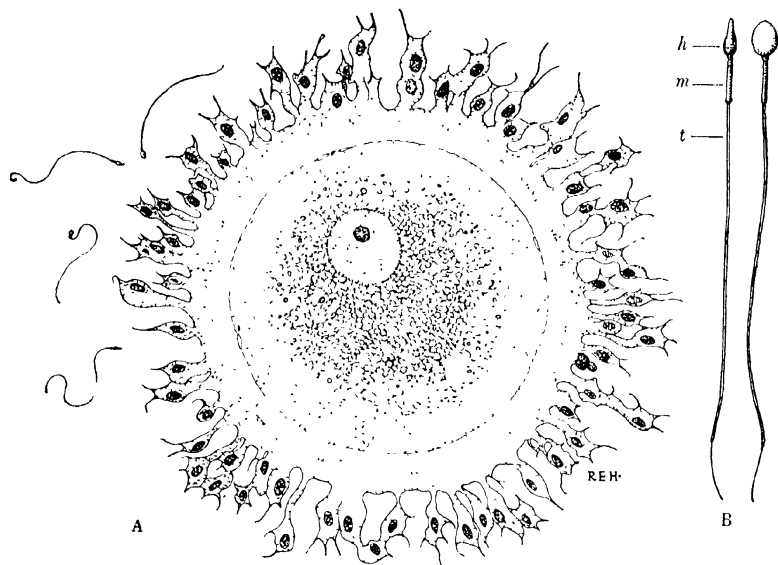


FIG. 177. Human egg and sperm. A, four sperm (*left*) and egg (*right*) just after release from the ovary, surrounded by ovarian follicle cells and egg membrane. The central part of the egg contains metaplastic bodies and large nucleus with nucleolus. Magnified about 400 times. B, two views of human sperm, *h*, head consisting of the nucleus surrounded by a cytoplasmic envelope; *m*, middle piece; *t*, tail or flagellum. Magnified about 2000 times.

wrappings about certain eggs, such as those of birds, have no relation to this subject since they are not secreted by the egg itself, but by glands in the wall of the oviduct, some time after fertilization has occurred, when the egg is passing through. (Fig. 176.)

The reactions of the egg cytoplasm that exclude accessory sperm are overshadowed in importance by other changes which upset the stable equilibrium of the egg and render its surface permeable, so that extensive osmotic interchanges take place between the cytoplasm of the egg and its surroundings. Most often this action is visible merely in a shrinkage of the cytoplasm due to loss of water, but sometimes contractions, amoeboid movements, or flowing of special cytoplasmic materials to definite regions of the egg are in evidence. In any event it is certain that profound changes occur in the cytoplasm: its organization as a gamete soon gives place to a reorganization that establishes the general outlines of its subsequent development as a new individual. (Fig. 173.)

SYNKARYON

The climax of fertilization is the union of the male and female GAMETIC NUCLEI, to form a single nucleus (SYNKARYON) of the zygote. Disregarding the flagellum of the sperm, which disappears as a sperm enters the egg, we find that the sperm nucleus moves through a quite definite path toward the center of the egg where the two nuclei meet. Both the gametic nuclei now become resolved into chromosomes lying free in the cytoplasm, while two centrosomes, each surrounded by an aster, appear and take up positions on either side of the chromosomes to form a typical mitotic figure. The two sets of chromosomes form an equatorial plate at the center of the spindle, thus establishing at once not only the mitotic apparatus for the first division of the egg, but also the intimate association on equal terms of chromosomes, with their potentialities from the two parents, to form a common structure—the nuclear complex of the new biparental individual. (Figs. 173; 174, I, II.)

Such are the outstanding facts of fertilization that a host of investigators have brought to light, chiefly within the past seventy years. It was not until 1839 that Schwann, with the establishment of the cell theory, recognized the egg as a cell, and twenty-six years more before the sperm was similarly understood; while the first realization that fertilization is an orderly fusion of two cells to form one came during the seventies of the last century. Then it became evident that in sexual reproduction each individual parent contributes to the formation of the offspring a single cell in which must be sought the solution of the problems of sex, fertilization, development, and inheritance. However, the concentration of attention on the cell—and now on the chromosomes and genes—has not simplified the solution of these fundamental problems, but rather has contributed to an ever-increasing appreciation of the complexities of cell phenomena and the difficulties of formulating them in general terms. (Fig. 506.)

SIGNIFICANCE OF FERTILIZATION

Quite naturally an early view held that fertilization fundamentally is reproduction, since the mature egg pauses in development and usually comes to naught unless a sperm enters. However, as we know, reproduction is cell division or the detachment of a portion of a living organism to form another, whereas fertilization is the union of two cells to

form one cell. The erroneous idea that fertilization is reproduction is due to the fact that if fertilization is to occur at all in higher organisms, it must occur at the period in the life history when the individual is but a single cell detached from the parental tissues—that is, at the time of reproduction.

More recently the primary significance of fertilization was regarded as a necessary stimulus for continued cell division and therefore for reproduction: a fundamental intrinsic phenomenon to prevent an inherent decline in vigor, or so-called protoplasmic senescence. However, recent experiments and a review of the available facts make it necessary to abandon this view, as will immediately appear.

In the first place intensive studies of long-continued cultures of unicellular animals have shown that some types can reproduce by division indefinitely—at least for many thousands of generations—when fertilization is prevented, and that others never undergo fertilization at all; it does not occur in their life history. Furthermore many higher plants exhibit unlimited ability to propagate solely by asexual processes. Again, certain tissue cells when removed from the vertebrate body will live, grow, and divide apparently indefinitely in tissue cultures apart from the parent, if favorable conditions are provided. Still again various plants and animals produce eggs that develop without fertilization (parthenogenesis), as in the well-known case of the eggs of the honey bee that produce males. Finally, the eggs of certain animals that normally require fertilization may be induced to develop by the application of various stimuli, chemical or physical or both; this is referred to as artificial parthenogenesis.

This array of established facts makes it evident that fertilization is not reproduction and also that it is not an intrinsically necessary stimulus for continued protoplasmic life, growth, and cell division. Fertilization is not “a primary attribute of living matter.” But, of course, this important conclusion does not negate the fact that when fertilization does occur it supplies a stimulus that induces an egg to divide, or the fact that following fertilization certain unicellular organisms exhibit renewed power of division.

Turning to the significance of fertilization in heredity we are on equally sure ground. All of many lines of evidence surely converge toward the view that the opportunities which fertilization affords for changes in the complex of the germ are of paramount importance. Fertilization establishes new diploid groups of hereditary characters by

combining diverse haploid groups from the male and female gametes. It makes possible the shuffling of germinal variations so that they are presented in new combinations. It is the pooling of the germinal changes of two lines of descent. Some of the new combinations may more effectually meet (be better adapted to) the exigencies of the environment, and so have a survival value for the organism in the struggle for existence. It is no wonder that usually in the lowest and always in the highest organisms provisions are made for a process which multiplies many-fold the opportunities for descent with change. (Fig. 243.)

In passing, it should be emphasized that provisions to ensure fertilization have had a profound influence on the morphology and physiology of organisms. Sex of the gametes and sex of the individual body are, of course, radically different, though the latter is indirectly an outcome of the former. The evolution of the gametes themselves is relatively simple: from those alike so far as structure is concerned, though physiologically different, to those in which one sex is smaller and more motile and the other larger and usually nonmotile. But the sexual evolution of the individual body in the Metazoa presents amazing phenomena. Witness the biological and physiological contrast of individuals that bear sperm and eggs respectively. Sex, indeed, becomes largely a dominating factor in the life of the lower animals, and even of man, where the primary function of somatic sexual differentiation to ensure fertilization appears to become largely submerged. "It is as though variety and beauty had become ends in themselves in the evolution of secondary sex characters, as exemplified in the plumage of birds, and in the strife and amenities of human social relations."

CHAPTER XIX

Animal Development (I)

The student of Nature wonders the more and is astonished the less, the more conversant he becomes with her operations; but of all the perennial miracles she offers to his inspection, perhaps the most worthy of admiration is the development of a plant or animal from its embryo.

—Huxley

The new individual, established by the orderly merging of a cell detached from each parent in sexually reproducing plants and animals, has before it the problem of assuming the adult form by a complicated developmental process. Its heritage as provided in the zygote must be realized. As we have seen, this involves, first, the cleavage of the egg, followed, in the Metazoa, by blastula and gastrula stages during which the primary germ layers are established—the fundament out of which the definitive form, organs, and organ systems of the adult are evolved. The description and comparison of these processes in different organisms constitute the content of one aspect of EMBRYOLOGY. (Fig. 11.)

It is unnecessary, as well as impossible, to survey the immense field included under embryology. Attention must be confined to the main features of development in a few representative types of animals. And one must be satisfied with little more than the realization that development, though it varies widely in producing the wonderfully diverse body forms, exhibits throughout a thread of similarity in its fundamental features. This “similarity in dissimilarity” may be visualized by bearing in mind the embryology of the earthworm as described below, while later consideration is given to that of the vertebrates, using as an introduction the relatively simple development of amphioxus. The early embryological stages of this protochordate resemble in many ways those of certain invertebrates and also exhibit the basic plan of vertebrate development.

DEVELOPMENT OF THE EARTHWORM

The eggs of an earthworm after fertilization proceed to divide first into two cells, then into four cells, then eight cells, and so on, with more or less regularity, until many relatively small cells are arranged about a central cavity. This stage of the embryo will be recognized as the blastula. (Fig. 178, *B*.)

The various cells of the blastula appear essentially the same except that those at one end are somewhat larger than those at the other. The larger cells now sink into, and nearly obliterate, the central cavity to form a typical gastrula composed of two layers of cells, ectoderm on the outside and endoderm on the inside. The infolded enteric pouch, or enteron, enclosing the enteric cavity, eventually becomes the main part of the alimentary canal of the worm. (Fig. 178, *G*.)

While these two primary germ layers are being established, the embryo shows the rudiments of the third germ layer (mesoderm) as two MESOBLAST CELLS leave their place in the wall of the embryo and take a position between the ectoderm and endoderm. Here the mesoblast cells divide to form, on either side of the enteric pouch, a linear series, or band of cells. These mesoderm bands gradually increase in size and spread out until, uniting above and below, they encircle the enteron as a continuous layer. Simultaneously with the growth of the mesoderm bands, there appears in each band a linear series of spaces which presages the future segmentation of the body. These cavities increase in size, and when the bands unite around the enteron, the corresponding cavities of each band also become continuous in the same regions. (Fig. 178, *B-K*.)

In this way the mesoderm itself becomes divided into what are essentially two cellular layers: an outer SOMATIC LAYER next to the ectoderm, and an inner SPLANCHNIC LAYER in contact with the endoderm. The space between these layers of the mesoderm is the body cavity, or coelom. This cavity, however, is not continuous from one end of the embryo to the other, because the mesodermal cells which separate the linear series of cavities in the respective mesodermal bands persist. These cells form a regular series of vertical sheets of tissue between the somatic and splanchnic mesoderm layers and thus divide the body of the worm into a series of essentially similar segments, the limits of which are indicated on the outside by a regular series of grooves encircling the body.

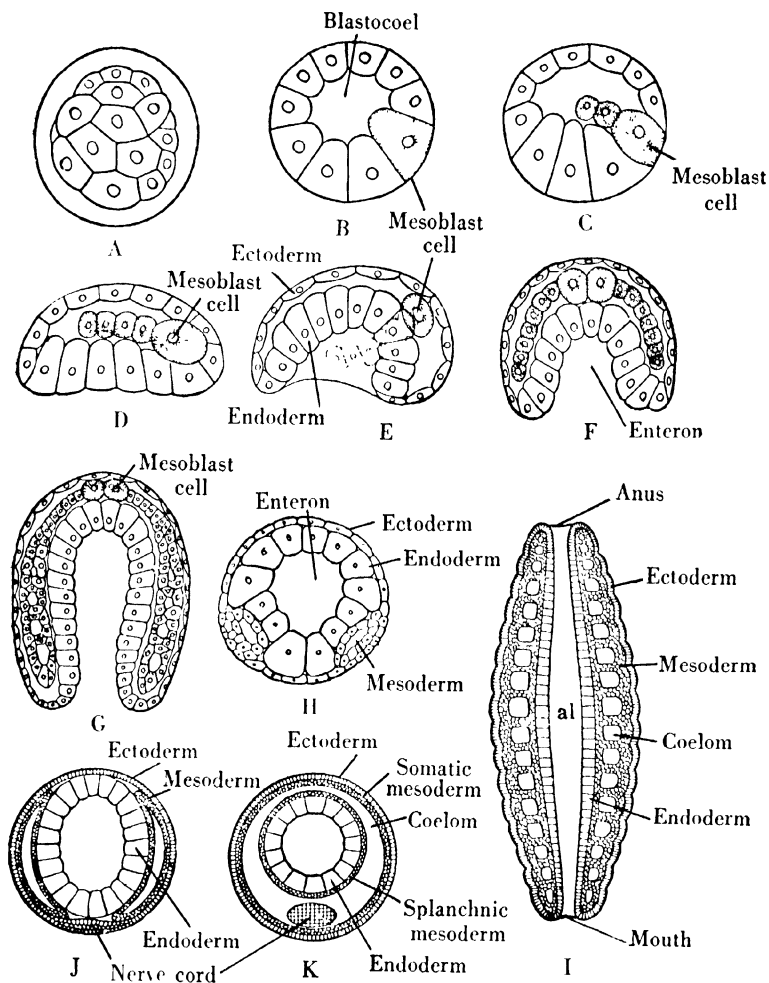


FIG. 178. Diagrams of stages in the development of the earthworm: A, blastula surrounded by egg membrane; B, section of a blastula showing blastocoel and one of the primary cells (mesoblast cell) of the mesoderm; C, later blastula with developing mesoderm bands; D, start of gastrulation; E, lateral view of gastrula showing invagination of endoderm, which as it proceeds leaves the mesoderm bands on either side of the body as indicated by the cells represented with dotted outline; F, section of E to show mesoblast cells, mesoderm bands, and enteric cavity. G, later stage showing coelomic cavities in the mesoderm bands; H, stage (G) in transverse section; I, longitudinal section of embryo after formation of mouth and anus (al, cavity of alimentary canal); J, stage I in transverse section; K, later stage in transverse section. (After Sedgwick and Wilson.)

While these processes are transforming the two-layered gastrula into a three-layered embryo that exhibits segmentation, coelom, etc., the embryo is gradually increasing in size and elongating. The opening from the enteron to the exterior constitutes the mouth, and at the opposite end the anus is formed, to establish the definitive alimentary canal. A transverse section perpendicular to the main axis of the worm at this stage of development presents the appearance of a circle within a circle. The inner circle is the wall of the alimentary canal which is separated by a space, the coelom, from the outer circle, or body wall. The alimentary canal is formed internally of endoderm and externally of splanchnic mesoderm; and the body wall, internally of somatic mesoderm and externally of ectoderm. Thus the coelomic cavity is enclosed by mesoderm. It is from these layers of cells that all of the tissues and organs of the adult worm arise through differentiation, thickenings, foldings, outgrowths, and the like.

DEVELOPMENT OF AMPHIOXUS

The maturation of the egg and sperm of amphioxus follows the typical process of gamete formation previously described. (pp. 234, 238.) The second meiotic division of the egg occurs just at the time of fertilization, so that the second polar body remains attached to the egg within the fertilization membrane that develops about the egg as the sperm enters. (Figs. 171, 179, 180.)

CLEAVAGE THROUGH GASTRULA

The first division, or cleavage, of the egg occurs a little over an hour after the union of the gametic nuclei to form a synkaryon, and

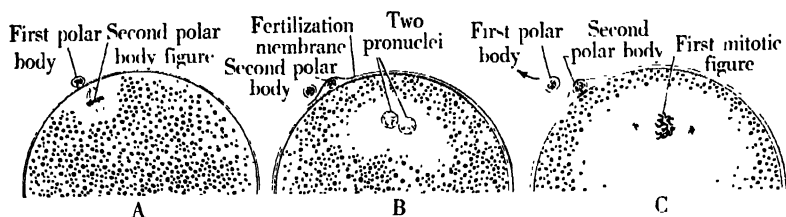


FIG. 179. Sections of upper pole (animal pole) of egg of amphioxus; A, at time of fertilization (sperm, not shown, enters at lower pole of egg); B, union of gametic nuclei; C, metaphase of first cleavage mitosis. The black spheres represent yolk. The jelly-like membrane that surrounds the egg is not shown. See Fig. 180. Highly magnified. (After Huettner.)

divides the zygote vertically into two equal cells that typically form the right and left sides of the animal. The second cleavage succeeds in about three-quarters of an hour, again vertically and at right angles to the plane of the first. And about a half hour later the third occurs horizontally at right angles to the first two, but the plane is slightly above the equator, so that the four cells of the upper, or animal, pole in the eight-cell stage are somewhat smaller (micromeres) than the quartet (macromeres) at the vegetal pole.

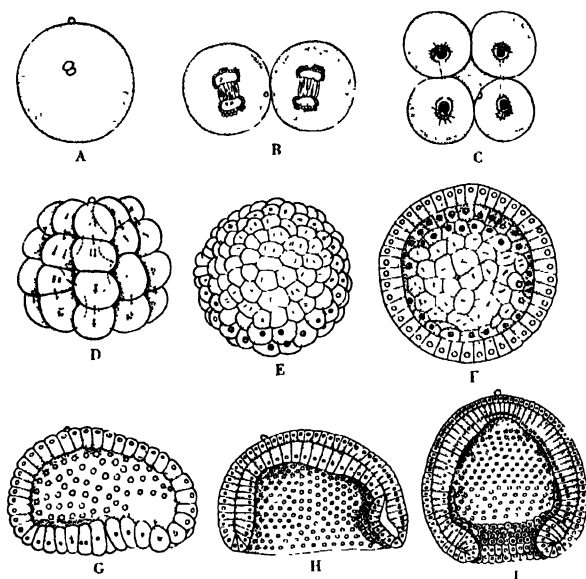


FIG. 180. General plan of the early development of the egg of a primitive chordate, *Amphioxus*. A, egg with gametic nuclei fusing, polar body at top; B, two-cell stage with nuclei in mitosis; C, four-cell stage; D, thirty-two-cell stage; E, blastula; F, section of blastula showing the central blastocoel; G-I, invagination of blastula to form two-layered gastrula, obliterating the blastocoel and forming a nutritive cavity, the enteron. (After Conklin. Redrawn.)

The cells continue to divide simultaneously, either vertically or horizontally, up to the seventh division with a gradual decrease in size of the cells. Meanwhile a space appears and increases in size within the cell mass. This is the blastocoel, and the embryo is now in the early blastula stage. At its full development the blastula comprises some 200 cells arranged in a single layer. Then the macromeres near

the vegetal pole form a flat area which soon invaginates and thereby obliterates the blastocoel. The embryo has now attained the early gastrula stage, consisting of two layers of cells: ectoderm on the outside that becomes ciliated and functions for locomotion, and endoderm on the inside forming the enteron, or primitive gut, that opens to the exterior by the blastopore. When first formed the blastopore is very large, but it gradually decreases in size until it is a tiny pore that becomes hidden from view by overgrowth of the ectoderm. And as the gastrula grows three important differentiations develop synchronously: the nervous system, notochord, and mesoderm with its secondary tissue products. (Fig. 180.)

NERVOUS SYSTEM AND NOTOCHORD

The entire central nervous system is indicated by a flattening of the dorsal surface of the elongating gastrula, the center of which becomes somewhat depressed to form the NEURAL PLATE. Then on either side of this plate arises a longitudinal ridge, or NEURAL FOLD, the two growing upward and over toward each other until they meet in the midline and roof over a groove in the neural plate to form the NEURAL TUBE. This remains open at both ends: anteriorly by the NEUROPORE to the exterior, and posteriorly by the NEURENTERIC CANAL leading through the blastopore into the enteron. Throughout life the central nervous system consists of this simple tube with merely a slight specialization at the anterior end to represent a brain. (Fig. 180.)

While the neural tube is developing, the notochord is established just below to form the skeletal axis of the animal. It is a longitudinal cord of cells above the enteron, and therefore between the ectoderm and endoderm, that appears to arise by being pinched off, as it were, from the roof of the enteron.

MESODERM AND DERIVATIVES

Simultaneously with the arising neural tube and notochord there develops dorsolaterally on either side of the endodermal enteron, between it and the ectoderm, a linear fold or ridge of cells. These folds are the fundament of the mesoderm and its derivatives. Soon each fold becomes divided by transverse partitions into a series of units, or MESODERMAL SOMITES. In the anterior region these are, apparently, outpocketings or pouches from the enteron and so from the start contain a cavity, but passing posteriorly toward the blastopore they be-

come progressively simpler until they are merely cords of cells in which cavities later appear.

As development proceeds the mesodermal somites become detached from their point of origin and continue to grow down on either side of the enteron until they meet and fuse in the mid-ventral line. The upper portion of each somite retains its segmentation, while the lower loses it so that lateroventrally there are two continuous layers of mesoderm enclosing a space, the coelom or body cavity. Later the segmented mesoderm above becomes separated from the lateral mesoderm and forms, in particular, the segmental muscle plates, or MYOTOMES. The two layers of the lateral mesoderm enclosing the coelom are an outer somatic layer that forms the lining of the body wall, and an inner splanchnic layer that forms the outer coat of the enteron, now the alimentary canal. With the union of these layers below the alimentary canal the coelomic cavities on both sides merge into one continuous body cavity.

The fundamental plan of development of the body of amphioxus has now been outlined, including the origin of two of the chief diagnostic chordate structures: dorsal nerve tube and notochord. For the purpose in hand it is necessary only to add that the characteristic gill slits arise as perforations of the alimentary canal and body wall in the anterior region, just behind the mouth, while somewhat posteriorly a large evagination from the alimentary canal into the coelom constitutes the liver. (Fig. 443.)

DEVELOPMENT OF THE FROG

With the general facts of earthworm and amphioxus embryology affording perspective, the reproductive systems of the frog, bird, and man will serve as suitable examples of the fundamental similarity in plan and the great diversity in details that are exhibited in the vertebrates.

For descriptive purposes the development of the frog may be divided into three periods: germ cell formation and spawning; fertilization and embryo formation; larval stages and metamorphosis.

GERM CELL FORMATION AND SPAWNING

The gonads, or testes, of a male frog are relatively small, ovoid bodies lying in the body cavity, one just ventral to each kidney and attached to it by a delicate membrane. Within the testes are numerous

fine tubules, the walls of which give rise to sperm that pass into the cavities of the tubules and then through small ducts to the associated kidneys. From the kidneys the sperm reach the ureters that function as sperm ducts (VASA DEFERENTIA) and carry the sperm to the cloaca and out of the body. Thus the ureters act in a dual capacity and are UROGENITAL CANALS. (Fig. 181.)

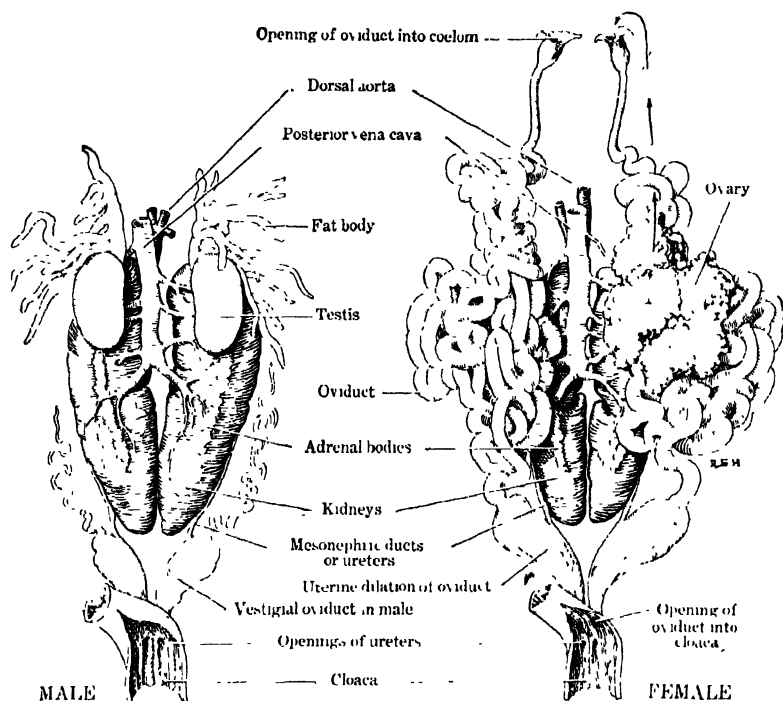


FIG. 181. Urogenital organs of male and female frogs. Diagrammatic.

The two ovaries of the female lie in a position similar to that of the testes in the male, but are irregular in form and during the height of the breeding season become so greatly distended with eggs that they are the most conspicuous organs in the body. Eventually the eggs are liberated into the body cavity and enter the funnel-shaped openings of the long, coiled oviducts, each with an enlargement, or uterus, just before it joins the cloaca. During the passage of the eggs down the oviducts, a gelatinous coating is secreted about them. (Figs. 170, 181.)

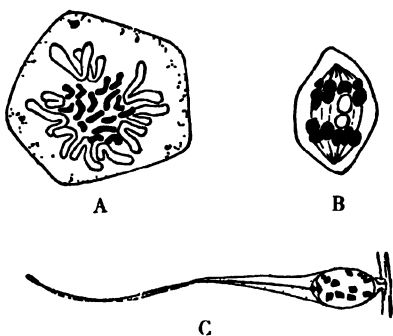
Spermatogenesis and oögenesis, involving the maturation of the gametes, follow the typical process. The first polar body is formed as the egg passes down the oviduct and the second at the time of fertilization. The eggs are covered with a continuous, gelatinous layer, secreted by the walls of the oviducts, so that when they are shed they adhere in strings, and later, as the jelly swells in the water, they are embedded in a large gelatinous mass which absorbs heat and affords protection.

FERTILIZATION AND EMBRYO FORMATION

The male, when mating, discharges sperm over the eggs as they pass from the cloaca of the female to the surrounding water. Fertilization occurs just as the eggs leave the body of the female and the eggs are left to their fate. The sperm pass through the jelly, and a single sperm enters each egg: the sperm nucleus uniting with the egg nucleus to form the synkaryon of the zygote.

Before the start of cleavage the zygote is organized to some extent because the axes of the future embryo are already defined, as indicated by the pigment pattern of the outer parts of the egg. The upper, or animal pole, contains a black pigment, and just below this is visible a gray crescent which on one side separates the dark region from the yellowish-white of the lower or vegetal pole, rich in stored food material, or yolk. (Fig. 183, A-F.)

FIG. 182. Stages in the spermatogenesis of the frog, *Rana temporaria*. A, Metaphase of a spermatogonial division showing the 26 chromosomes characteristic of this species. B, Second maturation division showing the x and y chromosomes (in outline). C, Immature sperm. (After Witschi.)



The presence of a large amount of yolk influences the character of the cleavage of the egg. Thus cell division is progressively more rapid, and accordingly the cells smaller, in the region with little yolk, the upper (animal) pole, than in the yolk-laden lower (vegetal) pole. The first and second division planes are from pole to pole, and give rise to four cells of equal size. The third division plane is just above the equator of the egg, at right angles to the former planes, and establishes

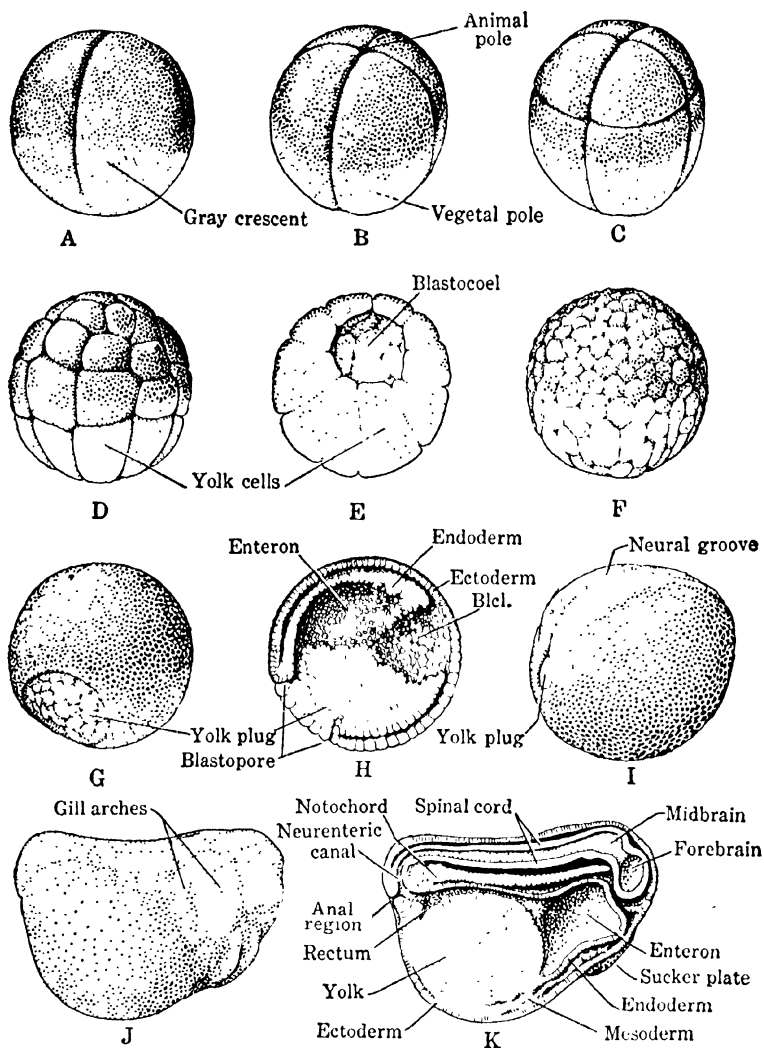


FIG. 183. Early development of the Frog. A, B, C, egg at two-, four-, and eight-cell stages; D, early blastula; E, section of D; F, late blastula; G, early gastrula: overgrowth of ectoderm (cells of ectoderm now too small to be shown in figure); H, section of G showing germ layers and internal structure (Bcl., blastocoel); I, late gastrula: formation of medullary plate with groove forming the foundations of the central nervous system; J, older embryo, with neural groove closed, assuming tadpole form; K, section of J showing internal structure.

four dark, pigmented cells above, and four larger, pale, yolk-laden cells below the equator. As division proceeds, soon there are many cells arranged in the form of a hollow sphere which will be recognized as the blastula. (Fig. 183, *E.*)

The typical transformation of the frog blastula into the gastrula by invagination is greatly obscured by the large amount of yolk in the embryonic endoderm cells. In fact, the endoderm is formed by a flat infolding of cells, just below the edge of the small dark cells, that finally results in a crescentic groove on the surface, which is the edge of the blastopore. But gastrulation is not completed until all the large endoderm cells are enclosed by ectoderm cells, and this is accomplished chiefly by the latter gradually creeping and folding over the exposed, pale endoderm cells (YOLK PLUG) until merely a small blastopore remains opening into the enteron. (Fig. 183, *H.*)

The development of the third germ layer, or mesoderm, takes place by the ingrowth of a layer of cells between ectoderm and endoderm along the edge of the blastopore where these two layers merge. Later when the mesoderm has grown forward and spread out between the ectoderm and endoderm, the lower portion (LATERAL PLATE) splits into somatic and splanchnic layers and thus gives rise to the coelomic cavity between. The upper portion of the mesoderm (VERTEBRAL PLATE) exhibits traces of primitive segmentation as its constituent

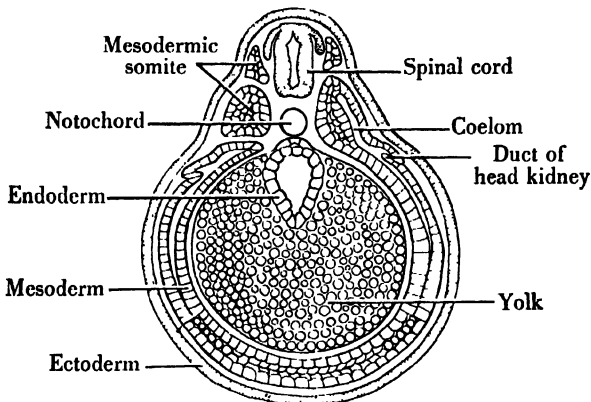


FIG. 184. Transverse section of a frog embryo at the beginning of elongation, *i.e.*, at about the same stage as Fig. 183, J, K. The splanchnic and somatic layers of the mesoderm are shown, the guide line ending in the inner, or splanchnic layer. (After Marshall. Redrawn.)

mesodermal somites form a series of muscle plates, or myotomes, on either side of the notochord which, in the meantime, has arisen from an axial, dorsal strip of cells above the enteron. (Fig. 184.)

During the later stages of gastrulation, the foundations of the central nervous system are established by the differentiation of an area of ectoderm cells, the medullary plate, on the dorsal surface of the embryo. Then a neural groove appears and, finally, the plate area is completely enclosed by the growth upward, over, and then fusion of the edges of the medullary plate. Thus the open plate is converted into the neural tube which is soon to be differentiated into forebrain, midbrain, hindbrain, and spinal cord. (Figs. 144; 183, *I*; 184.)

Simultaneously with the establishment of the central nervous system, the differentiation of the enteron into the alimentary canal, opening by mouth and anus, and also various other internal transformations have proceeded apace. Furthermore, the embryo has been gradually elongating so that it is nearly twice as long as broad by the time it begins locomotion by means of cilia distributed over the body surface. And soon thereafter the larva escapes from the jelly as an active free-swimming animal. (Fig. 185, *E, F*.)

LARVAL STAGES AND METAMORPHOSIS

The larva develops rapidly, and quickly becomes somewhat fish-like in form, with a vertically flattened tail which provides for locomotion during the rest of the animal's purely aquatic life as a TADPOLE. Independent existence demands sense organs, and these are already functioning in the head region. It also demands the intake of food which earlier was supplied by the yolk stored in the egg, and so the mouth develops a hard rim for scraping food material from the surface of aquatic plants. Moreover, increased respiration is necessary, and this is met by the appearance of branched external gills on the sides of the head, which are the first of a series of three different respiratory organs that succeed one another during the life history. Indeed, these external gills are soon covered over by a fold of the skin, the OPERCULUM, which finally leaves but a single opening, the SPIRACLE, to the exterior. And no sooner is the operculum fully developed, than the external gills are resorbed and a new set of fishlike internal gills take their place in the gill slits. Then hind legs slowly make their appearance, followed by the forelegs that are already developed under the operculum. (Fig. 185, *A, B, I, J*.)

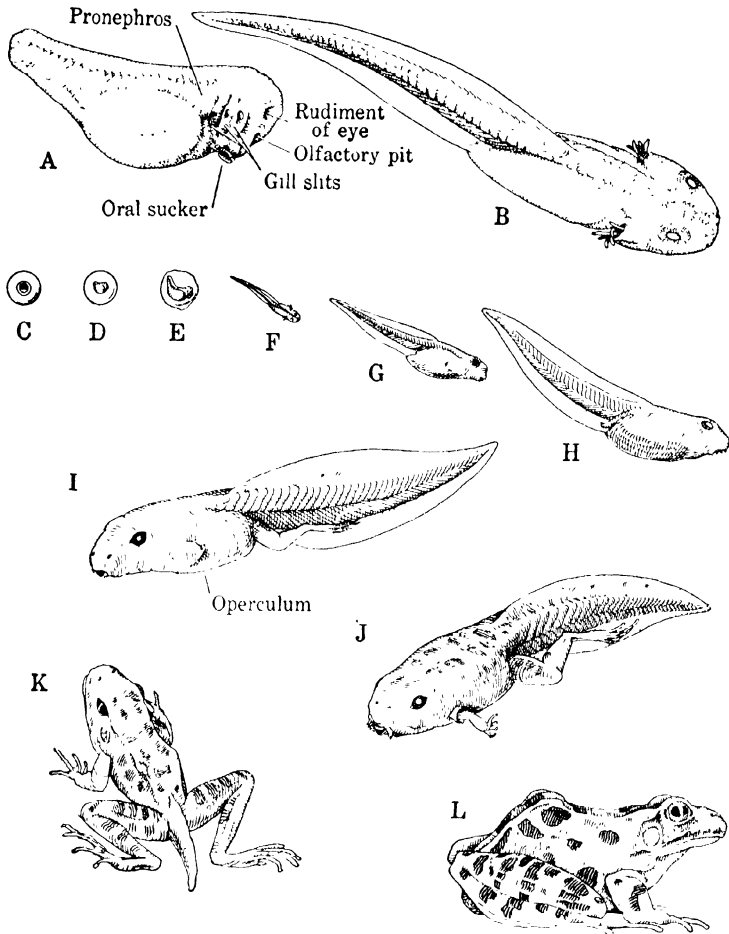


FIG. 185. Later stages of development and metamorphosis of the frog. A, B, stages closely following K in Fig. 183; C-L, stages from egg to adult drawn to scale. Note gradual changes during metamorphosis from an aquatic fish-like animal (G) to a terrestrial air-breathing type with legs and no tail.

Now the larva is ready for metamorphosis: its transformation from a gill-breathing tadpole to a lung-breathing juvenile frog. During metamorphosis one stage changes rapidly into the next: the tail is resorbed, the legs increase in size, the long coiled intestine becomes shorter and specialized to digest animal food, the internal gills are resorbed, and lungs are developed which make it necessary for the tadpole to come

to the surface of the water for air. Finally, the young frog transfers its abode largely to land, and grows. (Fig. 185, K, L.)

The process of metamorphosis varies in length from a few weeks to several years in different species of frogs. In all cases it is some time after metamorphosis before sexual maturity arises. Preceding the first breeding season, the gonads develop rapidly, their ducts become fully differentiated, and adult male and female individuals are fully established. (Figs. 170, 181.)

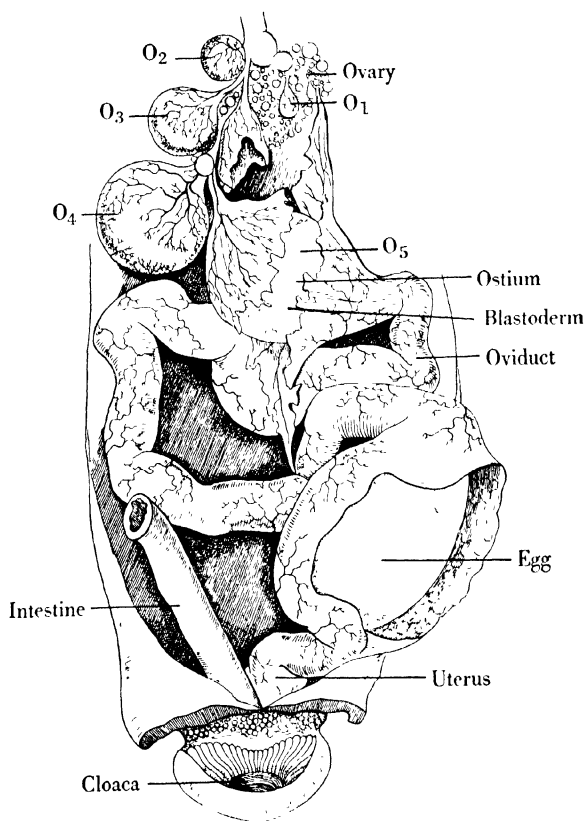


FIG. 186. Reproductive system of hen. The single ovary is shown above, with numerous ovarian eggs (O_1 , O_2 , O_3 , O_4) in various stages of development. The oviduct with opening (ostium) is shown receiving an egg, O_5 , just released from the ovary. Normally only one egg passes through the oviduct at a time. Posteriorly the oviduct has been opened to show a fully formed egg enclosed in a secreted shell. (After Duval, Modified.)

AVIAN DEVELOPMENT

The embryonic development of the higher vertebrates departs rather widely in many ways from that of the frog. Thus the eggs of reptiles and birds contain much more yolk, with consequently a still greater obscuring, though not obliteration, of the characteristic blastula, gastrula, etc. (Figs. 186, 187.) The first result of the great amount

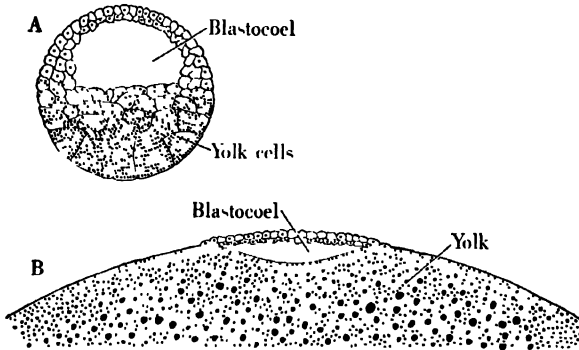


FIG. 187. Comparison of the blastula of the frog (A) and chick (B). Vertical sections. Diagrammatic. (From Huettner.)

of yolk is that complete division of the egg is impossible, so the egg really consists of two parts: the inert yolk and the protoplasmic region in which cell division occurs and eventually forms the embryo proper with its associated EMBRYONIC MEMBRANES. (Fig. 176.)

In the bird's egg the cleaving protoplasm consists of a tiny disc (BLASTODERM) which lies on the upper surface of the mass of yolk. Thus the embryo during its early stages is crowded upward and forms essentially a flat plate of tissues spread out on the surface of the spherical yolk, while embryonic membranous tissue is growing around the yolk to form the YOLK SAC. As development continues the embryo itself is gradually raised above and partly separated from the yolk, until only a narrow connection with the yolk sac persists. (Figs. 188, 189, 192.)

The embryonic membranes include the AMNION, CHORION, and ALLANTOIS. The amnion and chorion arise from a crescentic fold of extraembryonic tissue which finally completely surrounds the embryo and yolk sac with two membranous layers. The inner membrane, or amnion, encloses a fluid-filled space, the amniotic cavity, in which the

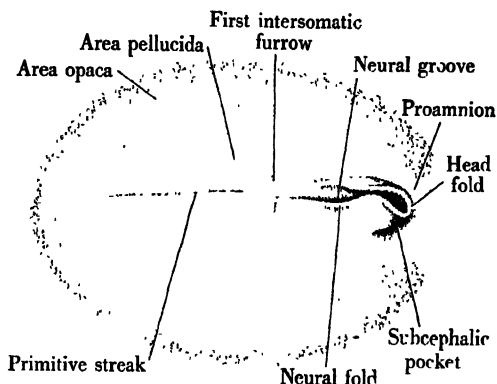


FIG. 188. Chick embryo after 22 hours incubation, showing differentiation of blastoderm and organization of embryo. Dorsolateral view. (From Huettner.)

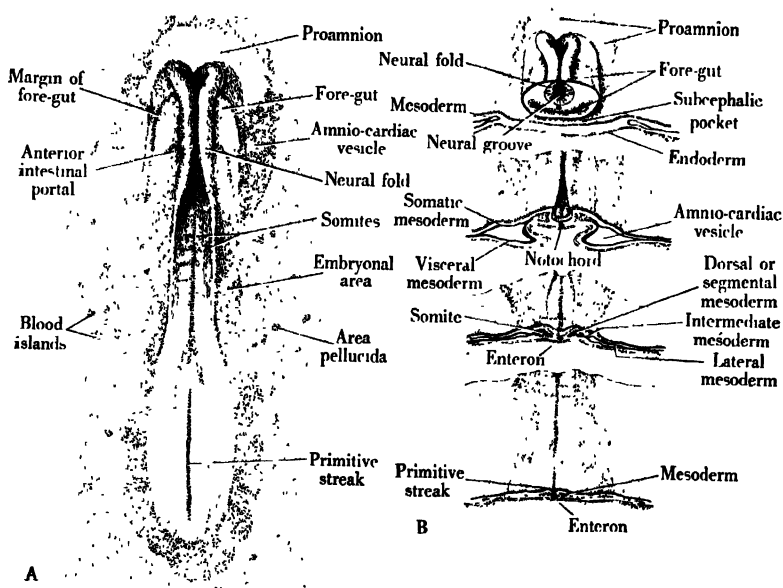


FIG. 189. Chick embryo after 24 hours incubation: A, surface view; B, four transverse sections of embryo through different sections of body. Somewhat diagrammatic. See Figs. 190, 191. (From Huettner.)

embryo lives. Thus the amniotic fluid affords, as it were, a "private pond": a substitute in terrestrial eggs for the aquatic environment of their ancestors. (Fig. 192.)

The outer membrane, or chorion, that arises from the amniotic fold, forms the external surface through which the interchange with the outer world takes place. This is made possible by the allantois which arises as a membranous outpocketing of the intestinal region of the embryo that gradually intrudes itself between the amnion and chorion. The allantois acts as a urinary bladder and, after the development of blood vessels in its walls, also serves for respiratory interchange through the investing chorion and the porous shell. (Figs. 190, 191.)

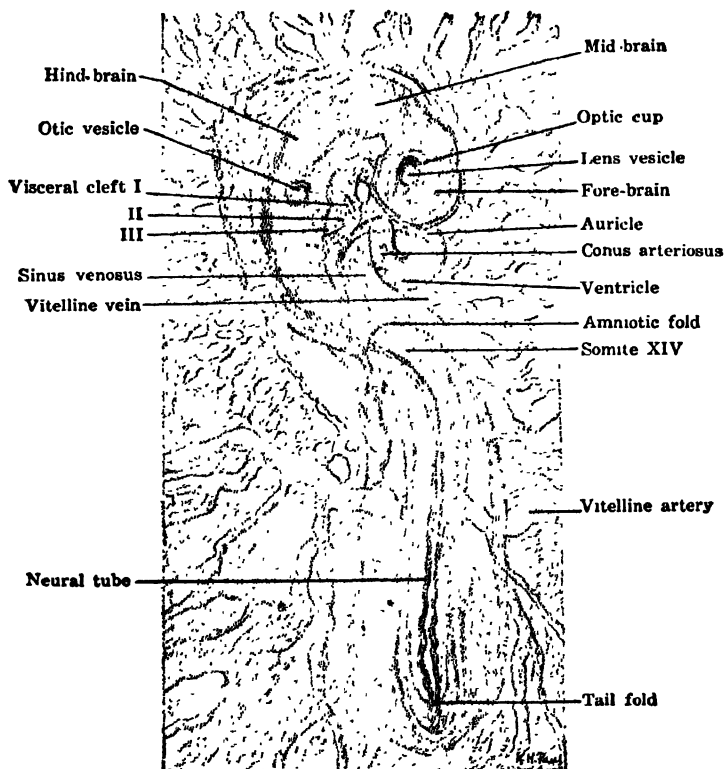


FIG. 190. Chick embryo after 48 hours incubation, surface view. Anterior end of embryo has been folded off from underlying yolk, and is seen from right side only. Posteriorly, embryo lies on surface of yolk. See Figs. 191, 192. Enlarged. (From Shumway.)

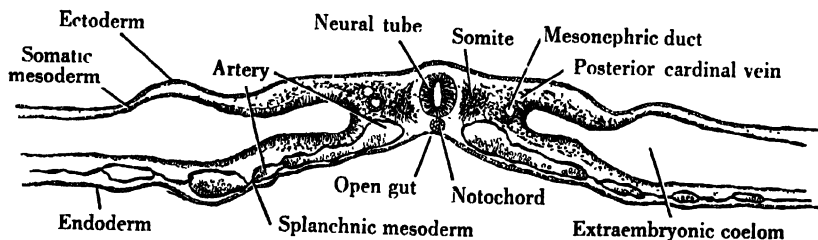


FIG. 191. 48-hour chick embryo. Transverse section through posterior part of body that has not, as yet, been folded off from the underlying yolk. (After Huettner.)

The embryonic membranes—yolk sac, amnion, chorion, and allantois—develop from the egg, but they do not constitute an actual part of the embryo. After performing their several functions they are discarded at the time of hatching. Such are the conditions in reptiles and birds, and they make understandable the conditions in the placental mammals.

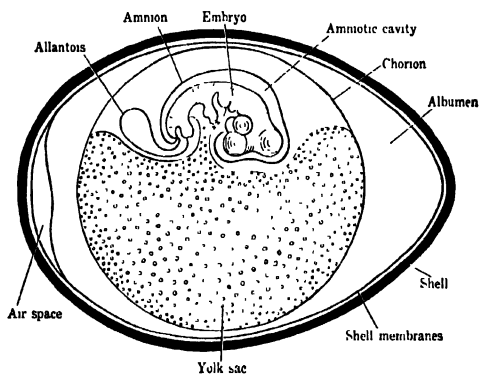


FIG. 192. Diagram of vertical section of hen's egg after five days of incubation. The embryo, now separated from yolk except for connecting yolk stalk, naturally lies on its side, but has been raised to show general body form.

CHAPTER XX

Animal Development (II)

MAMMALIAN DEVELOPMENT

The mammalian egg is very small, contains practically no yolk, and undergoes total cleavage, yet many of the developmental stages obviously are reminiscent of an earlier condition when a large supply of yolk existed—food material no longer needed because a functional relationship is soon established between embryo and mother. (Fig. 193.)

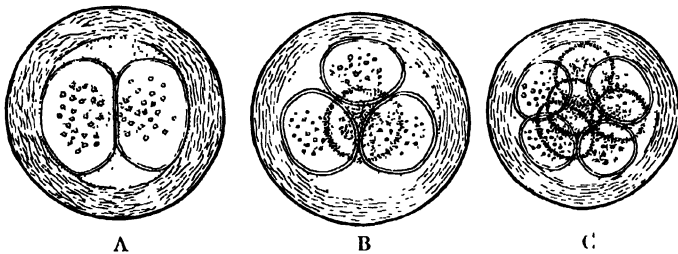


FIG. 193. Drawings from photographs of early stages in the development of egg of the rabbit. A, two-cell stage, 24 hours after fertilization, enclosed by thick surrounding membrane (zona pellucida); B, four-cell stage, 29 hours; C, eight-cell stage, 32 hours. Highly magnified. (After Streeter. Redrawn.)

The embryonic membranes are retained in mammals though they differ materially from those in reptiles and birds where food is supplied from the yolk sac. Since all the income of the mammalian embryo is derived from the mother, the chorion and allantois are modified to contribute to the marvelous maternal structure that makes this possible, the PLACENTA. (Fig. 194.)

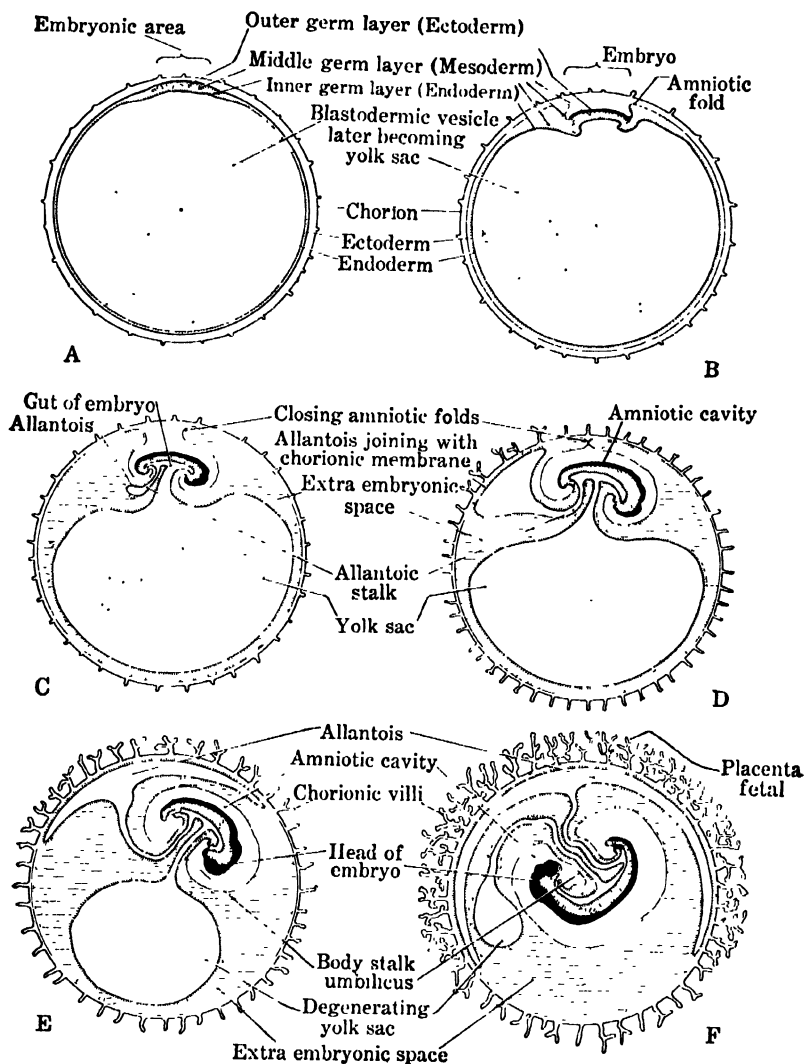


FIG. 194. Diagrammatic sections showing the development of the egg and embryonic membranes of a mammal. A, early stage showing rudiment of embryo at top, before the appearance of the amnion; B, embryo outlined, with developing amnion and yolk sac; C, embryo with amnion further developed and allantois appearing; D, embryo with amnion closing, and allantois joining with outer membrane, or chorion; E, F, embryos in which the vascular layer of the allantois is applied to the chorion and growing into the villi of the latter to form the placenta; yolk sac reduced; amniotic cavity increasing; mouth and anus established. Compare with chick embryo in Fig. 192.

In placental mammals the allantois and chorion form an intimate union. The chorion, in turn, develops a close union with the membrane lining the maternal uterus and thus constitutes the essential part of the fetal placenta. The area of attachment of the processes from the chorion, or **CHORIONIC VILLI**, with the uterine wall varies in different mammals. For example, in the horse and whale the villi cover the whole surface of the chorion, whereas in man they are restricted to a single discoidal area. The latter accounts for the name "placenta": a round, flat body. It appears that the dominant position of the Mammalia in the world of life is in no small part due to the protection and nourishment made possible for their offspring by the establishment of intrauterine development—and this by the development of the chief embryonic membranes to placental use.

The testes of the human male, ovoid in form, develop within the abdominal cavity, one near each kidney, but before birth they migrate posteriorly and pass from the cavity into an external pendant sac, the **SCROTUM**. Each testis is suspended in the scrotum by a spermatic cord which includes not only a part of the vas deferens, but also blood vessels and nerves. The testes consist chiefly of numerous convoluted tubules in whose walls sperm are developed. On leaving the testis the sperm pass

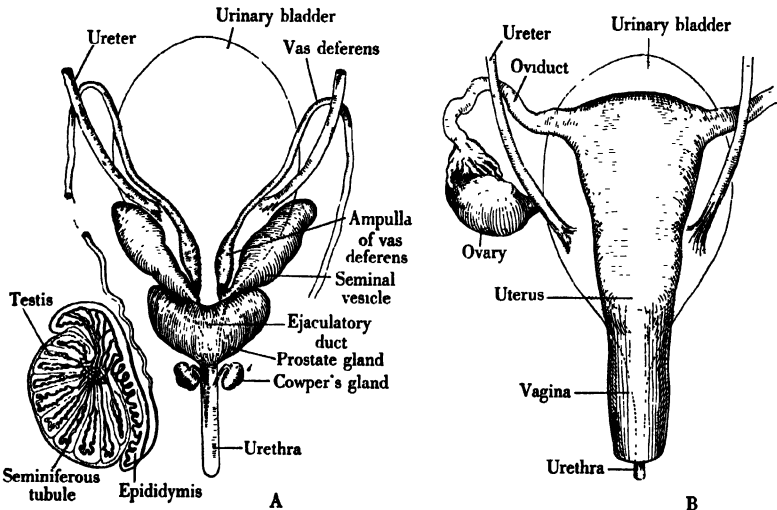


FIG. 195. Diagrams of the human urogenital organs. Posterior, or dorsal, views of left side. A, male; B, female. (From Hegner. Redrawn.)

through a long coiled tube, or EPIDIDYMIS, one closely apposed to each testis, and then to the vas deferens. The vas deferens from each testis passes into the abdominal cavity and there, after being joined by a sperm reservoir, or SEMINAL VESICLE, merges into an EJACULATORY DUCT which opens into the URETHRA leading from the urinary bladder. Also opening into the urethra at near the same point are the PROSTATE and COWPER'S GLANDS that contribute to the seminal fluid bearing the sperm. Accordingly the lower portion of the urethra in the male acts as a common urogenital duct that opens to the exterior through the penis. (Fig. 195.)

The two ovaries of the female develop and remain in the abdominal cavity near the kidneys. Each consists largely of a connective tissue matrix enclosed by an epithelium which gives rise to the eggs. When, during sexual maturity, an egg is released into the abdominal cavity by the rupture of the ovarian wall, it enters the funnel of the associated oviduct, or FALLOPIAN TUBE, and starts down toward the exterior. If fertilization occurs during transit, the egg becomes implanted in the uterus which is formed by the union of the lower ends of the two oviducts. Here development proceeds until birth.

In the human body, the attachment of the fertilized egg in the uterus is followed by the very rapid development of what may be regarded as a new uterine lining, profusely supplied with blood vessels. This soon surrounds the embryo and, as pregnancy proceeds, the embryo protected by EMBRYONIC MEMBRANES projects into, and finally completely fills, the gradually increasing uterine cavity. As the uterus enlarges, it exerts increasing pressure on the adjacent organs, and later shifts to a position higher up in the abdominal cavity where the flexible body wall more readily accommodates it. Throughout the entire period of pregnancy the embryo leads a parasitic existence at the expense of the mother's tissues, which supply it with food and oxygen, and also remove carbon dioxide, urea, and other metabolic wastes. This, of course, imposes a considerable amount of extra work on the various maternal organs, especially the lungs, kidneys, and digestive system, and therefore special provisions must be made for this intimate interchange of materials between the blood vascular systems of mother and offspring. (Fig. 196.)

The embryo at first is nourished by materials absorbed from the rich blood supply of the uterine wall, but soon this proves inadequate for the rapidly increasing demands of the growing embryo, and a new

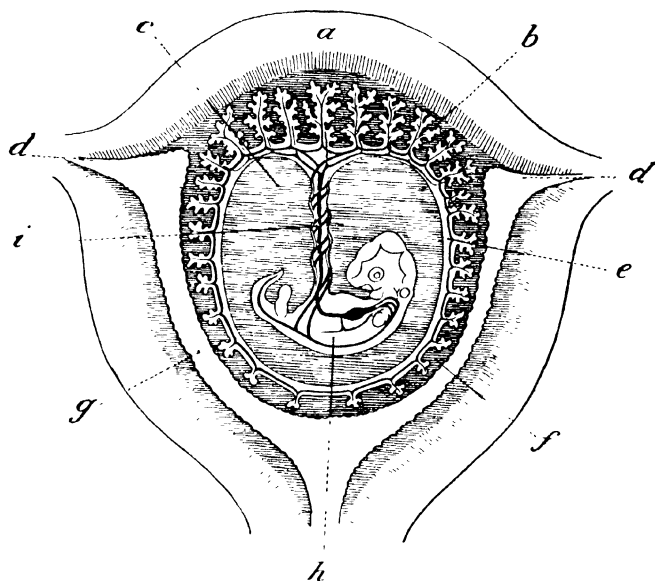


FIG. 196. Diagrammatic section of a human uterus with developing embryo. The embryo (*h*) is suspended in a fluid-celled cavity (*c*) surrounded by embryonic membranes (*e*) and by tissue (*f*) from the uterus. The sole path of communication between embryo and mother is by blood in vessels passing up through the umbilical cord (*i*), spreading out into capillaries in the placenta (*b*) and there coming into close relations with the maternal blood supply. There are no direct connections. The transfer of materials between mother and child is by diffusion and osmosis through the placental tissues. The openings of the oviducts (*d*) into the uterus become closed during the development of the embryo. *a*, dorsal wall of uterus; *b*, placenta; *c*, fluid-filled cavity of amnion; *d*, openings of oviducts (Fallopian tubes); *e*, embryonic membranes; *f*, uterine tissue; *g*, uterine cavity; *h*, embryo; *i*, umbilical cord.

structure, the PLACENTA, is formed jointly by the tissues of the uterus and embryo to meet the need. The connection of the embryonic body with the placenta is by the UMBILICAL CORD. The blood of the embryo passes by its arteries through the umbilical cord to capillaries in the placenta, and after exchanging various waste products for food, oxygen, etc. by diffusion with the maternal blood supply, returns by veins to the embryo. There is no direct intermixture of maternal and embryonic blood—merely the diffusion through a semipermeable membrane of substances in solution. These substances must comprise relatively small molecules; for example, proteins of large molecular structure must be broken up into components of smaller size and then,

after passing the placenta, be rebuilt by the embryonic tissues. Disease germs, in general, do not pass the barrier unless they injure the placenta, although possibly some of the virus particles are small enough to get through. Furthermore, it should be emphasized that there is no other means of communication between mother and child. "Not a single nerve fiber crosses the placental barrier; there is no channel for the transmission of feelings or intentions, moods, memories, or ideas," and therefore there is no support for the widely prevalent erroneous notion of so-called maternal impressions. But, of course, this does not deny that the well-being of the offspring is intimately related to that of the mother.

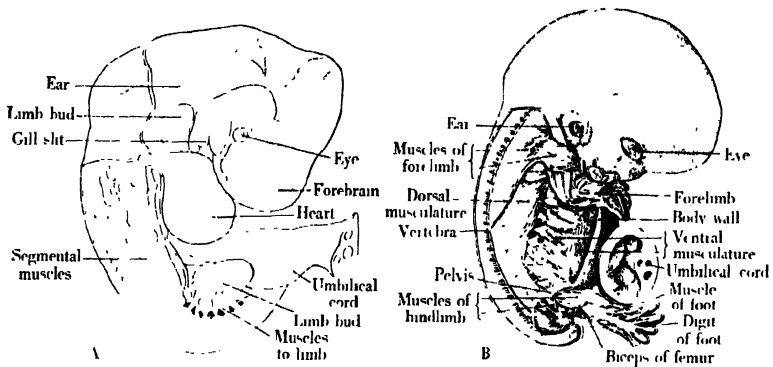


FIG. 197. Human embryos: A, external structure of a 5 week (9 mm.) embryo, partly dissected, X5; B, external structure of an 8 9 weeks (20 mm.) embryo, partly dissected, X2. Note the much greater development of the embryo shown in stage B. Somewhat diagrammatic. (From Davenport.)

In brief, the embryo from the beginning is a separate organism whose blood supply normally merely interchanges relatively simple chemical materials with that of the mother through the placenta. This temporary dependence is terminated when the child is expelled from the uterus, the umbilical cord is severed, and the offspring is born. A little later the so-called afterbirth, consisting of the placenta and embryonic membranes, is also expelled. (p. 268.)

Thus, except in the simplest animals, there is a special reproductive system: a series of organs connected with the reproductive function. But it must be emphasized that the essential organs are the gonads themselves and all the rest are accessory. Furthermore, in relation to

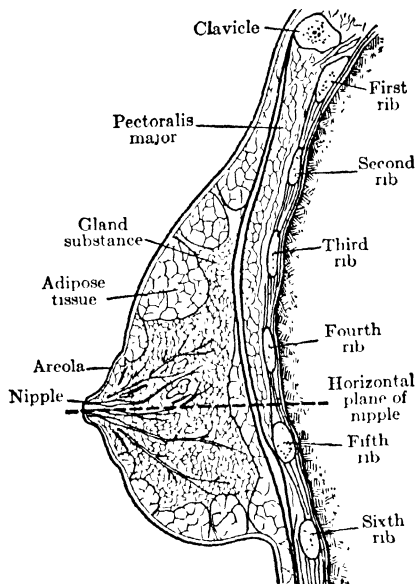


FIG. 198. Section through mammary gland of human female. Section through chest wall at right. Diagrammatic. (After Gerrish.)

the sexual differentiation of male and female individuals, many so-called **SECONDARY SEXUAL CHARACTERS** arise which are not directly connected with the reproductive organs, but nevertheless depend very largely for their development upon **HORMONES** liberated by the gonads. For example, early castration of the stag inhibits the growth of a distinctive male secondary sexual character, the antlers; while if performed later when the antlers are full grown, they are shed and abnormal ones take their place. In fact, the sexual life of most animals, including man, is largely conditioned by hormonal activity. (Fig. 118.)

THE VERTEBRATE UROGENITAL SYSTEM

The structural interrelations of the urinary and reproductive organs forming the **UROGENITAL SYSTEM** will now be considered. It has been pointed out that the nephridia, which combine to form the kidneys in some of the lower vertebrates, retain their funnel-like openings into the coelom and therefore afford a direct exit for waste material in the coelomic fluid. It is some of these nephridia that are employed in some fishes and amphibians for the transfer of the germ cells to the outside.

The testes of the male, which lie close to the kidneys, become connected with the nephridia (mesonephros) by a series of short delicate tubes. Through these tubes the sperm from the testes are transferred to the nephridia and by them to the kidney (mesonephric) ducts and so to the exterior with the urinary waste. In this way, during the period of sexual activity of the male, the kidney tubules satisfactorily perform two functions, and the mesonephric ducts become urogenital canals. (Fig. 126.)

In the female, the ovaries, which are situated in about the same position with relation to the kidneys as the testes in the male, do not enter into communication with a set of nephridia of the kidneys (mesonephros); probably because the eggs are too large to pass through the tubules. Instead, what appears to be the coelomic opening of a single nephridium-like structure on either side (which fails, so to speak, to enter the kidney complex) enlarges and becomes the funnel that connects with a new duct opening into the cloaca. In this way in the female urinary system a pair of entirely distinct oviducts arises. An egg liberated from the ovary is drawn into an oviduct and descends directly to the outside, or into an enlargement (uterus) of the terminal portion of the duct where development proceeds until birth occurs (Figs. 126, *D*; 181.)

The female reproductive system, though derived from the mesonephric system, has become entirely independent of it. Accordingly the disappearance of mesonephros and duct in higher male vertebrates, when it is replaced by the metanephros and the ureter as the functional urinary system, has little effect on the female reproductive system. As a matter of fact, the abandoned mesonephros and duct degenerate and disappear in the female, whereas in the male the mesonephric duct remains and becomes completely appropriated by the reproductive system. The sperm now pass directly into the former mesonephric duct, which thereby becomes solely a sperm duct. (Figs. 126, *E*, *F*; 195.)

Such is the historical origin of the foundations of the reproductive system as it occurs in the reptiles, birds, and mammals. Each of these groups, building on this foundation, has developed modifications and additions demanded by its special lines of evolution. It appears again that, whenever possible, available structures are employed to construct what is to be, and thus higher forms may exhibit in their bodies a partial record of their ancestry.

With this description of certain of the chief features of the embryology of representative animals it is possible to gain some appreciation of the complexity of the processes involved, as well as of the similarity of the basic method of development: cleavage, blastula, gastrula, primary germ layers, etc. Furthermore, for example, it will be recalled that typically the ectoderm forms the outer skin and nervous system; the endoderm supplies the lining membrane of the major part of the alimentary tract; while the mesoderm contributes muscles, blood vessels, reproductive organs, the membrane lining the coelom, etc. This similarity in origin of the organ systems from the primary germ layers, throughout the animal series above the coelenterates, is of the highest significance because it indicates a fundamental structural similarity in the body plan of all these forms. It is exhibited in the developmental process in each generation, even though the adult body in the various groups differs widely in form and arrangement of organs. Such a state of affairs clearly suggests a hereditary relationship throughout the animal series. (Figs. 178-180.)

PROBLEMS OF DEVELOPMENT

Embryology is something more than the description of the kaleidoscopic series of stages which seem to melt one into the other as development progresses. It attempts, especially at the present time, to look below and beyond structure to the physiological processes involved, and to determine how the sequence of events is brought about. This is but a repetition of the stages of progress in all science: a passage from the descriptive to the experimental. The results thus far secured have raised many, and answered some, problems of development that are of great practical importance and theoretical interest. Outlines of three major problems will be helpful as examples.

EPIGENESIS VERSUS PREFORMATION

From what the pioneer students of embryology during the seventeenth and eighteenth centuries saw, or thought they saw, with simple lens and newly invented compound microscope, there were gradually formulated two opposing views of development which, though long since swept aside in their original form as a result of the increase of knowledge, raised a problem that is still before the embryologist today.

In brief, one view virtually denied development by maintaining that the adult organism is nearly or completely formed within the germ,

that is, either in egg or sperm, which merely by expansion, unfolding, and growth produces the new generation. In this first crude form the PREFORMATION theory demanded the encasement of all future generations one within another in the gamete of existing organisms, so that when it was computed that the progenitor of the human race must have contained some two hundred million homunculi (a conservative estimate, to say the least) the *reductio ad absurdum* was irresistible. (Fig. 199.)

The other view was reached by careful studies on the transformation of the hen's egg into the chick, which soon made it clear that the chick is not preformed in the egg. The embryo arises by a gradual process of progressive differentiation from an apparently simple fundamēt; it is a true process of development, or EPIGENESIS. But the upholders of epigenesis were before long beyond their depth and in danger of attempting to get something out of nothing—lost in the miraculous.

A statement in such succinct form tends to accentuate the crudities of these two conflicting views—"preformation explaining development by denying it and epigenesis explaining development by reaffirming it"—and it may be well to remark that the early embryologists with the means at their command faced a stupendous task of which only recent work has brought a full appreciation.

The path to progress cleared by the realization that adult structures are not preformed as such in the egg, and that development is not an expansion but the formation—the becoming by an orderly sequence of events of structures of great complexity out of apparent simplicity—the problem of the embryologist was to determine what the egg structure actually is, and how it is related to that of the adult. To trace the development of these studies would involve the history of embryology since the formulation of the cell theory. We shall confine ourselves to the bare statement of the new guise in which the old theories of preformation and epigenesis confront us today as a result of recent research.

The reader already recognizes the fertilized egg as a cell, with its nucleus comprising a complex of quite definite elements—the chromo-

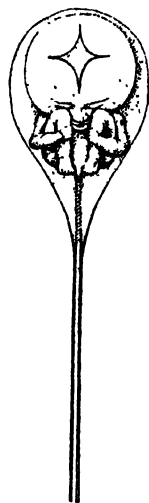


FIG. 199.
Human sperm with a complete homunculus as "seen" by a seventeenth century microscopist. (After Hartsoecker, 1694.)

somes—contributed jointly by the two gametes. To this extent, then, the nucleus and therefore the egg exhibit a ready-formed structural basis which (as we have already suggested, and will have occasion to elaborate later) is definitely related to characters which appear in the offspring. (pp. 238-240.)

Turning to the egg cytoplasm, one is confronted with conditions that are not so uniform but nevertheless highly suggestive. In the first place, before fertilization the egg possesses a definite **POLARITY**, expressed, for example, by the position of the nucleus and the distribution of yolk, pigment granules, and vacuoles. This polarity is traceable, in part at least, to the polarity of the oögonia, and through them to the germinal epithelium. In brief, the egg as a whole is *organized*; the invisible organization of the fundamental matrix of the cytoplasm being revealed, in part, by the disposition of various elements of the cell. Now this cytoplasmic organization undergoes more or less profound changes in establishing that of the new individual. In some cases the reorganization occurs at fertilization, while in others it is somewhat deferred. And herein, apparently, is to be sought the explanation of the difference in behavior—in potentialities—of various types of eggs during cleavage stages. Two contrasting examples will serve to bring the main facts before us. (Figs. 173, 201.)

The first type is well illustrated by the egg of a mollusk, *Dentalium*.

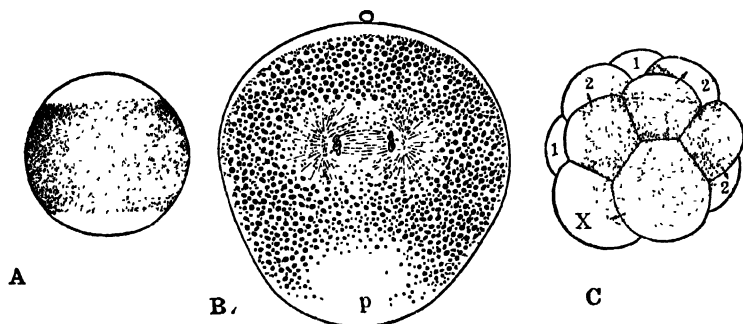


FIG. 200. Egg of a mollusk (*Dentalium*), showing cytoplasmic differentiation A, egg, shortly after being discharged from the ovary and before maturation is completed, showing three differentiated regions; B, section through an egg after fertilization, showing cytoplasmic rearrangement involving the segregation of clear polar lobe at p; C, normal sixteen-cell stage, with materials of polar lobe now in cell X. Removal of the polar lobe results in an abnormal embryo. (After Wilson.)

and a primitive chordate, *Styela*. The egg of the latter just after fertilization shows at least four clearly differentiated cytoplasmic regions. For the sake of simplicity these may be described as yellow, gray, slate blue, and white. As cleavage proceeds, these substances are distributed with great regularity to definite cell groups which, in turn, form special organs or organ systems of the animal. The yellow passes into cleavage cells that become mesoderm and muscles, the gray into cells that be-

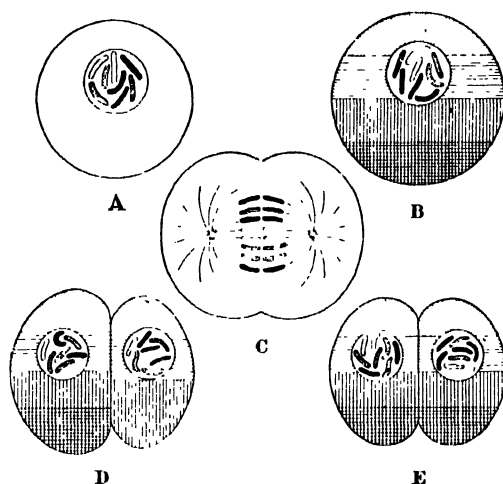


FIG. 201. Diagrams to illustrate how the character of the first division of a fertilized egg, or zygote, may influence the distribution of the products of cytoplasmic differentiation and, therefore, the potentialities of the resulting cells. A, immature egg, assumed to have no definite segregation of cytoplasmic stuffs; B, mature egg, with cytoplasmic zones established; C, first division of egg following fertilization; D and E, two types of two-cell stages; D, type with one cytoplasmic zone entirely distributed to one of the cells, and therefore each of the two cells, if separated, gives rise to an abnormal larva; E, type with equal distribution of the zones to both cells, and, therefore, if separated, each of the two cells gives rise to a normal larva. (From Wilson.)

come nervous system and notochord, the slate blue substance into endoderm cells, and the white material into ectoderm cells. Accordingly, within a few minutes after the fertilization of the egg, the anterior and posterior, dorsal and ventral, right and left poles are clearly distinguishable, and the substances that will give rise to various organs are plainly visible in their characteristic positions. Cleavage then segregates the cytoplasmic substances into particular cells so that the cells become differentiated

And further, the experimental removal of a cell or cell group in which a certain substance is segregated results in an embryo deficient in the very structures which this normally forms. In other words, the egg cytoplasm seems to be a mosaic of presumptive organ regions identifiable by so-called organ-forming substances which possibly themselves directly, but probably through more fundamental conditions of which they are but the visible expression, have a causal relation to definite adult structures. Just in so far as this is true, the adult is *predelineated* in bold lines, though not actually preformed, in the egg. (Fig. 200.)

In the second type of egg, as represented, for example, by the eggs of some sea urchins, the results obtained seem to be diametrically opposite. Although more or less clearly differentiated cytoplasmic regions appear to exist, frequently the removal of a part of the egg before division, or the separation of the cells at the two-cell stage, and sometimes even at the four-cell stage, has no permanent effect on the structural integrity of the developing embryo. Each of the cells has the power to develop into an embryo complete in every respect, but smaller than the normal. Or, to put it another way: a single cell of the four-cell stage, which normally forms one-fourth of the embryo, if isolated with one other cell, may form one-half of a normal embryo and, if isolated with two other cells may form one-third. And apparently the same phenomenon occurs in the case of human identical twins. The egg becomes separated into two parts during early development and results in two individuals with identical hereditary endowment. Identical quintuplets, all from one zygote, have become famous. In all such cases one may ask: what has become of the egg organization? (Fig. 202.)

At first glance the behavior of these two classes of eggs seems to afford results which are irreconcilable—the former supporting the doctrine of preformation in a refined form, and the latter its antithesis, epigenesis. But an explanation is not far to seek. The difference apparently depends, as already suggested, upon the time when chemical differentiation of the egg cytoplasm occurs and the products are localized in special regions. If this occurs before or at fertilization, so that the early divisions give rise to dissimilarly organized cells, then each of the cells is not *TOTIPOTENT*, and the mosaic type of development results as in *Styela* and *Dentalium*. But if the initial differentiation and localization is delayed until later, or is relatively slight so that all the

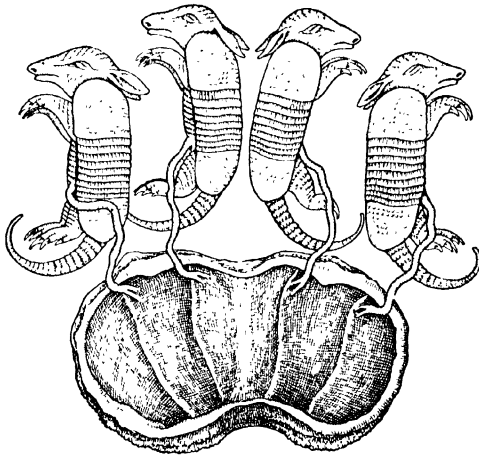


FIG. 202. Armadillo quadruplets developed from a single egg. The egg membranes (*below*) have been cut open, and the embryos removed but left attached by the umbilical cords. Diagrammatic. (From Newman.)

cells of the early stages are essentially similar, then during this period each cell is totipotent—the whole forms an EQUIPOTENTIAL SYSTEM—as exhibited by some of the early stages of the sea urchin. Thus we may regard from one standpoint the apparently contradictory behavior of the two classes of eggs, for it turns out to be reducible to a common factor: the time of chemodifferentiation and localization of the products. In one case this has progressed further than in the other during the early stages. In both cases, therefore, development is epigenetic in its obvious features.

However, since cytoplasmic differentiation is a fact whether it appears early or late, we have merely pushed the solution of the problem further back and the question becomes: Is there a primary differentiation and, if so, where? It is not necessary to discuss here the specific evidence on this point, but the reader's knowledge of the nucleus, and particularly its definite chromosomal architecture, will lead him to anticipate that modern research emphasizes the gene as representing a material configuration—probably a protein molecule of great complexity—which is transmitted, in a way "preformed", from generation to generation, and determines the cytoplasmic characteristics of the cells. As to how the specific physical basis of inheritance, the genes constituting the chromosomes, is related to cytoplasmic organization

and to characters which arise later, we can offer no satisfactory explanation or even guess. One must be content with the discussion in later chapters of some of the facts of heredity which show that genes in the chromosomes are causally related to the inheritance of specific characters.

But in so far as the nucleus possesses an organization definitely related to differentiations of the cytoplasm, organ-forming substances, or characters of embryo and adult, one may look upon the chromatin to this extent as representing a sort of primary preformation which is realized by a process of building up—epigenesis—as one character after another becomes established in the development of the individual. This is the guise in which the old problem of preformation versus epigenesis faces the biologist today.

So the early embryologists were right when, studying the egg of the frog or hen, they maintained that development *is* development and not merely the unfolding of an organism already fashioned in more or less definite adult form. But it took two centuries of research to reveal the fact that, below and beyond its superficial aspects, there is a germ of truth in the principle of preformation hidden in the nuclear architecture, the enormously complex physicochemical structure of the genetic basis, so that the origin of the individual, though obviously through epigenesis, is fundamentally from a sort of preformed basis. We no longer bother ourselves with the old conundrum as to which is more complex, the egg or the adult, but recognize that each is complex in its way—the simplicity of the egg being more apparent than real, as is attested by every endeavor to analyze cytoplasm, nucleus, chromosomes, genes, and beyond.

ORGANIZERS

It has been known for some time that the various regions of an embryo exert upon one another during their development highly important formative influences, but extensive experiments, in particular on amphibian embryos, have revealed a complexity of the problem that hardly would have been anticipated and have opened up a new approach to the problem of differentiation. This has been brought to the forefront by the discovery of various ORGANIZERS, substances of undetermined chemical constitution which play a fundamental role in the differentiation of tissues and organs during the development of both vertebrates and invertebrates.

It appears, for example, that a stimulus emanates from the embryonic cells (chorda-mesoderm) invaginated at the dorsal lip of the blastopore in the gray crescent region of the developing frog's egg. This stimulus induces in normal development the formation of a neural plate and tube, the fundament of the nervous system, and the primary axis of the future adult. When the dorsal lip is removed from an embryo and transplanted into another, the transplant continues characteristic gastrulation movements in its new environment and transforms the surrounding host material into so-called organ fields such as normally occur about the dorsal lip of the blastopore in its original position. (Figs. 183, 203.)

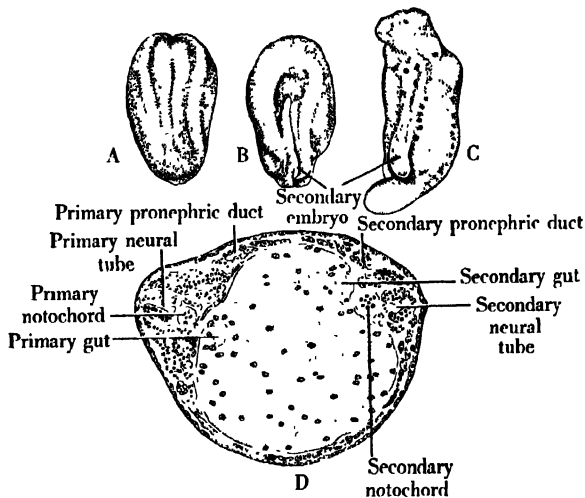


FIG. 203. Drawings to show the effect of transplanting, in an amphibian embryo, of organizer material from the dorsal lip of the blastopore. A, dorsal view of host embryo (*Triton taeniatus*) in medullary plate stage; B, right side view of same stage with secondary medullary plate induced by organizer from the donor (*Triton cristatus*) shown in white (center); C, later stage showing primary embryo in side view and secondary embryo in dorsal view; D, transverse section through C. (From Shumway, after Spemann and Mangold.)

Thus the grafted dorsal lip organizes about itself a new secondary embryo which is entirely independent of the normal embryo organized about the host's dorsal lip. The grafted dorsal lip itself becomes the notochord and mesoderm of the musculature of the second embryo which it organizes the neural plate, eyes, ears, heart, etc., from the tissue of the host. And in the process, the integrity of the germ layers

is violated because the organizer induces, for instance, ectoderm to form mesoderm and mesoderm to form ectoderm.

Furthermore, in addition to these primary organizers, so called because they induce the laying down of the primary axial pattern of the embryo, there are also secondary inductive agents. One example will serve as an illustration. In the normal development of amphibians, the eye cup induces the overlying epidermis with which it comes in contact to thicken and ultimately to become a lens. This is evident because, if the eye cup is surgically removed, the lens fails to develop. Moreover, the eye cup has the ability to form a lens out of, for instance, presumptive skin. This means that if tissue normally destined to form something other than a lens is brought into contact with the eye cup, the fate of such tissue is altered and a lens is induced to form.

And still again, the efficacy of an organizer, primary or secondary, is not confined to embryos of the same or even closely related species because, for instance, the organizer from a frog (an anuran) will induce a second embryo in a newt (a urodele) and vice versa.

What organizers are and how they act is perhaps the problem of the moment in the field of *CHEMICAL EMBRYOLOGY*. It appears that the organizers are chemical entities because the organizer tissue, such as the dorsal lip of the blastopore just considered, still retains its inducing influence when it has been crushed, dried, or boiled. Or it may impart its organizing power to inert material such as a bit of agar. Moreover, chemical substances which have inducing ability have been isolated from embryonic (and adult) tissues. But more than mere chemical stimulation is involved in the process of morphogenesis, for there seems to be an interaction between stimulating and stimulated tissues which is necessary for normal development. In other words, the stimulus to differentiation is controlled and modified, in as yet unknown ways, by the tissues in which the morphogenetic changes occur: action of stimulus plus reaction of tissue equals differentiation.

The fact that many adult tissues of invertebrates and vertebrates possess the power of inducing neural tube formation suggests that such influences may be responsible for certain puzzling pathological formations known as *TERATOMATA*. Indeed, it appears that organizer-action phenomena merge into those of the general hormonal regulation and coordination of the organism. It is possible that even gene action will prove to be explainable by a somewhat similar chemico-physical mechanism.

REALIZATION OF FUNCTION

One must not lose sight of the fact that embryologists are, of necessity, largely restricted to the study of the development of form, but that also interwoven with this field is the basic problem of the realization of function. For instance, as long since recognized, functional development begins in the germ cells that contain not only the elements out of which the body is formed but also those that give rise to mental behavior. Among these germinal elements of mental activity are *differential sensitivity* or the capacity of responding differently to different stimuli; *organic memory* or the retention of the effects of previous stimuli in the general protoplasm or in special organs; *tropisms* and *reflexes* or inherited methods of response to stimuli; *instincts* or chains of reflexes, usually adaptive; and *conditioned reflexes* and *habits* which are established by oft-repeated stimuli and responses. As development progresses differential sensitivity gives rise to special senses; reflexes and tropisms to instinctive behavior and habits; organic memory to associative memory and the ability to learn. Seeking satisfaction by the process of trial and error, together with associative memory, leads to intelligent responses; and conflicting stimuli and selective responses, to inhibition and choice or voluntary action.

Throughout the whole of this complicated process of physical and psychical development every step is a response of the individual to stimuli. In general it is a gradual progression from the relatively simple to the more complex, but there are certain critical stages when it seems to jump from a lower to a higher level. One of the most striking of these is when the egg or embryo becomes free-living, in mammals the period of birth. Another is when organic memory becomes associative memory and learning becomes possible. Another is when intelligent reactions to specific things leads to generalizations and reasoning, functions which apparently are limited to human beings. Still another level is reached when intelligence and reason become factors in shaping purposive behavior. And finally the highest level of human development is attained when purposive behavior, joined to social emotions, training, and habits, shapes behavior not only for personal but also for social satisfactions with all their ethical implications.

It is a far cry from the structures and functions of the egg to those of the fully developed human being, from the tropisms and reflexes of

embryos to the behavior of men and women, from the conditioned reflexes of infants to the habits and ideals of truth, freedom, love; but it is one continuous road. However, it should be noted that while "all these stages and processes of development are according to nature there is here no explanation of nature."

CHAPTER XXI

Reproduction in Plants

The synthetic act by which the organism maintains itself is fundamentally of the same nature as that by which it repairs itself when it has undergone mutilation, and by which it multiplies and reproduces itself.

—Bernard

Following the consideration in the preceding chapters of animal reproduction and development it is next in order to describe the specializations of structure and function associated with the process of reproduction in the plant kingdom. As described earlier in *Protococcus* all the life processes essential to the individual are found in relative simplicity and without obviously complicated apparatus. Moreover, the continuation of the race is provided for by binary fission, the division of the individual cell to form two new cells. Except for the intricacies of the mechanism of cell division, reproduction in *Protococcus* is a comparatively simple process, since it is not complicated by specialized organs for its performance. (Fig. 17.)

SPORE FORMATION

That cell division in multicellular plants results in the growth of the single individual is well illustrated by the simpler green algae, such as *Spirogyra* and *Ulothrix*, in which the plant body consists of a series of similar cells placed end to end to form a long threadlike body. In such types, cell division merely increases the length of the filament constituting the body, unless the newly formed cell becomes detached from the parent plant. As a matter of fact, in some species, under suitable conditions the protoplasmic content, or PROTOPLAST, actually makes its escape from the cell wall and swims about in the surrounding water. This independent protoplast is a SPORE. (Fig. 204.)

Moreover, this spore now begins a series of cell divisions which result in a new filament, a new individual. Therefore a spore is a cell,

or the essential part of a cell, the protoplast, which has separated from one plant body and is capable of producing another plant body. This statement might seem to indicate that spore formation is restricted to plants with multicellular bodies, but it is found that spore formation occurs in the life history of many unicellular plants as, for example,

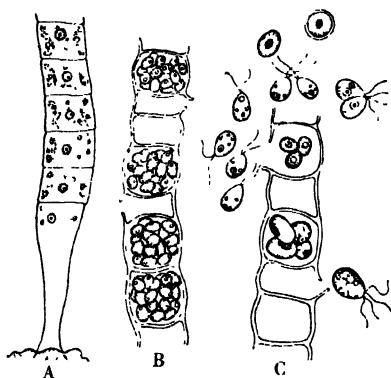


FIG. 204 *Ulothrix*, a filamentous green alga. A, modified cell for attachment of filament; B, cells of a filament which have formed spores, from three cells the spores have been liberated; C, part of a filament liberating a spore (*below*), and gametes (*above*) which pair to form spherical zygotes. Highly magnified. (From Coulter.)

Sphaerella. It will be noted that the cell divisions which produce the spores do not involve the cell wall; only the protoplast within divides to form many daughter cells which make their escape. (Fig. 205.)

Spore formation is therefore not a necessary result of the establishment of a multicellular body, but an inheritance from unicellular forms which makes possible one of the two effective types of asexual reproduction in the Metaphyta. The other type is FRAGMENTATION; this process consists essentially in the separation from the body of larger or smaller parts which later reproduce the whole plant. It is a familiar fact that

under proper conditions, cuttings, buds, bulbs, and sometimes pieces of leaves may reproduce or, as it is sometimes stated, REGENERATE a complete plant. This is just an expression of the same power which the spore, though a single cell, exhibits. It regenerates, as it were, a plant body similar to the one from which it has separated.

GAMETE FORMATION

During the life history of some unicellular plants, such as *Sphaerella*, under suitable conditions a cell divides many times to form a considerable number of small cells, instead of dividing to form a few spores. These cells are called GAMETES, and they fuse in pairs; it is this behavior that particularly distinguishes them from spores. In a general way, from the standpoint of their origin, gametes may be regarded as spores which have developed the habit of fusing to form a zygote.

Furthermore, the origin of gametes is the origin of sex, and the fusion of these sex cells is fertilization. (Figs. 205, 206.)

Another example will emphasize this point. The body of a fresh-water filamentous alga, *Ulothrix*, is composed of a linear series of cells

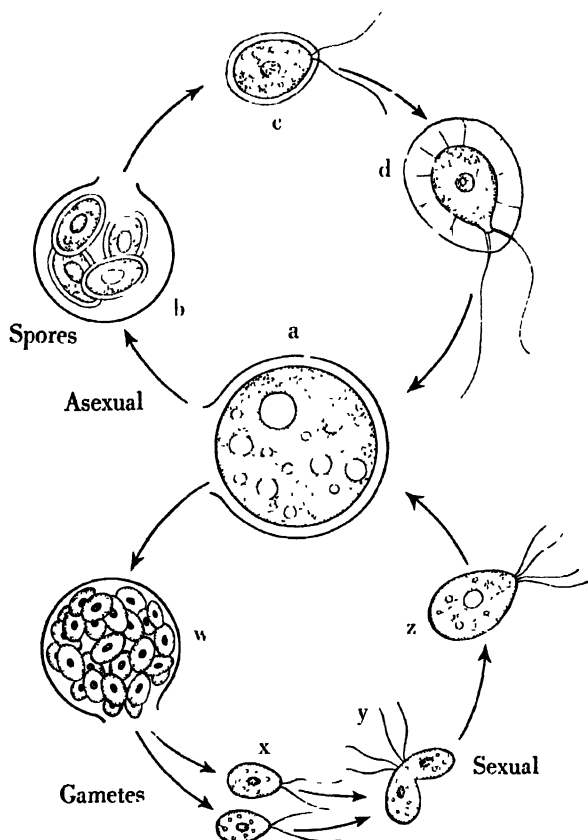


FIG. 205. General plan of the life history of certain unicellular plants, such as *Sphaerella*. a, b, c, d, asexual cycle; a, w, y, z, sexual cycle. (a) dormant cell enclosed within a protective cyst wall which has ruptured to allow the enclosed protoplast to escape; (b) division of the protoplast to form four spores (c) each of which grows, develops two flagella, and assumes the typical adult free living form (d). This may reproduce many times, each time forming four cells within a cyst, but eventually each cell assumes the dormant cell (a) again. Under other circumstances the protoplast from the dormant cell may divide until many small cells (w) are formed. These make their escape and are gametes (x) since they fuse in pairs (y). The composite cell resulting from fertilization is a zygote (z) which soon forms a cyst wall and assumes the dormant phase.

all of which are essentially the same in structure and function, except a terminal one for attachment. Under favorable conditions the cells divide and the plant grows in length. New individuals are not usually formed in this way, although the mechanical breaking (fragmentation) of the filament into two parts, owing to the simplicity of the body, gives two individuals. Under certain conditions, however, some of the cells cease to contribute to the elongation of the filament. Instead, the protoplasts begin to divide within their cell walls, and each forms 32 flagellated cells of different sizes, depending upon the number of divisions the parent protoplast undergoes. (Fig. 204.)

The behavior of the cells of different sizes is characteristic and significant. The largest cells and those of intermediate size are spores,

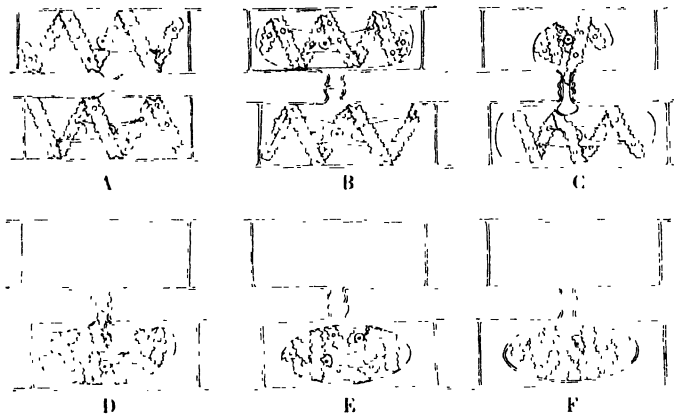


FIG. 206. *Spirogyra*. Stages (A, B, C, D) in the union of gametes which result in fertilization, and the formation of a resistant zygote (E, F). Highly magnified. See Fig. 24. (From Smith and others. Redrawn.)

because they soon settle down and develop into new filaments. On the other hand, the smallest cells unite in pairs, each pair fusing to form a single large cell. These cells, by fusing instead of germinating, behave sexually and therefore are gametes, and the product of this process is a zygote. It appears, therefore, that sexual reproduction arose when certain cells, apparently similar to spores, assumed the habit of pairing to form a zygote before germination.

It should be noted that sexual reproduction is not a different kind of reproduction, but merely reproduction *preceded* by the formation of a zygote. This is a fact very readily lost sight of in the higher forms,

where accessory phenomena connected with sexuality obscure the essential features, but it is quite apparent in *Ulothrix*. Here the zygote does not directly form a new filament; instead, after passing a longer or shorter time in a dormant condition protected by a heavy wall, the protoplast (zygote) within divides to form a number of swimming spores, each of which then develops into a new individual.

SEX DIFFERENTIATION

So far it has been shown that sex cells, the gametes, arose with the establishment of the habit of cells' uniting in pairs. This is obviously a statement of fact rather than an explanation of sex. Although the two cells which fuse show no morphological characters by which they can be distinguished from each other, certainly there is a *physiological* basis of sex which induces them to swim toward each other, to become oriented so that fusion begins at the flagellated ends, and to blend into a single cell. This is a reorganized cell with the complicated structural and physiological equipment of the two cells which entered into its construction. The zygote is therefore a cell which combines the characteristics of both the contributing gametes, and to this significant fact must be attributed the chief importance of sex phenomena in the life history of plants as well as animals. (pp. 245-247.)

Sexuality is first evident as a physiological difference between gametes which leads to their characteristic behavior (zygote formation) but structural differentiations appear even among the lower plants. In fact, a series of plants can be arranged so as to show the transition from gametes

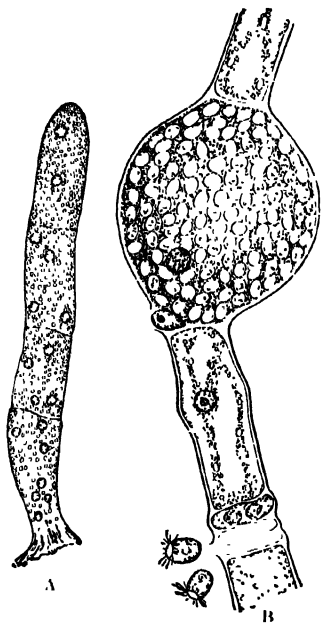


FIG. 207. *Oedogonium*, a filamentous green alga. A, young filament; B, portion of a filament forming gametes (egg and sperm). Below are two sperm which have just been liberated; above is a large egg with a sperm (*lower left*) just coming into contact with it to form a zygote. Highly magnified. (From Coulter.)

that appear morphologically identical to those that differ so widely that they seem to have little in common. Oedogonium, another filamentous alga, will suffice as an example since it affords an excellent illustration of gamete differentiation. One form of Oedogonium gamete, representing an entire protoplast of a greatly enlarged cell, is richly supplied with food materials and chloroplasts and remains motionless within the cell wall. The other type develops in pairs in small cells with greatly reduced chloroplasts and food content. Instead of being motionless, each cell is provided with a circle of cilia by which it leaves its place of origin, swims actively in the water, and, entering a cleft in the wall surrounding a large gamete, fuses with it to form a zygote. (Figs. 207, 208.)

In short, a female type of gamete, the egg, is a large nonmotile cell stored with food materials, while the other gamete, the sperm, is a small active cell largely devoid of food. This is typical of the conditions which are at the foundation of gamete differentiation throughout the plant and animal kingdoms, eggs and sperm expressing a physiological division of labor which entails structural specialization in opposite directions. (Figs. 6, 210.)

In Oedogonium sexuality is apparent both in the behavior and in the structure of the gametes, so that it is possible to identify the sex cells as male gametes, or sperm, and female gametes, or eggs. It will be noted that this is not the origin of sex, for sex arose when certain

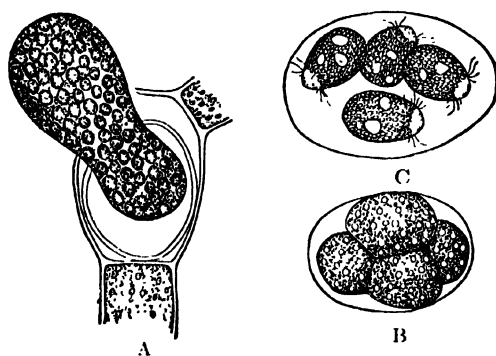


FIG. 208. Oedogonium. A, zygote emerging from cell of parent filament; B, division of zygote into four spores; C, mature spores with flagella, ready to escape and develop into new filaments. Note that the zygote does not give rise directly to a filament, but to spores, which then form filaments. Highly magnified. (From Coulter.)

cells by their behavior became gametes. In other words, sexuality is expressed by the fusion of two cells which reorganize as a single cell; and all obvious modifications of these cells, which enable them to function as gametes, are secondary.

REPRODUCTIVE ORGANS

Associated with the specialization of spores and gametes is a progressive modification of the cells or groups of cells which produce them, until highly developed REPRODUCTIVE ORGANS arise. The asexual reproductive cells, or spores, are formed in SPORANGIA, which may be merely vegetative cells in which the protoplast becomes transformed into a spore, or elaborate multicellular structures set aside for this one function. Similarly, with the origin of sexuality, the sex cells, or gametes, arise in GAMETANGIA, which later are distinguished as ANTHERIDIA, or sperm-producing, and ARCHEGONIA, or egg-producing organs. Although the terms male and female are strictly applicable only to sperm and eggs respectively, the antheridia and archegonia are called male and female organs; moreover, a plant body which bears only male reproductive organs is designated as a male plant, and one which bears female reproductive organs is known as a female plant. In short, the sexuality of the gametes is reflected back, as it were, to the organs and then to the individual that bears them, although the gametes are the actual sex cells. If this is kept clearly in mind it will obviate confusion in considering the remarkably specialized secondary features which sexuality imposes on the bodies of higher plants and animals. (Fig. 209.)

We may now review the facts before proceeding to further modifications of the reproductive pattern. Reproduction, divested of its

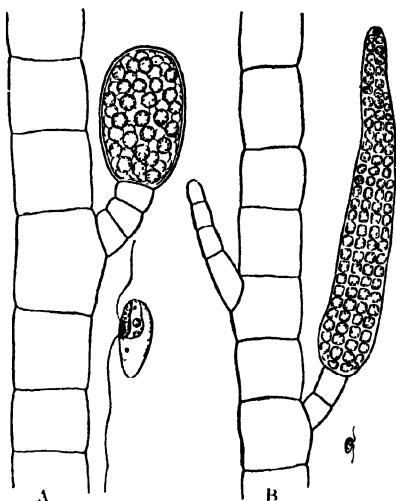


FIG. 209. A brown alga, *Ectocarpus*. A, portion of a filament, with a sporangium and a liberated spore; B, portion of filament with a gametangium and a liberated gamete. Highly magnified. (From Coulter.)

specialized features, is growth expressed in cell divisions. This primary potentiality of all cells may exist side by side with the development of cells specialized for asexual reproduction (spores) and sexual reproduction (gametes). In either case the products become separated from the parent body and develop new bodies. Furthermore, spores which in the lowest forms are developed from any of the vegetative cells of the plant body, in higher forms arise in asexual reproductive organs (sporangia), while gametes are produced in sexual reproductive organs (gametangia). With the morphological differentiation of gametes into sperm and eggs, a further specialization of the gamete-forming organs results in male and female reproductive organs (antheridia and archegonia). When sporangia and gametangia are borne by separate individuals, asexual plants (SPOROPHYTES) and sexual plants (GAMETOPHYTES) result. Finally, antheridia and archegonia may be borne on separate gametophytes, in which case male and female gametophytes result.

ALTERNATION OF GENERATIONS

From the standpoint of the evolution of the higher plants a significant fact stated above is that sporangia and gametangia may be borne by separate individuals, for this involves an asexual, spore-bearing generation, the sporophyte, and a sexual, gamete-bearing generation, the gametophyte. We shall outline this ALTERNATION OF GENERATIONS in the life history of a typical moss and fern as an introduction to a consideration of reproduction in the higher seed plants.

THE MOSS

The common mosses are a relatively inconspicuous but nevertheless an important part of our flora, because they form heavy growths or carpets of vegetation which hold back much of the rainfall so that it sinks into the soil. Although there are about 14,000 species which botanists include in the class *Musci* of the BRYOPHYTES, a general description of a typical common moss, such as *Polytrichum commune*, will suffice for the purpose at hand. (pp. 501-503.)

The shoot of a moss plant is differentiated into a very short stem with an upright branch bearing leaves—all of simple structure in comparison with those of the seed plants we have studied. True roots are not present, but their function is in part performed by filamentous outgrowths called RHIZOIDS. At the top of the leafy moss plant, incon-

spicuous reproductive organs are developed. Some species bear both antheridia and archegonia on the same plant, while others have only one type. The leafy moss plant is thus a sexual individual, or gametophyte. When the reproductive organs are mature, sperm escape from the antheridia and, swimming about in moisture which has collected on

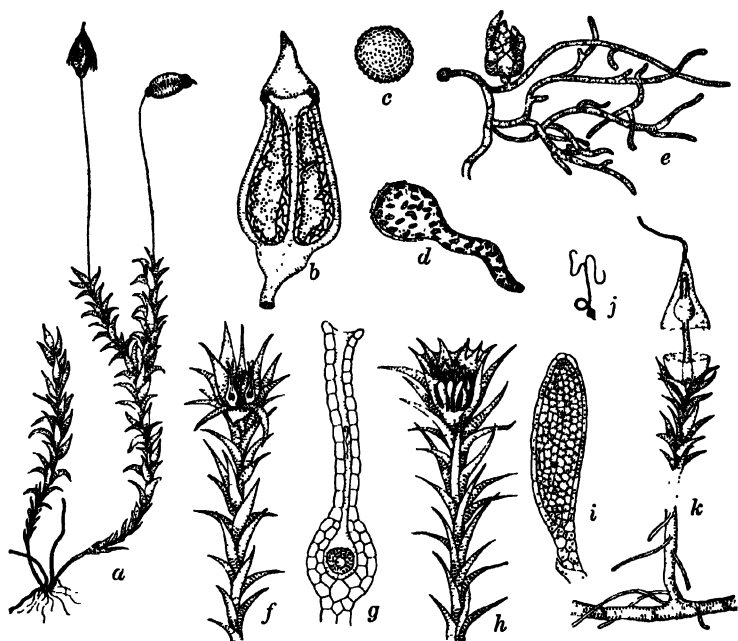


FIG. 210. The life history of a moss, chiefly *Polytrichum*. *a*, the entire plant (gametophyte and sporophyte), $\times 14$; *b*, median vertical section of the capsule in which spores are formed, $\times 6$, with spore (*c*) and germinating spore (*d*), $\times 300$; *e*, spore germinated to a protonema with a bud which forms leafy plant (gametophyte), $\times 75$; *f*, tip of gametophyte with two archegonia, $\times 2$; *g*, archegonium in section showing egg, $\times 16$; *h*, tip of gametophyte with antheridia, $\times 2$; *i*, antheridium, $\times 16$; *j*, a single liberated sperm, $\times 600$; *k*, gametophyte with sporophyte developing in enlarged and transformed archegonium. (After Ganong.)

the leaves, are attracted to the archegonia containing the eggs by a chemical substance secreted within these organs. A single sperm which has made its way down into an archegonium fuses with the egg to form a zygote. The fertilized egg retains its position in the archegonium and germinates. The result is a rod-shaped embryo which grows not only upward through the archegonium and so out into the world, but also

downward into the tissues of the gametophyte from which it secures practically all of its food materials. (Fig. 210.)

The essentially parasitic nature of the new individual renders the development of leaves superfluous, so it consists of a simple upright stalk at the top of which the reproductive organ is borne. This spore case, or CAPSULE, produces spores and accordingly the individual is a sporophyte. The ripe spores are liberated and, falling to the ground, each forms a filamentous outgrowth called a PROTONEMA. Soon there arises on the protonema a bud which develops into a leafy moss plant. The cycle is complete. (Fig. 211.)

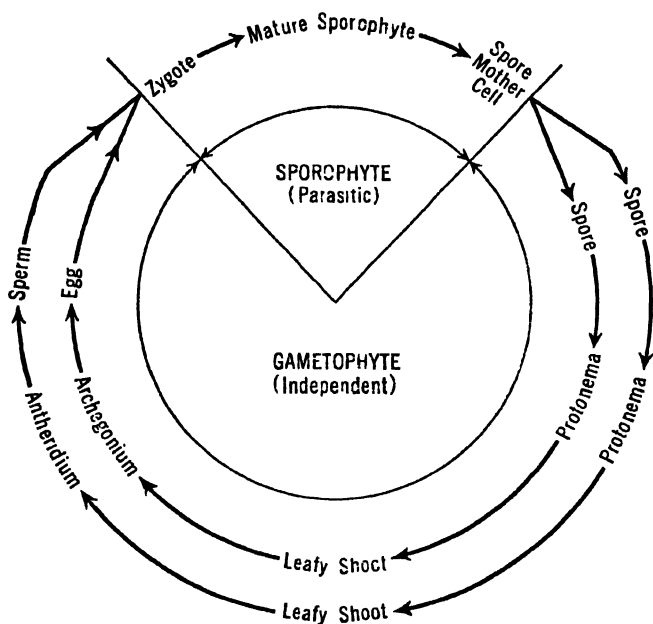


FIG. 211. Diagram of the life cycle of a moss. (After Smith and others.)

A common moss thus exhibits in its life history an alternation of sexual and asexual generations. The leafy moss plant, with antheridia and archegonia, produces gametes and is the gametophyte. The leafless generation, which develops from the fertilized egg in the archegonium, produces spores and is the sporophyte. So the gametophyte arises asexually but is itself sexual, whereas the sporophyte arises sexually but is itself asexual. The dominant generation from the standpoint of

both structure and nutrition—the plant one thinks of as a “moss”—is the gametophyte.

THE FERN

The common ferns comprise a group of some 8,000 species, usually referred to as *PTERIDOPHYTES*. Although the forms of different species are remarkably varied, the ensemble of characters and in particular the foliage is quite distinctive, so that one would recognize practically any member of the group as a fern. (pp. 505-506.)

The stems may be short and close to the ground, or upright as in the tree ferns, though creeping and underground stems, or rhizomes, are more common. The leaves, known as *FRONDS*, either arise in clusters from the tip of the stem as in tree ferns and many common species, or in some cases are distributed along the rhizome. Roots bring the stem into intimate contact with the food materials of the soil, though

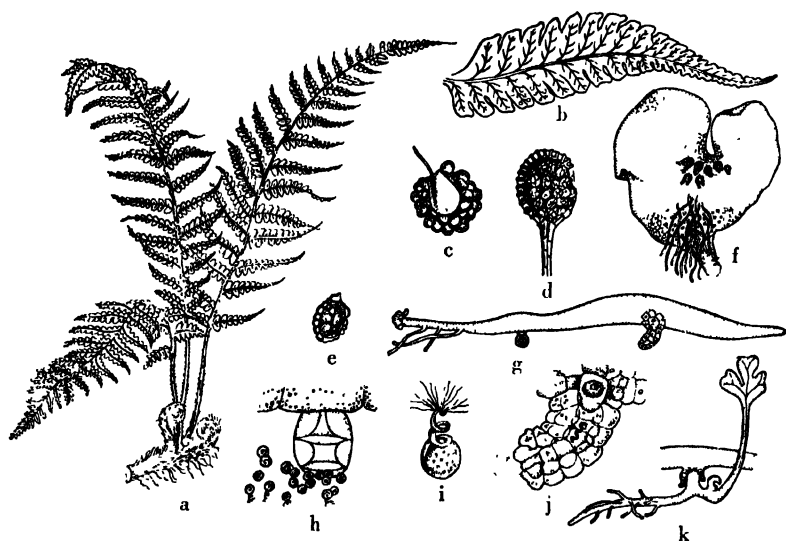


FIG. 212. The life history of a common fern, chiefly *Aspidium*. a, the entire sporophyte, $\times \frac{1}{10}$; b, portion of a leaf showing groups of sporangia (sori), $\times \frac{1}{2}$; c, a sorus showing sporangia, $\times 10$; d, a sporangium, $\times 50$; e, a single spore, $\times 100$; f, ventral view, $\times 3$, and g, a median section, $\times 6$, of a prothallus showing rhizoids, antheridia, and archegonia; h, antheridium liberating sperm, $\times 120$; i, single sperm still attached to a remnant of mother cell, $\times 300$; j, open archegonium with sperm passing down to egg for fertilization, $\times 120$; k, young sporophyte developing from zygote in archegonium. (After Ganong. Redrawn.)

rhizomes function to a certain extent as roots. An examination of the cellular structure of a common fern, such as *Aspidium marginale*, shows that it is much more complex than a moss, the tissues of stem and leaves being essentially like those we have seen in the seed plants, and accordingly ferns and their allies and seed plants are known as *vascular plants* or TRACHEOPHYTES. (Figs. 48, 365.)

The fern plant bears, on certain of its leaves, reproductive organs which are sporangia. These, of course, produce spores and therefore the plant commonly recognized as a fern is a sporophyte. The spores when ripe are liberated from the sporangia and fall to the ground, where they germinate. From a spore arises a tiny body, about a quarter of an inch in diameter, called a PROTHALLUS, which is essentially a plate of chlorophyll-bearing cells with rhizoids attaching it to the ground. On its lower surface are developed antheridia and archegonia which form gametes. The prothallus therefore is a gametophyte. (Fig. 212.)

Sperm are liberated from the antheridia and swim in the moisture,

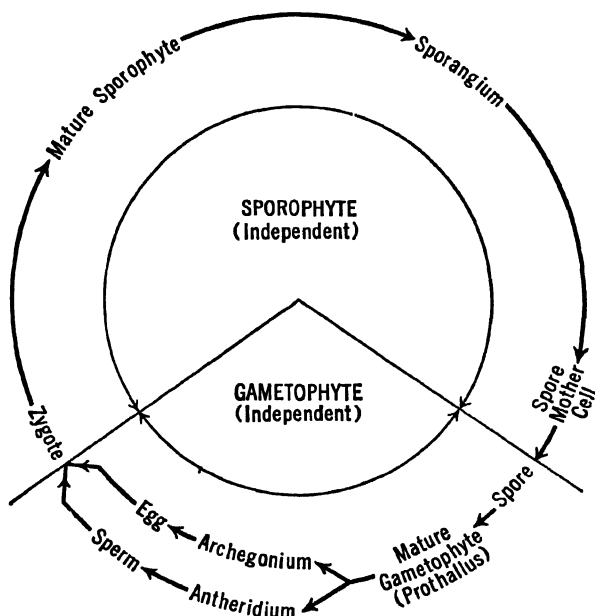


FIG. 213. Diagram of the life cycle of a common fern. See Fig. 211. (After Smith and others.)

from dew or rain, to the archegonia. A single sperm works its way down an archegonium and fuses with the egg to form a zygote. Then the zygote, which remains in the archegonium, proceeds to divide and forms at first a small plant with stem and leaf that grow upward and root that seeks the soil. During the process of root and shoot development the plant retains its attachment to the parent prothallus from which its food is secured. Later, when direct communication with the environment has been established by its own root and leaf, the new generation becomes entirely independent of the prothallus, which then degenerates and dies. The young plant gradually grows into the typical asexual leafy plant, which itself in due time produces spores. This completes the cycle. (Fig. 213.)

It is clear that in the fern, as in the moss, there is an alternation of generations. The leafy fern plant (sporophyte) gives rise to the prothallus (gametophyte). The leafy fern arises sexually, but is itself asexual; the prothallus arises asexually, but is itself sexual. The significant fact, however, is that the conspicuous leafy moss plant is a gametophyte, whereas the large leafy fern plant is a sporophyte; or, one may say, the "moss" is a sexual plant and the "fern" is an asexual plant. This ascendancy in dominance of the asexual and suppression of the sexual generation, which characterizes the fern life history as compared with the moss, is carried still further in the higher ferns and culminates in the seed plants.

WATER FERNS

As we have seen, the sporophyte of the common ferns produces spores on ordinary vegetative fronds or sometimes on more or less specialized sporophylls. In either case but one kind of spore is formed. However, in the water ferns and certain fern allies, spores of two kinds occur which, since they dif-

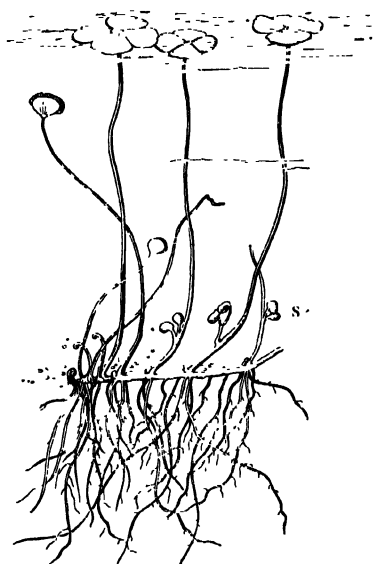


FIG. 214. The clover-leaf water fern (*Marsilea*) showing special spore-bearing cases (s) in which are microsporangia and megasporangia. (From Bergen and Davis.)

fer greatly in size, are called MICROSPORES and MEGASPORES. The production of two kinds of spores is known as HETEROSPORY and leads to the differentiation of the sporophylls into MICROSPOROPHYLLS and MEGASPOROPHYLLS. The microspores on germination form microgametophytes which produce sperm, and therefore are called MALE GAMETOPHYTES, while the megaspores develop into megagametophytes bearing eggs, and accordingly are known as FEMALE GAMETOPHYTES. (Fig. 214.)

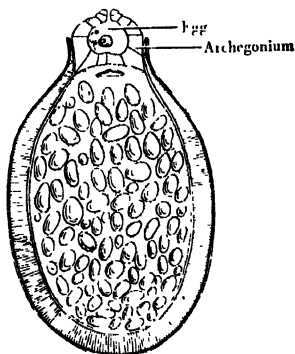


FIG. 215. Megaspore of *Marsilea*, enclosing food material (starch grains), and female gametophyte (top) comprising a single archegonium (with egg) at one end of the spore.

In these heterosporous forms the gametophytes are no longer even small independent plants, such as the prothallus of the common ferns; in fact, both male and female gametophytes are so greatly reduced that they practically remain permanently in the parent microspore and megaspore, respectively, which supply them with food. This, it will be noted, is just the reverse of the condition in the moss, where it is the sporophyte rather than the gametophyte that is the dependent generation. (Fig. 215.)

Reduction in the number of chromosomes always takes place sometime during the life history of plants, in association with sexual reproduction. In the ferns and seed plants, for example, reduction occurs at the formation of the spores.

Thus it follows that the cells of the gametophyte contain half as many chromosomes as the sporophyte, and the sporophyte number is restored by the union of the gametes. It must be borne in mind, however, that the familiar plants are sporophytes which, for all practical purposes, directly produce sporophytes because, as will be evident from the study of seed plants, the gametophyte generation is reduced almost to the vanishing point. The chromosome number in the cells of the parent sporophyte and the sporophyte in the seed is the same. From the standpoint of chromosome number, the plant sporophyte is comparable to the animal soma, and the gametophyte is represented in animals essentially only by the gametes. This condition is clearly illustrated in the diagram shown in Fig. 223.

SEED PLANTS

Consideration of the higher seed plants, or flowering plants, shows that they are heterosporous sporophytes, and the FLOWER represents a greatly modified stem (branch), the leaves of which are specialized as sporophylls and accessory structures. In order to make this clear it is necessary to review the structure of a typical flower. (Figs. 49, 216.)

A complete flower consists of four whorls of modified leaves. These arise near together at the top of a RECEPTACLE, representing the enlarged tip of the floral branch, which connects the flower proper with the main tissue systems of the plant as a whole. The outermost and lowest circle of leaves (CALYX) is composed of several parts (SEPALs) which usually are green and retain a leaflike appearance. Just within and above the calyx is the second circle (COROLLA) formed of larger leaves (PETALS) which are usually brightly colored. The calyx and corolla together form the PERIANTH, or floral envelope which surrounds the primary floral organs, the STAMENS and CARPELS.

The stamens represent the third circle of leaves, but are so highly modified that their leaf origin is not immediately apparent. Each consists of a slender FILAMENT at the apex of which is a small case known as the ANTHIER. Within the anther POLLEN GRAINS are formed. The pollen grains arise from microspores and, therefore, the pollen sacs of the anthers are MICROSPORANGIA and the stamens are microsporophylls. (Fig. 217.)

Finally, just within the circle of stamens is the fourth whorl of floral leaves, the carpels, in which specialization has gone so far that practically no suggestion of leaf structure remains. Each carpel consists of three parts: a lower, expanded portion termed the OVULE CASE, or "ovary," merging above into the elongated slender STYLE, the tip of which is the STIGMA. Such a fully developed carpel is known as a

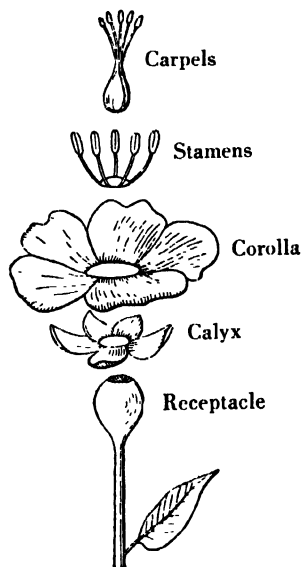


FIG. 216. Diagram showing the parts of a typical flower. See Figs. 217-220.

PISTIL and when, as frequently happens, the various carpels fuse to form a composite structure, this is called a compound pistil. Within the ovule case are developed the reproductive bodies known as OVULES which are MEGASPORANGIA, for within each is formed a megaspore. A carpel, therefore, is a megasporophyll. Incidentally, each ovule is a potential seed. (Figs. 216, 218.)

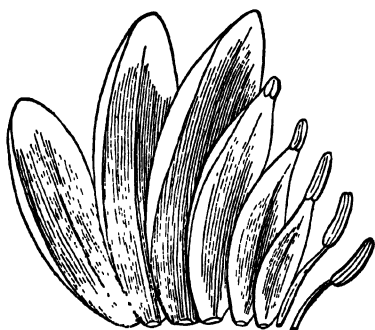


FIG. 217. Transitional stages between petals and stamens in a water lily. (After Gray.)

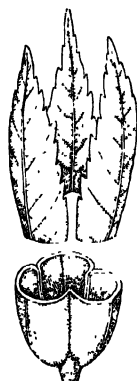


FIG. 218. Diagram to illustrate the method of union of three carpels (megasporophylls) to form the ovule case of a compound pistil. The edges which unite form the point of attachment of the ovules. (After Gray.)

So far it is clear that a flower is a group of sporophylls which produce microspores and megaspores. Since, however, such reproductive bodies always form male and female gametophytes, their development must now be considered.

The first fact to have clearly in mind is that the megaspore is never liberated by the megasporangium, and further that the latter remains just where it arose in the ovule case of the pistil. Consequently the megaspore germinates within the pistil, and it forms there a female gametophyte composed of only a few cells, including the female gamete, or the egg. Thus the female gametophyte generation of seed plants is invisible unless the contents of the pistil are examined microscopically. (Fig. 219.)

The pollen grains, or microspores, develop in the microsporangia of the anthers at the tips of the filaments. While each is still in the anther its nucleus divides and two cells are formed, but further de-

velopment does not occur until the pollen is transferred in some way, usually by insects or the wind, to the stigma of the pistil. The stigma secretes fluids suitable for the germination of the ripe pollen grain, which bursts its rigid wall and puts forth a cytoplasmic tube. This grows down through the tissues of the pistil until its tip enters the ovule case, and carries with it the two nuclei, one of which divides

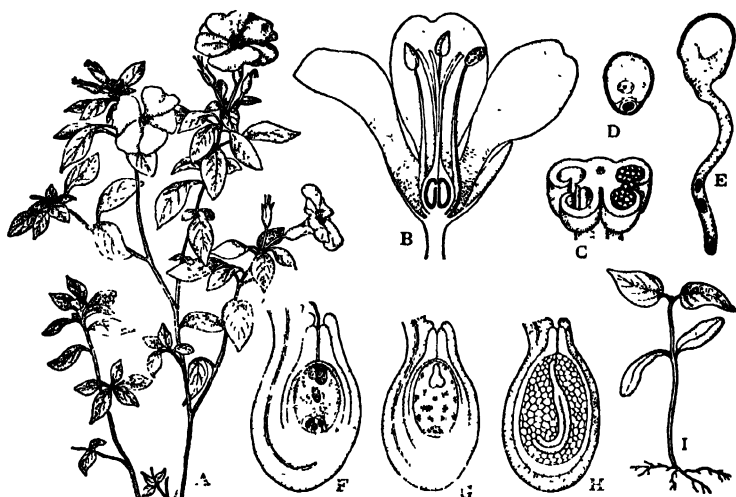


FIG. 219. The life history of a higher seed plant, from various species. A, shoot of a flax plant with flowers, $\times 1$; B, vertical section of a flower, $\times 1/4$; C, an anther cut to show four microsporangia containing pollen grains (microspores), $\times 6$; D, an ungerminated pollen grain, and one, E, which has formed tube (male gametophyte), $\times 110$; F, longitudinal section of an ovule enclosing megaspore and its contents (female gametophyte), $\times 20$; G, an ovule transformed into a seed with young embryo sporophyte and endosperm, $\times 10$; H, a mature seed, $\times 5$; I, young sporophyte from the germination of the seed, $\times 1/2$. (After Ganong.)

again to form two nuclei which represent sperm. The pollen has now completed its development and thus the contents of the pollen grain plus the tube constitute a greatly reduced male gametophyte. (Fig. 220.)

By the time the pollen tube reaches the ovule case, the megaspore within has formed, as already described, the female gametophyte with its egg. So the ovule case has indeed become an ovary. One of the sperm nuclei unites with the egg and forms a zygote which remains just where it is, surrounded by the tissues of the ovule which is itself attached to the ovule case, and proceeds to divide to form an embryo sporophyte with rudimentary root, stem, and leaf. Concurrently, the

ovary and associated tissues of the base of the pistil undergo more or less profound changes, or ripen, and become transformed into a **FRUIT**. The young sporophyte within, together with food material, or **ENDOSPERM**, for its further development, formed under the influence of the other sperm nucleus, is sealed by a seed coat into a special packet. It has become a **SEED**. In this form the new generation is prepared not only to leave the parent plant and withstand adverse conditions for a

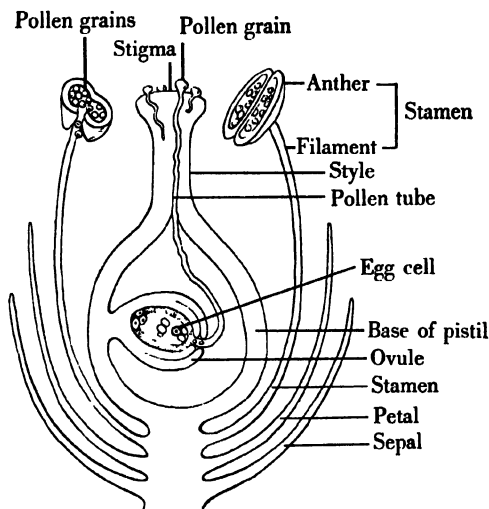


FIG. 220. Diagram of a vertical section through a typical flower, showing pollination and growth of pollen tube into the pistil and ovule. This will result in fusion (fertilization) of male and female nuclei, and the production of seed and fruit.

long time, but also to continue rapidly its development into an adult sporophyte when it falls upon favorable soil. (Figs. 221, 222.)

From the above description it is clear that the gametophyte generation of seed plants is reduced to its lowest terms—little more than sufficient to form the gametes. The whole generation is telescoped, as it were, within the flower of the previous sporophyte generation, so that sporophyte seems to produce sporophyte, whereas, as a matter of fact, three distinct generations contribute to the formation of the seed. The seed coat comprises tissue from the megasporangium of the parent sporophyte bearing the flower, and the embryo is the young sporophyte derived from the intervening gametophyte generation. Indeed, in lower

phytes to meet on common ground so that the sperm, which themselves have suffered reduction and lost their motility, can reach the egg and perform the act of fertilization. Frequently this sexual differentiation extends to the flower as a whole, since some flowers bear only stamens and others only carpels; such flowers are known as male and as female flowers, respectively. Moreover, male and female flowers may be borne on separate plants, in which case the plants themselves are called male and female. In brief, the terminology which strictly is

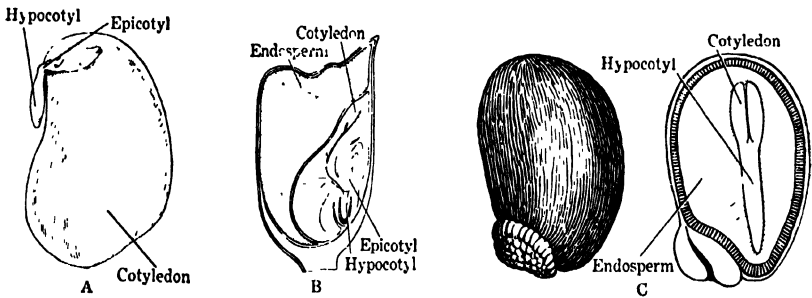


FIG. 222. Seeds. A, bean seed with seed coats and one cotyledon removed showing embryo sporophyte in position; B, grain of corn in longitudinal section with embryo; C, violet seed showing hard seed coat, and longitudinal section of seed with embryo. (After Smith, and Coulter.)

applicable only to the sexual generation is, for convenience, transferred to the asexual generation, to which accessory sexual functions are reflected through the almost complete suppression of the actual sexual generation itself.

SEED AND FRUIT

Still more emphasis must be placed on the seed, which is the chief characteristic of the seed plants, and which apparently is largely responsible for the dominance of this group in the modern flora. The essential feature of the seed habit, it will be recalled, is the partial development of the young sporophyte within the tissues of the parent sporophyte, and its release, provided with food and protected by special coverings, as a seed. Obviously such a body has greater chances of wide dispersal and survival than a spore, and so contributes much more effectively to the perpetuation of the species.

The three chief parts of a seed are the embryo, endosperm, and seed coat, and these differ considerably in details among various

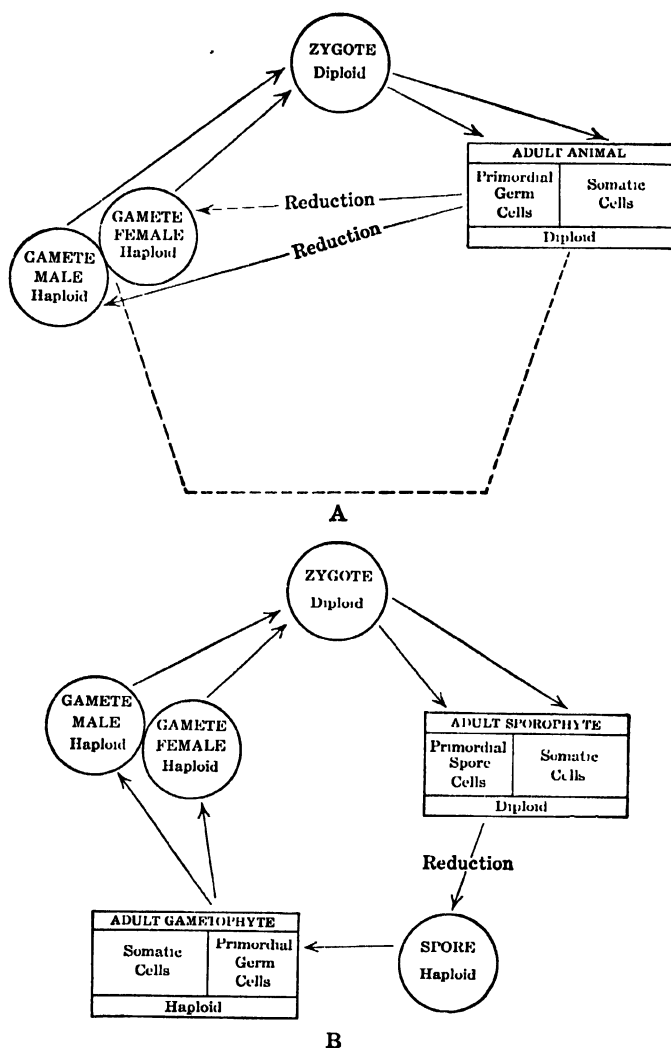


FIG. 223. Schematic representation of the life history of an animal (A) and of a plant, e.g., fern, (B) for a comparison of the diploid and haploid condition of the chromosomes.

plants. For example, the embryo in the dicotyledons has two nearly equal, laterally situated seed leaves, or **COTYLEDONS**, and between them a shoot, or **EPICOTYL**, above their point of origin, and a **HYPOCOTYL**, chiefly root, below. This is well shown in the bean. In the monocotyle-

dons the embryo has one lateral cotyledon and an epicotyl and a hypocotyl, as in a grain of Indian corn. (Figs. 222, 370.)

The endosperm usually is present in seeds, but this food-storage tissue may be quickly reduced by the absorption and storage of food in the cotyledons, as in the bean, or there may be a considerable amount of endosperm in the mature seed, as in the corn and violet.

The seed coat shows a scar, or **HILUM**, that marks its former point of attachment in the ovary, and it is perforated by a **MICROPYLE** toward which the tip of the hypocotyl points.

It is clear that the new generation is tightly sealed in a case practically impervious to water and gases except through the micropyle; it is in a dormant condition, with the life processes reduced to a minimum, awaiting conditions favorable for **GERMINATION**. Some seeds, such as those of the willows, must germinate, if at all, within a few days, while others have to undergo a considerable period of so-called **AFTER-RIPENING** before development can occur. In addition to internal factors, germination is dependent upon various environmental factors, chiefly water, oxygen, and a proper temperature. The intake of water causes an internal swelling so that the seed coat ruptures, the hypocotyl protrudes, and the young plant is on its way. The length of time during which seeds remain capable of germination shows great variation. Tobacco seeds have germinated after twenty years, but the statements that seeds have proved viable after much more than a century may be questioned. (Fig. 31.)

During the process of seed development the ovary surrounding the seed, often with other parts of the flower, becomes transformed into a fruit. The **SIMPLE** fruits are those formed from one flower, **AGGREGATE** fruits from a group of adherent fruits in one flower, and **MULTIPLE** fruits from a close cluster of flowers. Within these three chief types the variations in fruit structure are legion. Among simple fruits are the various *dry fruits* such as the **LEGUME** or **POD** of the pea and bean, the **CAP-SULE** of the lily, the **ACHENE** of the sunflower, the **GRAIN** of the grasses, and the **NUT** of the walnut; as well as *fleshy fruits* represented by the **BERRY** of the grape and tomato, the **DRUPE** of the peach, and the **POME** of the apple. The blackberry, raspberry, and strawberry are common aggregate fruits, while the mulberry and pineapple are multiple fruits. The three fruits last mentioned are also **ACCESSORY** fruits, because they comprise other parts of the flower in addition to the ovary. (Fig. 224.)

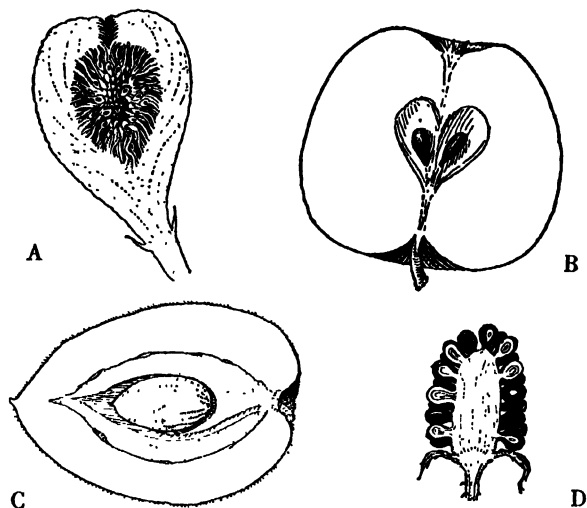


FIG. 224. Some types of fruits. A, fruit of the fig, comprising the hollow end of a branch enclosing a number of true fruits; B, apple, pome type of fruit; C, stone fruit (drupe) of peach, showing pit enclosing the seed; D, aggregate fruit of the blackberry.

Such an array of fruits naturally raises the question of their significance, and the answer is that they apparently afford one of the chief agencies for seed, and therefore species, dispersal. Some seeds and entire fruits are light and provided with long hairs or wings to facilitate distribution by wind. Others develop spines and hooks for attachment to the feet of birds or the fur of mammals. Fleshy fruits are eaten by birds and the indigestible seeds distributed. In still other cases the buoyancy of the seeds allows them to be carried long distances by water. A great many adaptations are found—almost as many as are

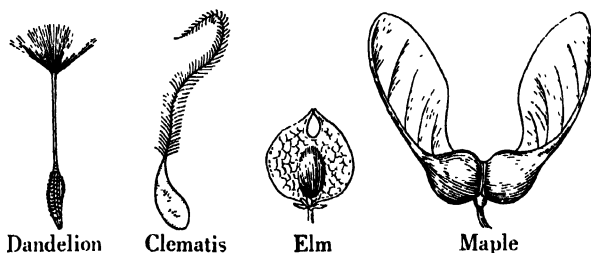


FIG. 225. Fruits and seeds structurally adapted for dispersal by wind.

provided in flowers to facilitate a wide dissemination of the pollen for cross-fertilization. (Figs. 225, 226.)

A survey of the reproductive processes in plants impresses one with the fact that reproduction is, to a very large extent, asexual. The great masses of thallus vegetation, represented by the algae and their allies, increase in bulk chiefly by vegetative cell division, and new individuals are formed in profusion by fragmentation and spore formation. In the mosses, where the sexual generation is prominent, beds of moss are developed chiefly by the asexual budding of the sexual plant, while

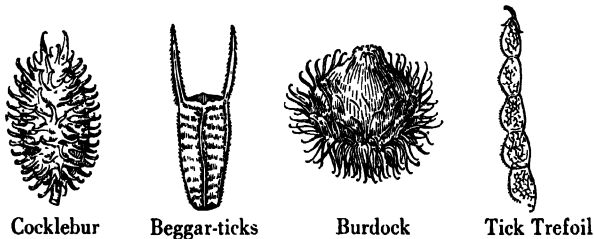


FIG. 226. Fruits and seeds structurally adapted for dispersal by animals.

spore formation holds a prominent place in the increase and dissemination of individuals. In the ferns and seed plants, which are to all intents and purposes asexual plants, since the sexual phase is relegated to an increasingly obscure position in the life history, reproduction is not only by spores, but also in many cases by cuttings, bulbs, fragments of leaves, etc. In brief, reproduction, unaccompanied by sexual phenomena, is apparently quite sufficient for the propagation of plants. (Fig. 37.)

However, it will be noted that sexuality has persisted from its simple origin in gamete formation by unicellular plants. The gametophyte generation in the life history decreases in importance structurally as we proceed from the lower to the highest plants; but, in spite of this, fertilization is retained and greatly modifies all phases of a plant's life. Indeed, the interpolation of the sporophyte generation between gametophyte generations greatly multiplies the progeny of a single zygote; the zygote, instead of producing one new plant, gives rise indirectly through the sporophyte to a multitude of plants with whatever changes fertilization has conferred. Obviously, important long-range advantages must be gained by fertilization or such complex devices culminating in the flower would not have been evolved for its preservation.

CHAPTER XXII

Genetics (I)

So careful of the type . . .
So careless of the single life.
—Tennyson

The old adage that like begets like expresses the general fact of heredity. Everyone recognizes that parent and offspring agree in their fundamental characteristics: they belong to the same species. And everyone realizes that the resemblance may be strikingly exact even in details of form or behavior. Family traits reappear. The mere statement of striking resemblances among the individuals of a family is a tacit admission that no two individuals are exactly alike; in other words, HEREDITY is organic resemblance based on descent—inheritance of the characters exhibited by the parents is not complete, there is VARIATION. Indeed “variation is the most invariable thing in nature,” but one must guard against the impression that there is an antithesis between heredity and variation. “Living beings do not exhibit unity and diversity, but unity in diversity. Inheritance and variation are not two things, but two imperfect views of a single process.”

We may now consider the problems of heredity and variation which are at the basis not only of what organisms have been in the past and are at the present, but also of whatever the future may have in store for them. Variations are the raw materials of evolutionary progression or regression. From a broad point of view, the origin of species and the origin of individuals are essentially the same question. If the relations of parent and offspring can be solved, the origin of species will largely take care of itself. As a matter of fact, historically the question of species origin was approached first, and through the work of Darwin became of paramount interest in the latter half of the nineteenth century. The twentieth century finds the individual—the hereditary relation of parent and offspring—the center of investigation, and this

area forms the science of GENETICS. ORGANIC EVOLUTION attempts to establish the general fact that all organisms are related by descent; genetics attempts to show how specific individuals are related by heredity.

Even further has the pendulum swung from the general to the particular. Today investigation is centered on the heritage of the individual as a whole, rather than on particular characters of the individual. Experimental work has shown that, for practical purposes, the individual may be regarded as an aggregate of essentially separate characters, both structural and physiological, that are relatively stable and may be inherited more or less as units. But the analysis does not stop even at this level. Each character is regarded as represented in the chromosomes of the germ cells by one or more determining factors, or GENES; and whether or not a given character will be shown in a tree or a man depends on whether the genes for this particular character entered into the nuclear complex of the fertilized egg which formed the individual. Therefore, geneticists are now studying the relative positions that the genes occupy on certain chromosomes, how they may cross over from one chromosome to the other of a synaptic pair, how they mutually influence one another, and so on.

During recent years there have been great advances in knowledge of the underlying factors of heredity, and the data accumulated are so vast that it is possible here to do little more than indicate the character and promise of the principles already discovered.

HERITABILITY OF VARIATIONS

In the lowest forms of life the problems of heredity confront us in their simplest, though by no means simple form. *Protococcus* or *amoeba*, as we know, divides into two cells which through growth and reorganization soon become exactly similar to the parent cell. The parent has become offspring, and one does not wonder that parent and offspring are alike—each is composed of essentially the same protoplasm. But when multicellular forms are considered, in which reproduction is restricted to special germ cells that involve fertilization, confusion is apt to arise unless one keeps clearly in mind—and perhaps exaggerates for the sake of concreteness—the distinction between germ and soma that has been previously discussed. Since in higher forms the sole connection between parent and offspring is through the germ cells, it follows that they must be the sole path of inheritance.

In other words, whatever characters the body actually *inherits* must have been represented by genes in the fertilized egg from which it arose: and furthermore, any characters that the individual can transmit must be represented in its germ cells. (Figs. 7, 17, 227.)

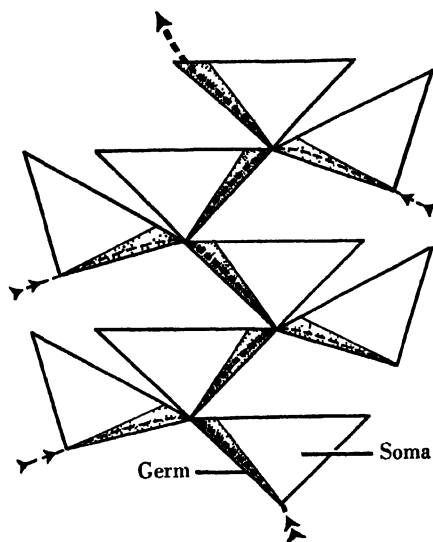


FIG. 227. Scheme to illustrate the continuity of the germ through successive generations. Each triangle represents an individual composed of germ (dotted) and soma (clear). The beginning of the life cycle of each individual is at the apex of the triangle where both germ and soma are present. In biparental (sexual) reproduction the germ cells of two individuals become associated in a common stream which is the germ and gives rise to the soma and germ of the new generation. This continuity is indicated by the heavy central broken line, and the collateral contributions at each succeeding generation by light broken lines. (From Walter.)

MODIFICATIONS

Every individual organism—a man, for instance—is a composite not only of inherited characters, but also of MODIFICATIONS of the soma produced by external conditions during embryonic development or later. The individual's environment, food, friends, enemies, the world as he finds it, as well as his education, work, and general reactions to this environment, all have their influence on body and mind and determine to a considerable extent the realization of the possibilities derived from the germ: what he makes of his endowment. He

acquires, let us say, the strong arm of the blacksmith, the sensitive fingers of the violinist, or the command of higher mathematics. In other words, what he *is* depends on his heritage and what he does with it. Now, if he does develop an inherited capacity, can he transmit to his offspring this talent in a more highly developed form than he himself received it? Or must his children begin at the same rung of the ladder at which he started and make their own way up in the world? This is the old question of the inheritance of modifications, or so-called ACQUIRED CHARACTERS. (Fig. 258.)

Is the great length of the giraffe's neck, to take a classic though crude example, due to a stretching toward the branches of trees during many successive generations, with the result that a slightly longer neck has been gained in each generation and inherited by the following? (Fig. 472.) If so, it is a result of the inheritance of modifications, because the changes were somatic in origin. Or is the length of the neck the result of the survival in each generation of those individuals which happened to be born with longer necks and accordingly were better adapted to foliage conditions than those which varied toward shorter necks? If so, it is not a result of modifications but of changes having their origin in the germ cells.

Today biologists almost unanimously deny the former and accept the latter interpretation. The consensus is certainly that modifications, or changes in the individual body due to nurture, use, disuse, or mutilations, are not transmitted as such. This conclusion is held chiefly because there is no positive evidence of the inheritance of modifications while there is much negative evidence; and also because there is no known mechanism by which a specific modification of the soma can so influence the germ complex that this modification will be reproduced as such or in any representative degree. However, it should be emphasized that biologists clearly recognize the potent influence of environment and the organism's reactions to the environment on the destinies of the race, even though they see, at present, no grounds for a belief that any specific modification can enter the heritage and so be reproduced. (Fig. 259.)

In this connection the question of the inheritance of disease will undoubtedly arise in the reader's mind. But this is really not a special case. If the disease is the result of a defect in the germinal constitution, it may be inherited just as any other character, physiological or

morphological, that has a germinal basis. But if the disease is a disturbance set up in the body by some accident of life or through infection by specific microorganisms, before birth or later, it is a modification and therefore is not heritable. Of course, the well-known fact that susceptibility or immunity to disease-producing organisms—the soil for their development—may be inherited is not an exception to this statement. It may, however, be suggested in passing that from the standpoint of the individual born malformed, structurally or mentally, as a result of parental alcoholism, syphilis, or other obliquities, it probably will not appear of the first moment that the sins have been visited otherwise than by actual inheritance. But the racial consequences are, of course, immense. It is, so to say, more difficult to eradicate a morbid racial gene than, for instance, to prevent or cure a bodily infection. (Fig. 320.)

The whole question of the nonheritability of modifications, or acquired characters, is a relatively new point of view which has been fostered by the elusiveness of crucial experimental evidence, by an ever-increasing knowledge of the details of the chromosome mechanism of inheritance, and by the general influence of Weismann's contrast of the soma and germ. Indeed, Lamarck a century ago did not question the inheritance of acquired characters and made it the cornerstone of his theory of evolution, while some have even gone so far as to say that either there has been inheritance of acquired characters, or there has been no evolution. However, the question is not so serious as that, as will be seen later on; though obviously it is profoundly important from many viewpoints, biological, educational, and sociological. Incidentally, it may be mentioned for those who would like to believe that acquired characters are inherited, that if desirable modifications were inheritable, undesirable ones would be also. Perhaps Nature is merciful! (Figs. 510, 515.)

RECOMBINATIONS

Turning from modifications which are useless to the geneticist, one finds that the most common inherited differences which appear in offspring are RECOMBINATIONS; these owe their origin to new groupings of the germinal factors, or genes.

Everyone is familiar with some of the more obvious hereditary differences following fertilization which are the result of recombinations

of parental characters represented in the egg and sperm: cases in which nothing is apparent which is not clearly related to the conditions expressed in the ancestors. For example, the offspring may exhibit a character of one parent to the exclusion of that of the other—the character appearing unmodified. This is termed **ALTERNATIVE** inheritance.

Or the character in the offspring may appear **INTERMEDIATE** between those of the parents. Or, again, it may be a sort of **MOSAIC** of the parental characters, each parent contributing a certain character but not to the exclusion of that of the other. Sometimes the parental traits seem to fuse, or **BLEND**. And as a final example, characters of grandparents or more remote ancestors may reappear, and constitute **REVERSION**. (Fig. 228.)



FIG. 228. Effect of crossing two varieties of wheat, one bearded (*left*) and the other beardless (*right*). The parents are shown on either side, and the hybrid offspring in the middle. A case of so-called intermediate inheritance.

MUTATIONS

But quite different results now and then occur. Characters which have no place in the ancestry appear and are transmitted to the descendants. Sometimes these new heritable variations, or **MUTA-**

TIONS, are only slight departures from the parental condition, whereas in other instances they are quite abrupt. But the significant fact is that mutations result from relatively radical alterations in the gene complex and so afford new opportunities for variation.

Thus recombinations and mutations represent all the heritable differences and contrast sharply with modifications which are not transmitted to the offspring and are the results of environing conditions on the soma during embryonic development or later. The importance of this distinction can hardly be overemphasized because it makes comprehensible many of the inconsistencies of earlier work on genetics, as will appear in the later discussion involving genic and somatic mutations. (Fig. 256.)

GALTON'S STUDIES

The statistical treatment of biological data as a method of studying inheritance was first brought prominently to the attention of biologists by the work of Galton, a cousin of Darwin, during the closing decades of the last century, and started the widespread investigation of genetic problems. In particular, his work on the inheritance of characters in man, such as stature and intellectual capacity, is a biological classic judged by the discussion it evoked. As a result of these studies, Galton formulated two principles of heredity which may be briefly stated as follows:

Ancestral Inheritance. The two parents contribute between them, on the average, one-half of each inherited faculty; each of them contributing one-quarter of it. The four grandparents contribute between them one-quarter, or each of them one-sixteenth, and so on.

Filial Regression. On the average any deviation of the parents from the racial type is transmitted to the progeny in a diminished degree; the deviation from the racial mean being two-thirds as great as that of the parents. (Figs. 229, 279.)

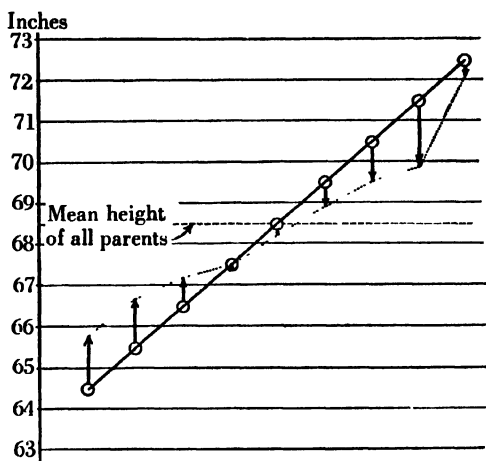


FIG. 229. Scheme to illustrate Galton's law of filial regression, as shown in the stature of parents and children. The circles represent the height of graded groups of parents, and the arrow heads show the average heights of their children. The length of the arrows indicates the amount of regression toward mean height of all parents. (From Walter.)

These so-called laws, taken by and large, undoubtedly express general truths—offspring inherit much more from their immediate than from their remote ancestors; and offspring of gifted or deficient parents, judged by the average standard of a mixed population, regress toward mediocrity, that is, toward the population average. But these laws are not particularly helpful in arriving at the fundamental principles involved in heredity because the data upon which they are founded include indiscriminately both heritable variations and modifications. The individual's somatic characters, which form the data, belie in many cases the underlying germinal constitution: what will be transmitted to the progeny. Thus, for instance, experiments on plants and animals show that when the *germinal* make-up of all the members of a group is the same with regard to a specific character, the regression is complete, no matter how far the particular parents may diverge *somatically* from the group average. The somatic divergence represents modifications that are not inherited. Conversely, when the divergence of the parents from the population average is due to characters which represent expressions of their germinal constitution, then there is no regression.

MENDELIAN PRINCIPLES

It was reserved for Gregor Mendel to apply statistical methods to facts observed in the progeny derived from carefully controlled experiments in breeding. In other words, to substitute for ancestral generations, controlled pedigrees—to look forward as well as backward and thus largely to remove the unknown and unknowable quantity which rendered the conclusions of Galton somewhat delusive. Mendel's studies that founded the modern science of genetics actually were made a score of years before Galton's, but failed to reach the attention of the biological world engrossed in the evolution theory; in fact were not known by Darwin to whom they would have meant so much in his work to secure experimental data on heredity. We can with advantage introduce the survey of genetic principles by a study of examples from Mendel's own work. (Fig. 511.)

Mendel chose seven pairs of **ALTERNATIVE** characters which he found were constant in certain varieties of edible peas, such as the form and color of the seeds, whether round or wrinkled, yellow or green; and the length of the stem, whether tall or short, and these he studied in the **HYBRIDS**. One ordinarily thinks of a hybrid as resulting

from a cross between two species or, at least, two characteristically distinct varieties of animals or plants; but as a matter of fact in nature the offspring of all sexually reproducing organisms are really hybrids because two parents seldom, if ever, are exactly the same in all of their germinal characters. Consequently the offspring are hybrids with respect to all the characters in which the parents differ; but in the following exposition the terms hybrid and pure are used solely in regard to the particular characters under analysis.

MONOHYBRIDS

Mendel found, from crossing pure tall and short varieties of peas, that all of the progeny of this PARENTAL (P) generation, in the FIRST FILIAL (F_1) generation, were tall like one parent, there being no visible evidence of their actual hybrid character. Accordingly tallness

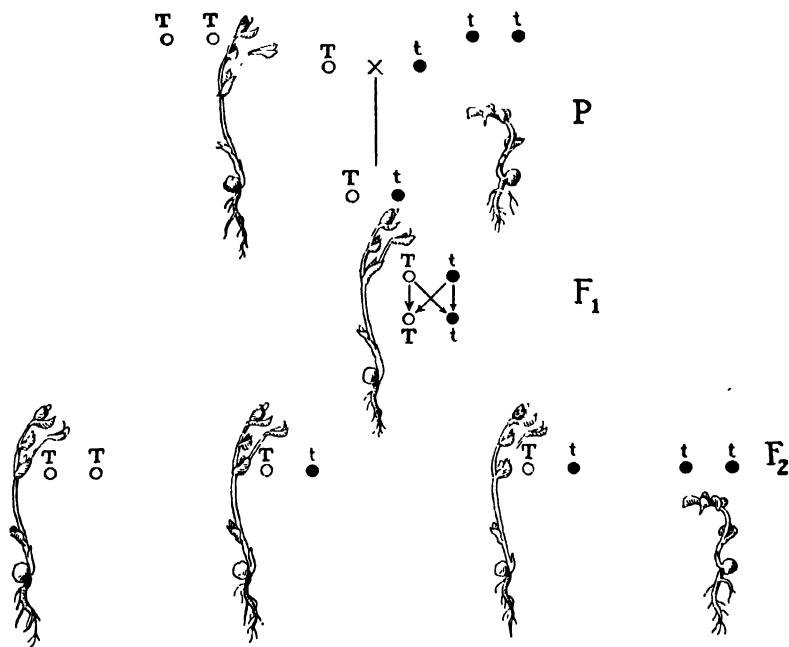


FIG. 230. Inheritance of size in offspring from matings (P) between a tall (T) variety and a short (t) variety of garden peas. The offspring in the first generation (F_1) inbred (self-fertilized) to produce the second generation (F_2). The circles represent the genes involved. See Fig. 231 which diagrams the same monohybrid matings.

was designated a DOMINANT (T) and shortness a RECESSIVE (t) character.

Mendel's next step was to follow the behavior of these characters in succeeding generations. Therefore the tall hybrids (F_1) were inbred (self-fertilized) and their offspring, the SECOND FILIAL (F_2) generation, were found to be tall and short in the ratio of three to one

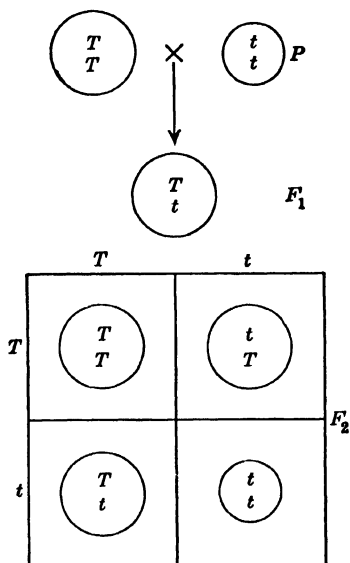


FIG. 231. Monohybrid cross. Results of mating tall (T) and short (t) pea plants. The circles represent the zygotes and the characters of the soma (phenotype); the letters within the circles, the germinal constitution (genotype). The letters outside the Punnett recombination square represent the gametes. Note that each of the parents (P) has a different phenotype and genotype; all the F_1 offspring (one shown) belong to the same phenotype and genotype; whereas the F_2 offspring represent two phenotypes (tall and short) and three genotypes (TT , Tt , tt). The expected number of individuals composing the F_2 phenotypes is 3:1, and genotypes is 1:2:1.

(3 T :1 t), or 75 per cent dominant to 25 per cent recessive individuals. But, of course, in dealing with a small number of individuals this ratio is merely approximate; the greater the number of offspring, the closer it is approached. In this particular case Mendel obtained 787 dominant and 277 recessive individuals: a ratio approximately 3:1. (Fig. 230.)

Continuing the work, Mendel found that the short plants (recessives) when inbred gave only recessives generation after generation, and accordingly were pure. On the other hand, the tall plants (dominants) when inbred proved to be of two kinds: one-third pure dominants which bred true indefinitely, and two-thirds hybrids like their parents, giving when inbred the same ratio of three dominants to one recessive in the THIRD FILIAL (F_3) generation.

Aside from his masterly foresight in realizing that success depended on simplifying the problem by dealing with definite alternative characters, Mendel's claim to fame lies chiefly in his discovery of a simple principle by which the results may be explained. Since the hybrids when inbred always give rise to hybrids and also to each of the parental types in a *pure* form,

it must be that the factors (genes) which determine the characters in question are sorted out, or SEGREGATED, in the ripe germ cells, or gametes. Assuming for illustrative purposes that a single gene determines a given character, it follows that after segregation the genes are distributed so that some gametes bear the gene for one character and other gametes bear the gene for the other character, but *no gamete bears the genes for both of the alternative characters*. This is known as the *purity of the gametes*. If the gametes of the original tall parent contain the gene for tallness (T), and those of the short parent the gene for shortness (t), then the hybrids will arise from a zygote which combines both genes (Tt), and since tallness is dominant over shortness all will be tall. Further, when the germ cells of this hybrid (Tt) mature, and these genes are segregated so that *half of the gametes bear T and half bear t*, then when such plants, each with this germinal constitution, are inbred there will be equal chances for gametes bearing the same, and for gametes bearing different, genes to meet in fertilization—hence three types of zygotes are formed. (Fig. 231.)

The zygotes are 1 TT:2 Tt:1 tt. But, since T is dominant, the offspring produced will be in the ratio of 3 tall to 1 short, which is the now widely established 3:1 ratio of dominants to recessives in the F_2 generation of a monohybrid in both plants and animals. The important point, however, is that these tall plants, although they all *appear* alike and therefore belong to the same PHENOTYPE, are actually of two kinds with respect to their germinal constitution; because one-third bear gametes all of which contain the gene T, and two-thirds bear gametes half of which contain T and the other half t. Consequently the tall phenotype is composed of two GENOTYPES which are distinguishable only by what they *produce*. (Figs. 230-232.)

It is thus apparent why the pure tall plants, when inbred, always breed true, and why the dwarfs, necessarily pure, do the same—all the gametes of one bear T and those of the other, t. The pure plants are HOMOZYGOUS with respect to the characters in question. It is also clear why the hybrids when inbred give rise to hybrids and pure dominants and recessives—half of their gametes bear T, and half bear t. The hybrid plants are HETEROZYGOUS.

The real difference then between the F_2 hybrids (Tt) and the pure dominants (TT) is that the former are heterozygous and the latter are homozygous with respect to the character in question. In order to tell

which is which, since they are phenotypically the same, it is necessary to breed them. When self-fertilization can be practiced, as with most plants, the result is secured directly; that is an individual's progeny are either all dominants or dominants and recessives in 3:1 ratio, and thus the gametic constitution of the parent is immediately known.

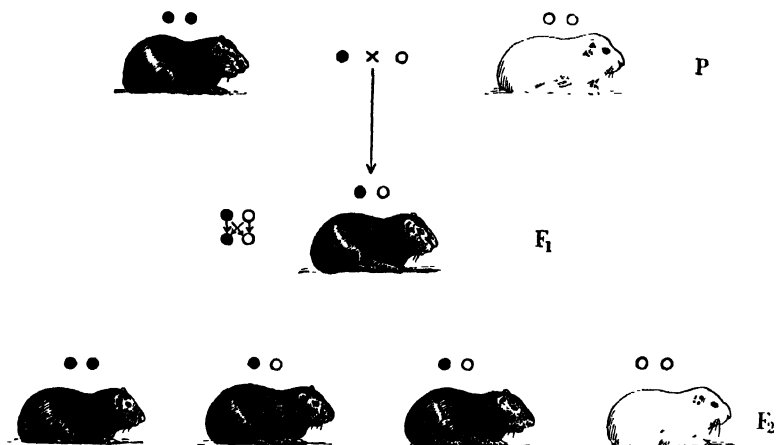


FIG. 232. Inheritance of color in a monohybrid cross between pure pigmented (black) and white (albino) guinea-pigs. The small circles represent the genes involved. Compare with results shown for garden peas in Figs. 230 and 231.

However, in the case of animals, where self-fertilization is impossible, the determination can be made by a BACK CROSS, that is, by mating the dominants with recessives; for a homozygous (pure) dominant then will give all dominants, whereas a heterozygous (hybrid) dominant will give half dominants and half recessives. Thus:

Gametes	=	$ \begin{array}{cc} D & D \\ \downarrow & \downarrow \\ d & d \end{array} $	$ \begin{array}{cc} D & d \\ \downarrow & \downarrow \\ d & d \end{array} $
Gametes	=		
Possible zygotes	=	100% Dd	50% Dd + 50% dd

So far we have considered inheritance in MONOHYBRIDS, that is cases involving one pair of alternative characters that can be interpreted as the resultant of one pair of genes termed allelomorphs or ALLELES, but now we proceed to cases where two, three, or more pairs of genes are involved, known as DIHYBRIDS, TRIHYBRIDS, etc.

DIHYBRIDS

Mendel investigated inheritance in dihybrids by crossing a pea producing yellow round seeds with one producing green wrinkled seeds. The plants in the F_1 generations produced only yellow round seeds, and therefore both yellow and round are dominant characters when paired with green and wrinkled. After self-fertilization such hybrid plants (F_1) produce offspring (F_2) with seeds showing all the possible combinations of the four characters (that is, not only yellow round and green wrinkled, but also two *new* combinations, yellow wrinkled and green round), and in the ratio of 9 yellow round seeds to 3 yellow wrinkled to 3 green round to 1 green wrinkled. (Figs. 233, 234.)

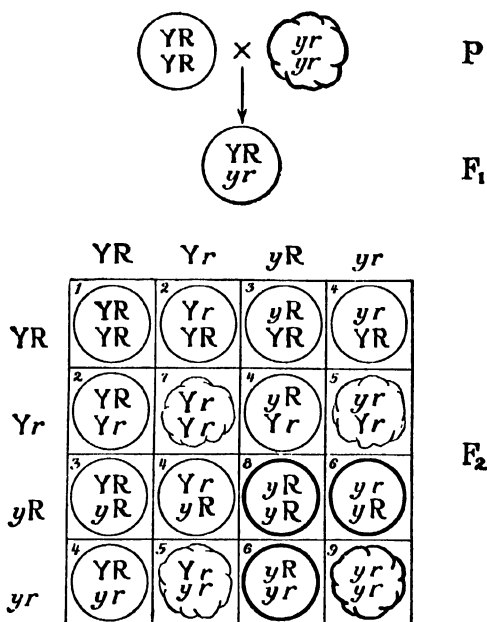


FIG. 233. Inheritance in dihybrids as described on page 322. Results illustrated are obtained by crossing peas (P) bearing the characters yellow and round (YYRR) with those bearing the characters green and wrinkled (yyrr). All the offspring (F_1) are dihybrids (YyRr) but look like one parent, since yellow and round are dominant over green and wrinkled. The F_1 hybrids produce four types of gametes (YR, Yr, yR, yr) and when interbred, produce 16 possible types of zygote in the F_2 generation as shown in the Punnett square above. In the F_2 there are four phenotypes (corresponding to the four gamete types) and nine genotypes. (See Fig. 234.)

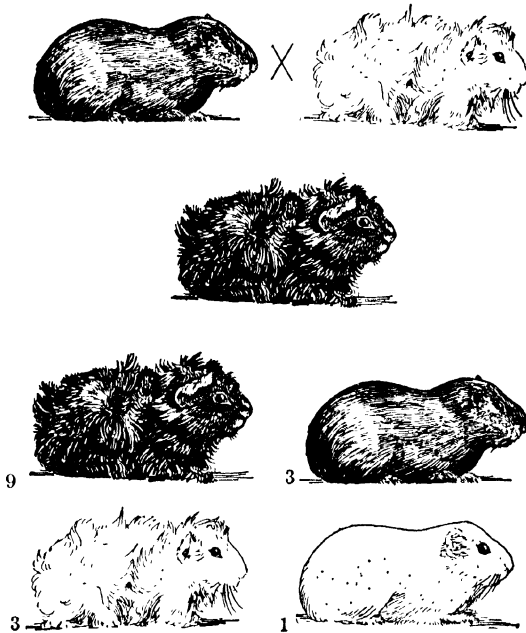


FIG. 234. Dihybrid inheritance in guinea-pigs. Results illustrated are obtained by mating smooth, black-haired animals with rough, white-haired animals. All of the F_1 offspring (dihybrid) are rough and black-haired, showing the dominance of these two factors and independent assortment. When the F_1 animals are inter-bred, they produce four types of offspring (F_2) with an expected ratio of 9:3:3:1, just as in garden peas. (See Fig. 233.)

These results can be interpreted only as indicating that one of the original parent plants bore gametes all containing the genes for yellow and for round peas (YR), whereas the other parent plant bore gametes all containing the genes for green and for wrinkled (yr). Such being the case, the resulting zygote contains the genes YRyr, and the hybrid which it forms develops gametes with all the possible combinations of these genes (except, of course, Yy and Rr), which are YR, Yr, yR, and yr; there is an INDEPENDENT ASSORTMENT of the genes as evidenced by the new combinations Yr and yR. Now, in turn, at fertilization there are sixteen possible combinations of gametes, since there are four different kinds of sperm and four different kinds of eggs with respect to the characters in question. Accordingly the F_2 generation, which is produced by the union of these

gametes, is represented by one pure dominant (YR^{YR}), one pure recessive (yryr), four homozygotes including the two just mentioned, and twelve heterozygotes. These sixteen individuals form nine genotypes but, since only the dominant character is expressed when dominant and recessive genes combine, they are resolvable into four phenotypes (YR, Yr, yR, yr) in the ratio 9 YR:3 Yr:3 yR:1 yr. Thus the 9:3:3:1 ratio for two pairs of alternative characters is merely the monohybrid 3:1 expanded. Both rest on the same fundamental assumption that the genes for alternative characters are segregated during gamete formation—both members of a pair of alleles never occur in the same gamete. The gametes are pure.

TRIHYBRIDS

Similarly in trihybrids, for example Mendel's cross between pure tall peas bearing yellow round seeds and short peas bearing green wrinkled seeds, or the cross between pure guinea pigs with short, rough, black hair and those with long, smooth, light hair, give in the F₂ generation 27 genotypes and 8 phenotypes, the number of individuals in the phenotypes being in the ratio 27:9:9:9:3:3:3:1. Of course, in nature there are few instances in which parents and offspring differ by only one, two, or three characters, but since characters arising from each pair of alleles can usually be treated singly, convenience demands that the analysis be made with respect to one or two pairs at a time, which therefore is the usual method of procedure. (Figs. 235, 236.)

Before passing to a consideration of certain extensions of the established hereditary principles, it may serve to clarify the subject if we restate the data in slightly different form and emphasize the essential facts so far discussed, chiefly on the basis of Mendel's own work.

Every cell of the body, or soma, of an individual carries a pair of genes for each alternative character (e.g., size in the case of the pea), one member of each pair of genes having been derived from each gamete which at fertilization contributed to the individual's heredity. When both genes of a pair are identical (e.g., either TT or tt) they are expressed in the soma (e.g., the plant is tall or short). The individual is homozygous with respect to a specific character. But when the two genes are not identical (e.g., Tt), one, the dominant (T), is expressed in the soma (the plant is tall), but the other, the recessive (t), is not expressed. The individual is heterozygous with respect to the character in question (e.g., size).

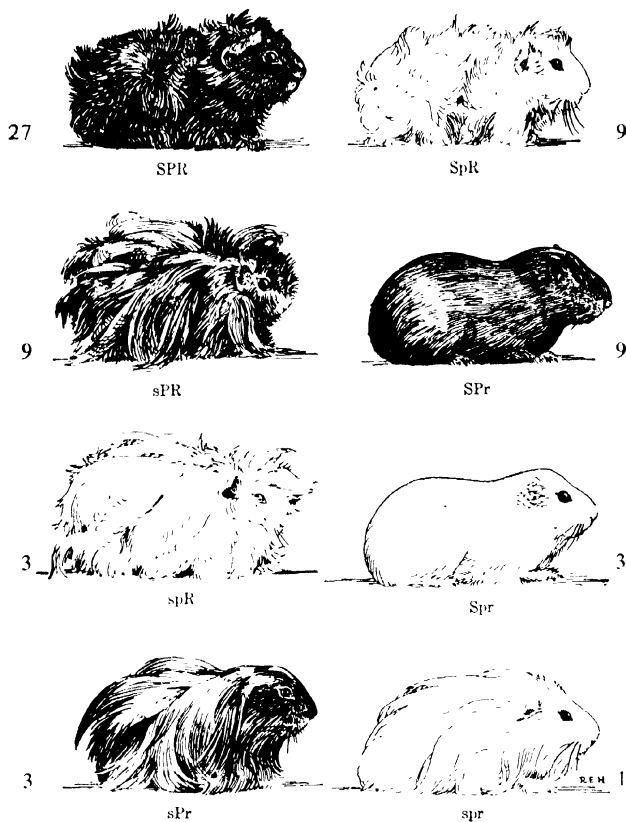


FIG. 235. Trihybrid inheritance. The eight phenotypically different kinds of guinea-pigs in the F_2 generation of a trihybrid. S = short hair, s = long hair, P = pigmented coat, p = non-pigmented coat or albino, R = rough coat, r = smooth coat. The hybrid parents (F_1) were phenotypically SPR. See Figs. 236 and 240 for an analysis of the trihybrid mating. (After Castle.)

It will be recalled that after synapsis of the chromosomes, during spermatogenesis and oögenesis, *segregation* of the chromosomes (genes) occurs with the result that each gamete receives only one gene for each character. Thus the gametes of homozygous individuals are all alike with respect to the gene in question (e.g., all bear either T or t), whereas the gametes of heterozygous individuals are of two numerically equal classes (e.g., 50 per cent bear T and 50 per cent bear t). (Figs. 171, 174; p. 234.)

Number of individuals in each class		GENOTYPES	PHENOTYPES	Number of individuals in each class
*	1	<i>SS PP RR</i>	<i>SPR</i> Short, pigmented, rough	27
	2	<i>SS Pp RR</i>		
	2	<i>Ss PP RR</i>		
	4	<i>Ss Pp RR</i>		
	2	<i>SS PP Rr</i>		
	4	<i>SS Pp Rr</i>		
	4	<i>Ss PP Rr</i>		
	8	<i>Ss Pp Rr</i>		
*	1	<i>SS pp RR</i>	<i>SpR</i> Short, albino, rough	9
	2	<i>Ss pp RR</i>		
	2	<i>SS pp Rr</i>		
	4	<i>Ss pp Rr</i>		
*	1	<i>ss PP RR</i>	<i>sPR</i> Long, pigmented, rough	9
	2	<i>ss Pp RR</i>		
	2	<i>ss PP Rr</i>		
	4	<i>ss Pp Rr</i>		
*	1	<i>SS PP rr</i>	<i>SPr</i> Short, pigmented, smooth	9
	2	<i>SS Pp rr</i>		
	2	<i>Ss PP rr</i>		
	4	<i>Ss Pp rr</i>		
*	1	<i>ss pp RR</i>	<i>spR</i> Long, albino, rough	3
	2	<i>ss pp Rr</i>		
*	1	<i>SS pp rr</i>	<i>Spr</i> Short, albino, rough	3
	2	<i>Ss pp rr</i>		
*	1	<i>ss PP rr</i>	<i>sPr</i> Long, pigmented, rough	3
	2	<i>ss Pp rr</i>		
*	1	<i>ss pp rr</i>	<i>spr</i> Long, albino, rough	1
64				64

FIG. 236. The different genotypes and phenotypes and the number in each class that are expected in the F_2 generation of the guinea-pig trihybrid, $Ss Pp Rr$. The eight homozygotes are indicated by asterisks. (See Figs. 235 and 240.)

Finally, there is an *independent assortment* of the genes for different characters, as evidenced by new combinations of characters in the progeny of dihybrids, etc. For example, size and color are independently inherited. This depends, as will be seen later, upon the genes involved being in different pairs of chromosomes. (p. 334.)

The principles of segregation and independent assortment are usually known as Mendel's laws.

ALTERATIONS OF MENDELIAN RATIOS

The immense amount of experimental breeding that has been carried on since Mendel's time has accentuated the significance of the principles of segregation and independent assortment, but has revealed

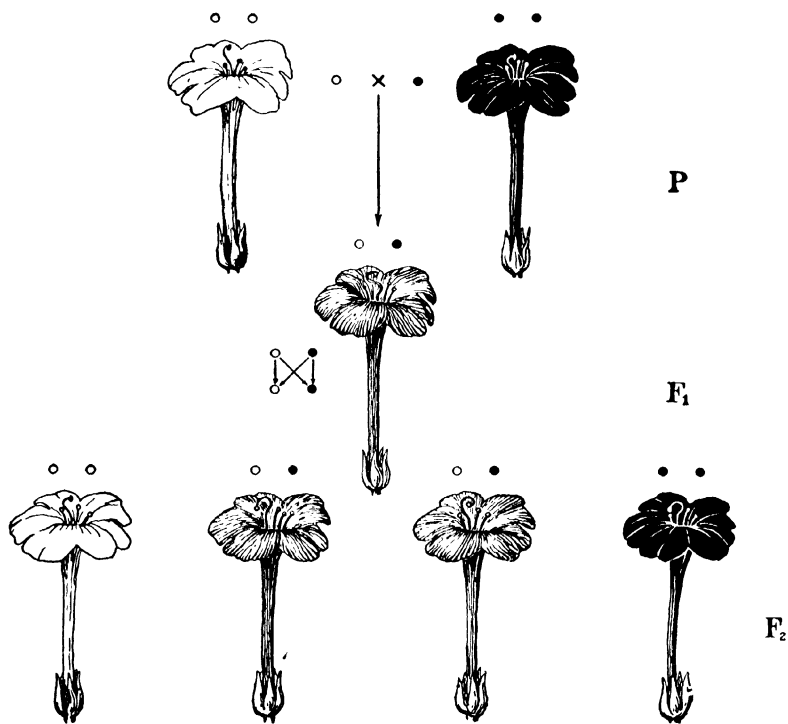


FIG. 237. Inheritance of color from matings (P) between white-flowered and red-flowered four o'clocks (*Mirabilis jalapa*). This is an example of incomplete dominance (blending inheritance). The phenotype indicates the genotype; the hybrids (F_1) are pink. This is a monohybrid condition as already seen in Figs. 230-231.

that dominance is by no means universal. A few examples will bring the main facts before us.

All the pairs of alternative characters in peas, which Mendel studied, showed essentially complete dominance of one character in each pair, but we now know a great many cases in which the hybrid (F_1) shows a different condition from either of the parents. For instance, on crossing homozygous *red* and *white* races of the four-o'clock, all the progeny in the heterozygous (F_1) generation bear *pink* flowers. Neither red nor white is dominant: the result is INTERMEDIATE. But inbreeding the hybrids gives three types of individuals in the F_2 in the ratio of 1 red: 2 pink: 1 white. Thus the typical 3:1 ratio is, so to speak, automatically resolved into the 1:2:1 ratio which, when one character is dominant, is evident only on further breeding. Segregation actually occurs as usual, because the homozygous progeny of the hybrid exhibit the original parental characters unmodified. (Fig. 237.)

In certain other cases, the hybrids, instead of being true intermediates, really exhibit the characters of *both* parents: neither character is recessive. Thus in shorthorn cattle, red and white when mated give roan, a color effect resulting from a close intermingling, or MOSAIC, of red and white hairs in the coat. Accordingly roan shorthorns are always heterozygous, but their offspring give the expected ratio of 1 red: 2 roan: 1 white which is clear evidence of segregation. Another example is the well-known blue Andalusian fowl. This will not breed true—it is a hybrid in which the characters of both parents are exhibited, apparently without blending though giving a somewhat intermediate effect. Its offspring show the ratio of 1 black: 2 blue Andalusian: 1 white-splashed-with-blue. In order to obtain all blue Andalusians—the type recognized by poultrymen—it is necessary to mate black with white-splashed-with-blue birds. So again it is clear that segregation is involved, as it is in innumerable instances where no sharp distinction can be made between complete and incomplete dominance. (Figs. 238, 239.)

Illustrations of some of the complications are afforded by cases of so-called BLENDING inheritance that result from the *cumulative* action of several pairs of genes (MULTIPLE GENES) as in the cross of white and black human races. The mulatto (F_1), from a cross between an individual homozygous for white and an individual homozygous for black, is intermediate in skin color between the parental types, and in

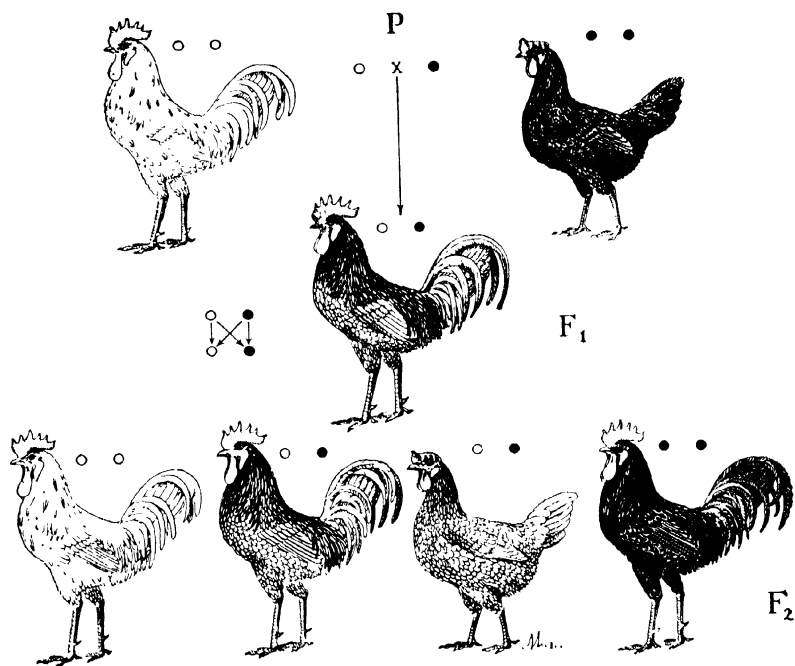


FIG. 238. Inheritance of color from matings (P) of white-splashed-with-blue chickens with black chickens. This is another example of incomplete dominance as in Fig. 237. All the F₁ offspring are blue Andalusians, and when interbred give the monohybrid genotype ratio (1:2:1) in the F₂, as in Figs. 231 and 237.

the F₂ and later generations gives a series of gradations between white and black but rarely pure white or black offspring. Assuming that three pairs of genes for color are involved, the genetic constitution of the black race may be represented by AABBCc and that of the white race by aabbcc. Accordingly the hybrid, or mulatto, has the genetic constitution AaBbCc and is intermediate in color since only half of the genes for black pigmentation are present. Furthermore, the progeny (F₂) of mulattoes show different degrees of color ranging from pure white to pure black, owing to the sixty-four possible recombinations of genes according to the trihybrid formula: the more black genes present, the darker the pigmentation of the skin. The infrequent appearance of pure white or blacks in the F₂ generation is because the chances are slight that, through segregation and independent assortment, all the separate genes for black or white will be brought to-



ROSE
RR pp



PEA
rr PP



WALNUT
Rr Pp



RP
WALNUT (9)



Rp
ROSE (3)



rP
PEA (3)



rp
SINGLE (1)

	RP	Rp	rP	rp
RP	RP RP Walnut	Rp RP Walnut	rP RP Walnut	rp RP Walnut
Rp	RP Rp Walnut	Rp Rp Rose	rP Rp Walnut	rp Rp Rose
rP	RP rP Walnut	Rp rP Walnut	rP rP Pea	rp rP Pea
rp	RP rp Walnut	Rp rp Rose	rP rp Pea	rp rp Single

FIG. 239. Inheritance of combs in chickens. The four phenotypes (rose, pea, walnut, and single) result from the independent expression and the interaction of the members of two pairs of alleles. The gametes and resulting offspring are shown in the square. Matings of rose and pea types produce all walnut offspring. When interbred the walnut type produces four types of comb, as shown, in a dihybrid ratio. (After Benedict, Knox, and Stone. Redrawn.)

when received from both of the parents. It is also possible for lethals to be effective during the gamete stage or as late as adult life. In the latter case, of course, it has a greatly deferred, and usually unrecognized, effect on the expected ratios. It is probable that future intensive study of lethals in man will prove of considerable importance in medicine.

Parents	Creepers × Creepers			
	Cc		Cc	
Gametes	C	c	C	c
	C		c	
Offspring	C	CC dies	Cc Creeper	
	c	Cc Creeper	cc normal	

FIG. 241. Diagram illustrating the inheritance of a lethal gene in the chicken. This produces a 2:1 ratio instead of the expected 3:1 ratio.

From these few examples it is apparent that the various types of inheritance can be satisfactorily interpreted on the fundamental principles of segregation and independent assortment. It is necessary merely to bear in mind that it is the genes which determine the development of characters, and not the characters themselves that behave as units; for now it is known that most characters are determined by many genes, and that even in cases where one gene seems to produce a character, other MODIFYING GENES may affect its development.

Within the past few years geneticists have been able by the multiple gene, modifying gene, and similar concepts to bring the inheritance of a large number of characters into agreement with Mendelian principles. Thus stature, proportions of the various parts of the body, as well as nearly all the physiological and mental characteristics in man are evidently dependent upon many genes. In certain fruit flies (*Drosophila*) eye color may be influenced by more than fifty pairs of genes and the wing characters by upward of a hundred. So it is becoming increasingly evident that what a given gene will produce is determined by the constitution of the gene plus its interaction with many, if not all, of the other genes of the complex. However, as has been seen, a single gene pair in many or most cases does have its most conspicuous effect on a certain character of the organism.

Furthermore, what the gene complex will produce bears an intimate relationship to the environment. For instance, the abnormal condition of extra legs in *Drosophila* is inherited in typical Mendelian manner when the flies are reared at a low temperature, whereas supernumerary legs do not appear in flies with the *same* gene heritage when bred at a higher temperature. Again, the character in *Drosophila* known as abnormal abdomen appears only in flies bred under especially moist conditions (Fig. 242). As the culture becomes dryer, the flies that emerge

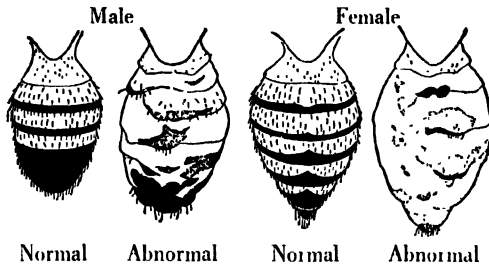


FIG. 242. Effect of environment on genic expression in *Drosophila*. Abnormal abdomen appears in the phenotype of the offspring only when the culture conditions are such as to give high humidity, even though the gene for this character is always present in the genotype. (From Morgan.)

are more and more normal until finally they cannot be distinguished from wild flies. Here, then, is a genetic character that is extremely sensitive to the environment. Still again, the so-called sun-red color of the kernels of corn is a heritable character that develops only when the kernels themselves are exposed to light by the removal of the husk. In short, the environment may act as a differential intensifying or diminishing gene action, and thus influence the realization of the potentialities of the heritage. Evidently, then, the so-called normal character of an organism is but a partial expression of the range of possibilities inherent in its genotype. (p. 350.)

So it happens, as is usually the case, the more a problem is studied the more complex it appears to become. Suffice it to say that our knowledge of inheritance is today immensely broader than Mendel conceived on the basis of his classic experiments, but it is evident that he supplied us with basic principles which are affording a common denominator for an ever-increasing number of facts in genetics.

CHAPTER XXIII

Genetics (II)

MECHANISM OF INHERITANCE

With the general outline of genetic principles, as discussed in the preceding chapter, before us, it is now necessary to bring them into relation with the facts so far discovered in regard to the structure of the germ cells. In other words, we have assumed, on the basis of the experimental results derived from breeding plants and animals, the existence of genes, the occurrence of segregation, etc.; but has the actual study of cells (CYTOLOGY) by means of the microscope given evidence of the physical basis of genes and of a segregating mechanism? The reader will at once answer this in the affirmative from the previous discussion of the origin and structure of the germ cells and their behavior in fertilization (Chapter XVII). Accordingly the essential facts may now be restated from this point of view. (Fig. 171.)

The egg and sperm each carry a definite haploid number of chromosomes and consequently after fertilization the zygote contains a double, or diploid, set. For each chromosome contributed by the sperm there is a corresponding, or HOMOLOGOUS, chromosome contributed by the egg. In other words, there are two chromosomes of each kind which may be considered as pairs. When division of the zygote takes place each chromosome splits into two chromosomes, so that each daughter cell receives a daughter chromosome derived from each of the original ones. Since all the cells of the organism are lineal descendants by similar mitotic cell divisions, all its cells contain two sets of chromosomes, one paternal and the other maternal; and since the primordial germ cells have a similar origin, they also have two sets of chromosomes. But during the maturation process synapsis occurs: that is, homologous chro-

mosomes of paternal and maternal origin unite in pairs—the process of fertilization which gave rise to the individual being consummated in the ripening of its own germ cells. But this synaptic union is only temporary; during the maturation process the maternal and paternal chromosomes of each synaptic pair are separated, and one of each (though very rarely all of the same maternal or paternal set) passes to the daughter cells; this is segregation. Thus each mature germ cell, or gamete, contains one member of every chromosome pair and the number of chromosomes is reduced one-half, that is to one complete haploid set. (Figs. 174, 243.)

It has been assumed that the genes for alternative characters segregate in the formation of the gametes of hybrids so that a single gamete bears one and not both genes of a pair of alleles. That is the genes, which come together in the zygote that forms the hybrid, separate again in the formation of the hybrid's own gametes. This is just what cytological studies show. Chromosome behavior exactly parallels the typical behavior of the Mendelian gene, because after synapsis, during spermatogenesis and oögenesis, each chromosome of paternal origin separates from the corresponding chromosome of maternal origin. Therefore it is clear that the genes are in the chromosomes. Moreover, since the genes similarly situated in homologous maternal and paternal chromosomes are HOMOLOGOUS GENES, or alleles, it follows that homologous genes are segregated in separate gametes during maturation—the two members of a pair of alleles pass to different gametes. This is the basis of the so-called purity of the gametes.

Furthermore, in considering dihybrids it was seen, for instance, that genes for yellow and round and for green and wrinkled seeds were inherited in a fashion which indicated that yellow and round are distributed independently of each other—there is an *independent assortment*, because all possible combinations with green and wrinkled occur. This clearly is fully accounted for, provided the genes for color and the genes for form are not in the same pair of chromosomes. (Figs. 233, 234, 243.)

In short, when two gametes unite, each contributes to the zygote a homologous haploid group of genes with the result that the offspring is of diploid gene constitution. Similarly, each gamete contributes a homologous haploid chromosome group so that the zygote is of diploid chromosome constitution. Thus *both* the chromosomes and the genes are present in the haploid condition in the gametes and in the diploid

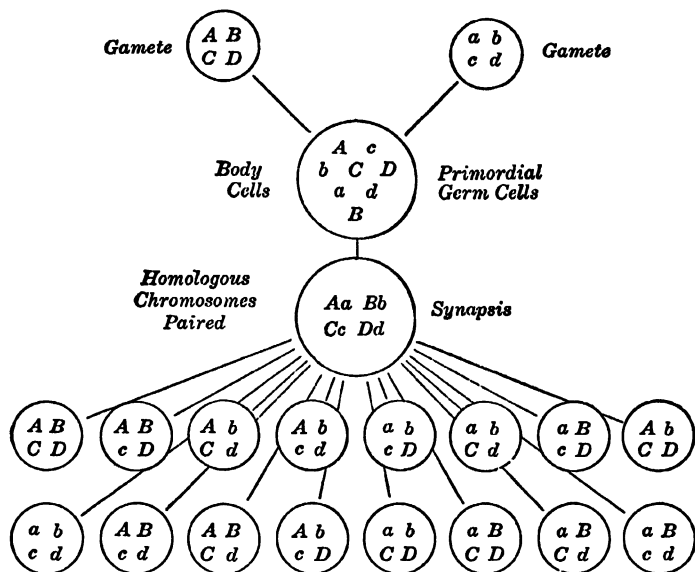


FIG. 243. Diagram to show the union of haploid groups of *either* chromosomes or of genes in the gametes at fertilization to form the diploid condition of the zygote, body cells, and primordial germ cells. Finally their pairing at synapsis, segregation, and independent assortment in the gametes. With four pairs of chromosomes or of genes (Aa , Bb , Cc , Dd) there are sixteen possible types of gametes.

in the zygote. This exact parallelism of the gene and chromosome behavior, first pointed out in detail by a young American cytologist, Sutton, in 1903, affords further proof that the chromosomes through their constituent genes determine the physical basis of inheritance, and that segregation and related phenomena are highly significant facts. For all practical purposes, A , B , C , D and a , b , c , d in Figs. 174 and 243 may be interpreted either as chromosomes or as genes.

Turning now to the inheritance of characters whose genes are borne by the *same* chromosome: these would seem to be indissolubly linked together. And since the chromosome number is usually not large—there are twenty-four pairs of chromosomes in man—compared with that of heritable characters, one would expect frequently to find characters linked together, that is, not separately inherited, or independently assorted, as are yellow and round in our example. In reality

many cases are known in which characters are definitely inherited together. The inheritance of sex and sex-linked characters will make the main point clear, and at the same time serve to bring before us the essential facts in regard to the determination of sex.

SEX DETERMINATION

Studies of the chromosomes in the somatic cells and in the germ cells before the maturation divisions have shown that in one of the sexes, usually in male animals, the two members of a certain pair of homologous chromosomes (synaptic mates) differ recognizably from each other in size or form or both. For example, one member, referred to as the X chromosome, may be similar to the other chromosomes, whereas its mate, called the Y chromosome, may be atypical in form or much smaller or, indeed, not present at all in certain species. Furthermore, if this is the condition in males, it has been found that in corresponding cells of females there are two X chromosomes. Thus the chromosome groups of males possess an X-Y pair, and those of females, an X-X pair. This difference between the chromosomes of the sexes naturally suggests that the X chromosome bears essential determiners for sex, and this proves to be the case. (Fig. 244.)

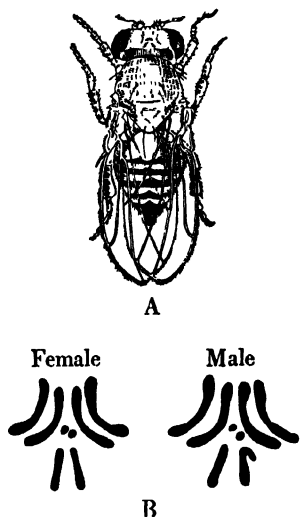


FIG. 244. A, fruit fly, *Drosophila*; B, chromosomes: in the female the lower pair is the X-X, and in the male the lower pair is the X-Y. See Fig. 246 for human chromosomes. (From Bridges.)

During spermatogenesis the maturation divisions following synapsis segregate the synaptic mates (X-Y) in the regular way, so that two classes of sperm result: half the sperm bear the X chromosome and half

the Y chromosome. Furthermore, in oögenesis the maturation divisions distribute an X chromosome (from the X-X pair) to each cell, and accordingly every egg bears an X chromosome. Thus, in man the somatic number of chromosomes is 48; males having 46 plus an X-Y pair, and females 46 plus an X-X pair. Half the sperm bear 23 plus X, and half bear 23 plus Y; while all the eggs bear 23 plus X. Males are heterozygous for sex, and females are homozygous. (Fig. 245.)

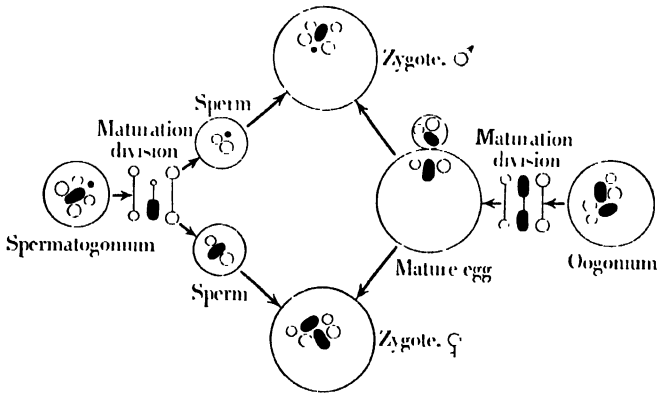


FIG. 245. Diagram to show the relation of the two classes of sperm in fertilization. Somatic diploid chromosome number shown as six. The formation of gametes in the male is shown at the left, in the female at the right; fertilization, producing the male zygote, ♂, or female zygote, ♀, in the center. X chromosome (large) and Y chromosome (small) in black. (After Wilson.)

Since there are equal numbers of sperm with and without the X chromosome, as many eggs on the average will be fertilized by one class of sperm as the other, with the result that half of the zygotes will contain one X and half two X chromosomes. The former will develop into males and the latter into females, since the somatic cells of males have one X chromosome and similar cells of females have two. (Fig. 246.)

So it seems clear that sex is typically determined at the time of

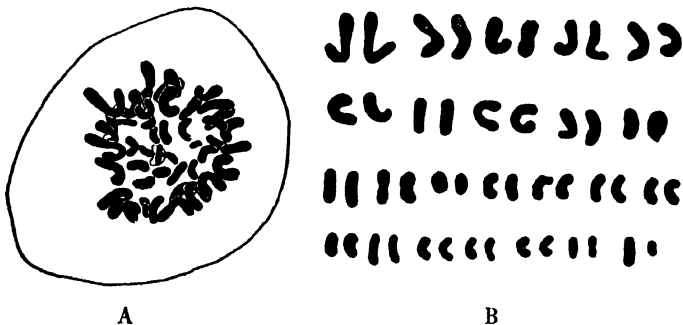


FIG. 246. A, Drawing of a human spermatogonium with 48 chromosomes; B, chromosomes arranged to show the 24 pairs of homologous chromosomes, or synaptic mates. The X-Y pair is at lower right. Very highly magnified. (From Painter.)

fertilization by the same fundamental mechanism that controls inheritance in general. Moreover, many genes are involved. The decision is given by certain genes in the X chromosomes, acting in connection with genes in other chromosomes. The genes in the X chromosomes turn the balance under the usual conditions of development so that a series of processes is initiated, involving the action and interaction of hormones, nutritional factors, and various environmental conditions, that lead to the later sex differentiation of the adult.

But many unusual cases, some normal and others abnormal, occur particularly among the lower animals. Thus it has been found that INTERSEXES—individuals exhibiting varying degrees of male and female characters—may result from abnormal sets of chromosomes in which the balance between the X and the other chromosomes is upset, as is well illustrated by studies on *Drosophila*. (Fig. 247.) Or hor-

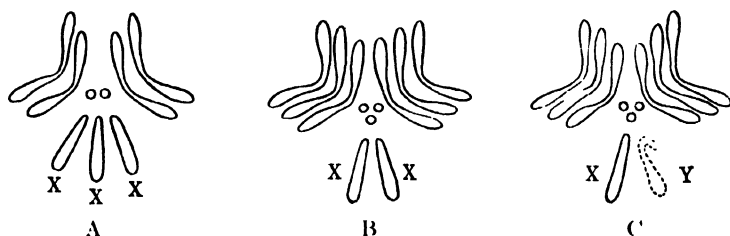


FIG. 247. Influence of the balance between X chromosomes and the other chromosomes on sex in *Drosophila*. A, super female; B, intersex; C, super male. See Fig. 244 for normal chromosome complex.

mones may have a modifying influence. Thus in cattle a male twin usually renders abnormal the development of its female twin in the uterus, so that a sterile freemartin results. (Fig. 248.) Or still again, SEX REVERSAL may occur through environmental factors acting on the early embryo, as in the case of the frog. And finally, the sex of the adult may change, sometimes periodically as in the oyster. Such marked departures from typical sex differentiation serve to emphasize that the final establishment of sex is indeed a resultant of many complex factors. (Fig. 249.)

LINKAGE

Since the basic mechanism that regulates sex is the same as that which determines the distribution of other characters in inheritance,

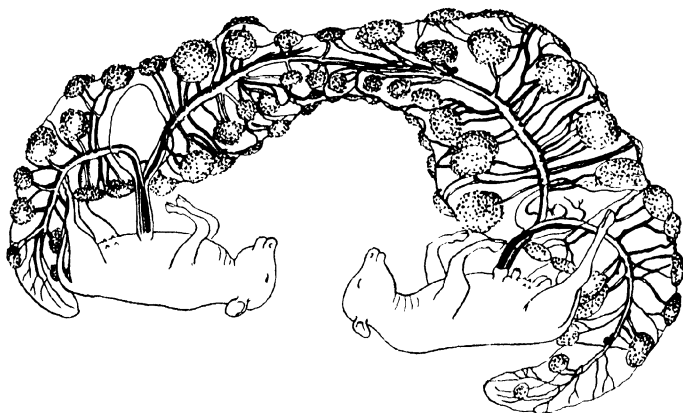


FIG. 248. Two embryo calves whose placentas are united. If they are of opposite sex, the female embryo will become a sterile freemartin as a result of the male hormone received from the male twin through the common placental circulation. (After Lillie.)

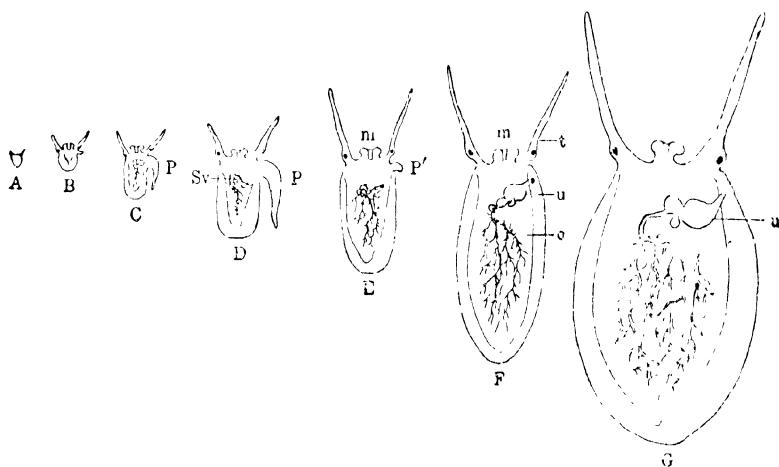


FIG. 249. Successive sexual phases in a mollusc, *Crepidula nummaria*, showing the development and reorganization of the male reproductive system preceding the female phase. A, recently hatched young; B, early male phase; C, young functional male; D, mated male; E, transition phase; F, G, female phases; m, mouth; o, ovary; p, penis; sv, seminal vesicle; t, tentacle; u, uterus and seminal receptacle. (From Coe.)

it might be supposed that the genes of other characters as well are carried in the X chromosome. As a matter of fact the behavior in inheritance of certain characters is such that it can reasonably be explained only on this assumption. Accordingly such characters are known as SEX-LINKED. This brings us again to the point at which we digressed to consider sex: the discussion of genes associated in the same chromosome.

Upward of thirty sex-linked characters are known in man, variously affecting the eyes, blood, skin, muscles, nerves, and glands. The best-known examples are congenital COLOR BLINDNESS in which the affected person is unable to distinguish red from green, and HEMOPHILIA in which the individual's blood has so little tendency to clot that bleeding from even a slight wound may be serious. Both abnormalities have long been known to be inheritable, and in the same peculiar criss-cross way. Color blindness is usually transmitted from a color-blind man through his daughters, who are normal, to half of his grandsons; and from a color-blind woman to all of her sons and none of her daughters. When both parents are color-blind, all the children show the defect. This behavior is readily accounted for if the gene for color blindness when present is associated with those for sex in the X chromosome, and if color blindness develops in males when it is received from one parent and in females when it is received from both parents. Accordingly a color-blind woman is homozygous for the character, whereas one who is heterozygous has normal vision, but is a carrier, that is, produces gametes half of which carry the gene for color blindness. From this fact it is obvious why color blindness is very much less frequent in women than in men. Incidentally, it is also clear that whatever characters are borne by the X chromosome are not transmitted by a father to his sons, and this perhaps minimizes, from the standpoint of heredity, the importance usually ascribed to descent in the direct male line. (Fig. 250.)

Color blindness and hemophilia thus serve to illustrate the association of genes of different characters in the same chromosome and the association later of their respective characters in the adult—*independent assortment* does not occur. This exception to the principle of independent assortment proves the rule. And it offers still further evidence, if such is needed, that the genes are in the chromosomes—the chromosomes are merely linkage groups of genes. The number of chromosomes and the number of linkage groups are the same.

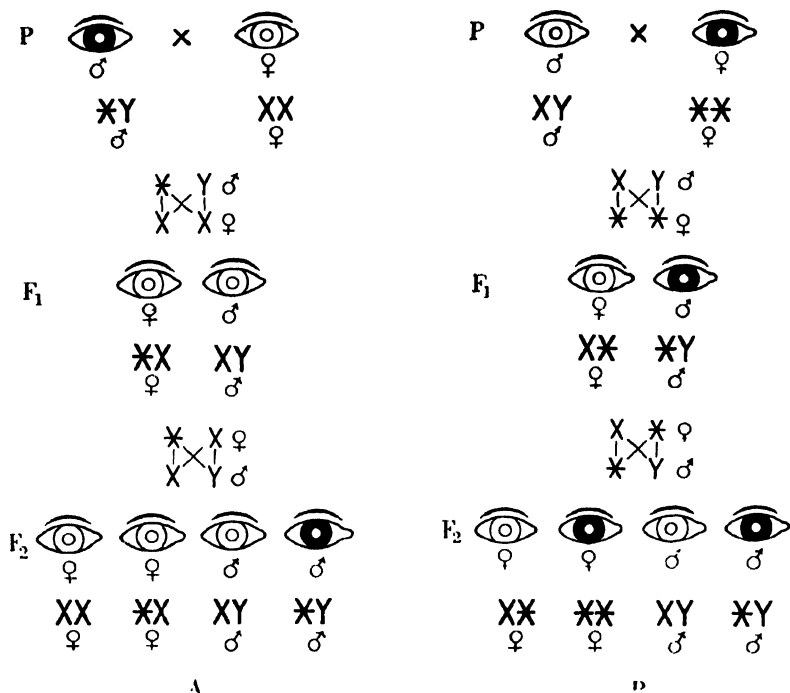


FIG. 250. Diagrams to show the inheritance of color-blindness: A, from a color-blind man and normal woman; B, from a color-blind woman and normal man. χ indicates the X chromosome with the gene for color-blindness. It will be noted that a color-blind man transmits the character through his daughters to half his grandsons (F_2), a color-blind woman transmits the defect to all of her sons (F_1), to half of her grandsons and half of her granddaughters (F_2).

The fact that characters represented by genes on the same chromosome are typically inherited together offers possibilities of great practical importance, because it affords the opportunity to predict the presence of latent genes, lethal or otherwise, on the basis of expressed gene mates on the same chromosome. For instance, Huntington's chorea is an inherited human malady, the result of a dominant gene whose action is deferred until middle life when it gradually overcomes its victim mentally and physically so that death is a blessing. If linked genes could be discovered that are expressed as characters early in life and inherited together with Huntington's chorea, the presence of the gene responsible for the chorea could be determined far in advance of its expression in the phenotype. And though the individual would still

be doomed, it is safe to say that no right-minded person would have children if he knew the chances were high that a similar fate awaited some of them.

CROSSING OVER

However, the presence of associated genes in the same chromosome by no means indicates that these genes must *always* be distributed together. Thus during synapsis homologous genes (alleles) often reciprocally **CROSS OVER** from one synaptic mate to the other, and so become separated from their former gene associates. When such occurs the exchanged genes are segregated independently of their former associates; they pass to different gametes and therefore to different individuals. Thus *gene recombination* is added to *chromosome recombination* with the result that a greatly increased flexibility is afforded the genetic mechanism. Variation, indeed, is still further provided. (Fig. 251.)

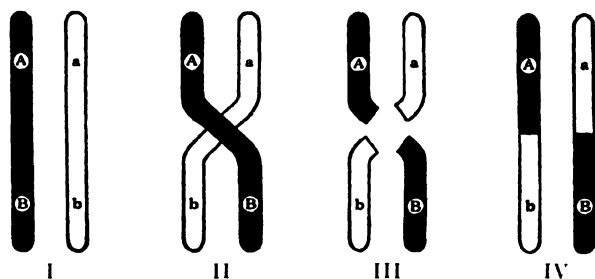


FIG. 251 Diagrams showing crossing over of homologous paternal and maternal chromosomes during synapsis. The letters on the chromosomes indicate the linear arrangement of the genes with alleles opposite each other. I, pair of homologous chromosomes with genes A, B and alleles a, b; II, chromosomes winding about each other at synapsis; III, separation of these chromosomes, involving breaks at the points of crossing; IV, their emergence from synapsis with the members of the pairs of alleles interchanged. (From Lindsey.)

In addition to its great importance in bringing about genetic change, crossing over affords the geneticist an opportunity to determine the relative positions of different genes in a chromosome. It has been found that the frequency of crossing over between two genes in a chromosome is, in general, proportional to the distance between them: the greater the distance, the more frequent is the crossing over. Therefore it is possible to estimate the distances between genes by de-

termining the amount of crossing over that occurs between them. Furthermore, it so happens that the chromosomes in the cells of the salivary glands of *Drosophila* are relatively huge so that it is possible to observe differentiated regions representing the positions of various genes. And these giant chromosomes are typically in pairs—so-called somatic synapsis—with identifiable homologous gene regions in apposition. Thus with data from very extensive breeding experiments and from microscopic studies of details of the chromosomes it is possible to construct CYTOGENETIC MAPS showing the relative positions of various genes in the chromosomes. In *Drosophila* the genes for more than six hundred characters have already been mapped, and estimates indicate that this fly has not less than 5,000 genes. And the mapping of the human chromosomes is rapidly becoming a reality. By a special technique, not involving crossing over, the number of relatively well-established gene positions in man now extends into the hundreds. (Fig. 252.)

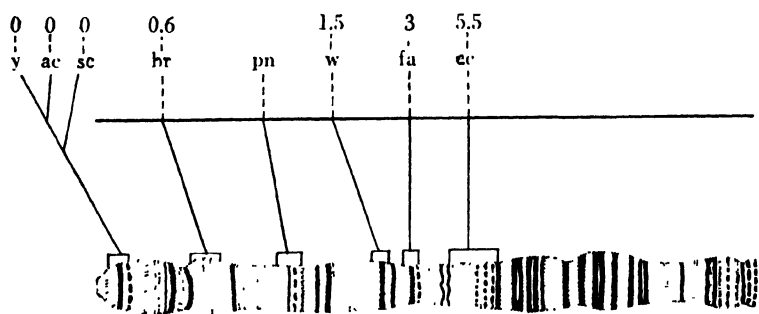


FIG. 252. Cytogenetic map. Terminal portion of an X chromosome from the salivary gland of *Drosophila*, with the locations of some of the genes and their corresponding characters indicated as determined by microscopic study of special preparations. Horizontal line above represents a portion of a chromosome map in which the positions of the same genes have been determined by crossing over experiments. ac, achaete; br, broad; ec, echinus; fa, facet; pn, prune; sc, scute; w, white; y, yellow. (After Painter.)

MUTATIONS

The possibilities of genetic change are not necessarily limited by the typical chromosome groups or by the crossing over that usually affords the material for recombinations. Frequently relatively radical alterations, or **MUTATIONS**, occur, often just before or during the matu-

ration of the germ cells, which thereupon are at the disposal of the regular genetic mechanism for segregation, etc. (p. 314.)

Mutations may be broadly classified as CHROMOSOME MUTATIONS involving changes in the normal number and arrangement of chromosomes, and GENE MUTATIONS arising from intrinsic changes in the individual gene. In fact some geneticists restrict the term mutation to gene changes. A few illustrations from the wealth of available data will supply the information about this mechanism.

CHROMOSOME MUTATIONS

There are many cases in which the normal complement (diploid number) has been reduced to the haploid number or increased to some multiple of the haploid number. The former condition is called HAPLOIDY, and the latter, POLYPLOIDY or, more specifically, TRIPLOIDY, TETRAPLOIDY, etc. Such symmetrical changes in the chromosome groups appear to be more frequent in plants than in animals. Thus the haploid sets of all the known species and varieties of wheat consist of 7, 14, and 21 chromosomes respectively. (Figs. 253, 254.)

Some marked instances of the actual origin of new types have

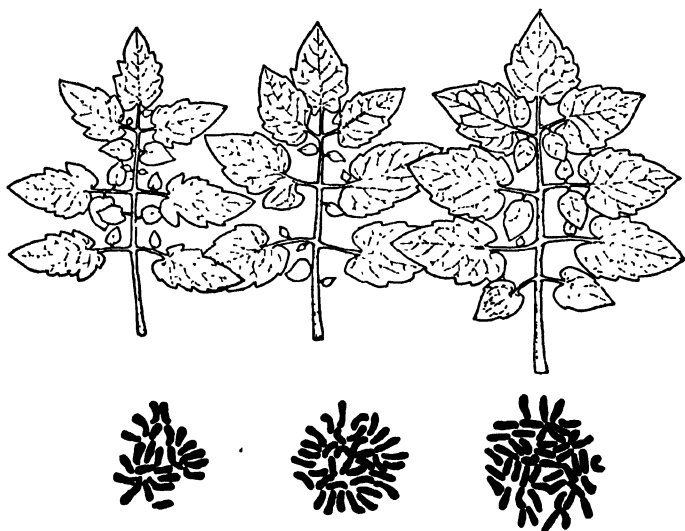


FIG. 253. Diploid, triploid, and tetraploid condition in the tomato plant. Upper row shows structure of leaves; lower row the corresponding chromosome complex (24, 36, 48) as found in the cells. (See Fig. 254.) (After Jorgenson.)

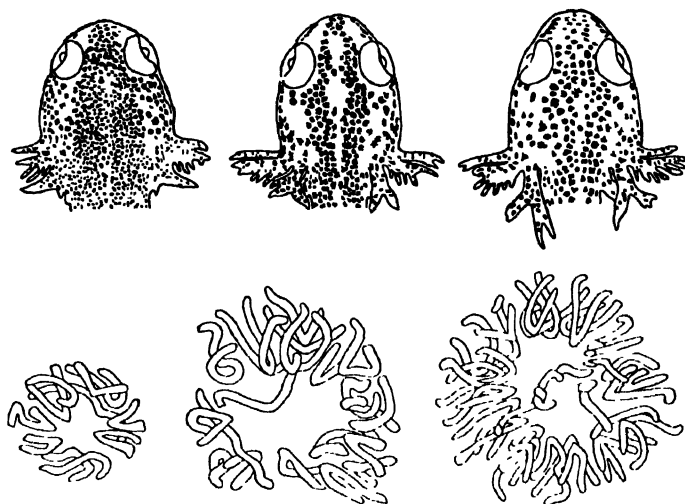


FIG. 254. Haploid, diploid, and triploid larvae of a newt, *Triturus viridescens*. Upper row, pigment pattern of the head; lower, the chromosomes (11, 22, 33) of the epidermal cells. (From Frankhauser and Griffiths.)

been observed in various plants, for example, the Jimson weed (*Datura*). The plants differ in size and several other characters that clearly are attributable to the doubling of the diploid number of chromosomes. They have 24 pairs of chromosomes instead of the typical 12 pairs. Equally interesting are certain observations on *Drosophila* which typically has 4 pairs of chromosomes. Individuals have appeared that differ markedly from the normal flies and possess 12 chromosomes as a result of the addition of another haploid set.

Another type of chromosome mutation, known as **HETEROPLIIDY**, involves only one, or rarely two, chromosomes and not an entire set. Thus again in *Drosophila*, the failure of the X chromosomes to separate after synapsis (**NONDISJUNCTION**) gives rise to individuals with nine chromosomes, including one Y and two X chromosomes. This may be regarded as a male complement of chromosomes plus another X chromosome, with the result that flies so endowed are females with a visibly altered heredity. Many other atypical combinations occur. (Fig. 247.)

Still other irregularities may involve only a portion of one chromosome. A part of a chromosome may be lost, or duplicated, or attached to another chromosome. For example, a race of *Drosophila* has been

obtained in which a part of the Y chromosome has become transferred (TRANSLOCATED) to the end of an X chromosome; and another race in which one of the X chromosomes has been broken into two nearly equal parts, one part being united to one of the other chromosomes.

Moreover, recent work emphasizes the significance of the order of arrangement of the genes in a chromosome, alterations of the usual position resulting in hereditary changes. Indeed the activity of a gene is determined by various internal factors: the chemical constitution of the gene itself, the genetic constitution of the gene system in which it acts, and the position of the gene in the gene system. And external factors in the environment are important in genic expression. (Fig. 258.)

All chromosome mutations, relatively rare and radical as many of them are, may be regarded, in a way, as a broad extension of the principle of recombination. They exert their influence by new relations and proportions of the genetic material, and offer new hereditary possibilities provided that they are not lethal.

GENE MUTATIONS

Intrinsic alterations in the individual genes themselves or even the origin of new genes probably are the most significant changes in the hereditary complex. Such gene mutations presumably are a result of an alteration in the physicochemical constitution of the gene. It appears that usually only one of a pair of homologous genes mutates at a given time, so the change is extremely localized and most frequently takes place just before or during maturation. Although gene mutations occur relatively rarely, about a thousand have been identified in *Drosophila*, chiefly by the elaborate studies of Morgan and his collaborators: studies involving many millions of fruit flies. These experiments have made this tiny insect the greatest contributor to our knowledge of genetics since Mendel's experiments with peas. (Fig. 512.)

Perhaps the best-known example of gene mutation in carefully pedigreed animals is the sudden appearance, at long intervals, of a single white-eyed *Drosophila* in a true-breeding red-eyed stock. The white-eyed mutant breeds true from its origin, and the genetic data indicate that a specific point on one chromosome—it has been mapped—suddenly changed so that the developmental processes that formerly gave rise to the usual red eyes thereafter produced white eyes.

Sometimes a series of relatively small mutations may occur at the

same point, or locus, in a chromosome. Thus, again in *Drosophila*, more than a dozen point changes or mutations at the same locus have occurred, forming a series of gradations between red and white eyes, ranging through so-called wine and coral to pearl and ivory. The gene for red eyes of the wild type (instead of being, as is typical, homologous with one other gene, or allele, to form a pair of alleles) is homologous with a series of alleles, or MULTIPLE ALLELES, any one of which may be present as its definitive allele, or as alleles of each other, in a given individual. The homozygotes form the graded series from red eyes, which is dominant, to each of the others. Many similar series occur in plants and animals. (Fig. 255.)

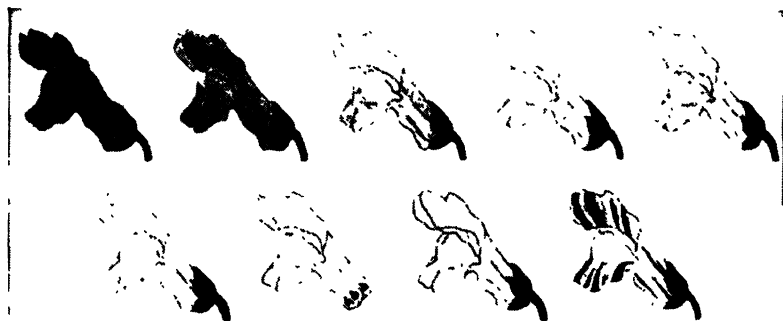


FIG. 255. Diagrams to illustrate a series of nine alleles of the gene governing flower color in the snapdragon. The series ranges from red (upper left) through pale shades to red-striped. (From Sinnott and Dunn, after Bauer.)

Instances are known of genes with more than thirty alleles. In man the well-known BLOOD GROUPS result from multiple alleles affecting the clotting relationship between the red cells and specific components of the blood serum. Knowledge of the blood groups is, of course, of first importance when transfusions are to be made, and may also be valuable in settling cases of disputed parentage. (Fig. 255.)

Such are a few of the types of mutations in the nuclear complex of the germ cells that are now known to give rise to genetic variations. Chromosomal mutations afford new relations and proportions of their constituent genes, whereas gene mutations actually determine the nature of the chromosomal elements themselves. In many instances, probably the majority, mutations produce lethal combinations in the gametes or zygotes—the altered hereditary constitution renders development or survival impossible. In other cases, individuals with the



FIG. 256. Mutation in sheep. A short-legged ewe, ancon-type, (*left*) with her heterozygous normal-legged mother. (From Landauer.)

mutant characters become established and produce offspring with these new characters and so supply the material for descent with change. (Figs. 256, 257.)

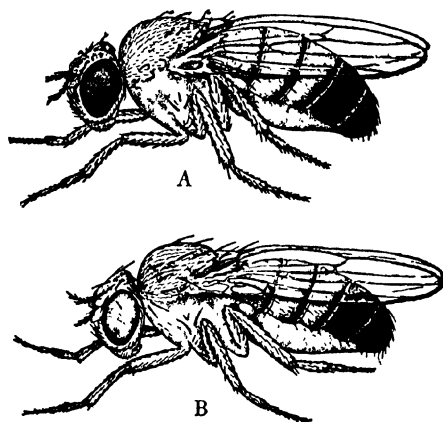


FIG. 257. Two *Drosophila* mutants which have appeared in laboratory cultures. One mutant (*above*) has abnormal bristles on thorax. The other mutant has an abnormal eye condition. (After Morgan.)

SOMATIC MUTATIONS

Finally it should be noted at this point that mutations also occur in somatic cells. Such **SOMATIC MUTATIONS** give rise to changes in the individual body which, of course, cannot be transmitted by the

germ cells, but may be perpetuated by vegetative reproduction. Thus many desirable types of fruit are produced solely by tissue descended from the original plants in which the mutations occurred. Pieces of the plant with the mutation are either planted directly or grafted onto other plants.

Important as is the recently acquired knowledge of some of the nuclear changes at the basis of mutations, we still do not know the fundamental factors underlying their origin, but recent experiments have afforded a most valuable clue. It has been found possible to induce mutations in certain animals and plants by subjecting their germ cells to unusual conditions—the most effective so far employed being irradiations (X rays, etc.) and certain temperature changes. As yet, desired specific mutations cannot be induced, although, for example, when *Drosophila* is subjected to moderately severe doses of X rays, the percentage of offspring with white eyes or dwarf wings or other mutations can be predicted within reasonable limits. However, since mutations are actually provoked by controlled and measured external agents, the way seems to be opening for crucial experimental studies on the problem of the origin of mutations in nature, which apparently is the basis of organic evolution.

NATURE AND NURTURE

Even after making due allowance for the possibilities of genetic change involved in mutations, the individuals still may be considered a composite of very many characters which usually behave in a definite way in inheritance. Expressed somewhat fancifully, individuals may be regarded as temporary kaleidoscopic combinations of the genetic factors belonging to the species; the act of reproduction, especially the maturation divisions involving segregation, and subsequent fertilization, providing the new turn of the kaleidoscope.

But since the life of an organism is one continuous series of reactions with its surroundings, it follows that nurture has an immensely important function in molding the individual on the basis of its heritage. Indeed one is likely to overlook the fact, already mentioned, that every character is a product both of factors of the heritage and of the environment and can be reproduced only when both are present. Those characters that appear regularly in successive generations are those whose development depends upon factors always present in the normal surroundings. Other characters, potentially present, do not become

realized unless the unusual environmental conditions necessary for their development happen to be met. Witness the examples, already mentioned, of supernumerary legs in *Drosophila*, and sun-red color in Indian corn. (p. 332.)

To disentangle the closely interwoven influences of heredity and environment is one of the most important and perplexing problems of the science of genetics. This is especially true in the case of man. Development is a form of behavior, and how a child develops physically and mentally is determined not by his heritage alone nor by his environing conditions alone, but by both in intricate combination. Heredity and environment are collaborating artists with different rôles to play as molders of the individual. (Fig. 258.)



FIG. 258. Corn of a single variety (Leaming dent): at the left the plants are grown well spaced; at the right they are badly crowded. The heredity of each plot of corn is the same; the striking differences in growth are therefore solely due to the environment. They are modifications. (From Blakeslee.)

Although apparently we do not inherit the direct effects on our forebears of their surroundings and training, nevertheless we are the heirs to their customs—each generation builds upon the intellectual and material foundations of all of its predecessors—and this entails added responsibilities as well as opportunities for each succeeding

generation. Already in certain fields the applications of science to human affairs tax the ability of man to use them wisely. Witness the release of atomic energy. Thus social heredity bids fair to outstrip our conservative and essentially unchanging inherited nature. The EUTHENIST emphasizes nurture, the EUGENIST emphasizes nature. As is so often the case, however, when doctrines are opposed, the truth combines both; though we cannot doubt, knowing what we know of the genetic constitution of organisms, that from the standpoint of permanent advance—racial rather than individual—the path to progress is chiefly through eugenics, the science of being well born. (Fig. 259.)

This distinction between heritage and acquirements leaves a fatalistic impression in many minds, which to a slight extent is justified. We cannot get away from inheritance. On the other hand, although the organism changes slowly in its heritable organization, it is very modifiable individually; and this is man's particular secret—to correct his internal organic inheritance by what we may call his external heritage of material and spiritual influences. It is therefore clear that the problem of human improvement has two aspects: in the first place, the effects of culture on the individual which, though not inherited, are cumulative from generation to generation through training; and secondly, racial betterment through breeding the best. (pp. 471-477.)

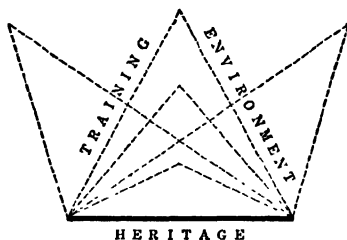


FIG. 259. Scheme to illustrate the contributions of nature and nurture to the make-up of the individual. The triangles represent various types of individuals which may be produced by the same germ cells (heritage) if environment and training are variable. Note that the foundation of the "triangle of life" is heritage. (After Conklin.)

To summarize our survey of genetics, it is evident in the first place that the basis of inheritance is in the germinal material rather than in the somatic constitution of the individual. A character to be inherited must be represented by one or more genes in the germ cells, although the environment is not unimportant in the development of the character from the gene complex. Secondly, there is no satisfactory evidence that modifications of the body, acquired characters, can be transferred from the body to the germ complex and so be inherited.

And thirdly, the germinal basis of characters, genes, may be dealt with essentially as units. The chromosomes—linkage groups of genes—undergo segregation and independent assortment during the development of the gametes of an individual, so that paternal and maternal contributions may be readjusted in all the possible combinations. Finally, mutations afford still further changes in the gene complex for distribution by the genetic mechanism, and so provide crucial opportunities for variation, that is, for descent with change. (pp. 384-395.)

CHAPTER XXIV

Origin of Species (I)

The process of evolution has its outcome in personalities who have discerned its magnificent sweep.

—Thomson

From the time of the Greek natural philosophers there always have been men who have sought a naturalistic explanation of the origin of the diverse forms of animals and plants, and who have suggested that the present ones arose from earlier forms by a long process of descent with change, or EVOLUTION. However, with the revival of natural history studies after the Middle Ages, the prevailing ideas in regard to creation led the majority, perhaps almost unconsciously, to assume that there is a limited number of kinds of organisms, all of which were established at one time. This is not so strange as it might appear at first glance, when one considers that nearly all the important facts which have been reviewed in the preceding pages were yet to be discovered, and that the number of known kinds of animals totalled but a thousand or so instead of about a million as today.

The pioneer work of the early Renaissance naturalists consisted principally of collecting and describing animals and plants. This involved making a catalog of the different kinds—classifying them in some way; consequently, some basis of CLASSIFICATION was sought. Attention was accordingly more definitely focussed on the kinds, or SPECIES, and, if only for practical reasons, the species assumed a prominence which overshadowed the individuals that composed it. (pp. 489, 527, 578.)

Indeed, today biologists are hard put to it to define a species. Darwin himself said, "No one definition has satisfied all naturalists, yet every naturalist knows vaguely what he means when he speaks of a species." Certainly it is widely recognized that there are many kinds of animals and plants, and also that many individuals are essentially the same.

Groups may be formed of individuals which differ less among themselves in the sum of their characters than they do from the members of any other group of individuals. And further, the members of a group produce other individuals which are essentially similar. It is such a group of individuals that is regarded by the biologist as a species. But it is difficult to formulate a satisfactory brief definition of a species, unless perhaps it be "a group of interbreeding individuals that do not differ from one another in excess of the limits of individual diversity, actual or assumed." With but slight exaggeration it may be said that a species is largely a concept of the human mind: it is a time concept—"a cross section at a given moment through a gradually changing and genetically connected series of life forms." The real unit in nature is the individual animal or plant, and an understanding of the differences between individuals should give us the key to the differences between species. In the final analysis, the problem of the origin of species is a problem in genetics. (Figs. 274, 276.)

This seemingly obvious point of view has been clearly grasped by biologists only fairly recently, and the species rather than the individual has loomed large in the discussions of how plants and animals came to be what they are today. As a matter of fact, during the eighteenth century the greatest student of plant and animal classification, Linnaeus, crystallized the idea that each species represents a distinct thought of the Creator, and that the object of classification is to arrange species in the order of the Creator's consecutive thoughts. This point of view is somewhat whimsically expressed by the old naturalist who found a beetle which did not seem to agree exactly with any species in his collection and solved the difficulty by crushing the unorthodox individual under his foot. His credulity surely would have been strained by the estimate of a modern entomologist that if all the species of insects were known they would total some three million. (Fig. 499.)

The consensus up to the middle of the last century was overwhelmingly on the side of SPECIAL CREATION and FIXITY OF SPECIES, and therefore against the idea occasionally advanced by men, ahead of their times, as it now appears, that DESCENT WITH CHANGE is the true explanation of the origin of the diverse forms of plants and animals. However, as nearly everyone knows, a complete reversal of opinion has occurred since 1859. Today professional scientists and most educated laymen accept ORGANIC EVOLUTION—the view that all

living things are one by birth and the system of living nature is historically a unit, a consistent whole and not a collection of isolated and independent species. This view has been accepted in the preceding sections of this work; but, lest this appear to have been prejudging the question, the explanation is that the genetic connection of organisms is the guiding principle of all modern biology. The mere fact that an unbiased presentation of the data seems to prejudge the question is the most cogent presumptive evidence for evolution. It is true that there are differences of opinion among biologists in regard to the *factors* which have brought about the evolutionary change, but there are none in regard to the *fact* of evolution itself. It will be convenient, therefore, first to summarize a few of the *evidences* of evolution, and then to present certain modern views in regard to the *methods* of evolution. (pp. 652-657.)

EVIDENCES OF ORGANIC EVOLUTION

To one who has thoughtfully followed the preceding pages there must immediately occur many facts which are readily and reasonably interpreted from the point of view of descent of one species from another, but which are entirely obscure from that of the special creation of species. For instance, one cannot but be profoundly impressed by the similarity of the protoplasmic physical basis of life, the cellular

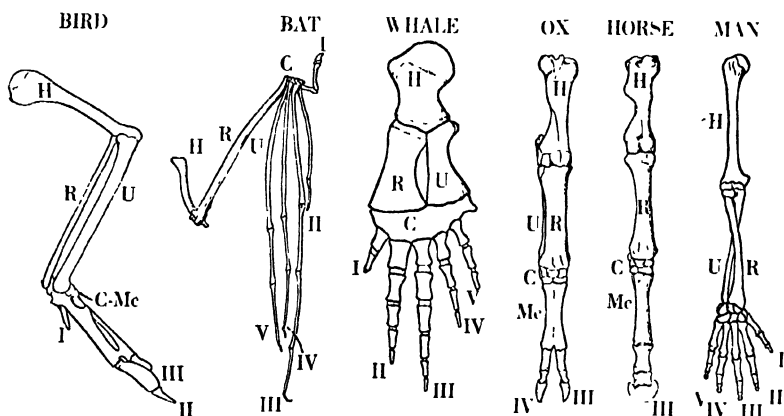


FIG. 260. Vertebrate forelimbs to show homologous skeletal structures. Bird, left wing; bat, right wing; whale, left flipper; ox, right foreleg; horse, right foreleg; man, right arm. C, carpals; H, humerus; Mc, metacarpals; R, radius; U, ulna; I-V, digits. (After Scott. Redrawn.)

structure, and the genetic mechanism of all organisms; the method of origin and the fate of the germ layers in animals; the interrelationship of the urinary and reproductive systems in the vertebrates; the comparative anatomy of the vascular and skeletal systems of vertebrates; the gradual reduction of the gametophyte generation in the life history of the higher plants: in brief, the "unity in diversity" that pervades the world of living things. (Figs. 126, 128, 131, 260.)

In general, such are the types of data which support the evolution theory. Although the evidence, from the nature of the case, must be indirect, it is none the less convincing, chiefly because the facts for evolution are from such diverse sources and all converge toward the same conclusion. The theory of evolution reaches the highest degree of probability, since in every branch of botany and zoology all the data are most simply and reasonably explained on the basis of descent with change. It is a cardinal principle of science to accept the simplest conception that will embrace all the facts.

Assuming the reader's familiarity with the contents of this volume up to the present point, some of the most important evidence from various subdivisions of biology may now be summarized. As will soon appear, however, it is impossible to arrange the facts in natural groups because the evidence interlocks, one line of evidence merging into another.

CLASSIFICATION

The world of life, however it arose in the past, now exhibits a varied pageant ranging from the simplest microscopic unicellular forms to the highly complex and often gigantic multicellular plants and animals—a multiplicity of types that is bewildering. So in any survey of organisms, first of all it is necessary to arrange the various kinds, or species, in some order; that is, to classify them by placing near together the kinds that are closely related in structure and function, and separating those that are less closely related. And if *relationship* is the basis of classification, we should know what the biologist means by relationship. The answer is: blood relationship, or descent with change from a common ancestor. The object of a natural classification is to express the pedigrees of the organism, but most classifications are, at best, still very far from realizing this ideal.

The species, as already noted, is the unit in classification and, for the moment, may be broadly defined as a group of individuals which are

alike in all their essential characters, structural and physiological, and which produce similarly endowed individuals. The scientific name of a plant or animal consists of two words, written in italics, the first denoting the GENUS and the second the SPECIES. All sunflowers, for example, are members of the genus *Helianthus* and the common garden sunflowers comprise the species *annuus*; the botanical name of the garden sunflower therefore is *Helianthus annuus*. (Fig. 381.)

One might wonder why it is necessary to employ unfamiliar Latin or Latinized names for organisms, until it is recalled that a plant or animal may have dozens of local names in one country, and, again, that the same name may be applied to different organisms in various countries. Witness the loblolly pine (*Pinus taeda*) with over 30 local names in America; and the word corn which in England is applied to wheat, in Scotland and Ireland to oats, and in America to maize, or Indian corn, whereas the scientific name of maize, *Zea mays*, means just one species to biologists the world over. (Fig. 383.) For our purpose, classification can be reduced to a minimum—just enough to facilitate a synoptic view of the diversities of organisms.

When the serious study of biological classification was well under way, biologists found increasing evidence of the similarity, or affinity, of various species of animals and plants. Not only is it possible to arrange organisms in essentially ascending series of increasingly complex forms, but also in many cases it is difficult or impossible to decide just where one species ends and the next begins. That is, the most divergent individuals within a given species frequently approach those of a closely similar species. There are *intergrades*. (Fig. 274.)

As just noted species themselves can be naturally arranged in a more comprehensive group, the genus. For example, the common gray squirrel represents the species *carolinensis*, and the red squirrel the species *hudsonicus*. Both are obviously squirrels, and therefore both species are grouped under the genus *Sciurus*. Accordingly, each animal is given a name composed of two words: the first generic, and the second specific. The gray squirrel is *Sciurus carolinensis* and the red squirrel is *Sciurus hudsonicus*. Thus to give a scientific name to an animal or plant is really to classify it, because the first word of the name indicates that it possesses some fundamental characteristics in common with the other species of the genus, in fact, is more like them than it is like any other group of organisms.

However, the members of the genus *Sciurus* have many characteristics in common with other animals which obviously are not true squirrels. The chipmunks, or ground squirrels, for instance, differ not only in certain obvious features, but in the possession of internal cheek pouches, etc. This dissimilarity within the fundamental similarity is expressed by placing these creatures in a different genus, *Tamias*, but in the same family, *Sciuridae*. The familiar eastern chipmunk is *Tamias striatus*.

Moreover, while the beaver (*Castor canadensis*) differs still more from the squirrels than do the chipmunks, and therefore is placed in a distinct family, the *Castoridae*, it nevertheless agrees with both in many fundamental ways and is accordingly placed in the ORDER *Rodentia*, which also includes the squirrels and chipmunks, as well as many other families and genera. Other orders, such as the *Ungulata* (horses, cattle, etc.), the *Carnivora* (cats, dogs, bears, etc.), and the *Primates* (monkeys, apes, man), while they differ widely from the rodents, still agree with them in possessing hair, and milk glands for suckling the young. This basic likeness is expressed by including all in the CLASS *Mammalia*.

The mammals in turn are readily distinguished from birds, reptiles, amphibians, and fishes, each of which forms a separate class, but nevertheless are constructed on the same basic plan, comprising a dorsal central nervous system surrounded by skeletal elements forming the skull and vertebral column. All are therefore included in the larger group *Vertebrata* which, with certain minor groups, comprises the PHYLUM *Chordata* and stands in contrast to all the invertebrate phyla, which include hydra, earthworm, crayfish, etc.

The classification of the gray squirrel, *Sciurus carolinensis*, may be outlined as follows:

- KINGDOM — Animalia
- SUBKINGDOM — Metazoa
- PHYLUM₁ — Chordata
- SUBPHYLUM — Vertebrata
- CLASS — Mammalia
- ORDER — Rodentia
- FAMILY — Sciuridae
- GENUS — *Sciurus*
- SPECIES — *carolinensis*

This classification serves to illustrate the general method of classification of any organism, but is particularly important because it places concretely before us the fact that organisms show such fundamental similarities with obvious dissimilarities. In short, the mere fact that animals and plants naturally arrange themselves, as it were, in classes, orders, families, genera, species, etc., raises the question of the origin of species. Is the more plausible explanation to be found in special creation implying fixity of species, or in descent with change? (pp. 639-641.)

The unavoidable answer is descent with change—evolution—because the principle in accordance with which the groups of increasing comprehensiveness are formed is solely the greater or lesser similarity in the structural features of the organisms. It is much more reasonable to assume that the thread of fundamental similarity which runs, for instance, through all the vertebrates is the result of inheritance, while the differences of orders, families, genera, etc., are due to changes brought about under different unknown conditions, than it is to assume that each is the result of a special creative act. This becomes especially apparent in view of the fact that in a very large number of cases it is difficult or impossible to decide the limits of a species, owing to variations among the individuals comprising it, and it is necessary to resort to *SUBSPECIES* and *VARIETIES* in classification. Again, among genera, intergrading forms demand *SUBGENERA*; among orders, *SUBORDERS*; among classes, *SUBCLASSES*; and so on. If one admits the origin, by descent with change, of the subspecies and varieties, there is no logical reason for denying the same origin of species, orders, and higher groups. The difference is one of degree and not of kind. Before the recognition of evolution, classification was a groping after an elusive ideal arrangement which naturalists intuitively felt, but which they were unable to express except in artificial form and in transcendental terms. Under the influence of the theory of evolution, classification became the natural expression of biological pedigrees. (Fig. 441; pp. 695-698.)

COMPARATIVE ANATOMY

The evidence from classification is, as has just been shown, really evidence from comparative anatomy, since modern classifications are based chiefly on anatomical characters. The various groups—classes, orders, families, genera, and species—are founded not on a single

difference, nor on several differences, but chiefly on a large number of similarities. For instance, the differences exhibited throughout the five classes of the vertebrates are relatively slight in comparison with the basic resemblances. This similarity in dissimilarity is brought out by the science of comparative anatomy. A few definite examples, some of which are already familiar, will serve to bring the main facts clearly before us. (pp. 641-642.)

The forelegs of frogs and lizards, the wings of birds, the forelegs of the horse, and the arms of man are built on the same basic plan. The same is true of the hind limbs.

Clearly all are HOMOLOGOUS structures, such variations as exist being brought about chiefly by the transformation or absence of one part or another. In short, all the chief parts of both the forelimbs and the hind limbs are homologous throughout the series. All are composed of the same fundamental materials disposed in practically the same way; nearly all the bones, muscles, blood vessels, and nerves are homologous. Similarly, one may compare the digestive systems of the same forms, or the excretory and reproductive systems. One has but to recall that, in an earlier chapter, it was possible to describe in general terms these systems as they exist

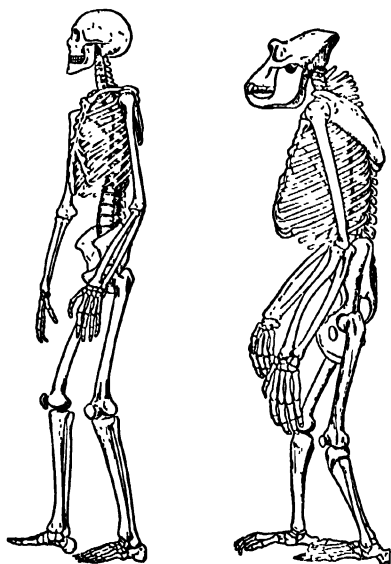


FIG. 261. Skeletons of man and gorilla. (From Lull.)

throughout the vertebrate series, in forms as obviously different as a fish and a man. All are fundamentally the same. (Figs. 93, 126, 128, 145, 260, 261, 478.)

Turning to the invertebrates, the reader may be reminded that all the appendages of the crayfish are built on the same simple plan, as exhibited in the swimming legs (swimmerets) of the abdomen. The highly specialized walking legs, great claws, jaws, and feelers (antennae and antennules) are all reducible to modifications of the simple swimmeret type. In short, all are homologous structures, though they

differ widely in function. This is a most striking example of serial homology, although we have seen the same principle exhibited in the vertebrates where the forelimbs and the hind limbs of each animal are homologous. Moreover, the appendages of the crayfish are not only serially homologous among themselves, but are also homologous with the appendages of all the other members of the class Crustacea, just as the limbs of one vertebrate are homologous with those of all other vertebrates. (Figs. 75, 78, 260.)

Another class of facts exhibited in comparative anatomy is derived from VESTIGIAL ORGANS. In the human body there are nearly a hundred structures which appear to be useless and sometimes are harmful. One thinks at once of the VERMIFORM APPENDIX of the large intestine, apparently a remnant of part of the caecum that serves a useful purpose in certain herbivorous mammals. Equally suggestive are the muscles of the ear, which in some individuals are sufficiently developed to move the external ear; or the so-called third eyelid at the inner angle of the eye which corresponds to the lid (NICITATING MEMBRANE) that moves laterally across the eye of reptiles and birds; or the terminal vertebrae (COCCYX) of the human spinal column. Other animals likewise possess many such structures. Porpoises have vestiges of hind limbs enclosed within the body, and certain species of snakes bear tiny useless hind legs. The splint bones of the horse are skeletal remnants of lost toes. (Figs. 262, 263.)

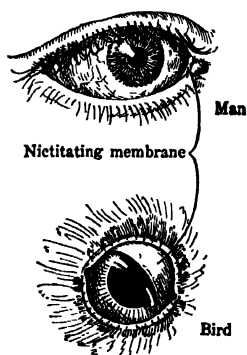


FIG. 262. The nictitating membrane, or third eyelid, in the eye of man and of bird.

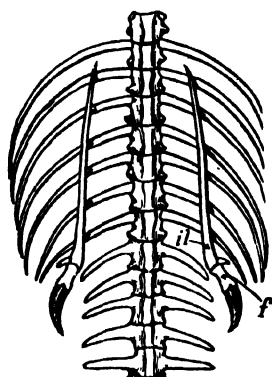


FIG. 263. Vestigial hind limbs of a snake, *Python*, which are not evident externally. *f*, femur; *il*, ilium. (From Romanes.)

In another class of examples, the organs or remnants of organs of a lower type are altered or completely made over, as it were, into new organs of the higher form. The milk glands of mammals are transformed sweat glands of the skin, and the poison glands of snakes are specialized salivary glands. During the embryonic life of vertebrates gill slits are present, but in higher forms all of them vanish except one pair which remains as passages (EUSTACHIAN TUBES) connecting each middle ear with the pharynx. Gill arches, which function as supports for the gills in the aquatic vertebrates, persist in highly modified form as skeletal structures associated with the jaws and tongue and entrance to the lungs (LARYNX) in terrestrial forms. Finally, in this connection the reader will recall the transformations of the vertebrate

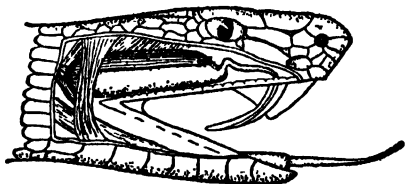


FIG. 264. Head of a rattlesnake, with the skin and part of the jaw muscles removed. The long oval body in the upper jaw, which is connected by a duct with the curved tooth, or fang, is the poison gland. (From Smallwood.)

blood vessels that occur with the substitution of lungs for gills, and also the variations and interrelationships of the excretory and reproductive systems in the ascending series of vertebrate classes. (Figs. 264, 273.)

One may, of course, conclude from all these facts that the various species of vertebrates have each been independently created according to the same precon-

ceived plan—and likewise all the great numbers of orders, families, genera, species, etc., of each of the five classes that these forms represent. Or one may conclude that all have arisen by descent with change from a primitive vertebrate organism possessing the fundamental similarities exhibited in the series. The latter interpretation is accepted by biologists today.

PALEONTOLOGY

Huxley once said that if zoologists and embryologists had not put forward the theory of evolution, it would have been necessary for paleontologists to invent it. What then are the main facts offered by PALEONTOLOGY, the study of the FOSSIL remains of extinct animals and plants?

In the first place it must be made clear that geologists are able to determine, with remarkable accuracy in most cases, the sequence in

time, or CHRONOLOGICAL SUCCESSION, of the rock strata composing the earth's surface. The main outline of this scheme of geological chronology was understood before the evolution of organisms was a crucial question, so we may consider the evidence which it affords of the chronological succession of the fossil remains exhibited by the various strata, as impartial testimony to the order of appearance on the earth of the different types of animals and plants. However, geologists reciprocally find fossil types of great aid in identifying strata. (Figs. 265, 266, 474.)

<i>Eras and Approximate Length in Years</i>		<i>Periods or Epochs</i>	<i>Dominant Animal Types</i>	<i>Dominant Plant Types</i>	
500 million years	{	Cenozoic (75 million years)	Recent Pleistocene	Man	Flowering plants
		{	Pliocene	Mammals	
			Miocene		
			Oligocene		
			Eocene		
	Mesozoic (125 million years)	Cretaceous	Reptiles	Gymnosperms (conifers and kin)	
{	Jurassic				
	Triassic				
750 million years	{	Paleozoic (300 million years)	Permian	Amphibians	Spore plants (mosses, ferns, and kin)
		{	Carboniferous		
			Devonian	Fishes	
			Silurian	Shell-bearing marine animals	
			Ordovician		
	{	Archeozoic	Cambrian	Shell-less invertebrates	Algae
Proterozoic			Simplest animals (inferred)	Blue-green alga	
				Simplest plants (inferred)	

FIG. 265. Correlation of geological time and dominant types of organisms. See Fig. 266.

The geological timetable briefly summarizes the panoramic succession of life as it is seen by the palcontologist. The best evidence at present, chiefly from the breakup of radioactive minerals in the rocks, justifies the estimate that life probably has existed on the earth for nearly one and a quarter billion years. Perhaps the conservative esti-

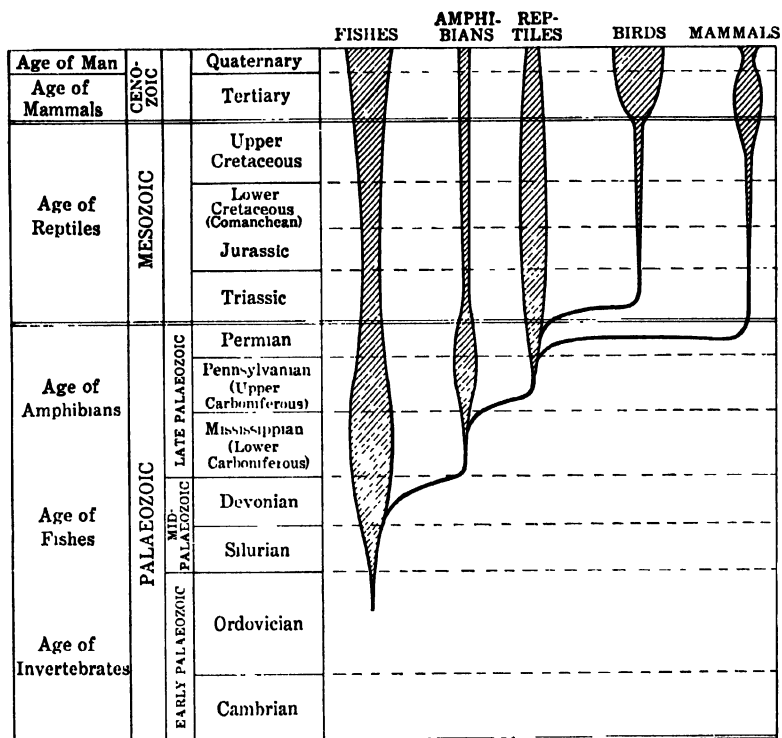


FIG. 266. Diagram to show the correlation of the origin and development of vertebrate classes with geological time. Each higher class arises from less specialized members at the base of the lower class. (After Osborn.)

mate of two billion years, much more than half of which was before the Paleozoic era, will serve to spell the earth's unfathomable past and to afford some idea of the immensity of time available for evolutionary changes. Ten thousand years are but as yesterday in the history of species.

Even a casual survey of this history—natural history—of the earth and its inhabitants must surely impress one with the fact that, taken all in all, there has been a continuous, though not always a uniform, advance in the complexity of organisms from the most ancient times, and that many of the older types seem gradually to melt into modern forms as the more remote geological eras merge into the more recent. Only the shortness of human life allows us to speak of species as permanent entities. Invertebrates appear in the Proterozoic era; fishes.

amphibians, and reptiles in the Paleozoic; birds and primitive mammals in the Mesozoic; higher mammals and man in the Cenozoic. Mosses and ferns arise before conifers, and the latter before the familiar flowering plants. In proportion to the completeness of the geological record is the unequivocal character of its testimony to the truth of the evolution theory. For the sake of concreteness two examples may

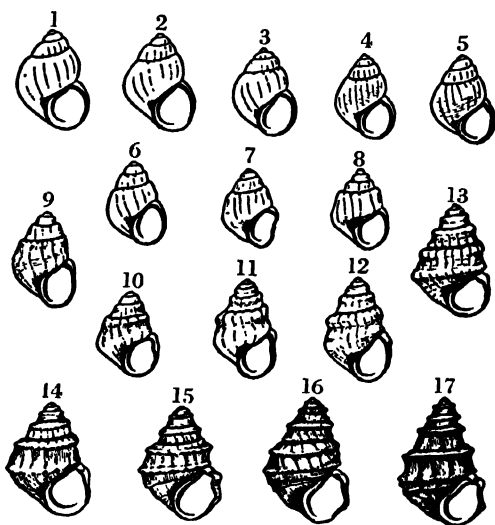


FIG. 267. Successive fossil forms of a snail, *Paludina*, from the Tertiary deposits of Hungary. (After Neumayr.)

be selected from the wealth of material offered by the paleontologist. (Figs. 267, 268.)

At first glance there seems to be little but contrasts between a typical reptile and a typical bird; between a cold-blooded, scaly-skinned lizard, let us say, and a warm-blooded, feathered pigeon. And yet the zoologist is convinced that birds have evolved from a reptilian stock, because, in spite of superficial dissimilarities, there are fundamental structural resemblances not only between adult reptiles and birds, but also between their embryological stages. Further evidence is to be found in the fact that the fossil remains of very primitive birds, *Archaeornis* and the closely similar *Archaeopteryx*, have been found which form, in many ways, connecting links between reptiles and birds as we know them today. (Fig. 269.)

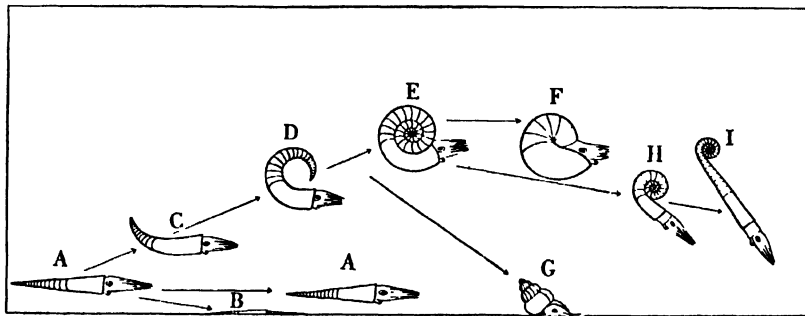


FIG. 268. Evolution of molluscan shell form and its relation to mode of life in the Cephalopoda. The primitive shell, A, was not buoyant. Its bearer could swim, but rested upon the sea floor when inactive. Type B represents one of the few grovelers which developed very depressed shells. Type C has begun to develop a buoyancy due to the secretion of gas into the spaces behind the body. This gives a little more independence of the bottom and tends to tip the animal forward. Still resting on the substratum when not actively swimming, the animal keeps a horizontal attitude and its shell grows more rapidly on the venter and becomes curved. This leads to stage D, and culminates in E, or the nautilus type, F, in which the animal is balanced beneath the spacious gas tanks of its fully buoyant shell. Such forms probably become independent of the bottom, even though, like *Nautilus*, some of them hovered near it. A few forms descended again to the bottom and adopted a creeping habit, developing thereby a spiral coil, G. Others outgrew their living chambers, whereupon their buoyant shells suspended them head downward until the shell finally uncoiled, H and I. (See Fig. 426.) (From Dunbar.)

Archaeornis was undoubtedly a bird about the size of a pigeon, but with jaws supplied with many small teeth; with a long lizardlike tail formed of many vertebrae, each bearing a pair of quill feathers; with a free-fingered reptilian hand; and so on. In brief, just such a creature as the imagination of an evolutionist would picture for a primitive bird

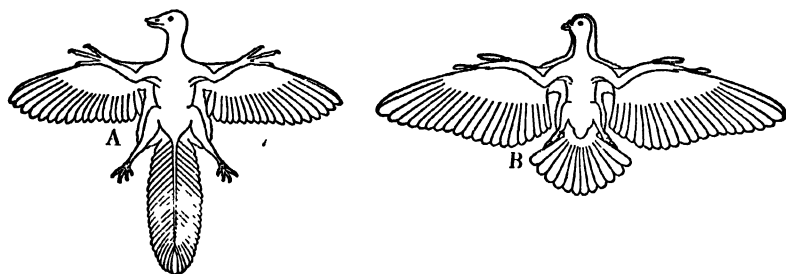


FIG. 269. Fossil reptilian bird, *Archaeornis* (A), compared with pigeon, *Columba livia* (B). (From Lull.)

has been actually discovered in the lithographic stone quarries of Bavaria, representing the later Jurassic period some 140 million years ago.

The ancestry of the modern horse has been the most impressive fossil pedigree, ever since Professor Marsh collected the famous series of fossil skeletons from the western United States and arranged them in the Peabody Museum at Yale University. They have been referred to as the "first documentary record of the evolution of a race." Huxley studied this collection and regarded it as conclusive evidence of evolution.

The essential facts of the evolution of the horse are these horse-like animals probably arose from an extinct group, similar to the *Condylarthra*, which had five toes on each foot and a large part of the sole resting on the ground. However, the first unquestionable horselike

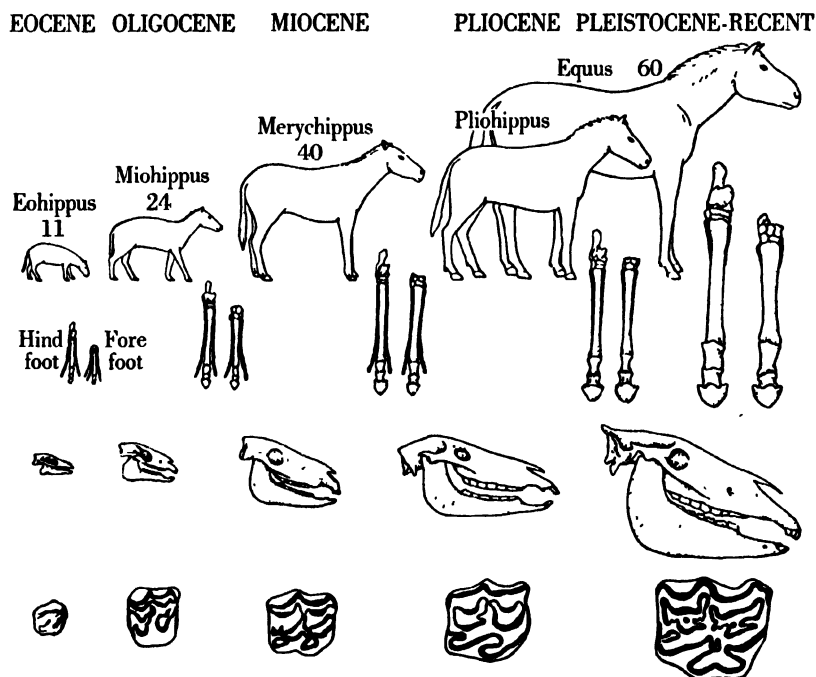


FIG. 270. Graphic representation of the evolution of the horse. General structure and shoulder height in inches are shown in the upper row of figures, followed by corresponding foot structure with reduction in digits, skull structure and patterns of the grinding surfaces of second upper molar. (From Storer, after Lull, Matthew, and Stirton.)

forms found in North America are little animals about a foot in height, known as *Eohippus*, from rocks of the EOCENE epoch. The forefoot of *Eohippus* has four complete toes (digits 2, 3, 4, and 5) but no trace of the inner digit, or thumb, while the hind foot has three complete digits (2, 3, and 4) with vestigial remains, or SPLINTS, of the first and fifth. Later in the Eocene appears *Orohippus* showing a somewhat larger central digit in the forefoot and the disappearance of the splints in the hind foot. Passing up to the OLIGOCENE epoch, *Miohippus*, an animal about the size of a wolf, occurs with fore and hind feet three-toed, but with the side toes much smaller than the central one, and just a trace of the fifth digit in the forefoot as a splint. Then *Merychippus* appears in the MIOCENE epoch, with still shorter side toes (digits 2 and 4) so that they do not reach the ground, and the weight is borne solely on the hoofed tip of the third digit. This same general reduction of the lateral digits and advance in size and functional importance of the middle digit are carried further during the PLIOCENE epoch in *Pliohippus*, which is usually regarded as the first type of one-toed horse, and leads finally to the genus *Equus* which has continued from the PLIEISTOCENE epoch to the present. This genus includes the modern horse, *Equus caballus*, with one functional digit on each foot and vestiges of two more (digits 2 and 4) as the splint bones. (Figs. 270, 271.)

In this outline of what must be interpreted as the fossil ancestors of the horse of today, we have merely selected several representative forms to emphasize changes in foot structure. Of course, many other equally significant changes were involved in the transformation, during perhaps 60 million years, of the *Eohippus* type into that of *Equus*. This much appears certain to the biologist: that "in early Eocene times there lived small five-toed hoofed quadrupeds of generalized type, that the descendants of these were gradually specialized throughout long ages along similar but by and by divergent lines, that they lost toe after toe till only the third remained, that they became taller and swifter, that they gained longer necks, more complex teeth, and larger brains. So from the short-legged splay-footed plodders of the Eocene marshes there were evolved light-footed horses running on tiptoe on the dry plains." It should be noted that extinction does not necessarily mean failure; it frequently indicates the acme of achievement. For example, some of the now extinct three-toed horses passed "the torch of prog-

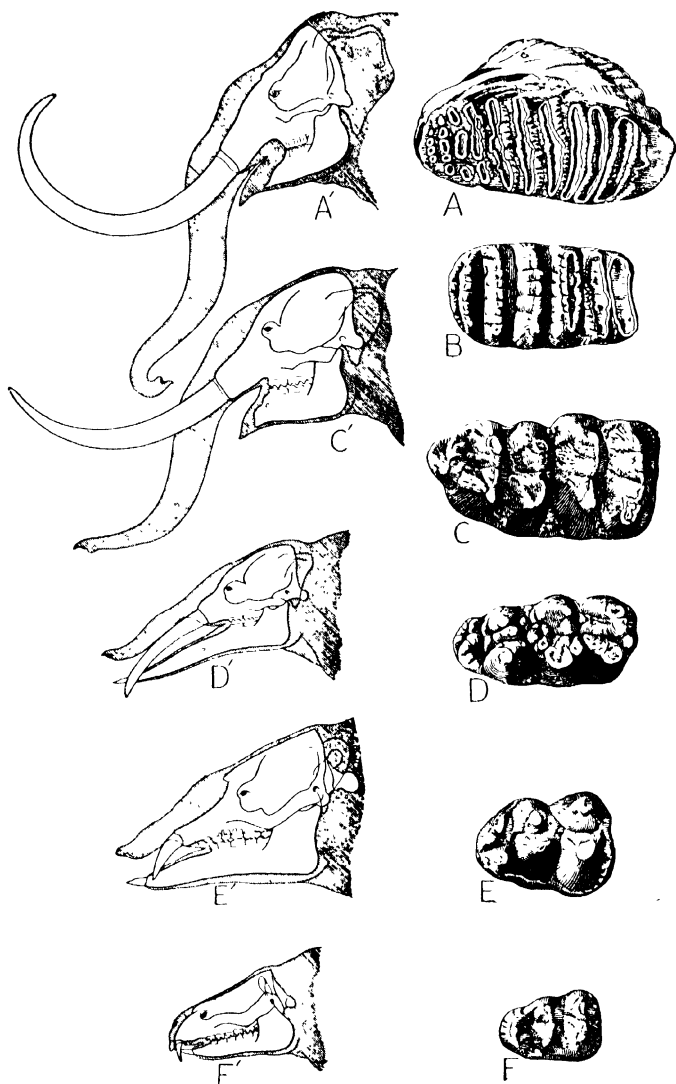


FIG. 271. Evolution of the head and molar teeth of elephants as shown by fossil types. A, A', *Elephas*, Pleistocene; B, *Stegodon*, Pliocene; C, C', *Mastodon*, Pleistocene; D, D', *Trilophodon*, Miocene; E, E', *Palaeomastodon*, Oligocene; F, F', *Moeritherium*, Eocene. (From Lull.)

ress" to their descendants, the one-toed horses, and thus gained survival for their kind.

Before leaving the geological vista of life which has emphasized the variation of organisms through the ages, it is important to recognize the remarkable stability of certain organisms that have retained their characters for countless generations. The Foraminifera, for example, are represented today by certain genera that lived in the seas some 300 million years ago. Again, the Echinoderm genus, *Antedon*, flourished now as it did before the reptilian bird *Archaeornis*, about 140 million years ago. Moreover, the Brachiopod genus, *Lingula*, has persisted for nearly half a billion years through the geological upheavals since Paleozoic times. And passing to the vertebrates, the specimen of a lobe-finned fish recently caught has been called a "living fossil," because it represents the little-changed descendant of a type supposed to have become extinct some 50 million years ago. (Fig. 272.)

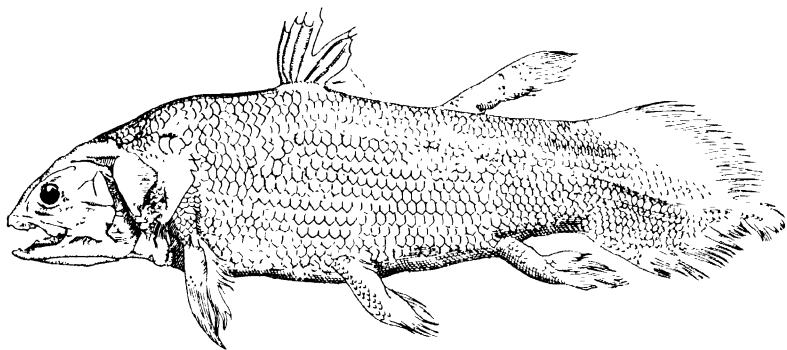


FIG. 272. This remarkable fish, *Latimeria chalumnae*, whose discovery is regarded as one of the most important in natural history in the twentieth century, is a type believed to have become extinct in Mesozoic times, more than 50 million years ago. The fish was taken by trawlnet at a depth of 40 fathoms off the African coast, some miles west of East London, in December, 1938. It was 5 feet long, a bright metallic blue, and weighed 127 pounds. Note the solid fringed fins, very like limbs. The little tufted stump at the hind end represents the degenerate true tail. (From T. L. B. Smith. Redrawn.)

So it may be reiterated: "What is more impressive than the duration of frail living matter, showing a stability far greater than the physiographic features of the earth's surface, unless it be the richness of its evolution within the period of its duration." (Fig. 474.)

Truly, the stupendous and ever-increasing record of ancient forms

of life is not that of a disordered multitude. Newly discovered fossil remains, one after another, fall into the scheme of a common tree of descent—descent with change. “To the evolutionist everything is an antiquity, the past living on in the present, though often transfigured.”

EMBRYOLOGY

If evolution is a fact, one would expect to find evidences of the genetic relationships of organisms in their embryological development from egg to adult. Under former headings there have been incidentally mentioned embryological data which point toward evolution. Attention may now be confined to an attempt to make clear a fact of importance: the history of the individual frequently corresponds in broad outline to the history of the race as indicated by evidence from comparative anatomy, etc. In the light of the earlier discussion of vertebrate anatomy, just a few typical examples will suffice to suggest the type of evidence which supports the so-called RECAPITULATION THEORY, or BIOGENETIC LAW. (p. 569.)

Lower vertebrates, such as the fishes, have a heart composed of two chief chambers: an auricle which receives blood from the body as a whole, and a ventricle which pumps it to the gills on its way to supply all parts of the body. Among the members of the next higher group, the amphibians (frogs, toads, etc.), the auricle is divided into two parts, while the ventricle remains as before; these forms therefore have a three-chambered heart. In the reptiles, most of the lizards, snakes, and turtles are found to have the ventricle partially divided into two chambers, whereas the more specialized crocodiles and alligators have a complete partition and therefore a four-chambered heart. This is the condition in all adult birds and mammals, but the significant fact is that, in the development of the heart of the individual bird and mammal, progressive embryonic stages parallel in a general though remarkable way this sequence from a two-chambered to a four-chambered condition as exhibited in the adults of the lower vertebrates. (Figs. 128, 133.)

Or consider the development of the brain in the vertebrate series. Even in the human embryo the fundement of the brain arises by simple transformations of the anterior end of the neural tube, which at first are nearly indistinguishable from the conditions that exist in the lowest vertebrates. Then the changes become progressively more complex

along lines broadly similar to those occurring from fish to mammal, until finally the complex human brain is formed. (Figs. 144, 145.)

A similar picture is presented by the development of the skull, the reproductive system, the excretory system, and so on. It is also interesting to note that the chick embryo "recapitulates in a chemical sense." At first, in general, it behaves like an aquatic organism and excretes ammonia, then after a few days it excretes urea like an amphibian, and finally the chief end product of nitrogenous metabolism is uric acid.

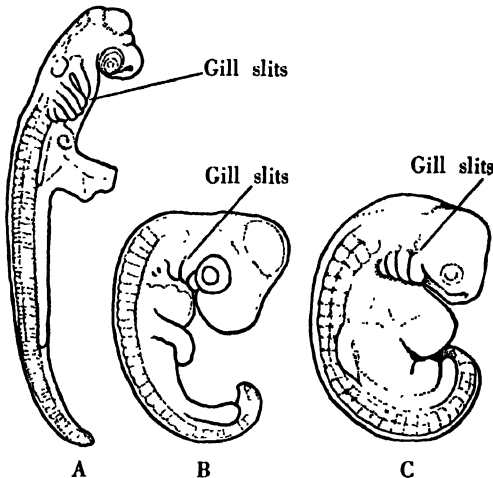


FIG. 273. Embryos in corresponding stages of development. A, fish (shark); B, bird; C, man. See Fig. 197. (From Scott.)

Accordingly one cannot avoid the fact that the higher animals during development pass through stages which correspond with the larval or adult condition of similar organs in lower forms. The correspondence is far from exact—to be sure, there are gaps and blurs—but it is not an exaggeration to say that embryological development is parallel to that which anatomical study leads us to expect. A knowledge of the anatomy of an animal actually gives a sound factual basis from which to predict in broad outline its embryological development. (Figs. 126, 273.)

What bearing do these facts have on the theory of evolution? It is perfectly logical to conclude that it is an architectural necessity, let us say, for the four-chambered heart to arise from a two- and three-

chambered condition; and undoubtedly if this were the only example of ontogeny repeating phylogeny the conclusion would be justified. But when one considers the widespread general correspondence of the developmental stages in higher forms with conditions as they exist in the adults of lower forms, the facts almost overwhelmingly force us to go further and conclude that the similarity has its basis in inheritance, in actual blood relationship between the higher and lower forms—in descent with change. (pp. 648-651.)

Again, it is interesting to find that certain tissues of invertebrates, with one exception, contain arginine phosphate, and those of vertebrates have creatine phosphate, whereas the tissues of an “intermediate” form, the protochordate *Dolichoglossus*, have *both* phosphates. Moreover, the tissues of the one exception among the invertebrates, the echinoids, which show embryological similarities to certain protochordates, also have both phosphates. Biochemical data are therefore added to the developmental evidence to support the view that chordates have evolved from a stock near to that of the echinoderms.

(Figs. 442, 444.)

In regard to chemical differences, some of these are highly significant, as has been revealed, for example, by the type of crystals formed by the hemoglobin of the blood. When orders, families, genera, or species are clearly separated by anatomical criteria, the crystals are correspondingly markedly differentiated. Thus from crystal form it is evident that the common white rat is the albino type of the Norway rat (*Mus norvegicus*) and not of the black rat (*Mus rattus*), and that bears are related more nearly to seals than to dogs.

There are other important chemical differences, not determinable by ordinary chemical analysis, between the blood even of closely related species, long known by the fact that the transfusion of the blood of one species into another is attended by physiological disturbances usually leading to death. It has been found by innumerable transfusions and also by so-called PRECIPITIN TESTS of the blood *in vitro*, that is, outside the body, that the degree of the reaction is in many cases proportional to the degree of relationship of the species involved, as indicated by their classification on the basis of anatomical structure.

For example, human blood, as one would expect, shows by the precipitin tests closer chemical relationships with the blood of the highest apes than it does with that of the Old World monkeys, closer relationships with the blood of the latter than it does with that of the New

World monkeys, and closer with the blood of these than with that of the lemurs, and so on. Or, among the reptiles, paleontology indicates that there is a close relationship between lizards and snakes and also between turtles and crocodiles, and that the reptilian ancestor of the birds was probably more closely allied with the latter than the former groups.

PHYSIOLOGY

Fundamental structural similarities throughout a series of organisms imply fundamental physiological similarities, for structure and function go hand in hand, each being an expression of the other. This is strikingly corroborated by a large amount of data which show that a common chemical basis pervades all life, and also that species are characterized both by morphological attributes and by specific biochemical constitution and reactions. A few examples must suffice.

It will be recalled that many of the most important carbon compounds in living matter are identical throughout the entire scale from the lowest plants to man. This is a remarkable fact when one considers the thousands of patterns into which these same carbon atoms might have arrayed themselves; indeed, the explanation of such recurrences, except for the common chemical inheritance of all organisms, is virtually impossible.

Furthermore it is significant that the chemical coordinators, the hormones, seem to be largely if not completely interchangeable from one species of vertebrate to another. For example, a deficiency in the secretion of insulin in the human body may be compensated by insulin supplied from the pancreas of a fish or a sheep; similarly, thyroxine controls basal metabolism throughout the vertebrate series. Since the same keys turn myriads of locks, it is reasonable to assume that the mechanisms are related—that the chemical regulators have been inherited. (p. 164.) Indeed, serologic techniques are being used more and more in taxonomic work, and in general the serological ranking of species agrees with that based on structural characteristics. Thus chemical characteristics, in particular protein specificity, may soon prove to be necessary criteria in the classification of animals. Furthermore, there are chemical differences within species; witness the so-called blood types in man that must be determined before transfusions are made.

However, in spite of specific changes, it appears that the general chemical characteristics of blood are remarkably constant. The inorganic salts present in the various circulating fluids of animals correspond in nature and relative amounts to what there is good reason to believe was the composition of the ocean some hundreds of millions of years ago. In evolutionary terms, a common property has persisted in the blood of animals throughout the ages that have elapsed during their evolution from a common ancestor; the blood, though showing specific characteristics, is perhaps the most conservative of all the systems in retaining its ancestral condition. "Blood relationship" is a fact. (pp. 401-403.)

DISTRIBUTION

Everyone recognizes, and we have already emphasized, that there are wide variations in the fauna and flora of different parts of the earth. There is a characteristic life on mountain, plain, and seashore, and in the sea, as well as in pond and puddle, and also in arctic, temperate, and tropical regions. Furthermore, the study of plant and animal distribution involves the investigation of both the relations of the various organisms to the general environmental conditions and the interrelations of the species with each other. Confining attention merely to the geographical distribution of organisms, we may consider some clear-cut examples and see whether or not evolution offers a reasonable explanation of the facts. (Figs. 274, 307, 308; pp. 396, 421, 523-526.)

Various species of walnuts, members of the genus *Juglans*, now have a discontinuing distribution over limited areas of the Eastern and Western Hemispheres, whereas during the geological past, from the Cretaceous to the Pliocene epochs, these trees flourished over immensely wider regions. It appears clear that the discontinuous distribution of modern species represents merely the segregated remnant of the past. (Fig. 275.)

Again, a characteristic genus of mammals, the tapirs, is represented today by distinct species in two widely separated regions: Central and South America and southern Asia and adjacent islands. But the key to the present distribution is to be found in the distribution in the distant past. Paleontological studies show that in the Pliocene epoch tapirs were distributed over nearly all of North America, Europe, and northern Asia, and thereafter gradually became extinct so that by the close

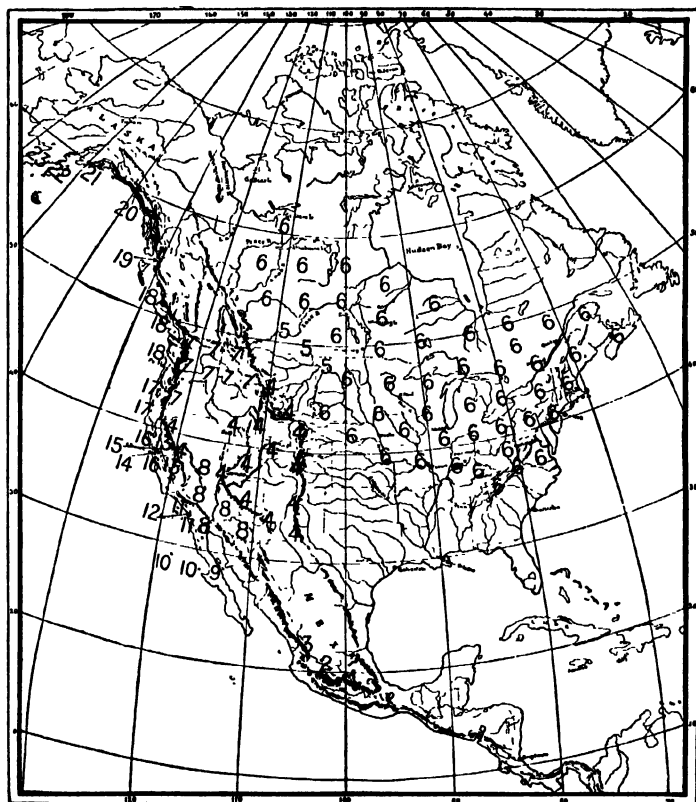


FIG. 274. Geographical distribution of 23 of the 29 subspecies of song sparrows. Each number indicates a subspecies and the distribution. "We find complete intergradation in color and in size. Nowhere can one draw the line. As the climatic conditions under which the birds live change, the birds keep pace. Here we have a species in flower, as it were, a single song sparrow stalk with its 29 blossoms, any one of which might make an independent growth as a species if it were separated from the parent stem. Doubtless some day the separation will come, when we shall have several species, each with its groups of races, but at present we have only one species, divided into some twenty-nine subspecies, or species in process of formation." (Chapman.)

of the Pleistocene epoch the remnants were distributed as they are today. (Fig. 470.)

In brief, the present *discontinuous* distribution represents the remnants of world-wide walnut and tapir populations, and the differences between the existing species are such as one might expect to find

among the members of a genus long isolated in different environments by geographical barriers. It is known, for example, that a litter of European rabbits was introduced on the small island of Porto Santo during the fifteenth century, and by the middle of the last century the descendants had become so distinct from the parent form that they were described as a new species.

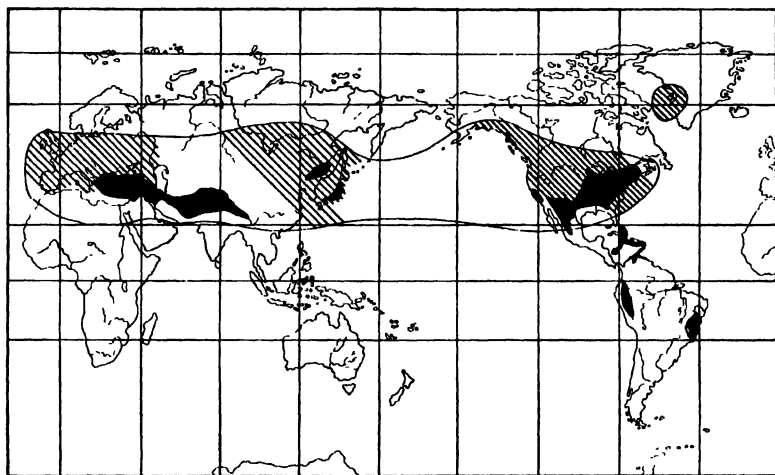


FIG. 275. Present distribution of the walnut tree (solid black) and area (lined) which they are known to have occupied during the geologic past. (From Berry. Redrawn.)

In fact it was the characteristic fauna and flora of islands that particularly impressed Darwin with the need of some interpretation of their origin other than by special creation. During his famous three years' voyage around the world on the *Beagle*, he stopped at the Galapagos Islands, situated about 600 miles off the west coast of South America, and was astonished to find that, although the fauna as a whole resembled fairly closely that of the mainland, nevertheless the species for the most part were different; moreover, even those of the separate islands were distinct, the islands nearest to each other having species most similar. Darwin wrote: "My attention was first thoroughly aroused by comparing together the numerous specimens, shot by myself and several others on board, of mocking thrushes, when, to my astonishment, I discovered that all those from Charles Island belonged to one species (*Mimus trifasciatus*); all from Albemarle Island to

M. parvulus; and all from James and Chatham Islands (between which two other islands are situated as connecting links) belonged to *M. melanotis*." And again: "We have the truly wonderful fact that, on James Island, of the thirty-eight Galapageian plants found in no other part of the world, thirty are exclusively confined to this one island."

Darwin's observations of such facts as these have been corroborated in the Galapagos and extended to isolated island faunas and floras all over the world. For instance, half of the species of insects and four-fifths of the species of seed plants that occur on St. Helena are found nowhere else. Darwin's explanation of the phenomena is the most plausible extant. Continental islands secure their living organisms from the mainland before the land connections are broken, and oceanic islands, after their formation by volcanic action, secure their types independently or aided by coral growth. In either event the organisms inhabiting islands are isolated from the main stock of the species, and they diverge, in proportion to the length of time and the degree of isolation, until they constitute separate races and species. Isolation promotes divergence apparently to a considerable extent by preventing new types from being swamped by interbreeding with the old, and by allowing many mutations to become established that would not have survived in a more competitive field. Furthermore, new conditions may afford new problems to be met by mutations. Evolution may be regarded as a response of life to its environment. Each species peculiar to each isolated island can reasonably be interpreted as having arisen by descent with change. (p. 388.)

We have now summarized a few concrete examples of the chief types of evidence indicating that the species of living organisms have come to be what they are today through a long process of descent with change. This evidence, considered in conjunction with that presented, so to speak, on and between the lines throughout this book, should place the reader in a position to form a more or less independent judgment of the question. It is only necessary to remind him again that, although the evidence for descent with change in the past must, from the nature of the case, inevitably be indirect, its force is tremendously increased by its amount. And the reader must not forget that, with only a very limited amount of the data before him, he cannot fully appreciate the overwhelming impressiveness of all the concordant evidence for organic evolution.

CHAPTER XXV

Origin of Species (II)

FACTORS OF ORGANIC EVOLUTION

Granted the fact of evolution, what now are the factors which have brought this process about? This is quite a different question but one which has often brought confusion to the popular mind. Although biologists are in general agreement on the basic factors involved, there is much debate in regard to their relative importance and method of operation. The layman frequently has mistaken the questioning of one factor or another for a questioning of the fact.

No purpose will be served at this point by an historical account of the origin of the present-day point of view. Suffice it to say that the idea of evolution is a generalization which has crept from science to science—from astronomy to geology, from geology to biology, thereupon becoming organic evolution. The idea in one form or another is as old as history, but for all practical purposes we may begin with the biologist Lamarck, who, during the early part of the nineteenth century, formulated the first consistently worked-out theory of organic evolution. (Fig. 515.)

LAMARCKISM

The evidence for organic evolution offered by Lamarck was necessarily limited in amount and in some cases neither happily selected nor convincingly presented, so it was laughed out of court by biologists and laymen alike. His evolution factor was essentially the change of the organisms through the use and disuse of parts, the physiological response of the organism to new needs offered by new conditions of life. These changes, somatic in origin, he believed were transmitted to

the progeny. His first statement in 1809, freely translated, is as follows:

"First Law: In every animal which has not exceeded the term of its development, the more frequent and sustained use of any organ gradually strengthens this organ, develops, and enlarges it, and gives it a strength proportioned to the length of time of such use, while the constant lack of use of such an organ imperceptibly weakens it, causing it to become reduced, progressively diminishes its faculties, and ends in its disappearance.

"Second Law: Everything which nature has caused individuals to acquire or lose by the influence of the circumstances to which their race may be for a long time exposed, and consequently by the influence of the predominant use of such an organ, or by that of the constant lack of use of such part, it preserves by heredity and passes on to the new individuals which are produced, provided that the changes thus acquired are common to both sexes, or to those which have given origin to these new individuals."

Lamarck's first law is, in general, sound, but the second—the inheritance of acquired characters—is highly questionable to say the least, because, as we have seen, there is no evidence that modifications are heritable. But this weak point was not the one which caused the rejection of the theory by Lamarck's contemporaries. The various antagonistic influences may be summed up by saying that the time was not ripe for evolution.

Very recently there has arisen in Soviet Russia a cult, based upon a perversion of the evidence in genetics and evolution, which takes a scientifically untenable stand in support of the inheritance of acquired characteristics. This pseudogenetics, popularly known as Lysenkoism, in honor of its contemporary "originator," is the politically motivated "official" doctrine of the U.S.S.R., in regard to the much-disputed biological and social problems relating to human heredity and environment.

DARWINISM

A generation after Lamarck, Charles Darwin appeared in England. With a better background prepared for him, in part through the progress being made by the evolution theory in geology, he published his *Origin of Species* in 1859. In this book he did two things: he presented an overwhelming mass of *facts* that could be explained most reasonably by assuming the origin of existing species through descent.

with change from other species; and he offered as an explanation of the origin of species the *theory* of "NATURAL SELECTION, or the preservation of favoured races in the struggle for life." It was the combination of the facts and the theory to account for the facts that won the thinking world to organic evolution—a common height from which we view the whole world of living beings. (Fig. 517.)

What, in brief, was the theory? In the first place, Darwin showed the great amount of VARIATION in nature. Any and all kinds of heritable variations were, broadly speaking, important, though he questioned the inheritance of acquired characters.

The universality of variations established, Darwin emphasized the fact that the POWER OF REPRODUCTION of organisms far exceeds space for the offspring to live in and food for them to eat. Some recent data will illustrate this point. A microscopic *Paramecium* possesses the power to eat, grow, and reproduce—to transform the materials of its environment into *Paramecium* protoplasm—at the rate of 3000 generations in five years. All the descendants (if they actually existed) would equal 2 raised to the 3000th power, or a volume of protoplasm approximately equal to 10^{1000} times the volume of the earth! The plant lice, or aphids, may produce a dozen generations in a year. The final brood, on the assumption that the average number of young produced by each female was one hundred and that every individual produced its full complement of young, would consist of ten sextillion individuals: a procession, if it could be marshalled, that "would extend from the earth out into space far beyond the furthest star that has ever been discerned by the telescope." The common housefly under favorable conditions may lay as many as six batches of eggs, of about one hundred and forty eggs each, during its short life of approximately three weeks. Assuming that all the progeny survived and multiplied at the same rate, "the progeny of a single pair, if pressed together into a single mass, would occupy something like a quarter of a million cubic feet, allowing 200,000 flies to a cubic foot." And the all too familiar mosquito may have nearly two hundred billion descendants during one summer. Similarly, the common rat produces astounding numbers of offspring. (Figs. 310, 317, 329.)

The number of individual organisms on the earth is essentially infinite. If it is assumed that the average life span of an individual is a year—a day would probably be nearer the truth—then it follows that this infinitude of individuals is each year wiped out, and replaced

through the process of reproduction. Such "almost explosive expansion of a population" under favorable conditions is appalling, and serves to afford an appreciation of the enormous realized and unrealized potentialities of living matter to make more living matter—to reproduce. "The problem of organic evolution is that of the evolution of an organic mass consisting of an infinitude of individuals reproduced during an infinitude of generations."

Something must—and does—suppress the inherent power of each species to overpopulate the earth, and Darwin emphasized the STRUGGLE FOR EXISTENCE between the individuals within a species. Thus "a plant which annually produces a thousand seeds, of which on an average only one comes to maturity, may be said to struggle with the plants of the same and other kinds which already clothe the ground. . . . Battle within battle must be continually recurring with varying success; and yet in the long run the forces are so nicely balanced that the face of nature remains for long periods of time uniform, though assuredly the merest trifle would give the victory to one organic being over another." In other words, the struggle is so keen that a heritable variation, however slight, which fits (adapts) an individual to its surroundings better than its neighbors are adapted, will more often than not give its possessor an advantage in the struggle, and accordingly such an individual will tend to survive and to pass on the favorable variation to its progeny. In this way NATURAL SELECTION brings about THE SURVIVAL OF THE FITTEST: the survival of those individuals, and therefore species, which are best adapted to the peculiar conditions of their environment and mode of life. It should be observed that this theory offers an explanation of the fact of adaptation itself.

This explanation is so simple from one point of view and so complex from others, that it may well be restated in Darwin's own words: "As many more individuals of each species are born than can possibly survive, and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be naturally selected. From the strong principle of inheritance any selected variety will tend to propagate its new and modified form."

Nothing succeeds like success, and Darwin's theory once started gradually swept away nearly all opposition. In fact, some of its advocates in their enthusiasm extended Darwin's theory to a point not

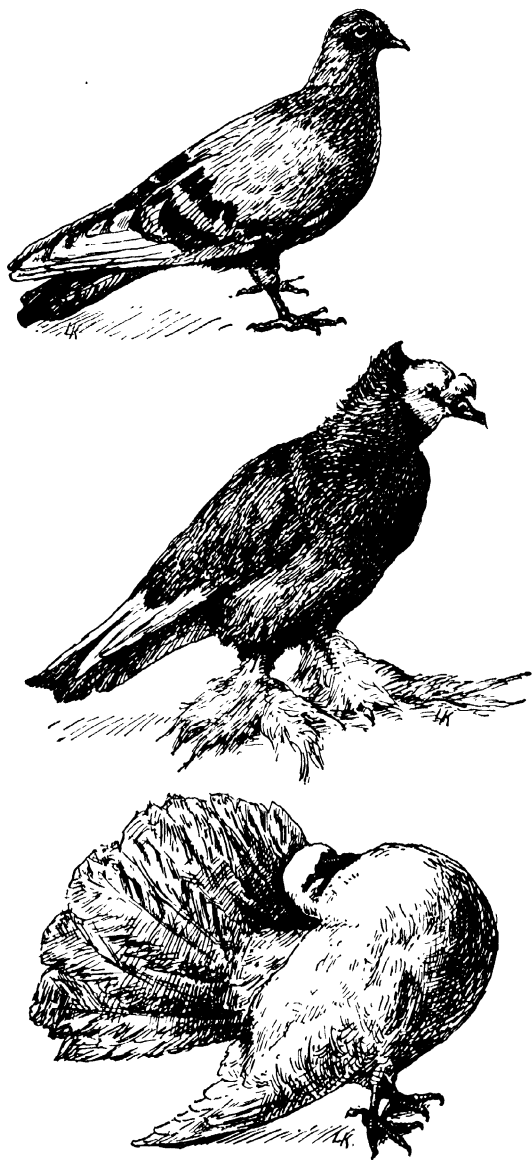


FIG. 276. Drawing of the blue-rock pigeon, *Columba livia*, (top), the basic type from which some 150 different breeds of pigeons have been derived by selection. Two noteworthy highly diverse pigeon-types are also shown: the tumbler (center); and the fantail pigeon (below). Drawings from laboratory specimens. (See Fig. 282.)

justified by his own conservative statements. Then, as was to be expected, the reaction came. One objection after another was raised as the problem was studied from nearly every standpoint by biologists the world over. It is, however, unnecessary to obscure the main issue by entering into these controversies. What is the status of the theory of natural selection today? The answer must be sought in the light of genetics. (Figs. 274, 276, 281.)

GENETICS AND EVOLUTION

Evolution is not a closed book, an event which has been completed in the past, but rather a process which is actively going on now. It may even be an accelerating process that is gaining momentum. Perhaps today it is but little beyond the beginning of its revelations. There is every reason to believe that the factors involved in present-day evolution are essentially the same as those which have operated in the past. It is now realized that organic evolution is an "aerial view" of the results of heredity since the origin of life; the facts of inheritance hold the key to the factors of evolution. Therefore it is necessary to consider the relations of recent discoveries in genetics to the problem of the origin of the fitness of organisms. (pp. 651-652.)

Selection. The process of selection has long been successfully practiced by man to establish desirable types of domestic animals and plants. As has been indicated above, Darwin assumed that a somewhat similar but automatic selective process determines the survival of the better-adapted wild forms in nature. Darwin clearly recognized that selection in itself can produce nothing; its efficacy depends on the materials afforded by variation. But he did not and, of course, could not make the modern sharp distinction between modifications, recombinations, and mutations. In general he accepted all variations as at the disposal of selection, but emphasized the importance of small, finely graded, fluctuating variations in gradually producing, through many generations, a cumulative effect in the direction of selection—variations that today are known to be, in part, modifications.

The modern approach to the critical analysis of significant variations was opened by the work of two botanists, deVries and Johannsen. DeVries laid stress on the importance of discontinuous variations which he called **MUTATIONS**, a class of variations already discussed; while Johannsen made it clear that selection is ineffective in a homozygous germ complex, or **PURE LINE** (see below).

Some of the problems of selection will be clarified by an example. Take, say, a quart of beans and sort them into groups according to the weight of each bean. Then put each group into a separate cylinder and arrange the cylinders in a series according to the weight of the enclosed beans. Now, an imagined line connecting the tops of the bean piles in the cylinders will take the form of a normal curve of probability, or variability curve. A similar figure would be obtained by the statistical treatment of nearly all fluctuating characters among the members of any large group of organisms, or of the size of the grains in a handful of sand, or the deviations of shots from the bull's-eye in a shooting match. In other words the variations with respect to a given character very closely approximate the expectation from the mathematical theory of probability, or chance, and the reasonable conclusion is that such finely graded fluctuating variations are the resultant of a large number of factors, each of which contributes its slight and variable quota to the inheritance expressed in a given individual. (Figs. 277, 278.)

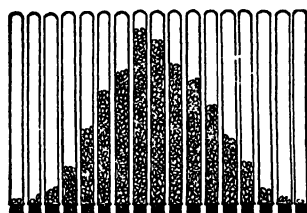


FIG. 277. Diagram to illustrate the population in a quart of beans assorted according to weight.

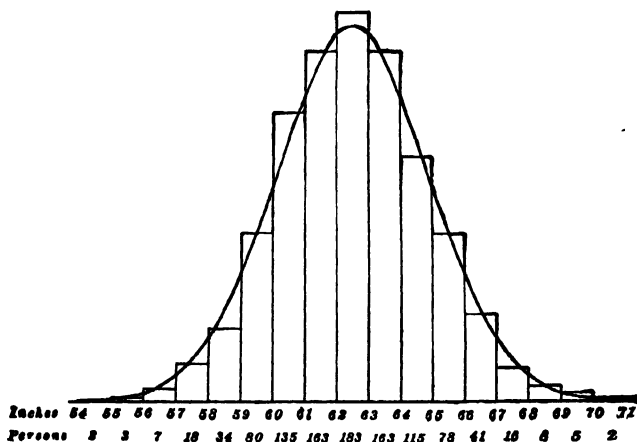


FIG. 278. Normal variability curve plotted from measurements of the height of 1052 women. The height of each rectangle is proportional to the number of individuals of each given height in this population. (After Pearson.)

The question is, what results are obtained by breeding from individuals which exhibit such a fluctuating variation to a greater degree than that of the mean of a mixed POPULATION? In view of Galton's principle of filial regression, one will naturally expect, and rightly, that the offspring usually will exhibit the character to a greater degree than the general population, but to a lesser degree than the parents. The top (mode) of the curve will have moved, so to speak, slightly in the direction of selection. Now, by continuing generation after generation to select as parents the extreme individuals, that is, those exhibiting the character in question to the greatest extent, is it possible, with due allowance for some regression, to take one step after another indefinitely, until the character is expressed to a degree which did not exist previously? The experience of practical breeders gives a partial answer, since the continual selection of the best animals for mating and the best plants for seed has proved a profitable venture. It has long been known, however, that such selection, after it has been practiced for some time, may cease to be effective and thereafter serve chiefly to keep the character at the higher level attained. (Fig. 279.)

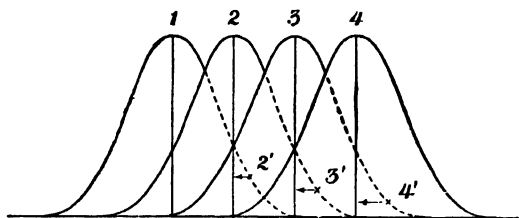


FIG. 279. Schematic representation of the effect of selection from the viewpoint of Galton's law of filial regression. 1, mode before selection; 2, 3, 4, new successive modes, the results of selections of individuals at 2', 3', 4'. The mode has been shifted in the direction of selection (toward the right); but each time there has been the amount of regression indicated by the length of an arrow. See Fig. 229.

The crux of the problem is in regard to exactly what the variations are. Both modifications and recombinations are usually included, and this mixture of nonheritable and heritable variations is the source of the confusion. If we rule out recombinations, by inbreeding or by self-fertilization of homozygous individuals, we soon establish PURE LINES. Then the variations are all modifications, and selection is ineffectual with characters that are not inherited.

The importance of this point was discovered by Johannsen in care-

ful experiments on the inheritance of characters in single pure lines of a brown variety of the common garden bean. For example, by keeping the progeny of each individual bean separate from that of all the rest, he was able to isolate a number of pure lines which differed in regard to the average weight of the beans. Thus selection resolved the bean population with which he began into its constituent "weight types," or lines, each of which exhibited a characteristic variability curve of its own with a mode departing more or less from that of the population. But when Johanssen selected *within* a pure line (ruled out recombinations) no change resulted; he was unable to shift the mode because he was dealing with nonheritable characters. In other words, selection sorts out pre-existing pure lines (lines with homogeneous germinal constitution) from a population and then stops. Thereafter a mutation must occur in the pure line for selection to be effective; but by the mutation the single pure line becomes two. Certain of the best varie-

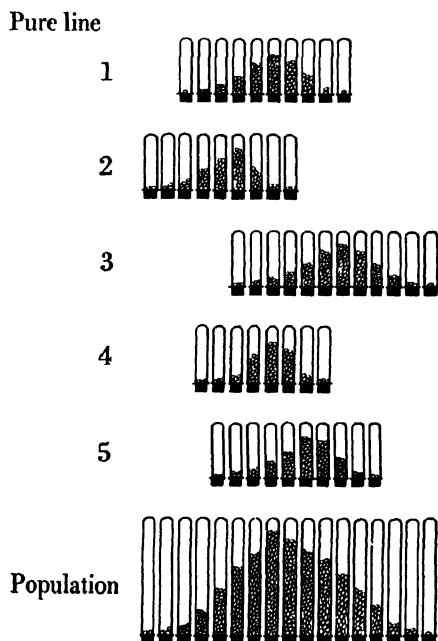


FIG. 280. Diagram to illustrate a population of beans and its five component pure lines. The beans are assorted according to weight. Tubes containing beans of the same weight are placed in the same vertical row. See Fig. 277. (From Walter, after Johanssen.)

ties of cotton, wheat, and other commercially valuable plants are pure lines, in some cases tracing their origin back to a single seed. (Fig. 280.)

The concept of the pure line has served to clarify our ideas in regard to selection by focusing attention on the actual nature of the variations concerned. It discriminates sharply between modifications, which are a result of environmental influences, often recurrent in each generation and so *seemingly* inherited, and variations which are heritable because they are the result of changes in the germ cells.

However, it will be recognized at once that nature, as well as the animal or plant breeder, in general deals with hybrid stock, heterozygous in regard to many characters. Indeed, the expression of individual characters may be the resultant of multiple genes, cumulative in effect, and so of the number of these genes present. Furthermore, pure lines may not stay pure; mutations may occur. Hence natural selection has ample material at its disposal so it can and does segregate new combinations and accumulate mutations in the direction of selection. If selection is carried on over a sufficiently long period, the extent of the change may be very great—the result of a more or less continuous progression in the direction of selection. (p. 378.)

It appears that ISOLATION, usually with change in environment, is generally necessary in order for natural selection to be highly effective in the formation of species. Random mating in a natural species population tends to distribute the various genes throughout the population. Since mutations usually occur in only one member of a gene pair and, furthermore, are recessive, they appear in the phenotype only when they meet similar genes. Therefore isolation, since it encourages INBREEDING, increases the likelihood that similar recessive mutant genes will meet and appear as characters. Hence stocks isolated on mountains, islands, or in special ecological niches tend to exhibit and fix mutations that their wide-ranging, freely interbreeding ancestral stock fails to show.

It should be noted, however, that inbreeding may lead to decrease of vigor. In a wide-ranging species where OUTBREEDING is the rule, individuals with unfavorable dominant genes tend to be eliminated by natural selection, whereas those with unfavorable recessive genes, less often within the reach of natural selection, may prosper. Inbreeding in such a population may well bring these defects from the genotype to the phenotype as the individuals become homozygous, just as cousin

marriages in man sometimes reveal unfortunate recessives because close relatives are likely to carry the same ones.

Furthermore, if to this revealing of recessive mutations in an isolated community there are added new environmental conditions, the stock will be reduced in general to the relatively few individuals that are best fitted to survive. The revealing process will then proceed still more rapidly and, in the long run, natural selection will favor individuals unlike the original stock. On this basis it is no wonder that a species may have a wide range of distribution on the mainland while each of the adjacent islands has its own species. Nor is it surprising that mountain ranges with their diverse features usually have a greater number of distinct species than the adjacent country of much greater area.

Geographic isolation, though the most obvious, is by no means the only kind of isolation. Mutations that produce seasonal variation in the reproductive period, physiological incompatibility, infertility, etc., may be highly effective isolating factors. It may well be that such changes have had the most important influence in evolution. If a mutant stock is thrown out of competition with the ancestral group and outbreeding is prevented on account of structural or physiological changes, it appears that an important step in the origin of new species has been made.

Another complicating factor may be mentioned incidentally. It is well known that hybrids are often more vigorous in certain ways than their parents. Hybrid corn is a good example. The explanation of this so-called HYBRID VIGOR, or HETEROSIS, is not entirely clear, but it appears to be due in part to the fact that outbreeding brings forth in the offspring the highly selected dominants of both parents. (Fig. 281.)

METHOD OF EVOLUTION

A synoptic view of some of the essential facts, presented from a different angle, may serve to clarify our view of evolution as fundamentally a complex problem in genetics.

It may be reiterated that though variations are the rule and not the exception, some are of importance for evolution and some are not. All the evidence indicates that the effective variations are germinal and not somatic. Changes arising in the soma (modifications) are unable to attain representation in the germ plasm so that they are "born again," although modifications impressed anew on the soma in each

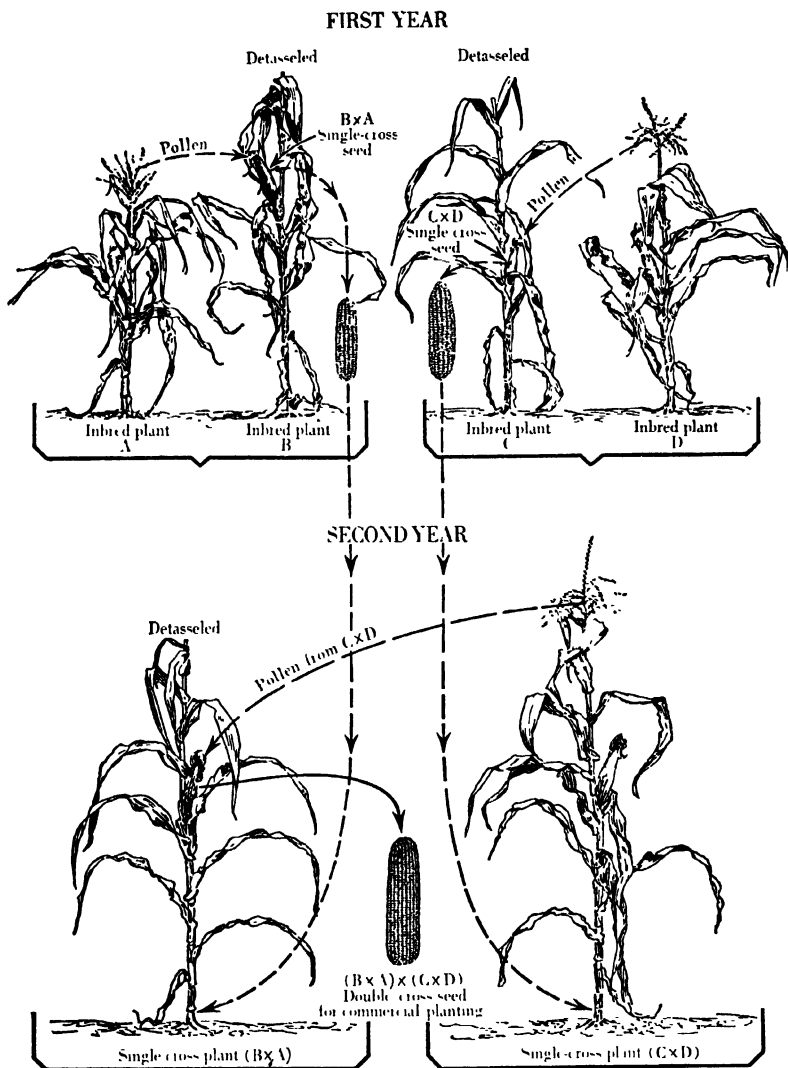


FIG. 281. Diagrams to illustrate the method used in breeding hybrid corn by the production of double-cross seed. (After Benedict, Knox, and Stone.)

generation may enable a race to survive until appropriate recombinations or mutations appear. Evolution, then, must be brought about by changes in the germinal complex—by the evolution of the germ plasm itself. Accordingly selection must operate to eliminate the unfit germ plasm (genotype) rather than the unfit soma (phenotype), though as a matter of fact the fitness of an individual is determined largely by somatic characters. Dominant genes are directly within the reach of natural selection, whereas recessive genes may slip by because they are frequently concealed by dominants. This condition adds to our mental picture of the operations of selection a complication that did not exist before our modern concept of phenotype and genotype. Since individuals frequently belie their genotypic condition, in what they can pass on to their progeny, natural selection has, so to speak, a more devious though not less sure path. (Fig. 282.)

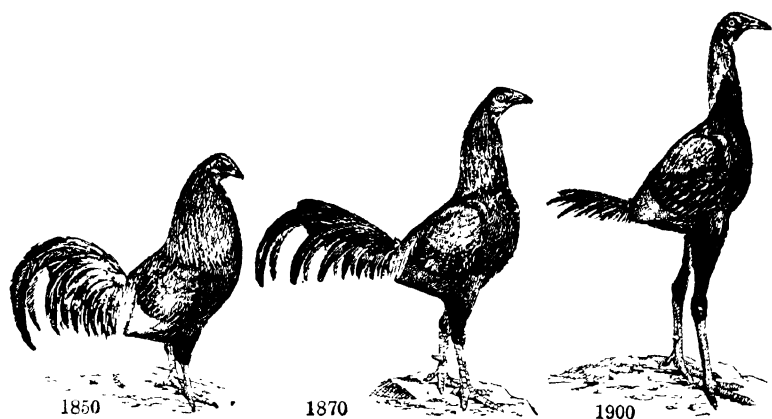


FIG. 282. The evolution of the game cock. Results produced by selection before the present knowledge of the mechanism of inheritance was available. (From Metcalf, after Wright.)

Natural selection may automatically act as a “sieve” and sort out the new combinations and mutations presented, retaining the fit and discarding the unfit, and so afford a natural explanation of adaptation. It seems to be a strictly scientific explanation of the fitness of living things, in spite of the fact that it does not explain, and does not attempt to explain, the *origin* of fitness. “If peas are rolled down an inclined plane, the largest go fastest, the smallest slowest, and the round ones go straight to the bottom, while the irregular ones deviate toward the sides. This may be an efficient means of sorting peas, al-

though the origin of the differences in the peas is unknown." (Fig. 282.)

How does the germ plasm change? True, germinal alterations result from the usual processes of chromosome recombination and gene recombination (crossing over), as well as from the more radical mutations—chromosomal and intrinsic gene changes. But what is the nature of the intrinsic gene changes? No one has ever been aware of seeing a gene. Genes are known by their works. We already have a biochemical account of some thirty-five genes concerned in the production of the chief blue, purple, and red water-soluble sap pigments that produce variations in flower color of more than a dozen species of plants. All the pigments prove to be derivatives of one substance, pelargonidin, through the action of specific dominant genes that insert various chemical side chains in the basic pigment molecule.

So it appears that single genes may control simple biochemical differences. However, the genes themselves are not simple. Their properties probably are dependent to a large extent upon their molecular structure: huge protein molecules with side chains that may change in number and position to give gene mutations. Presumably multiple alleles, such as we have seen represented in the eye color of *Drosophila*, represent a series of mutations of one gene. Moreover, the fact that graded series of mutations (in *Drosophila*, from red to white eyes) occur, suggests progressive, or directional, changes in the chemical structure of the gene. This may possibly offer an explanation of the fact that evolution in many cases seems to show definite directional trends, referred to collectively as ORTHOGENESIS. Obviously, all these changes afford a wealth of opportunities for alterations in the self-reproducing nucleoprotein systems, the genes, and so for the appearance of new characters in organisms. (Fig. 255.)

While it is true that mutations are infrequent in comparison with nonheritable changes of somatic origin, nevertheless it must be borne in mind, not only that somatic changes are more readily apparent, but also that the majority of mutations lead to a decrease in vitality or even to death. This is to be expected, for an apparently random change in a highly complicated "mechanism" such as a living organism, which has long survived in a severely competitive environment, is far more likely to upset than to improve the nicety of its internal and external adaptation; in fact, it has been shown that the greater the effect of a mutation, the more likely it is to be nonviable. Natural selection is

conservative unless a changing environment is presenting new conditions to be met. In general, natural selection hews to the line and tends to keep wild types within specific bounds. (Fig. 256.)

Relatively little information is available in regard to the basic factors that induce mutations, but recent experimental work indicates that environmental factors, such as irradiation, etc., acting directly on the genetic complex are not without influence, and mutations have been produced in this way. Therefore it seems probable that both external and internal environmental conditions, particularly the new cellular environment of the genes following hybridization, are potential inducers of mutations and so of new variations at the disposal of natural selection. However, when all is said, we have little appreciation of the fundamental physicochemical changes in the germinal material itself that are responsible for the characters. Characters may emerge that cannot be recognized as the computable or additive result of newly associated genes; the expressions of the genes may change, new properties may emerge from new relations—"emergent evolution." Witness the properties of water that emerge from an exact association of hydrogen and oxygen. (pp. 343-349.)

One may well inquire whether geneticists in their extensive experiments during the past few decades have succeeded in creating a new species. The answer is largely determined by one's concept of a species—a problem we have already discussed. (p. 353.) It is fair to say that some biologists hold that new species have been "created," whereas others who are more conservative prefer to consider the new forms as "artificial species." Certainly the new forms have distinctive characters, breed true, and sometimes are sterile with the parental forms, as a result of alterations in the genetic complex. Indeed, many of the chromosomal changes studied in pedigreed strains in the laboratory are also found in wild populations and often distinguish recognized races and species. Some of the newly established forms are actually more distinct from the species of their origin than are other generally admitted species of the same genus. Probably all would agree that some of the new types would be regarded as true species were their origin not actually known.

The question, however, is not so important as it may appear at first glance. The essential fact is that we now understand, at least to a considerable extent, the mechanism of inheritance and variation that is at the basis of similarity and dissimilarity of individuals, parents, and

offspring—the mechanism that surely is crucially involved in the differentiation of groups of similar individuals, or species. (pp. 356-359.)

To epitomize: the facts from genetics, taken in connection with the wealth of data from geographical distribution, the succession of types in the geologic past, and the other evidence at our disposal, provide the modern background for attempting to form an opinion of the method of evolution. The opinion of most biologists is that natural selection is the guiding principle underlying the establishment of the adaptive complexes of organisms. Evolution is the result of mutations, germinal variations, largely though not entirely independent of environing conditions. Many of these variations give rise to characters which neither increase nor decrease the adaptation of the organism, and consequently are neutral from the standpoint of its survival. With regard to such characters natural selection is essentially inoperative. Other germinal changes occur, some of which produce adaptive and others unadaptive characters, and here natural selection is effective. It may eliminate the unadaptive and leave the adaptive variations and so make possible the survival value of the latter in the struggle for existence. The germ plasm never ceases to experiment, or natural selection to discover. Variability affording opportunity for adaptability is expressed in "evolvability," a profoundly significant characteristic of life.

It will be noted that this is essentially a clarified view of Darwin's idea of natural selection, which has been made possible by recent intensive studies of the intrinsic nature and the origin of variations. Natural selection still affords the most satisfactory explanation of that coordinated adaptation which pervades every form of life; it shows how nature can be self-regulating in establishing adaptations. But it is probable—indeed, positive—that there are more factors involved than are dreamt of in our biology. (pp. 652-657.)

In the words of Thomson: "The process of evolution from invisible animalcules has a magnificence that cannot be exaggerated. It has been a process in which the time required has been, as it were, of no consideration, in which for many millions of years there has been neither rest nor haste, in which broad foundations have been laid so that a splendid superstructure has been secured, in which, in spite of the disappearance of many masterpieces, there has been a conservation of

great gains. It has its outcome in personalities who have discerned its magnificent sweep, who are seeking to understand its factors, who are learning some of its lessons, who cannot cease trying to interpret it. It looks as if Nature were Nature for a purpose." Indeed Aristotle, in effect, emphasized that the essence of a living being is not protoplasm, but purpose. This thought, however, carries us beyond the accepted sphere of science into the fields of philosophy and theology.

CHAPTER XXVI

Organic Adaptation (I)

Every creature is a bundle of adaptations. Indeed, when we take away the adaptations, what have we left?

—*Thomson and Geddes*

Since organisms are dependent for their life processes upon energy liberated by physicochemical processes in protoplasm, any and all influences which induce changes in the structure or functions of an organism must initially modify the underlying metabolic phenomena. In other words, organic response is a problem of metabolism. Although it is highly important that this cardinal fact be clearly grasped, the science of biology today is not in a position to interpret the responses of organisms in these fundamental terms. Accordingly we can merely describe some representative instances to illustrate the fact that the response of organisms, as exhibited in active adjustment—ADAPTATION—of internal and external relations, overshadows in uniqueness all other characteristics of life and at one stroke differentiates even the simplest organism from the inorganic.

Overwhelmingly striking as is the fitness of organisms to their physical surroundings, one must not lose sight of the fact that the environment itself presents a reciprocal fitness. This apparently results from the "unique or nearly unique properties of water, carbonic acid, the compounds of carbon, hydrogen, and oxygen. . . . No other environment consisting of primary constituents made up of other known elements, or lacking water and carbonic acid, could possess a like number of fit characteristics, or in any manner such great fitness to promote complexity, durability, and active metabolism in the organic mechanism which we call life." (L. J. Henderson.)

ADAPTATIONS TO THE PHYSICAL ENVIRONMENT

In any consideration of the reciprocal relations which must exist between organisms and their surroundings, of first importance is the

inconstancy of the latter. Uncertainty is the one certainty in nature and accordingly the response of living things—their adaptability to environmental change—is at once the most striking and indispensable adaptation.

ADAPTATIONS ESSENTIALLY FUNCTIONAL

Although the changes of the environment are almost inconceivably complex—witness the kaleidoscopic series of events exhibited in the hay infusion microcosm—there are certain general conditions that every environment must supply, and without which life cannot exist. These are water, oxygen, various elements, carbon compounds suitable for food, and definite limits of temperature and pressure.

Food. As we know, food is the continuous stream of matter and source of energy required for the metabolic processes of living matter. Moreover, each and every element that forms an integral part of protoplasm must be available. Since all protoplasm consists chiefly of a dozen chemical elements, these, of course, must be present; and further, since protoplasm is a colloidal complex in which water is of fundamental importance, life processes without water are impossible. But the old adage that what is food for one is another's poison has a broader significance than is immediately apparent. Although it is true that there are food elements which all life demands, it is equally true that the combinations in which these elements must be presented to the organism, in order to be available for its metabolic processes, are subject to the widest variation. (pp. 27-31.)

We have studied and contrasted the nutrition of a typical animal, green plant, and colorless plant, and have seen the reciprocal part which they play in the circulation of the elements in nature; so it is necessary, with these facts in mind, only to cite special cases in order to illustrate the adaptation of certain groups of organisms to unusual conditions of existence. (Figs. 20, 21.)

The sulfur bacteria, representatives of a relatively small group of autotrophic bacteria, have the power to manufacture their own food with energy derived from inorganic substances and without the aid of the energy of sunlight; a process known as CHEMOSYNTHESIS. These bacteria live in water containing hydrogen sulfide, from which by oxidation they obtain energy and store up within the protoplasm free sulfur in the form of tiny crystals. Then by further oxidation they transform the sulfur into sulfuric acid, which immediately becomes a

sulfate and is excreted. Thus a gas which is poisonous to nearly all organisms is for these bacteria a necessary condition of life.

As another example of the versatility of bacteria, it may be noted that certain species, though without chlorophyll, actually are able to employ the energy of light in their synthetic processes.

The yeasts include a host of microscopic colorless plants which have an important part in the simplification of organic compounds. An ounce of brewers' yeast contains about five billion cells. These organisms are devoid of chlorophyll and lack photosynthetic powers, though

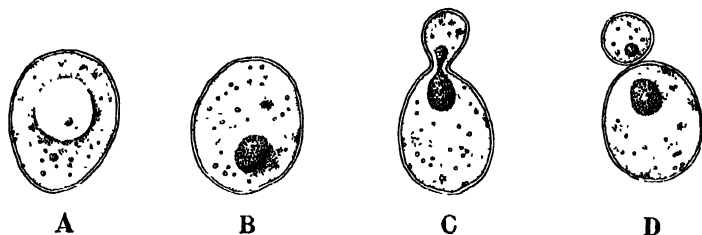
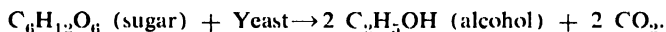


FIG. 283. Yeast cells, very highly magnified. A, cell showing granular cytoplasm and a large vacuole; B, showing nuclear material; C, cell undergoing reproduction by budding; D, mother cell and bud after division is completed.

like many other colorless plants they are not dependent upon proteins for nitrogen but obtain it in less complex form. The essential fact of interest at present is the chemical changes associated with yeast metabolism, the transformation of a large proportion of the sugar content of the medium in which these plants live into alcohol and carbon dioxide. This process of ALCOHOLIC FERMENTATION may be approximately expressed by the formula:



The explanation is not far to seek. When deprived of an adequate supply of air, yeast utilizes the energy released when, with the decomposition of the sugar, the carbon and oxygen unite as CO_2 . The formation of alcohol as the by-product of the sugar molecules is, from the standpoint of the plant, a mere incidental factor which is unavoidable. However, from the broad point of view, the waste products of the action of the yeast plant's enzymes represent an important phase in the general simplification of organic compounds in nature. Man turns to account in numerous ways both products of the plant's destructive powers: the alcohol and the carbon dioxide. (Fig. 283.)

The yeasts are practically independent of free oxygen and in this respect they resemble many kinds of bacteria as well as some animals, chiefly parasitic forms, which are able to secure the necessary energy by the rearrangement of the atoms within, or the disruption of, molecules containing oxygen. Indeed, certain species of bacteria not only do not need free oxygen at all, but are killed when it is present in any considerable amount. All such organisms are termed ANAËROBES. An important example is *Clostridium tetani*, which inhabits garden soil and street dust and produces TETANUS, or lockjaw, in man and certain domesticated animals when it gains entrance and develops in the tissues.

Temperature. Although protoplasmic activity is restricted to ranges of temperature which do not seriously interfere with the chemico-physical processes involved, it is a commonplace that various species are adapted to different degrees of temperature. Each has its optimum at which it thrives best and its maximum and minimum beyond which life ceases. The great majority of organisms find their optimum temperature between 20° C and 40° C, though species inhabiting the polar and tropical regions show adaptations to the temperature extremes of their surroundings. As a matter of fact, it is not possible to state the upper and lower limits beyond which all active life ceases, but some protozoa are known to multiply in the water of hot springs, certainly at temperatures slightly higher than 50° C, and others to remain active in water until freezing actually occurs.

Many of the lower forms of life, such as the bacteria and protozoa, have the power of developing, particularly under unfavorable surroundings, protective coverings of various sorts about themselves and of assuming a resting condition in which all the metabolic processes characteristic of active life are reduced to the lowest terms. In this spore or encysted state they are immune to extremes of temperature and of dryness to which they readily succumb during active life. The spores of some bacteria can successfully withstand a temperature of nearly -200° C for six months, and about -270° C for shorter periods, while others can endure for a short time a temperature at least as high as 140° C. Moreover, some organisms survive rapid freezing in liquid air though they succumb when slowly frozen at only -2° C. (Fig. 284.)

It is clear that the great majority of organisms are at the mercy of environmental temperatures. This is true of all except the warm-blooded animals, the birds and mammals. It is significant that these homothermal

animals possess a highly complex mechanism which keeps their body temperature practically constant—in man at 37°C (98.6°F)—and any considerable departure from this temperature results in death.

The heat regulatory mechanism represents, so to speak, the final result of the assembling and elaborating, throughout vertebrate evolution, of various elements, the origin of which is found among the fishes. In the mammals it comprises insulating material in the skin, a closed blood vascular system, power of rapid oxidation, endocrinal and other glandular products, evaporation surface of the lungs and skin, “trophic”

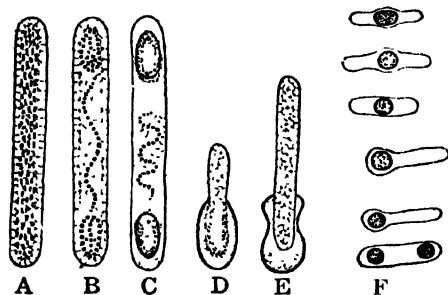


FIG. 284. A-E, *Bacillus butschlii*: A, cell structure; B, C, spore-formation; D, E, germination of a spore. F, various types of spore-formation occurring among bacilli. Very highly magnified. (From Smith and others; A-E after Schaudinn.)

and “temperature” nerves, coordinating centers, etc.,—the whole complex rendering its possessors largely independent of the surrounding temperature and making possible a carrying on of the various bodily functions with such nicety as the life of these forms demands. Indeed, this mechanism makes it entirely possible for a man to stay in a hot dry chamber sufficiently long to see a chop actually cooked. It is hardly probable that the human brain, for instance, could have developed to function as it does if its cells were subject to wide temperature variations as are those of a fish or frog.

Pressure. The metabolism of organisms, in common with chemical processes in general, is influenced by the surrounding mechanical pressure. It is evident that the pressure of either the water or air plays an important part in the operation of the life functions. There are many organisms adapted to even the greatest depths of the ocean where the pressure is several tons to the square inch—so great that some forms adapted to it burst when brought rapidly to the surface. Indeed, keeping within a zone of tolerable pressure is a real problem

for sea animals, the problem of moving neither downward nor upward being met in various ways, as by gas bladders, oil droplets, and so-called flotation processes. However, many marine organisms have a remarkable capacity for rapid adaptation to great changes in pressure. This is unusually conspicuous in whales, which are able to dive rapidly to a depth of nearly a mile without untoward effects although the pressure increases, one atmosphere (15 pounds per square inch) for every 33 feet of depth. (Fig. 285.)

Terrestrial organisms have a much simpler though by no means insignificant problem, since the greatest difference in pressure to which they normally can be exposed is considerably less than one atmosphere. Some, of course, are adapted to live at high altitudes and to soar still higher where the air pressure is relatively low. Again, many of the terrestrial vertebrates, includ-

ing man, possess an adaptive mechanism which renders them less dependent on a constant atmospheric pressure. Moreover, man has now developed artificial means to meet the conditions of stratosphere flight.

Sea to Land. These examples suffice to emphasize the general environmental conditions necessary for life, and to suggest that within these broad limits organisms are adapted to special environmental conditions so that there is scarcely a niche in nature untenanted. However, the reciprocal integration of the organism and its surroundings may be further shown by reference to some of the physicochemical adaptations of life, generally believed to have had its origin in the sea, as living creatures invaded progressively fresh water and dry land in their evolutionary development.

Apparently the fundamental physicochemical conditions under which life is possible have remained essentially the same since its origin in the sea, and therefore the evolution of different forms of life has necessitated the development of mechanisms for maintaining within the animal an environment similar to the original conditions. Proto-plasm, as we know, is adjusted to and dependent upon the properties

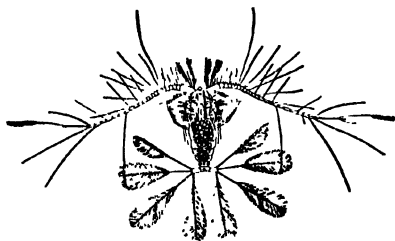


FIG. 285. A tiny marine crustacean, belonging to a copepod group, which shows extreme development of setae as extended flotation processes. Magnified. (After Giesbrecht.)

of the surrounding solution, and accordingly transfer to fresh water necessitated the development of mechanisms to keep the salt content of the body fluids independent of, and higher than, the surrounding water. The sea contains about 100 times more salt than fresh water, and probably this is the chief hurdle that organisms surmounted in colonizing the fresh water environment.

The blood of different animals today shows very great similarity; it could not be otherwise, since slight variations in osmotic pressure produce such profound changes in cells. Osmotic independence had to be attained and, in general, this was done by semipermeable boundary membranes of limited area, and by excretory organs capable of secreting a hypotonic urine and therefore doing osmotic work to maintain the osmotic gradient between the external and internal environments. Thus the composition of the blood has remained the same, not by a static process, but by being actively maintained as life became adapted to new habitats.

Adjustment to a terrestrial habitat involves, of course, still other adaptations. Much lower viscosity and more abundant oxygen make possible a general speeding up of the vital processes, but now provision also is necessary for the conservation of water which is so essential for all the functions of life. This is met in part, for example, by waterproof coverings and by certain changes in the kidneys and colon which enable them to reabsorb water otherwise destined to be lost. Since fats, as compared with proteins and carbohydrates, afford a larger percentage of metabolic water, animals in danger of undergoing desiccation emphasize the oxidation of fats.

In general the characteristic nitrogenous waste product of primitive aquatic animals is ammonia, which can readily diffuse into their environment. But in amphibious animals ammonia is replaced by urea because it is nontoxic in relatively high concentrations and so can be temporarily retained by the tissues without deleterious effects. Urea formation therefore may be regarded as an adaptation to water shortage and as such might be expected to persist in truly terrestrial forms. However, this is the case only in the mammals, since the birds and most strictly terrestrial reptiles find special conditions imposed by their early development in eggs protected by shells; instead of converting ammonia into urea, which is not easily eliminated, they change it into uric acid, which can be precipitated without disturbing the osmotic balance and discarded with the embryonic membranes at hatching.

It seems reasonable to believe that the primary needs of protoplasm are basically the same today as they were when it had its origin in the sea, and that, with the evolution of complex bodies adapted to changed surroundings, the problem of adaptation was met in part by the blood—at first probably little different from sea water—maintaining an *internal* environment approaching that of the parental sea.

ADAPTATIONS ESSENTIALLY STRUCTURAL

The view of the plasticity of organisms may now be broadened by a consideration of adaptations to the environment that are essentially structural. Here as elsewhere, however, it is absolutely impossible to distinguish sharply between structure and function which, obviously, are only reciprocal aspects of the fitness of living creatures.

In the final analysis, of course, every adaptation must favor survival or, at least, not run counter to it. The problem of self-preservation is paramount in nature and involves a very real and ever-present struggle for existence. This is reflected in the variety of adaptations for defense and offense, involving: the attainment of speed by land, water, and air; the use of stealth and surprise, deception and ambush; the display of alluring baits and warning signals; the elaboration of nets, traps, and parachutes; the formation of a protective armor of plates and spines; and the development of poison fangs, stings, noxious gases, and smoke screens.

Among all the various adaptations, most of which are paralleled in human warfare, "perhaps none is so important, so widely distributed, or so perfect as that which renders animals inconspicuous, and often well-nigh invisible in their natural surroundings." Concealment appears to be one of the chief adaptive responses in the evolution of animals, and is most frequently attained by variations of color and form, that is, by camouflage.

Animal Coloration. Probably the most generally striking characteristic of organisms is their color and color pattern. Among plants this applies chiefly to the flowers and fruit of the higher forms, though here and there throughout the plant series the typical green color is replaced or rendered inconspicuous by others. The absence of photosynthetic pigments in animals and their relatively active life have permitted more latitude in body color, and accordingly it is in the animal world that color adaptations are more numerous and varied. Some colors and color patterns are, of course, merely incidental to the

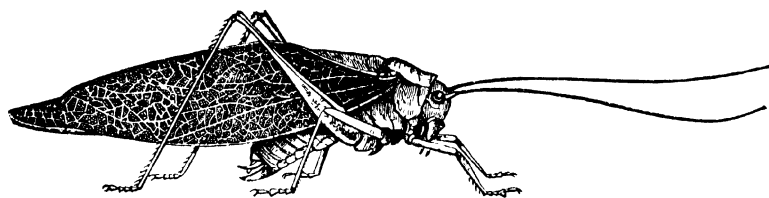


FIG. 286. The common green katydid, *Microcentrum*. (From Riley.)

chemical composition of the whole or parts of the body. Others, however, irresistibly arouse our interest and demand a less simple explanation because they are apparently of special service to their possessors. A few examples will serve to define the problem and indicate the class of facts involved.

The color and color patterns of many animals are such that they harmonize or fuse with the usual surroundings of the creatures and render

them practically indistinguishable from their immediate environment. Every frequenter of the open knows innumerable instances. The song of the green katydid readily guides one to its immediate vicinity, but it is quite another matter to distinguish the leaf-green wings among the foliage of its retreat. Again, one is attracted by the striking colors of an underwing moth in flight, but is at a loss to find the insect when scarlet or orange is obscured by the overlapping, grayish-mottled forewings blending with the tree trunk where it has come to rest. (Figs. 286, 287.)



FIG. 287. Dead-leaf butterfly, *Kallima*; the insect is shown below with conspicuously colored wings opened, and just above, to the right, with wings closed to give the inconspicuous dead-leaf pattern. (From Guyer.)

The white of the foxes, hares, and owls of alpine and arctic regions; the green color of foliage-dwelling toads and frogs; the tendency toward fawn and gray of desert insects, reptiles, birds, and

mammals; the olive upper surface of the bodies of brook fishes; the steel gray above and white below of sea birds that harmonize with sea and sky when viewed from above and below respectively—the number of such cases is legion. Gazelles living on the lava fields of volcanic regions are dark gray, while those of the great stretches of sand plains are white, the same species exhibiting regional variations in color which blend with the surroundings. Furthermore the same individual may vary in color with the seasonal changes in its environment, or exhibit different color schemes in different localities. Thus the summer coat colors of the arctic fox and the weasel harmonize with the browns of rocks; and the winter coat of white, with snow-clad nature. The ability to change color very rapidly, so that self-effacement often results, is by no means the unique ability of chameleons; rapid color changes in various animals are brought about by readjustments in the pigment content of the color cells of the skin under the influence of nervous or hormonal stimuli or both.

Confusion is increased further when to harmonizing color is added harmonizing form, striking examples of such *protective resemblance* being afforded by the leaf butterflies of the East Indian region, the familiar “walking sticks,” and the caterpillars (inch worms) of geometrid moths. (Figs. 288, 289.)

Although the general tendency in nature is for *sympathetic* coloration—indeed, it is frequently possible to infer the habitat of an animal from its color—there are numerous cases in which the colors and color schemes seem to be in striking contrast to the animal's usual background. Sometimes, however, the contrast which is so striking with the bird in the hand, proves to be *obliterative* with the bird in the bush: a conspicuous color pattern, expressing gradations of light and

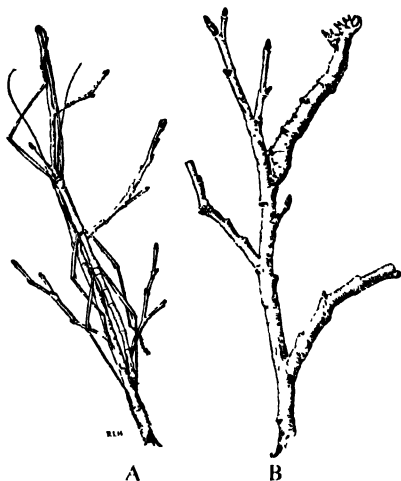


FIG. 288. Walking-stick insect on a twig (A); larva of a geometrid moth extended from a twig to which it is attached (B). (Modified, after Jordan and Kellogg.)

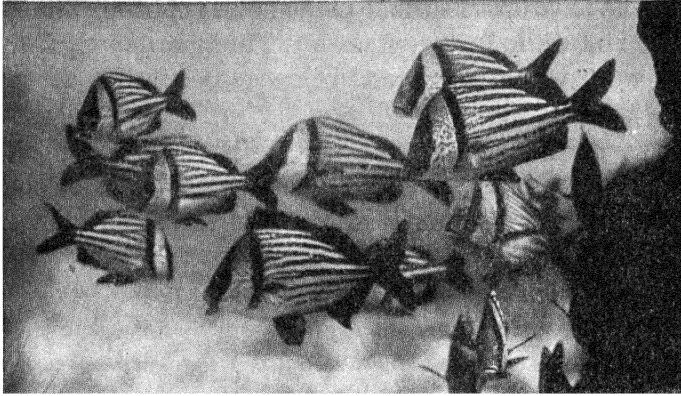


FIG. 289. Coral-reef fish. These are among the brightly colored species characteristic of coral reefs. Natural size, about 10 inches long. (From Hegner, after photograph by Longley.)

shadow, and countershading, blends with a background of light and shadow afforded by the background, so that camouflage results. It is hardly too much to say that concealment appears to have been one of the main ends attained in the evolution of animals, an adaptation for self-preservation. (Figs. 289, 290.)

Nevertheless, examples of color patterns which by the most liberal stretch of the imagination cannot be interpreted as harmonious with the animal's usual surroundings are not far to seek. Brilliant yellows and reds, for instance, render many wasps, bees, butterflies, and various species of snakes actually conspicuous. It is suggestive that very many of these forms are provided with special means of defense, such as poison glands and formidable jaws, or special secretions which render them unpalatable or otherwise undesirable. The conspicuous

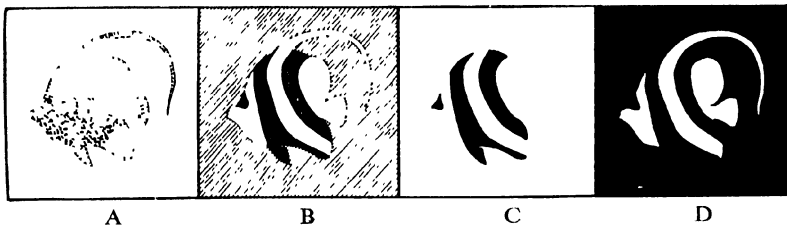


FIG. 290. Diagrams of a fish to show differential blending: A, when seen as a self-colored object without pattern; B, C, D, when seen with a disruptive pattern against different backgrounds. (From Cott.)

markings and odor of the skunk is a case in point. Moreover, what is still more interesting, many animals possessing this protective conspicuousness, which renders them easily identified and advertises that they are to be avoided by their foes, are frequently mimicked in color pattern and form by defenseless creatures. For instance, commonly associating with the various species of bees hovering about flowers are defenseless flies which are so bee-like in appearance that they are usually mistaken for bees, and accordingly avoided by human observers, and presumably also by other enemies. (Fig. 292.)

Now, what is the significance of such phenomena of animal coloration and form? Biologists perhaps have sometimes been too ready to interpret individual cases as "protective," "aggressive," "alluring," "confusing," or "mimetic." But it must be admitted that nowhere else is the universal adaptability of organisms better illustrated, and that, taken by and large, many of these adaptations are of crucial importance in the life and strife of species. Experiments have demonstrated in certain cases that ani-

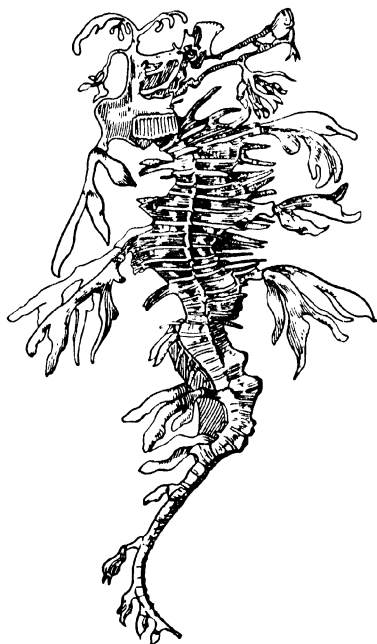
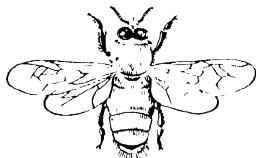
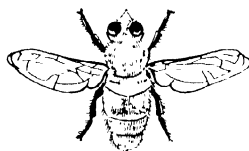


FIG. 291. Sea-horse, *Phyllopteryx eques*, which lives on and resembles one of the brown algae, *Sargassum*. Great floating masses of this algae form the "Sargasso Sea." See Figs. 353, 451. (After Boulenger. Redrawn.)



A



B

FIG. 292. Protective mimicry. A, drone honey bee; B, a bee-fly, *Eristalis tenax*. (From Folsom. Redrawn.)

mals possessing them enjoy a degree of immunity from their enemies which is of considerable selective advantage. Apparently the origin of such variations must be sought in mutations, the unadaptive ones being eliminated in the struggle for existence.

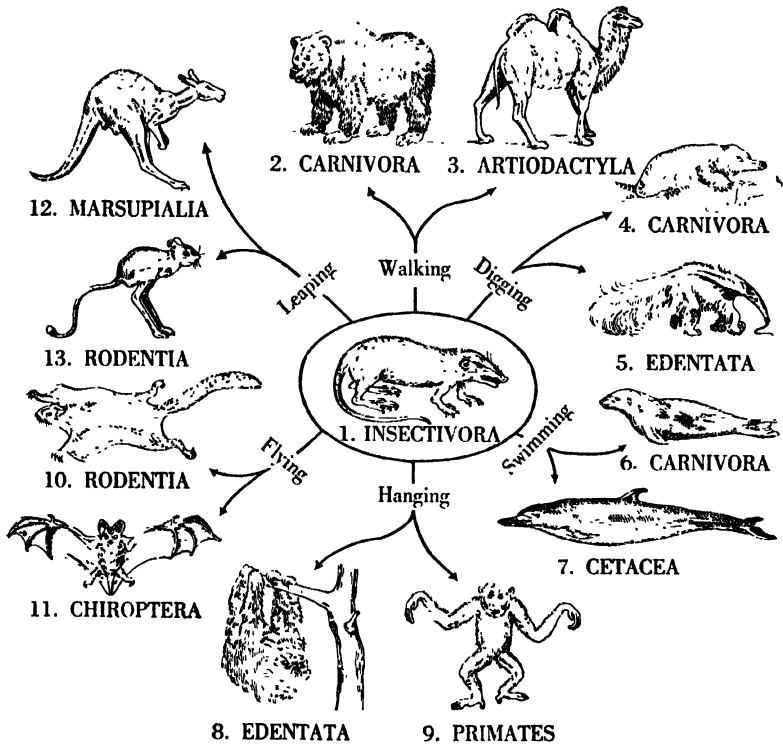


FIG. 293. Diagrams to illustrate parallelism in evolution and adaptive radiation in mammals. 1, *Gymnura*; 2, bear; 3, camel; 4, badger; 5, anteater; 6, seal; 7, dolphin; 8, sloth; 9, gibbon; 10, flying squirrel; 11, bat; 12, kangaroo; 13, jerboa. (From Hegner, after Newman and others. Redrawn.)

Adaptive Radiation of Mammals. Among the mammals, forms are to be found which are extraordinarily modified in adaptation to the most diverse environmental conditions. From a more or less primitive type, or focus, there radiate, as it were, types specialized for very different habitats and modes of life. We may select from the placental

mammals a small Malayan insectivorous animal known as *Gymnura*, which is allied to the hedgehogs, as most similar among living mammals to the generalized or focal type of terrestrial mammal. *Gymnura* has relatively short pentadactyl limbs with the entire palms and soles resting flat upon the ground (PLANTIGRADE) and therefore essentially adapted for comparatively slow progression. (Fig. 293, p. 601.)

Radiating from this focus, adaptations for rapid running (CURSORIAL adaptations) are chiefly evident in a lengthening of the limbs. For example, in the dogs, foxes, and wolves, the effective limb length is increased by raising the wrist and heel from the ground and walking merely upon the digits (DIGITIGRADE); while in antelopes, horses, and hoofed runners in general, the chief limb bones themselves are lengthened, subsidiary ones are suppressed, and the wrist and ankle are raised still further from the ground, so that merely the tips of one or two digits of each limb support the animal (UNGULIGRADE). Thus the typical cursorial forms represent the culmination of mammalian adaptation to plains and steppes, regions where long distances must frequently be traversed in quest of food, and safety is to the swift. (Fig. 294.)

Another line of adaptive radiation is presented by the tree dwellers—ARBOREAL forms which inhabit the world of foliage high above the ground. Such are the sloths, which are really tree climbers that walk and sleep upside down suspended from branches; the tailless apes that swing among the boughs chiefly by their arms; and the squirrels that scamper along the branches. Some squirrels and the so-called flying lemurs take long soaring leaps, during which they are supported by wide folds of skin between the sides of the body

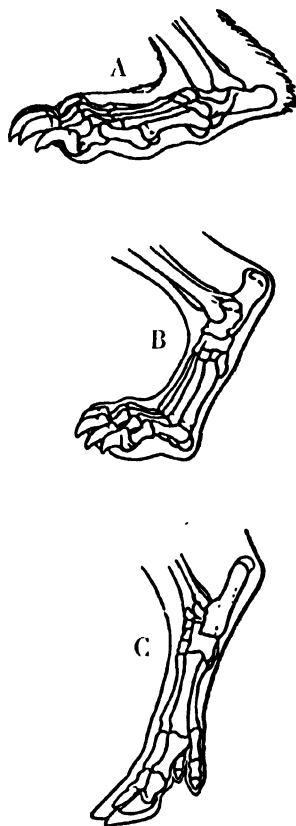


FIG. 294. Foot postures of mammals. A, plantigrade; B, digitigrade; C, unguligrade. (From Lull.)

and the extended limbs. The mammals have not left even the air untenanted, for truly VOLANT forms are represented by the bats, in which the forelimbs with greatly elongated fingers form the framework of true wings. (Fig. 295.)

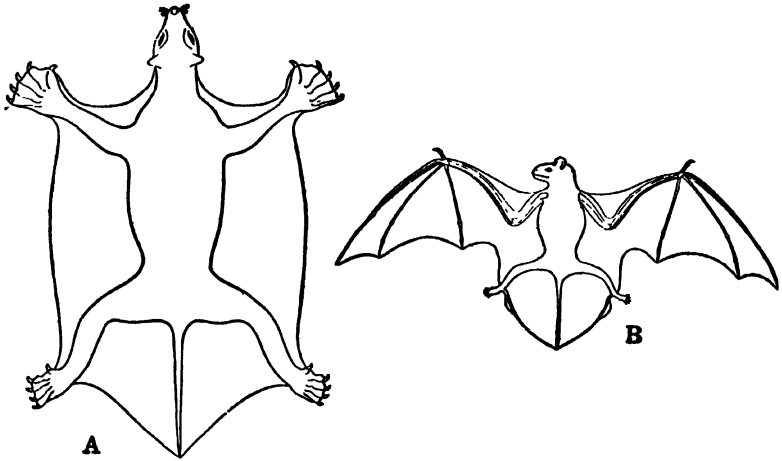


FIG. 295. A, flying lemur, *Galeopithecus volans*; B, bat, *Vespertilio noctula*. (From Lull.)

Below the surface of the earth, FOSSORIAL mammals are found, such as the woodchucks, gophers, and especially the moles, which are adapted to a subterranean existence by bodily modifications that facilitate digging. Furthermore, the gap between terrestrial and aquatic mammals is bridged by the muskrats, beavers, otters, and seals, forms which are more or less equally at home on land and in the water. (Fig. 296.)

The truly AQUATIC mammals, such as the porpoises and whales, have completely abandoned the land of their ancestors of the geo-

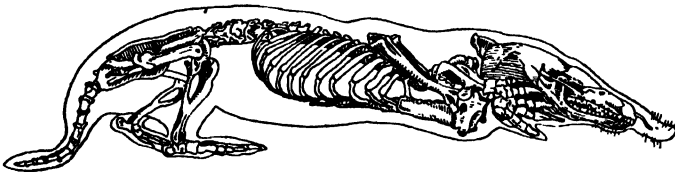


FIG. 296. Skeleton of a mole, *Talpa europaea*. (From Pander and D'Alton. Redrawn.)

logical past and today approach, in adaptations to a marine life, the general contour of the primitively adapted aquatic vertebrates, the fishes. (Figs. 297, 470, 471.)

Thus the various lines of adaptive radiation of the placental mammals from a generalized terrestrial type, such as *Gymnura*, have provided forms fitted for all sorts and conditions of the environment; representatives are competing with members of other groups beneath, on, and above the earth, and in the water.

Every organism is in a state of equilibrium with its environment; it is adjusted to meet the demands made upon it, with the greatest pos-

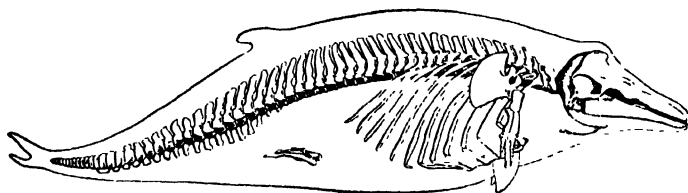


FIG. 297. Skeleton of a porpoise. The vestigial pelvic bones are shown embedded in the flesh. (From Pander and D'Alton.)

sible efficiency that its heredity allows. A disturbance of this equilibrium, resulting from changes in habits or environment, must result in readjustments to meet the new conditions, if the organism is to survive. One more example, this time from the marsupial mammals, will serve to emphasize such problems in adaptation. (pp. 600-601.)

"When we unravel the entire history of the tree kangaroos, we find that they have gone through an amazing series of changes of habits. Their original ancestors, like all primitive mammals, no doubt were structurally adapted to walking on the ground. Then they took to living in trees, and their feet adjusted themselves to grasping branches. Then they descended to the ground again, and their grasping feet were readjusted to walking. In the course of time these walking animals developed into leaping animals like the true kangaroos, and their feet became extremely highly specialized structures. When these leaping animals finally took to living in trees once again their feet had become so highly specialized for leaping that they could no longer readjust themselves into grasping organs, and so the existing tree kangaroos climb by bracing their feet against the trunk of a tree, as bears do. Most of the steps in this series of transformations are represented by

existing marsupials that have gone no farther than one or another of the stages in the series." (Fig. 298.)

Somewhat similar problems in adaptation are, of course, exhibited throughout the living world, especially among the insects, though there seems no doubt that the adaptability of the mammalian stock—its

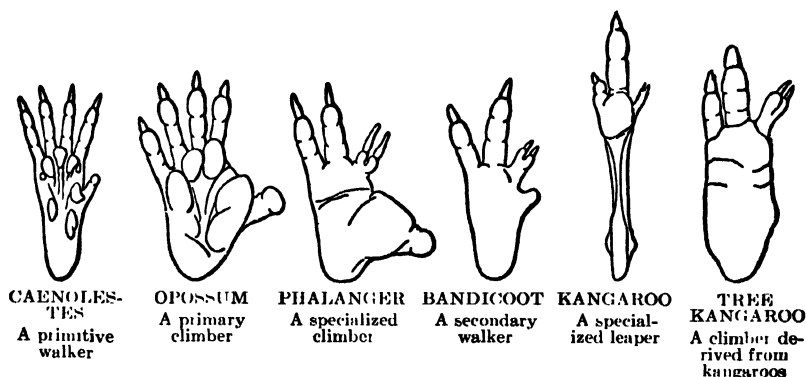


FIG. 298. Hind feet of a series of marsupial mammals, showing the history of the feet of the tree kangaroo, *Dendrolagus*. (From Davis.)

potential of evolution—is in no small degree responsible for the dominant position which the mammals hold in the world today. (Fig. 299.)

The Appendages of the Honeybee. From time immemorial the honeybee (*Apis mellifera*) has been the subject of wonder and study; we know the price of strained honey in the time of the Pharaohs! And today there is no more interesting example of adaptation than that

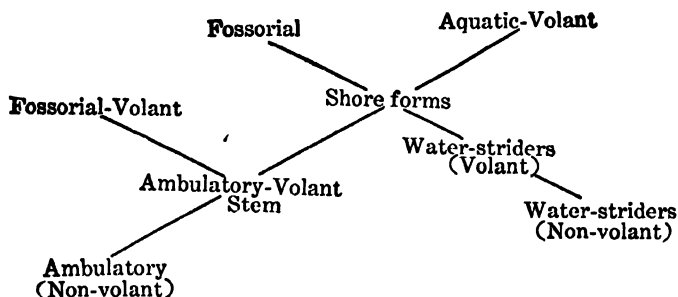


FIG. 299. Diagram of the adaptive radiation of a group of insects, the Hemiptera, or bugs. (From Lindsey.)

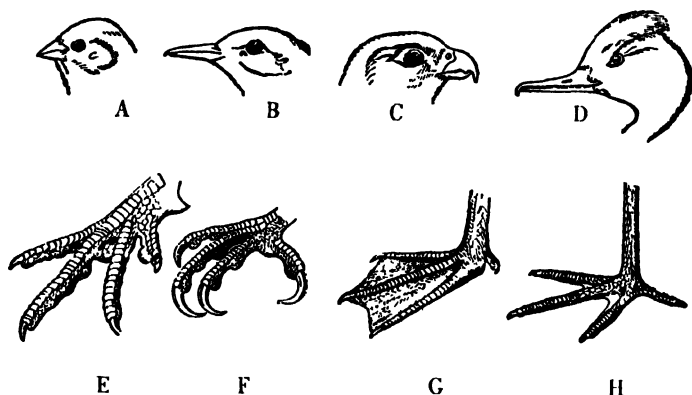


FIG. 300. Representative adaptations of the bills and feet of birds. A, seed-eating (sparrow); B, insect-eating (thrush); C, tearing (falcon); D, fish-catching (merganser); E, scratching (pheasant); F, grasping (falcon); G, swimming (duck); H, wading (heron). (After Sedgwick. Redrawn.)

exhibited by bees in relation to the specialized community life of the hive. (Fig. 301.)

An average hive comprises some sixty-five thousand bees of which one is a QUEEN, several hundred are DRONES, and the rest WORKERS. The queen is the only fertile female and accordingly she is the mother of nearly all the other members of the hive. Throughout her life of a few years she is tended and fed by her numerous offspring. The drones, or males, contribute nothing to the work of the hive but, after the old queen departs at the SWARMING, one of them during the nuptial flight mates with a virgin queen which then becomes the new queen



FIG. 301. The honeybee, *Apis mellifera*: worker (left), queen (center), drone (right). (From U. S. Bureau of Entomology. Redrawn.)

of the hive. Thus the queen and the drones represent an adaptation of the colony to communal life—a physiological division of labor which involves a specialization of members solely for reproduction, while the daily work and strife of the colony devolves upon the workers. The workers are sexually undeveloped females which do not lay eggs but spend their time carrying water, collecting nectar and pollen, secreting

wax, building the comb, preparing food, tending the young, and cleaning, airing, and defending the hive.

The worker is a “bundle of adaptations” for its varied duties. The primitive insect appendages have become specialized in the worker bee so that collectively they constitute a battery of tools adapted with great nicety to the uses for which they are employed. This applies to all the appendages of the insect’s body, but we shall neglect those of the head and consider only the specializations of the three pairs of legs. These, as in all insects, arise from the THORAX: the anterior pair from the first segment of the thorax (prothorax), the second, or middle, pair from the second thoracic segment (mesothorax), and the posterior pair from the third, or last, thoracic segment (metathorax). A typical insect

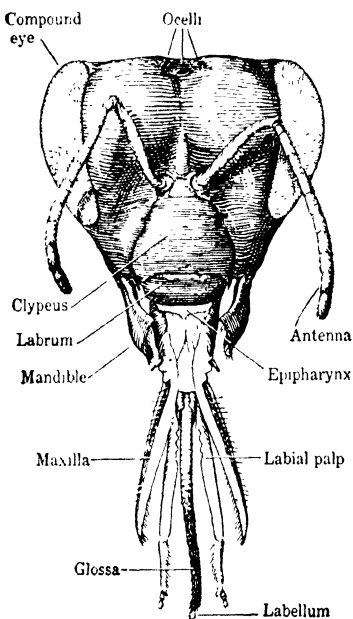


FIG. 302. Head of a worker honeybee.

leg consists of several parts: the COXA, which forms the junction with the body, followed in order by the TROCHANTER, FEMUR, TIBIA, and five-jointed TARSUS, or foot. (Figs. 302, 303.)

The worker bee’s PROTHORACIC LEGS show the following specializations. The femur and tibia are covered with long, branched FEATHERY HAIRS which aid in gathering pollen when the bee visits flowers. The tibia, near its junction with the tarsus, bears a group of stiff bristles (POLLEN BRUSH) which is used to brush together the pollen grains that have been dislodged by the hairs of the upper leg segments. On the opposite side of the leg is a composite structure, the ANTENNA CLEANER, formed by a movable platelike process (VELUM) of the

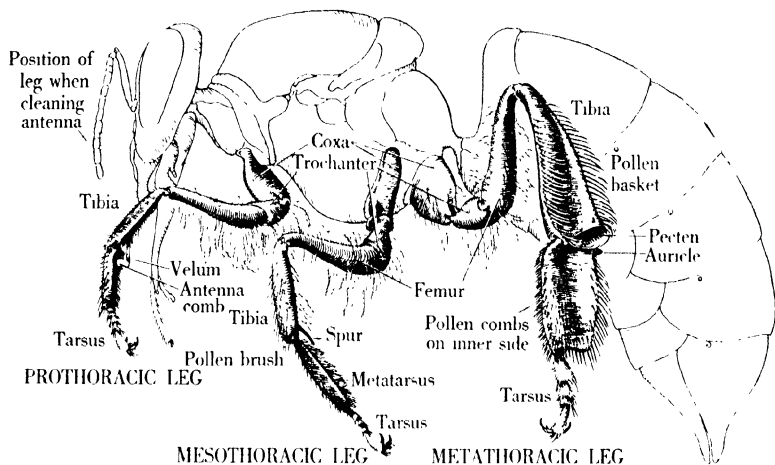


FIG. 303. Legs of the worker honeybee attached to the thorax.

tibia which fits over a circular notch in the upper end of the tarsus. The notch is provided with a series of bristles that form the teeth of the ANTENNA COMB. The ANTENNAE, or feelers, which are important sense organs of the head, are cleaned by being placed in the toothed notch and, after the velum is closed down, drawn between the bristles and the edge of the velum. On the first segment of the tarsus is a series of bristles, or EYE BRUSH, which is used to remove pollen and other particles adhering to the hairs on the head about the large compound eyes and interfering with their operation.

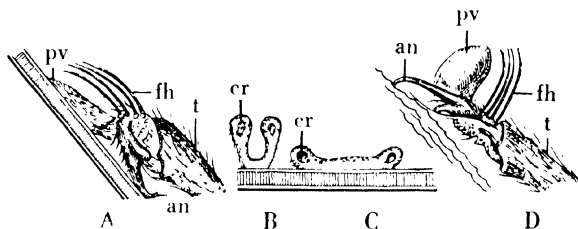


FIG. 304. Foot of the honeybee in the act of climbing, showing the automatic action of the pulvillus. A, position of foot on a slippery surface; B, section of a pulvillus just touching a flat surface; C, the same applied to the surface; D, position of foot in climbing on a rough surface; an, claw; cr, curved rod; fh, tactile hairs; pv, pulvillus; t, last segment of tarsus. (From: Packard, after Cheshire. Redrawn.)

The terminal segment of the tarsus of each leg is provided with a pair of notched **CLAWS**, a sticky pad (**PULVILLUS**), and a group of **TACTILE HAIRS**. When the bee is walking up a rough surface, the points of the claws catch and the pulvillus does not touch, but when the surface is smooth, so that the claws do not grip, they are drawn beneath the foot. This change of position applies the pulvillus, which clings to the smooth surface. Thus the character of the surface automatically determines whether claw or pulvillus shall be used. There is another adaptation equally remarkable. "The pulvillus is carried folded in the middle, but opens out when applied to a surface; for it has at its upper part an elastic and curved rod which straightens as the pulvillus is pressed down. The flattened-out pulvillus thus holds strongly while pulled along the surface by the weight of the bee, but comes up at once if lifted and rolled off from its opposite sides, just as we should pull a wet postage stamp from an envelope. The bee, then, is held securely till it attempts to lift the leg, when it is freed at once; and, by this exquisite yet simple plan, it can fix and release each foot at least twenty times per second." (Fig. 304.)

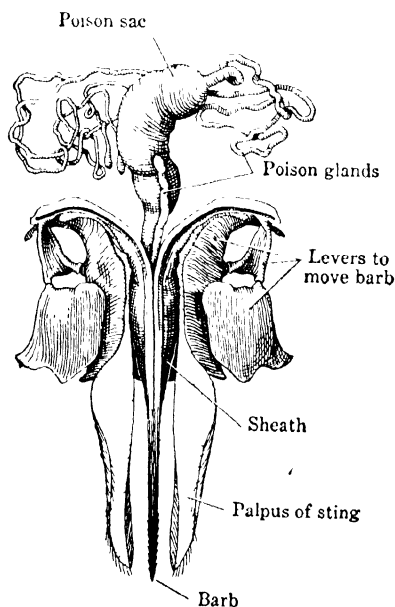


FIG. 305. Sting and associated structures of a worker honeybee.

The characteristic structures of the middle (**MESOTHORACIC**) legs of the bee are a small **POLLEN BRUSH** and a long spine, or **POLLEN SPUR**.

The **METATHORACIC** LEGS exhibit four remarkable adaptations to the needs of the insect, known as the **POLLEN COMBS**, **PECTEN**, **AURICLE**, and **POLLEN BASKET**. The pollen combs comprise a series of rows of bristlelike hairs on the inner surface of the first segment of the tarsus: the pecten is a series of spines on the distal end of the tibia which is opposed by a concavity, the auricle, on the proximal end of the tarsal segment; while the pollen basket is formed by a depression on the outer surface of the tibia which is

arched over by rows of long curved bristles arising from its edges.

Thus the worker is fully equipped. Flying from flower to flower, the bee brushes against the anthers laden with pollen, some of which adheres to the hairs on its body and legs. While the bee is still in the field, the pollen combs are first brought into play to comb the pollen from the hairs, while the pectens scrape the pollen from the combs.

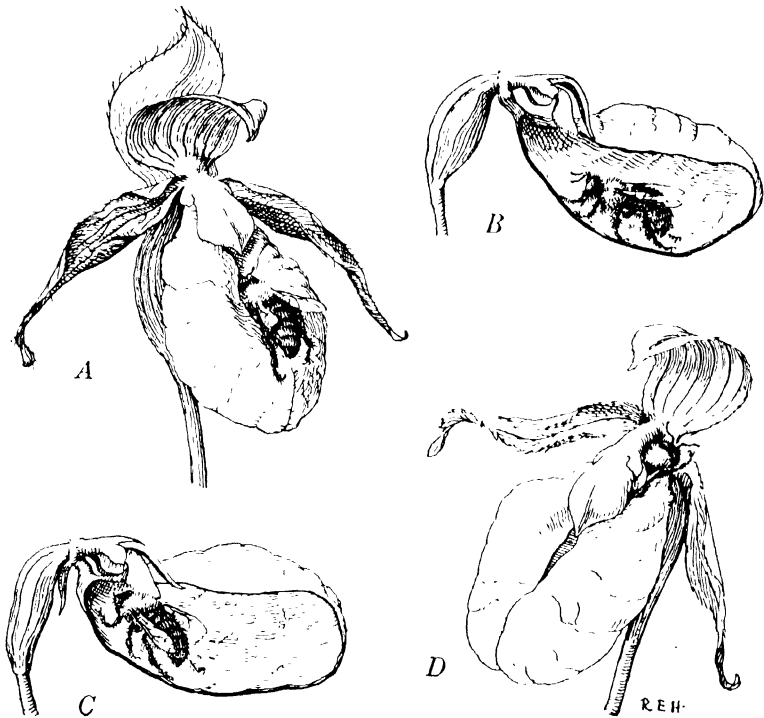


FIG. 306. Pollination of an orchid, a lady's slipper (*Cypripedium*), by a bumble bee. *A*, bee forcing its way into the flower; *B*, bee obtaining nectar in the flower; *C*, bee starting to escape brushes pollen upon the stigma of the flower; *D*, before finally escaping the bee receives another load of pollen from the anther.

Then the auricles are manipulated so that the accumulating mass of pollen is pushed up into the bristle-covered pollen baskets. This process is repeated until the baskets are full; then the insect returns to the hive where the contents of the pollen baskets are removed by the aid of the spurs with which the mesothoracic legs are provided. (Figs. 305, 306.)

The structural adaptations of the worker bee are but one aspect of a reciprocal fitness. Many of the flowers which the bee visits show remarkable adaptations for the reception of the bee and for dusting it with pollen, because bees are effective agents in transferring pollen from flower to flower and thus ensuring cross-fertilization. And so the bee, which has been given as our final example of adaptation to the physical environment, serves also as an introduction to the consideration of adaptation to the living environment. No better proof could be asked of the futility of attempting to classify the adaptations of organisms. The organism is a unit, a complex of adaptations to any and all of its surroundings, inanimate and animate; otherwise it could not exist.

CHAPTER XXVII

Organic Adaptation (II)

ADAPTATIONS TO THE LIVING ENVIRONMENT

Consideration may now be given more specifically to some striking interrelations of organism with organism, in order to make possible an appreciation of the devious means to which living creatures have recourse—to what extent the strands of the web of life become entangled—in the competition for a livelihood.

The interdependence of organisms in the biotic environment is, in the final analysis, the result of the primary demands of all creatures: proper food, habitat, reproduction, defense against enemies and the

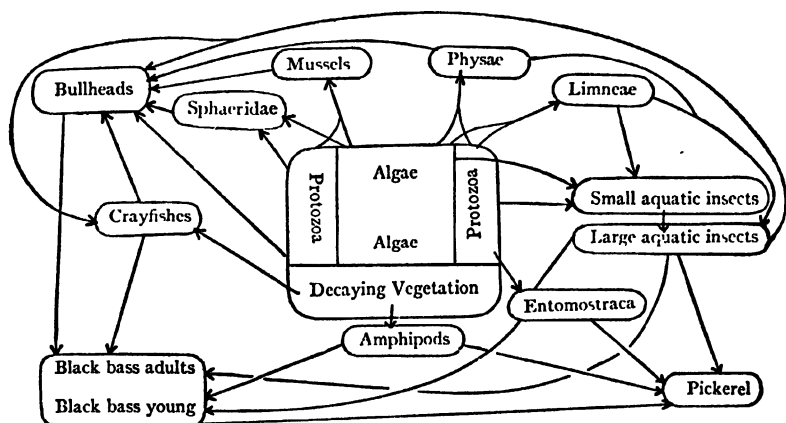


FIG. 307. Diagram of the web of life and the equilibrium of nature, as illustrated by the food relations in a pond community. Arrows point from the organisms eaten to those doing the eating. The task of the ecologist is to decipher the patterns of the web of life. (From Shelford.)

forces of nature. The web of life is an expression of the cooperation, jostling, and strife of individual with individual, and species with species, for these primary needs; and the activities which follow from these relationships form the foundations of life in the lowest as well as the highest. A little patch of meadow soil two feet square has revealed, within an inch below the surface, over a thousand minute animals and three thousand plants. There is a struggle for existence. (Figs. 307, 308. 337.)

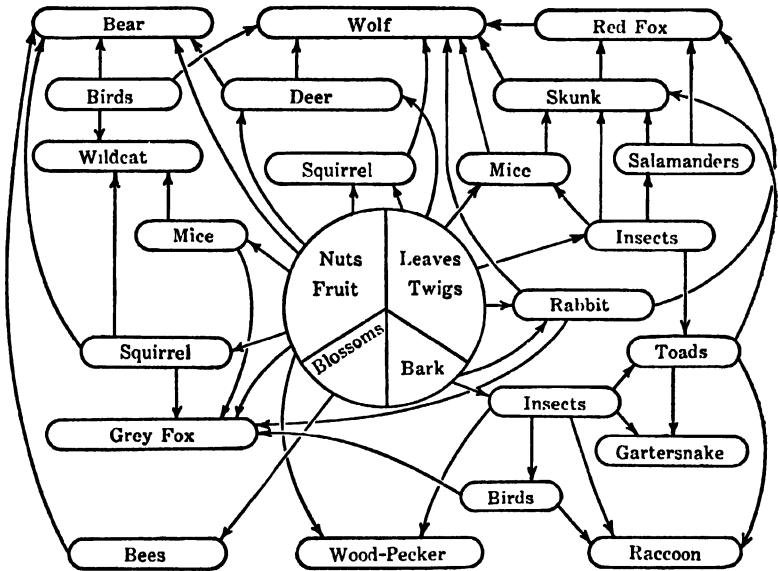


FIG. 308. Diagram to show equilibrium in food relations in a forest community. Arrows point from plant or animal eaten to animal which eats it. (From Shelford.)

The struggle for existence among higher types may be shown by a further example. A common food fish, the squeteague, captures butterfish or squids, which in turn have fed on young fish, which in their turn have fed on small crustacea, which themselves have utilized microscopic algae and protozoa as food. It is evident that the food of the squeteague is actually a complex of all these factors, and such a *nutritional chain* is no stronger than its single links. Circumstances that modify or suppress the food and thereby reduce the abundance of the algae and protozoa of the sea are reflected in correlative changes

in the abundance of economically important food fishes. And this same principle is true throughout living nature, though only occasionally is it possible to trace it. Nature is a vast assemblage of food linkages.

PLANT ASSOCIATIONS

Easily recognizable associations of different species of plants occur as a result of adaptation to similar environmental conditions, inorganic and organic, and so the plants become to some extent mutually dependent upon each other (Fig. 309.) One of the most important

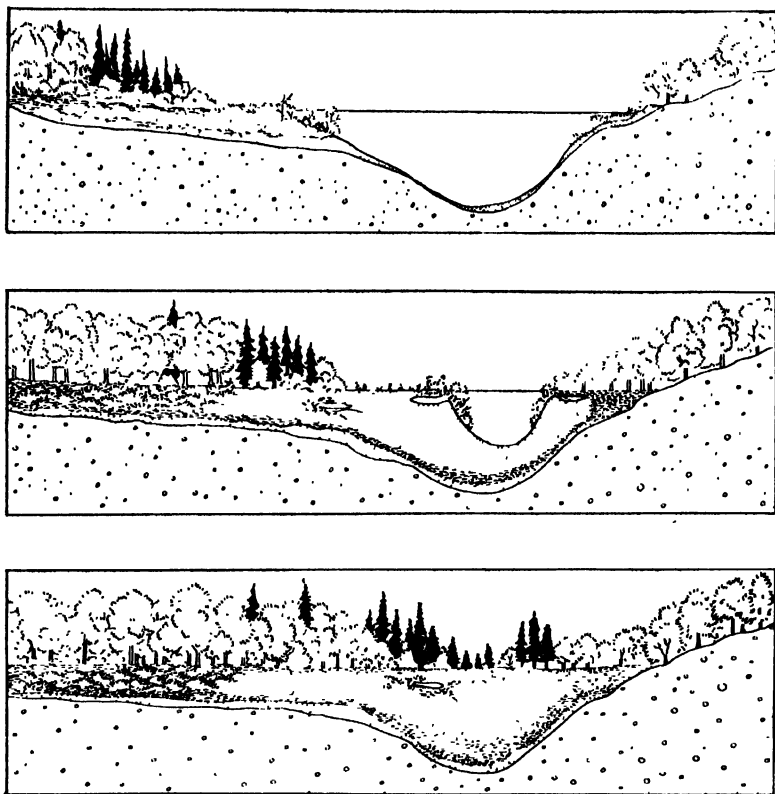


FIG. 309. Plant succession. Drawings show three stages in the filling of a lake with a deposit of peat which is finally covered by forest. Stages in the succession as shown are aquatic plants, bog plants, shrubs, coniferous forest, and deciduous forest, the last type being the climax vegetation. (From Geological Survey of Ohio, after Dachnowski. Redrawn.)

factors in determining plant communities is the available water supply. Thus various species show inherited adaptations to greater or less moisture: characteristics that lead to their designation as **HYDROPHYTES** or plants that live partly or completely submerged, **MESOPHYTES** or the great majority that require a moderate supply of water, and **XEROPHYTES** or drought-enduring species.

A plant community of sea beach or swamp, forest or desert, and so on, may comprise plants that are very different in size, structure, and kind, though each includes certain species or groups of species that are characteristic and give communities their names, such as sedge-cattail swamp association or beech-maple forest association. (pp. 523-526.)

Although all plant communities appear static, most of them slowly but surely change. Thus they may extend their range until all the available suitable environment has been taken over; and in doing this their very presence brings about other changes—they may encroach upon the domains of other plant communities. All this and more results in a **SUCCESSION** of plants or plant communities as time goes on, until stability is reached by the appearance of species that are practically permanent for the particular region: the definite **CLIMAX ASSOCIATION**. Obviously the innumerable adaptations involved in such communities form an important aspect of plant **ECOLOGY**. (Fig. 309.)

COMMUNAL ASSOCIATIONS

Perhaps the simplest associations of animals are represented by **GREGARIOUS** species, such as wolves which hunt in packs, and buffaloes and horses which roam in herds for protection. The association is more or less temporary and there is no division of labor between the members, other than leadership by one member of the group.

COMMUNAL animals, however, exhibit highly complex associations in which the members merge their individuality, as it were, in that of the community, a larger organization than the family. This relationship is well exhibited among the bees, ants, wasps, and termites, where structural differentiations have given rise to classes of individuals especially adapted for the performance of certain functions in the economy of the community. Thus, through the cooperation of specialists, nests and shelters are made more adequate, enemies are more readily repulsed, food can be cultivated as in colonies of fungus-growing species,

reproduction can be more adequately adjusted to the population needs, and hostile environments can more readily be invaded. Insects and man have accomplished these feats through societal systems, and the fundamental forces which have guided social evolution in these species have some similarity.

However, the differentiations of various members of a colony of insects are limited to their bodies and are practically fixed and irreversible, while in human society, differentiations are no longer confined to the bodies of individuals. Man's ingenuity has devised what are to all intents and purposes artificial, accessory organs: tools and machines. Accordingly it is here that we find the highest expression of communal cooperation, or societal life, because increased intelligence, in particular, makes flexible the stereotyped life as exhibited in the lower forms; the human individual is adaptable to the various tasks of community living. (pp. 628-630.)



FIG. 310. Rose aphids visited by ants.

SYMBIOSIS

Associations of different species are by no means always an expression of cooperative adaptations. All gradations occur from those which are mutually beneficial to the parties in the pact. to those in which one member secures all the advantage at the expense of the other.

A simple type of association in which both members profit is represented by the relation that occurs between ants and plant lice, or aphids. The defenseless aphids are protected, herded, and "milked" by the ants to supply their demand for honeydew, a secretion of the aphids which the ants greedily devour. (Fig. 310.)

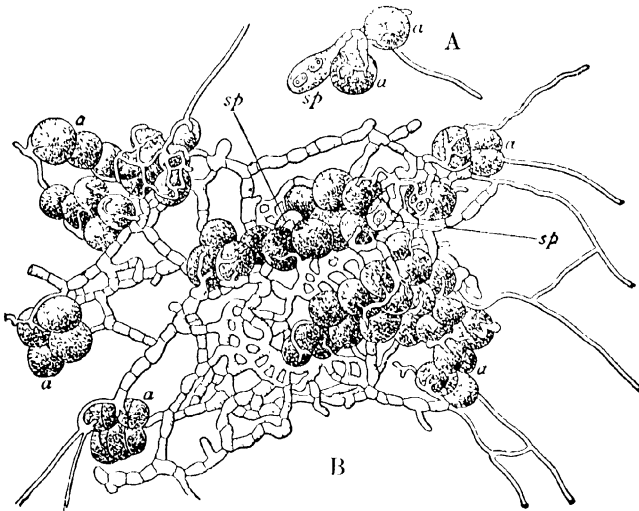


FIG. 311. The formation and structure of a lichen, *Physcia paratina*. The lichens are a combination of an alga and a fungus. A, germination of a fungus spore (*sp*), whose filaments are surrounding two cells (*a*) of the unicellular alga, *Cystococcus humicola*. B, later stage in which spores have formed a web of filaments (mycelium) enveloping many algal cells. Highly magnified. See Fig. 359. (From Bonnier.)

The most intimate associations in which the organisms involved are mutually benefited, if not absolutely necessary for each other's existence, are termed SYMBIOTIC. A familiar case is the common green hydra (*Chlorohydra viridissima*), which owes its color to the presence of a large number of unicellular green plants that live in its endoderm cells. The products of the photosynthetic activity of the plant cells are

at the disposal of the hydra, and the hydra in return affords a favorable abode and the materials necessary for the life of the plants. An essentially similar type of relationship exists between herbivorous animals, such as cattle, and certain bacteria that dwell in the alimentary canal and digest the cellulose, which is thus made available for the animals.

Another common example of symbiosis is afforded by the lichens which represent intimate combinations of various species of colorless plants (fungi) and simple green plants (algae). In each case the fungus supplies attachment, protection, and the raw materials of food, while the alga performs photosynthesis. Each can live independently under favorable conditions, but in partnership they are superior to hardships with which many other plants cannot cope, and thus some lichens become the vanguard of vegetation in repopulating rocky, devastated areas. (Fig. 311.)

From the practical standpoint of agriculture the symbiotic nitrogen-fixing bacteria are of first importance. It will be recalled that these bacteria form small nodules on the roots of higher plants and make atmospheric nitrogen available to the latter. Again, there are symbiotic relationships between the mycelial filaments of various species of fungi and the roots of higher plants. The filaments, or MYCORRHIZA, surround the roots, enter the outer region of the root tissue, and apparently facilitate the intake of materials through the roots by acting essentially as accessory root hairs. Indeed, there is a wide range of similar symbiotic relations. For instance, certain seeds are unable to germinate without an association with a fungus. Moreover, in some cases, the associations merge into parasitism. (Figs. 21, 22, 312.)

Finally, it is often difficult to distinguish between symbiosis and relationships such as exist when two species are so associated that one profits without the other either profiting or suffering. An instance of such COMMENSALISM is shown by certain tiny crabs that share an oyster's shell, without apparently inconveniencing the oyster, while partaking of the host's food and enjoying protection. The ancient

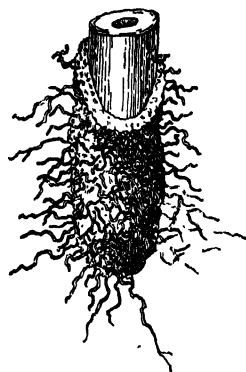


FIG. 312. Root tip of a beech coated with a growth of mycelial filaments, or mycorrhiza. (After Pfeffer. Redrawn.)

Egyptians depicted this relationship in their hieroglyphics to symbolize the dependence of man on his friends.

PARASITISM

Most numerous are associations in which one organism, the **PARASITE**, secures the sole advantage at the expense of the almost helpless associate, the **HOST**. It has been estimated that at least half the animal kingdom are parasites, and these justly receive considerable notoriety because many human diseases are the result of man's unwilling part in such associations. In fact, **PARASITOLOGY** has become an important subdivision of biology, both practical and theoretical: practical, as a cornerstone of public health; and theoretical, because many of the most remarkable functional and structural adaptations are exhibited

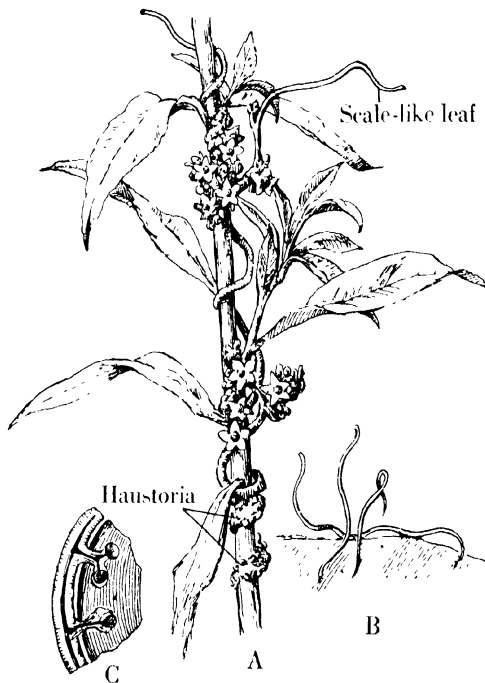


FIG. 313. Dodder, a parasitic seed plant, entwined about A the stem of its host, a golden rod. C, part of a transverse section of stem of host to show penetration by Dodder roots (haustoria); B, several dodder seedlings growing in the soil before attachment to a host. (After Strasburger. Redrawn.)

by parasites in fitting themselves for this apparently highly successful method of gaining a livelihood, and by the hosts in bearing the burden at least cost. Generally speaking, the effect on the parasite consists in a simplification of the various organs of the body devoted to food getting, locomotion, etc., since these duties are performed by the host; while the organs and methods of reproduction are highly specialized and elaborated, owing to the necessity of producing enough offspring to compensate for the hazards involved in reaching a proper host. For in the majority of cases a parasite is adapted to live in a specific host, and death ensues if this residence is not attained at the proper time. (Figs. 313, 322, 396.)

Probably the most generally interesting example of parasitism is the cause of the disease known as MALARIA. Man is subject to at least three types of malaria, each the result of infection by a different malarial organism. The malarial parasites are all unicellular animals, protozoa,

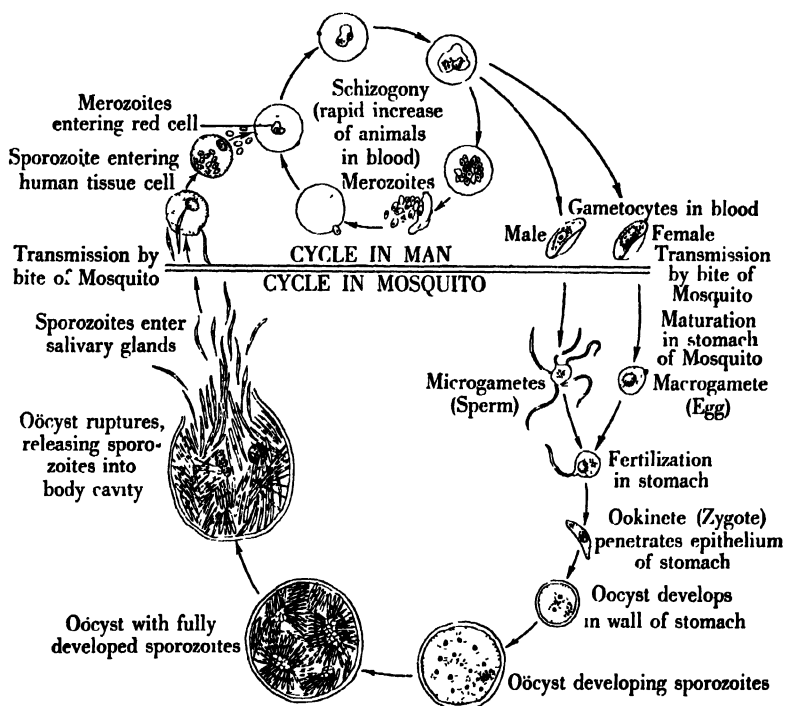


FIG. 314. Life history of a malarial parasite, *Plasmodium malariae*.

with complicated life histories which are adaptations to the specific demands of their parasitic existence. One part of the life history, the asexual, is passed in the cells of the human body; the other, the sexual, occurs in cells of the digestive tract of certain species of mosquitoes. (Fig. 314.) The parasites inoculated into the human vascular system by the bite of an infected mosquito invade various tissues of the body where they multiply in the cells. From here the progeny reach the blood stream and enter red blood cells and again reproduce. The progeny, liberated from the destroyed cells, similarly attack other cells and multiply, repeating the process until an immense number of blood cells are parasitized. Poisonous products of the life processes of the parasites provoke the chills and fever characteristic of the disease, when perhaps a hundred million red blood cells are destroyed at one time. (Fig. 315.)

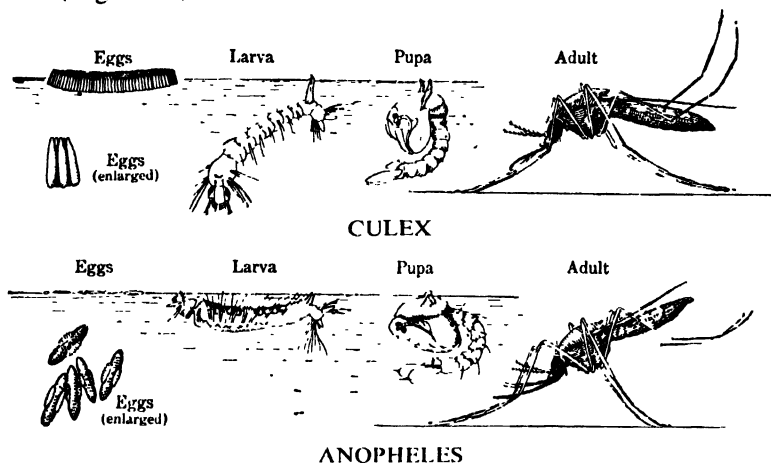


FIG. 315. Mosquito life histories. Mosquitoes of the genus *Anopheles* (below), which transmit the malaria parasite, differ from the common *Culex* (above), in every stage, as shown in the drawings. Note also that the adult *Culex* when at rest holds its body parallel to the surface, whereas *Anopheles* holds it nearly perpendicular.

However, the parasites must make their escape before the human host successfully combats the toxic substances, kills the parasites by taking quinine, quinacrine (atabrine), or other drugs, or succumbs. Some trillions of malarial parasites perish when the human host dies. The escape is accomplished, if at all, by a mosquito's biting the host and taking with the blood certain sexual stages of the parasite which

can develop in the cold-blooded insect. Certainly not more than one out of untold millions of mosquitoes bites an infected person. But this hazard overcome, the mosquito is the host. In its stomach the sexual phase of the life history of the malarial parasite takes place, fertilization occurs, and finally the numerous products of the zygote work their way to the mouth parts of the insect where they await an opportunity for transfer to the human blood.

The life history of malarial parasites exhibits a continuous series of adaptations to parasitic life, the nicety of the adjustment being especially well illustrated at the transfer from man to mosquito, since all the parasites which enter the stomach of the insect are digested except those sexual forms which are ready to initiate the sexual part of the cycle in the insect host. (pp. 439-441.)

The climax of parasitic associations is attained when the adaptations of parasite and host have become so complete that the latter "pays the price" without ill effects. Serious disturbance or death of the host is usually disadvantageous to the parasite, so during the course of evolution those parasites which "do not trifle with their luck, but live in harmony with their host succeed in the struggle for existence, and those which bite the hand that feeds them are doomed to destruction." Thus the antelopes and similar mammals in certain regions of Africa harbor in their blood various species of protozoan parasites, known as *TRYPANOSOMES*, without any apparent discomfort. But if the intermediate hosts, which are tsetse flies, transfer certain species of trypanosomes to the blood of imported horses or cattle, or of man, serious diseases result which are usually fatal. (Fig. 316.) Indeed, the opening up of large regions of Africa has been greatly retarded by the ravages of trypanosomes in new hosts to which they are not adapted. Generally speaking, pathogenic species may be regarded as aberrant forms which are not yet adapted to their hosts or are not in their normal hosts. These are the parasites which are especially forced upon our attention, though there are no organisms without their specially adapted parasites—the parasites themselves not excepted. Thus a frog may harbor in its rectum a ciliated protozoon, *Opalina*, whose cytoplasm is infested by an *Endamoeba* which, in turn, is invaded by the spores of a fungus, *Sphaerita*. And a parasite of *Sphaerita* is known. Verily, "big fleas have little fleas"—a relationship technically called *HYPER-PARASITISM*.

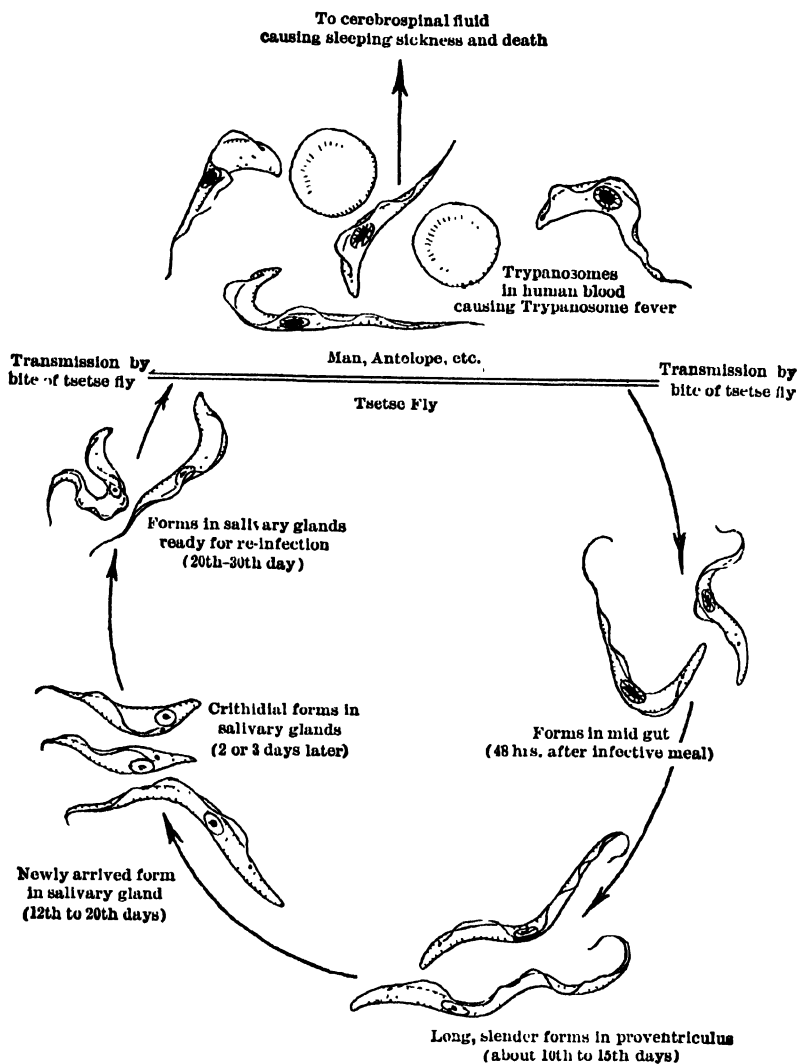


FIG. 316. Life history of the Trypanosome, *Trypanosoma gambiense*, that produces African sleeping sickness in man. Magnified about 1500 times. (Modified, after Chandler.)

IMMUNITY

At best the position of the host cannot be regarded as ideal, and devious types of protection against parasites exist which, in so far as they are effective, bring about IMMUNITY. Usually among the higher animals, including man, immunity to the ravages of pathogenic micro-organisms seems to depend chiefly upon the activities of the white blood cells and upon specific chemical substances in the blood, termed ANTIBODIES.

The white blood cells have been called the policemen of the body because, under the influence of invading organisms, some of the cells make their way through the walls of the capillaries in the region of the infection and, in amoeboid fashion, engulf and digest the intruders. When acting in this capacity the white cells are termed PHAGOCYTES. Cells specialized for phagocytosis are also found as integral elements of various parts of the body, such as the lymph nodes, spleen, and bone marrow. They are strategically located to remove bacteria and other harmful invaders from the blood stream.

The antibodies may be classified, in general, according to their method of action. Thus the ANTITOXINS neutralize the poisonous products (toxins) of certain bacteria, the PRECIPITINS precipitate foreign proteins of bacterial or other origin, the AGGLUTININS clump bacteria, the LYSINS actually destroy foreign cells, and the OPSONINS in some way render bacteria vulnerable to phagocytic action.

The antibodies are produced in response to ANTIGENS, usually specific proteins, from the parasites themselves. Thus the individual may acquire immunity by undergoing the disease, either in its usual form, or in a mild form by the artificial inoculation of a weakened strain of virus, dead bacteria, or their toxins, as in VACCINATION. In any case a defense mechanism is established in the body of the host, so that it is prepared to produce the specific antibodies in the event of a later infection. In certain cases, such as diphtheria, temporary immunity may be afforded by the inoculation of the antibodies themselves, instead of the antigens.

Indeed, the subject of immunity has become a science in itself (IMMUNOLOGY)—a science which has as its fundamental basis the investigation of the marvelous power of adaptation of protoplasm as exemplified in coping with disease-producing parasites, and even with those ultramicroscopic agents of disease, the viruses, such as produce

yellow fever, smallpox, measles, poliomyelitis, and influenza. Some of the viruses consist of a single protein molecule; nevertheless, they have the power to multiply when in the protoplasm of host cells and so exhibit one fundamental characteristic of life. Their further study is certain to be of immense practical and theoretical importance. (pp. 482-483.)

INDIVIDUAL ADAPTABILITY

We may now turn to a survey of possibly the highest expression of adaptation evolved by nature: temporary functional adaptive responses which appear as TROPISMS and other elements of BEHAVIOR in the lower organisms, gain definiteness and content in the higher animal series, and become the basis of INTELLIGENCE and all that the human mental life involves. It is the adaptation which renders man essentially superior to adaptation—enables him to a large extent to control his environment, instead of being controlled by it. “It seems that nature, after elaborating mechanisms to meet particular vicissitudes, has lumped all other vicissitudes into one and made a means of meeting them all” through the nervous mechanism.

That organisms respond to environmental changes, we are well aware. Life itself is the result of—in fact, is—a continuous flow of physicochemical actions, interactions, and reactions with the surroundings. “That which above all else characterizes organisms is organization and the regulations and correlations, both internal and external, which condition their wholeness and their capacity to survive in the struggle for existence through appropriate behavior.” By behavior is meant specifically the reactions of the organism as a unit, rather than the internal processes in the economy of its life. Surveyed from a broad point of view, there is discernible in the behavior of animals, just as in their structure in general and in their nervous system in particular, from the lowest to the highest, a great though gradual increase in complexity. The behavior of amoeba and *Paramecium* is an expression of the primary attributes of protoplasm: irritability, conductivity, and contractility. So is the behavior of hydra and earthworm in which special cells constitute a definite coordinating or nervous system. And so is the complex behavior of the higher animals, including man, with their elaborate series of sense organs and highly developed sensorium, the brain.

“Let us now try to form a picture of the behavior of *Paramecium*

in its daily life under natural conditions. An individual is swimming freely in a pool, parallel with the surface and some distance below it. No other stimulus acting, it begins to respond to the changes in distribution of its internal contents due to the fact that it is not in line with gravity. It tries various new positions until its anterior end is directed upward, and continues in that direction. It thus reaches the surface film. To this it responds by the avoiding reaction (Figs. 10, 58), finding a new position and swimming along near the surface of the water. . . . Swimming forward here, it approaches a region where the sun has been shining strongly into the pool, heating the water. The Paramecium receives some of this heated water in the current passing from the anterior end down the oral groove. (Fig. 59.) Thereupon it pauses, swings its anterior end about in a circle, and finding that the water coming from one of the directions thus tried is not heated, it proceeds forward in that direction. This course leads it perhaps into the region of a fresh plant stem which has lately been crushed and has fallen into the water. The plant juice, oozing out, alters markedly the chemical constitution of the water. The Paramecium soon receives some of this altered water in its ciliary current. Again it pauses, or if the chemical is strong, swims backward a distance. Then it again swings the anterior end around in a circle till it finds a direction from which it receives no more of this chemical; in this direction it swims forward. . . .

“In this way the daily life of the animal continues. It constantly feels its way about, trying in a systematic way all sorts of conditions, and retiring from those that are harmful. Its behavior is in principle much like that of a blind and deaf person, or one that feels his way about in the dark. It is a continual process of proving all things and holding to that which is good.” (Jennings.)

The behavior of Paramecium leaves one with the impression that the animal is largely at the mercy of its surroundings—that the environment rather than the organism itself is the dominant factor, and this is true to a considerable degree. But Paramecium is not merely an automaton. Its behavior is modifiable and, in the long run, is adapted to the usual changes of its surroundings. It forms immense aggregations where food and other conditions are favorable. That the reactions are adequate for the simple life and methods of reproduction of Paramecium is attested by its success. It is one of the most common and widely distributed animals.

In such simple MOTOR RESPONSES and TROPISMS, which result from DIFFERENTIAL SENSITIVITY or the power of responding differently to different stimuli, must be sought the largely automatic responses of animals, such as the REFLEXES, the INSTINCTS or chains of reflexes, and ORGANIC MEMORY or the retention of the effects of previous stimuli. All reactions are chiefly the result of inherited nervous structure and therefore may be regarded as inherited behavior. Increase in the complexity of life processes has involved an increase in the number and complexity of reflexes and instincts. The primitive reflexes and instincts lead hydra to seize small organisms within reach of its tentacles and pass them to its mouth, the earthworm to swallow decaying leaves as it burrows through the soil, the crayfish to grasp its prey with its large claws, tear it into pieces by means of certain appendages about the mouth which are adapted just for the purpose—and so on to the higher vertebrates where the feeding instincts reach their maximum of complexity. The remarkable behavior of ants and bees is essentially a complex of instincts. Moreover, instincts of fear, self-defense, play, care of the young, etc., render a considerable part of the behavior of even the higher organisms more automatic than is immediately apparent. (Figs. 143, 148.)

Just as the behavior of Paramecium and its allies is modifiable, so reflexes and instincts which seem the most fixed show at least a slight degree of adaptability to unusual conditions. Indeed new reflexes, known as **CONDITIONED REFLEXES**, may be established as the result of experience during the life of the individual. It is this ever-present power of modifiability, which man calls "choice," that leavens the whole and becomes the dominant factor in the behavior of the highest animals, while reflex action and instinct are relegated to a subsidiary though by no means unimportant role. A large part of human education consists in establishing other fixed adaptive responses called habits, which join the earlier reflexes and instincts in relieving the conscious life of innumerable simple factors of behavior, and leave it more or less free for the higher intellectual processes. The cerebrum, regarded as the organ of the mind, is superimposed upon the system of automatic, machinelike responses of the reflex centers. It is the executive that reacts to the state of affairs as a whole and coordinates or alters behavior when the routine responses are inadequate. The progress of modifiability toward conscious choice responses to external conditions constitutes a gradual and ill-defined transition from instincts

to ASSOCIATIVE MEMORY, or newly conditioned responses, to learning and the highest intellectual processes. (pp. 283-284.)

Mind and intelligence, in the biological sense, are expressions for that integration of nervous states and actions which makes possible an otherwise impossible nicety of adaptation of behavior to environmental conditions, and this integration is in fact the chief means of adaptation. Nevertheless, it is a serious mistake to minimize the importance of the vast gulf between human nature and that of the most highly developed lower animals. In no respect are these differences more marked than in the various forms of learning which collectively form the means of education. While associative memory, or conditioning, will account for the various non-instinctive actions of man's animal associates, human racial history and the individual's experience contain much which baffles explanation in such terms. Indeed, in the highest reaches of consciousness we recognize that it is able to form strange conceptions; that it has not only memory of the past, but also anticipation of the future. We can brood and meditate and understand in part. We are guided by the past, present, and future in making adaptations. "The largest fact in the story of evolution is the growing dominance of the mental aspect of life."

It is clear that, with all the variations in structure and function, organisms all possess in common the character of irritability; all exhibit adaptive responses which enable them to exist in spite of surrounding changes. "Adaptability appears to be the touchstone with which Nature has tested each kind of organism evolved; it has been the yard-stick with which she has measured each animal type; it has been the counterweight against which she has balanced each of her productions. However well adapted to a specific environment a type might be, did it lack ever so little of its possibilities in this direction it was sooner or later relegated to the scrap heap. Some forms, to be sure, persisted in special environments where they were protected from competition, or where the conditions were fairly constant, but the general course of evolution has been always in the direction of increasing adaptability or increasing perfection of irritability." And now at the summit is man, consciously trying to carry on what nature has been unconsciously attempting these millions of years—trying to secure mastery of his environment. The individual's heritage is, in fact, the cumulative result of the adaptations of the race, including adaptability.

CHAPTER XXVIII

Biology and Human Welfare (I)

Man is part of a web of life which he continues to fashion, and the success of his weaving depends upon his understanding.

—Thomas

Now that a general survey has been made of the foundations of biology, it is important to emphasize some of the outstanding contributions of biology to human welfare—contributions made, for the most part, within a century, but already so interwoven with our everyday life that they have become indispensable.

Indeed, some of the great biological generalizations have in daily affairs profound practical significance, a fact which is easily overlooked: for example, the cellular structure of all living things, implying the existence of a fundamental similarity in organization throughout the living world; again, the basically similar life stuff, protoplasm, demonstrating that all living nature is united by a common bond of cellular organization and also of a protoplasmic basis to which all life phenomena are referable; still again, the transformation by protoplasm of nonliving material into living material, proving that living matter is ordinary matter uniquely organized; finally, organic evolution which teaches that all nature is one.

These and other great biological truths have a far-reaching import to everyone, because collectively they unmistakably lead to the comprehensive conclusion that human life must be interpreted in terms of all life. Man must conform to the general order of living nature of which he is an integral and dominant part. Remove one of the essentials of life and man perishes like the beasts. But he differs in the capacity to understand and to take advantage of circumstances. Human welfare, therefore, demands that man “control” nature by consciously adapting himself to it. Indeed, the chief purpose of education is the adaptation of the individual and the promotion of adaptability:

adjustment to the basic internal and external conditions of life, without a loss of plasticity. It is evident that biology affords the natural foundation of the science and art of right living which human welfare demands.

MEDICINE

Health, the adaptation supreme, is a priceless possession whether it be estimated from the standpoint of the well-being of the individual or in terms of national wealth. Accordingly, medicine, in the broadest sense of the word, is without doubt the most important aspect of applied biology. Human anatomy and physiology, on which the foundations of medicine rest, are special parts of the biological sciences dealing with the anatomy and physiology of all organisms. In fact the interpretation of human anatomy is impossible except in the light of the comparative anatomy of vertebrates, while human physiology owes its present state of development to the fundamental principles derived from experimentation on the lower animals. Moreover, further advance is chiefly dependent upon similar investigations on animals which have been rendered insensible to pain by anesthetics. To mention one example: experimental surgery practiced on animals has demonstrated the possibility of innumerable operations which no conscientious surgeon would have ventured to perform for the first time on man. In the words of Darwin, who gave up the sport of hunting because of his great sympathy with the suffering of animals: "Physiology can make no progress if experiments on living animals are suppressed, and I have an intimate conviction that to retard the progress of physiology is to commit a crime against humanity."

MICROORGANISMS AND DISEASE

No one will deny that discoveries in preventive and curative medicine rank among the most important contributions of scientific research to civilization, and nearly all these discoveries have their foundation in studies by generations of biologists. Though Pasteur's first investigations were in chemistry, his subsequent work, which pointed out the way for preventing and eradicating diseases due to microorganisms, followed naturally from his discovery that the souring of wine and milk is the result of the activities of organisms from the air which induce chemical changes. Injure the skin of a grape, and organisms from the atmosphere enter and fermentation begins. Exclude air

or sterilize it, and fermentation is prevented. Lister immediately saw the importance of this for surgery, and modern aseptic surgery—one of the greatest blessings of mankind—was born. (Figs. 347, 498.)

Proceeding on the theory that, since fermentation is the result of the activities of microorganisms, certain diseases of plants and animals are likewise caused by the invasion of the body by similar germs, Pasteur turned to the study of cholera in French fowls and to anthrax in sheep and cattle. The treatment he employed so greatly reduced the death rate of the animals that it is estimated to have saved the French nation in twenty years not less than the amount of the war indemnity of 1871. Then Pasteur devised the treatment that is now universally employed for rabies, a virus disease which man contracts by infection from the bite of a mad dog.

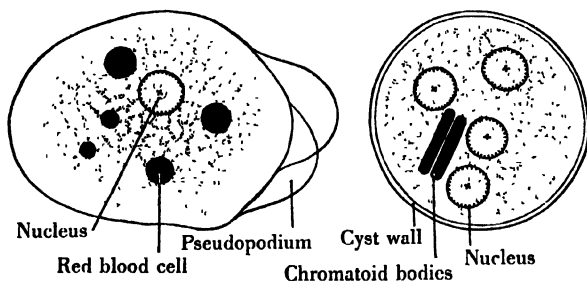


FIG. 317. *Endamoeba histolytica*, a parasitic amoeba of the human intestine, which gives rise to amoebic dysentery. At the left, an active amoeba showing nucleus and three ingested human red blood cells; at the right an encysted amoeba with four nuclei, preparatory to division into four individuals. It is estimated that nearly ten per cent of the people of the United States are infected, most of them being carriers who show no symptoms. But a single carrier in one day may discharge some 300,000,000 cysts to menace community health. (From Hegner.)

During the past half century a host of investigators, following the lead of Pasteur, have secured undreamed-of results in discovering preventive measures and curative treatments for a long series of diseases of man, domestic animals, and plants. One thinks immediately of diphtheria, tuberculosis, bubonic plague, typhoid fever, pneumonia, malaria, syphilis, amoebic dysentery, and African sleeping sickness—all the results of the infection of man by microorganisms. It is hard to realize that as recently as 1884, Koch, probably the greatest successor of Pasteur, proved that tuberculosis is caused by a specific type of bacteria, and thereby revolutionized the treatment of this disease

which has been estimated to cause about one-seventh of all the deaths in the world each year. (Figs. 316, 317.)

Only second in importance to the prevention of human diseases due to microorganisms, is the suppression of diseases of domestic animals. For example, the Chief of the Bureau of Animal Industry estimates that the bacteria which produce infectious abortion in cattle are responsible for an animal loss of approximately fifty million dollars each year in the United States. Moreover, the study of this disease is proving of increasing significance from the recognition that undulant fever in man is caused by a member of the same group of bacteria—an excellent instance of how knowledge leads to further knowledge.

The way in which interlocking data from several biological fields are frequently necessary to determine the causative agent of a disease can, perhaps, be best illustrated by a brief outline of the development of our knowledge of malaria, yellow fever, and syphilis.

Malaria. From ancient times malaria, as the name indicates, was supposed to be due to foul air, especially from swampy regions, but the first step toward the correct explanation was made in 1880 when Laveran found specific microscopic parasites always present in the blood of malarial patients. Nearly two decades later Ross demonstrated similar parasites in the body of a mosquito, and then a long series of studies by various investigators, among whom Grassi stands foremost, showed that when a female mosquito of the genus *Anopheles* bites a malarial patient, it secures with the blood some of the parasites such as Laveran had discovered, and thereupon the mosquito becomes the host of the malarial organism. Within the mosquito, the parasite undergoes a complicated series of changes, including rapid reproduction. This finally results in myriads of parasites located in the salivary glands of the insect, ready to be injected into the blood of the next individual bitten and to begin the other phase of its life history in man. (Figs. 314, 315.)

So stated, it appears simple enough, but years of study by specialists on insects (ENTOMOLOGISTS), by specialists on protozoa (PROTOZOOLOGISTS), and by physicians highly trained in general medical zoology were responsible for clearing the way to eradicate a disease which, it is estimated, each year costs the United States not less than one hundred million dollars and the British Empire three times that amount. In India alone it is responsible for a death list of about two million people annually while some one hundred million suffer from the mal-

ady. In the United States deaths from malaria have decreased more than 60 per cent since the turn of the century, but the disease is still a serious problem. However, present conditions in the Canal Zone and the Pontine Marshes of central Italy, for instance, show what adequate measures of eradication will accomplish. (Fig. 318.)

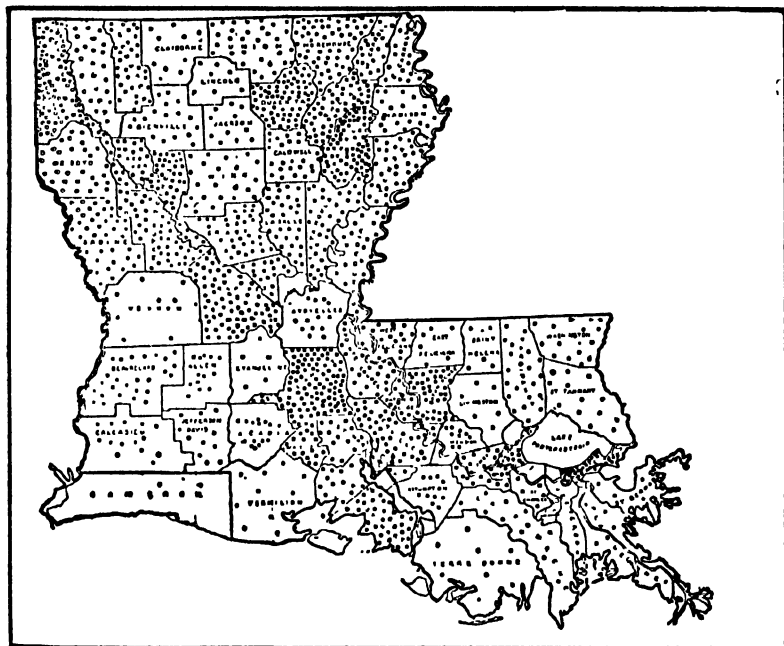


FIG. 318. Map used in an earlier anti-malaria campaign in Louisiana. Each dot represents a death from malaria. The public health importance of malaria, however, is more accurately measured by the sickness rate and the loss of efficiency than by the loss of life. It has been estimated that for each death 2000 to 4000 days of sickness must be included in the total burden of loss and suffering. There has been a steady decline of malaria in the United States in recent years, and it now appears that the disease will soon be of relatively minor importance in this country. One of the major factors in this favorable situation has been the control of the insect vector, the anopheline mosquito. (La. State Board of Health.)

It must be emphasized that the difficulties in controlling malaria, as well as many other diseases due to parasites, are being greatly increased by modern means of rapid transportation. Apparently a fast mail-carrying French destroyer was responsible in 1930 for the introduction of *Anopheles gambiae* into Brazil from equatorial Africa. In

the new environment the gambiae-carried malaria worked havoc, with the human mortality in certain districts estimated at 10 per cent. Thanks to the heroic efforts of biologists from the Rockefeller Foundation this serious invasion was repulsed by 1940. However, in spite of all precautions, a few gambiae have since been found on airplanes reaching Brazil, so as long as this species holds its grip on a vast region in Africa, east and south of Dakar, danger threatens the New World. (Fig. 319.)

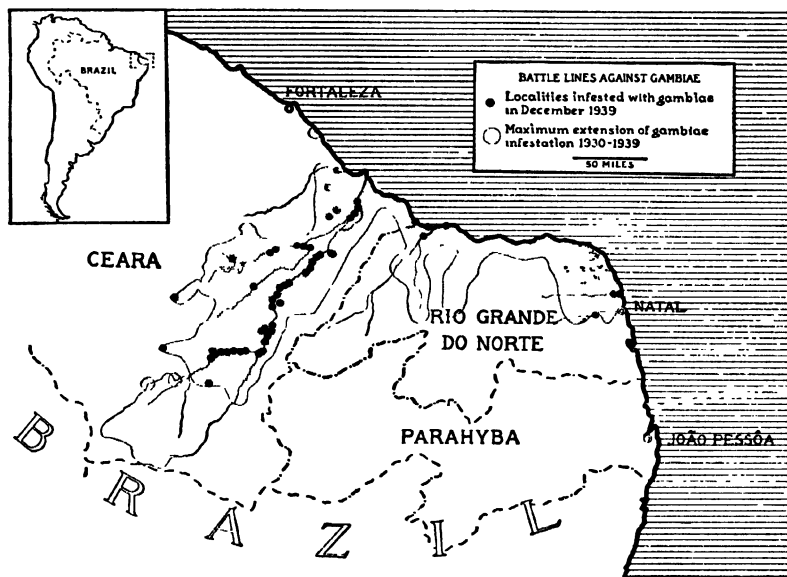


FIG. 319. The invasion of Brazil by *Anopheles gambiae*. (From the Rockefeller Foundation.)

Another serious aspect of the problem is the fact that apparently complete recovery of an individual from a disease such as malaria and amoebic dysentery, as well as from some diseases resulting from parasitic worms, does not necessarily mean that the human host is not a "carrier," that is, one who harbors the parasites in his body, perhaps for many years, without showing clinical symptoms but who still is a source of infection. Herein lies one of the dangers that may be introduced by our armed forces returning from infected regions.

Yellow Fever. Proof that malaria is due to a protozoon which can be transmitted to man only by members of a certain genus of mos-

quitoes, was largely the work of English, French, and Italian biologists; but the demonstration that another kind of mosquito, *Aedes aegypti*, is responsible for the transmission of the parasite which causes yellow fever is due to Reed, Lazear, and other members of the United States Yellow Fever Commission working in Cuba in 1900. This discovery was followed by an intensive campaign with the result that Havana was rendered free from yellow fever in just eighty days—for the first time in 400 years. Furthermore, the Panama Canal became possible; the earlier attempt by France was unsuccessful largely on account of yellow fever.

Now we even have to be reminded that half a million cases of yellow fever occurred in the United States during the past century; the epidemic of 1793 took a total of one-tenth of the population of Philadelphia, and that of 1878 killed more than thirteen thousand in the Mississippi Valley alone. Although it is now several years since aegypti-borne yellow fever has been definitely recorded in America, the discovery in the jungles of South America and Africa of so-called jungle yellow fever, involving other species of mosquitoes as vectors and other vertebrate hosts than man as reservoirs, has made the problem much more complex and the complete control of the fever less certain than it appeared to be a few years ago. It is important to note, however, that an effective yellow fever vaccine has recently been developed. During the past decade many millions of persons have been inoculated, and our troops in World War II, battling in regions where yellow fever is present, were protected from the disease.

Syphilis. The brilliant investigations of the protozoologist Schaudinn, in collaboration with Hoffmann, in 1905 revealed the unicellular parasite, *Treponema pallidum*, as the cause of syphilis—one of the greatest scourges of mankind since it became widespread during the sixteenth century. The ravages of the parasite produce many symptoms, frequently a type of general paralysis with a gradual loss of the mental faculties and eventual death. The discovery of the parasite made possible intensive studies of measures to combat it. These investigations resulted in the discovery of certain organic arsenic compounds of great specific value, but recently the antibiotic, penicillin, derived from a mold of the genus *Penicillium*, has proved far more effective and has revolutionized the treatment of the disease. While syphilis, of course, is not inherited, it may result from the infection of infants before or at the time of birth. (Fig. 320.)

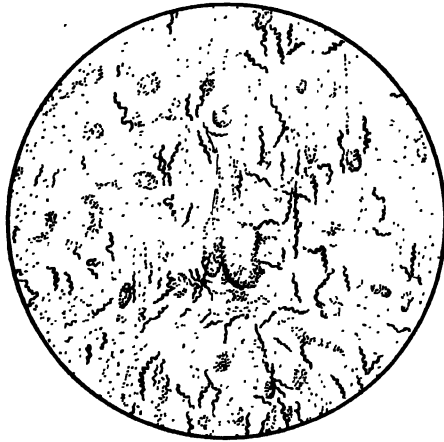


FIG. 320. *Treponema pallidum* seen as spiral bodies in liver tissue from a child with congenital syphilis. Highly magnified.

PARASITIC WORMS

Thus far consideration has been given to the causative agents of disease which are popularly called microbes, and we now turn from this "world of the infinitely little" to somewhat larger organisms which form a most important part of medical zoology. This field may be illustrated by the various kinds of parasitic worms.

Trematodes. There are many parasitic flatworms, related to the free-living Planaria, that comprise the group TREMATODA. Parasitic species usually exhibit complicated life histories whose unravelling taxed the patience and ingenuity of biologists. Among the numerous species, the liver fluke is perhaps of most interest. (Figs. 163, 321.)

The adult liver fluke is a worm about an inch long which lives in the bile ducts of the liver of sheep, cattle, pigs, etc., and occasionally of man. It is hermaphroditic, and in its isolated position is almost continually producing fertilized eggs. In fact, one fluke may liberate over five hundred thousand eggs which pass down the bile ducts of the host (sheep) into the intestine and finally leave the body with the feces. An egg that happens to reach moisture develops into a ciliated larva, or MIRACIDIUM, which escapes from the eggshell and swims actively. For further development to occur the larva must encounter within a few hours a certain species of fresh-water snail, otherwise death results. Once it has bored into a snail's body, the parasite re-

ceives a new lease of life involving a series of changes. After about two weeks it has become a saclike creature, or **SPOROCYST**, which in turn proceeds to develop within itself a brood of another larval stage, the **REDIA**. Each redia liberated from a ruptured sporocyst usually gives rise to one or more generations of rediae, and the final generation of these produces a third kind of larva, known as a **CERCARIA**. (Fig. 321.)

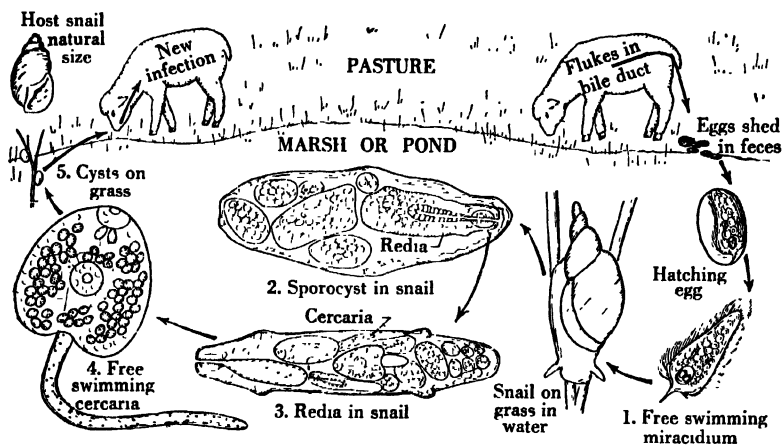


FIG. 321. Diagrammatic drawings to illustrate the life cycle, in two hosts (sheep and snail) of the liver fluke, *Fasciola hepatica*. The larval stages of the parasite about $\times 75$. (From Storer, after Thomas.)

All these stages arise in the snail's body, but now the swarm of cercariae emerges from the snail, and each swims about in the water and finally encysts on a blade of grass. Here again the life of the parasite hangs in the balance, for death follows unless the grass with the cyst is eaten by a sheep and the cyst reaches the animal's intestine. This location successfully attained, the cercaria escapes from the cyst, and makes its way to the bile ducts where it soon develops into a mature fluke, the cause of liver rot in sheep. The life history is completed.

The large number of eggs produced by a single fluke increases the chances of a ciliated larva meeting the essential species of snail, while the various generations within the snail multiply manifold the number of cercariae from a single egg, and just to that extent increase the opportunities for at least one to reach another sheep. This life history, while remarkable, is by no means unique, and is presented as a type which is broadly representative of a large group of parasitic flatworms. No

wonder that years of study are required by specialists in different branches of zoology to discover the various stages of the different species and determine their relationships.

Cestodes. The group of flatworms known as the CESTODA comprises the numerous species of tapeworms which infest the lower animals and man. The best-known species are *Taenia solium* and *Taenia saginata*, both living as adults in the human digestive tract, while the larvae of the former infest pigs, and those of the latter, cattle. (p. 549.)

Taenia is a long ribbonlike worm comprising a small knoblike head, or SCOLEX, which is an organ for attachment to the lining of the human digestive tract, and a large number of similar segments, or PROGLOTTIDS. These are formed by growth just behind the scolex so that the oldest and largest proglottids are at the posterior end of the animal. (Fig. 322.)

The adult tapeworm is hermaphroditic and each of the older pro-

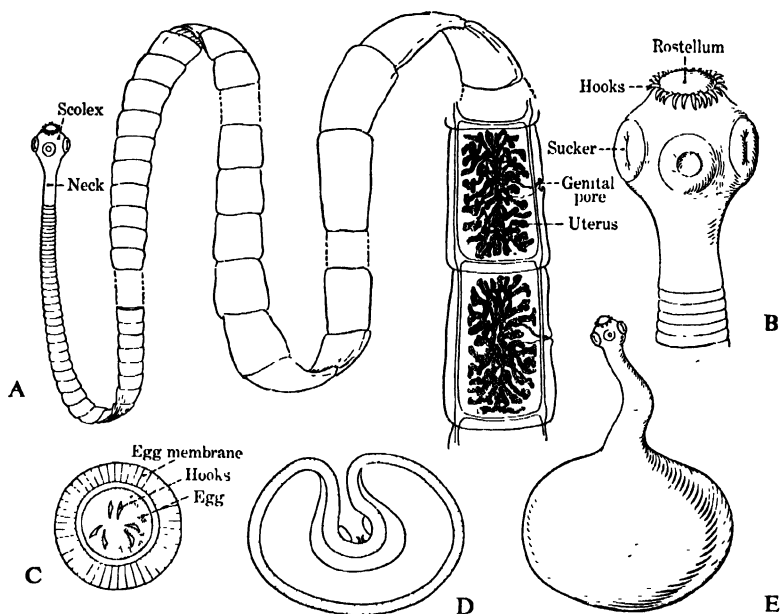


FIG. 322. Tapeworm, *Taenia solium*. A, anterior and posterior parts of a specimen about 8 feet long containing some 900 proglottids. Uteri filled with eggs are shown in the last two proglottids. B, Scolex more highly magnified. C, egg with embryo. D, Bladder worm (cysticercus) before head (scolex) is protruded. E, same after protrusion. (From Hegner.)

glottids contains both male and female reproductive organs, while the terminal mature ones are almost completely filled with eggs which have already developed into embryos. One by one the ripe proglottids become detached from the worm and pass from the host with the feces. For development to proceed further an embryo must be swallowed by a pig, whereupon it bores through the walls of the animal's intestine, passes to the voluntary muscles and there encysts. In this position it develops into the **BLADDER WORM**, or **CYSTICERCUS**, stage. To complete the life history, infected meat, insufficiently cooked, must be eaten by man. If this transfer is successfully accomplished, upon attaining the human digestive tract the parasite gradually assumes the adult form, the scolex becomes attached, and a series of proglottids begins to develop.

Another common tapeworm, *Dipylidium caninum*, occurs in dogs and cats and their wild relatives all over the world. In a few cases it has been found in children. The intermediate hosts are fleas and lice.

Since tapeworms, which live as adults in man and the higher animals, secure their food by absorbing that of their host, they may seriously interfere with nutrition, but larval stages are even more dangerous. Thus, the larvae of a tapeworm (*Echinococcus*), which lives as an adult in the intestine of the dog and other carnivora, produce in the brain, liver, etc., of man, pig, and sheep large vesicles, or **HYDATIDS**, usually with fatal results. Such larvae in the brains of sheep were a stumbling block for the early exponents of biogenesis, since, with the life history unknown, biologists could not account for the larvae except by the theory of spontaneous generation.

Nematodes. Passing now to the **NEMATODA**, or roundworms, we come to a group which, from the standpoint of medical zoology, is of as much importance as the flatworms. Free-living forms are found literally everywhere in water, soil, and air, and blown about by the wind. Most nematodes are harmless, but some are of great economic interest because of their injury to the roots and other parts of plants. Thus the destructive "spring dwarf" disease of the cultivated strawberry results from the activities of a microscopic nematode; sometimes there may be ten thousand in an infected bud. Among the nematodes parasitic in man and the higher animals, *Trichinella* and the hookworm will serve as examples. (Figs. 411, 412.)

TRICHINELLA is the cause of a serious disease in man, pigs, and rats, known as **TRICHINOSIS**. Man becomes parasitized by eating in-

fectured pork, insufficiently cooked, and pigs contract the disease by eating waste pork products in garbage or infected rats. The larvae from the meat quickly mature in the wall of the human intestine, and each female worm produces nearly ten thousand larvae. These pass by the lymphatics and blood vessels to all parts of the body, localize in the voluntary muscles, and there encyst to await a possible getaway from the body at death. Since thousands of cysts, which retain viability for several years, may occur in a single gram of muscle, the riddling of the tissues is not only very serious, but may be fatal. (Fig. 323.)

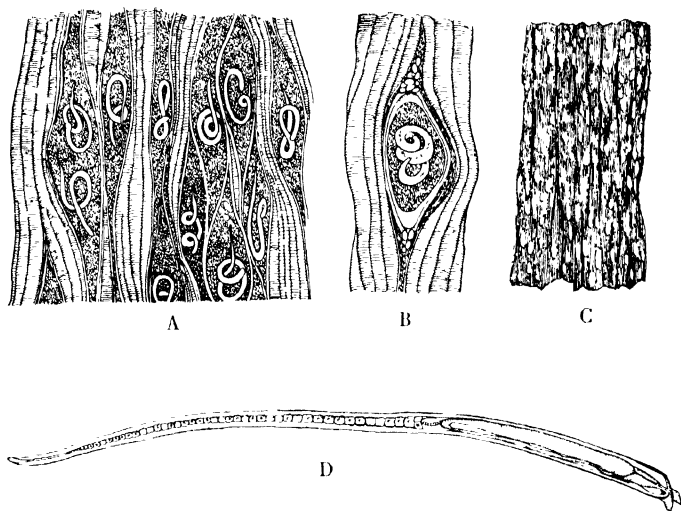


FIG. 323. *Trichinella spiralis*. A, numerous active larvae in muscle tissue; B, a single inactive larva encysted among fibers; C, piece of pork containing many encysted worms, natural size; D, adult worm, magnified. (From Leuckart.)

The widespread distribution of the several species of HOOKWORMS and their insidious effects make them also of great practical importance. The tiny worms, just visible to the naked eye as whitish threads, are hatched in a warm moist soil, make their way through the skin of the human foot, enter the circulatory system, are carried to the lungs, and finally work to the intestine. Here, as adults, they become attached, feed upon the blood of their host and liberate eggs. These pass out with the host's feces to become the source of infection for others. The spread of knowledge of the essential facts and of vermifuges to expel the parasites has been an important contribution of the Inter-

national Health Board which has carried on a campaign in over fifty countries. It has been estimated that not less than two million persons in the United States are afflicted with the disease, but the recently acquired facts in regard to the control of the parasite should result eventually in its almost complete eradication. (Fig. 324.)



FIG. 324. American hookworm, *Necator americanus*. The circular mouth, left, is equipped with "teeth" for attachment to intestinal wall. Enlarged about 8 times.

HEALTH AND WEALTH

It has been aptly said that health and wealth are essentially synonymous, and this is amply shown by the fact that medical progress is reputed to have added at least twenty years to the average human life span during the past century—mainly years of the highest efficiency from the age of thirty-five to fifty-five years. It is conservative to say that the increase in longevity has effected a saving of more money than has ever been expended in support of every kind of scientific investigation, and this without taking into account the economic value of the lives or the immensely greater factor of human happiness which follows from healthful and unbroken family life.

The same can also be said for the leading role which medical zoology has played in rendering vast regions of the tropics relatively safe for human habitation: regions which must offer an outlet for the rapidly increasing human population. Statistics make it clear that the population of the world has more than doubled during the last century; what it will do during the next century, experts in vital statistics are actively computing. Better nutritive and health conditions, following World War II, have already brought marked increases in birth rates in overpopulated areas. This much is certain: it is merely a matter of time before regions now untenanted by civilized man must be encroached upon more and more, not only for food and other materials but also for a place of abode; and the first step necessary to make this possible is the survey of the innumerable biological competitors in the form of parasites, etc., which man must encounter in adjusting himself to this environment, as will be amply corroborated by many of our armed forces.

Again, knowledge is power: the best investment from the standpoint

of health and wealth is in support of research. It is easy to forget that studies on the life history of microorganisms, fleas, rats, and the rest have made impossible today such epidemics as have many times in the past swept over the world. During the Christian era more people have succumbed to the plague than constitute the total population of the earth today. It is easy to forget that the biological forces of disease are costing the United States nearly four billion dollars annually, a loss largely preventable by an efficient dissemination of knowledge and an efficient application of biological principles already well established. Civilizations in the past have succumbed to the onslaughts of pestilences, and the hope of our immensely more complex community life depends upon the development of knowledge of these living agents of disease.

CHAPTER XXIX

Biology and Human Welfare (II)

BIOLOGY AND AGRICULTURE

It is true that man cannot live by bread alone, but it is equally true that the fundamental urge of all living things to secure food and to multiply is, in the final analysis, at the basis of human endeavor. Modern agriculture represents the body of knowledge gradually accumulated by mankind to meet the increasingly exacting food demands as community life became more and more complex. Some appreciation of this relationship has already been gained from the discussion of economically important plants. But it should be emphasized that agriculture is dependent upon many fundamental biological sciences, as, indeed, is the cognate science of OCEANOGRAPHY which includes the study of our great marine resources that still remain relatively undeveloped. A few examples will bring the most significant points before us. (Fig. 325.)

PLANT AND ANIMAL FOOD

To restate the basic fact, all animals, including man, are entirely dependent for their food upon the photosynthetic activities of plants. Green plants must manufacture enough food for themselves, and to spare for the rest of the living world as well. Animals must have ready-made food which, after they have used it, is useless both for animals and for green plants. Here, it will be recalled, the bacteria and other colorless plants come in and make possible the completion of the biological cycle of the elements in nature by putting the materials in such a condition that they are again available to green plants. (Figs. 20-22.)

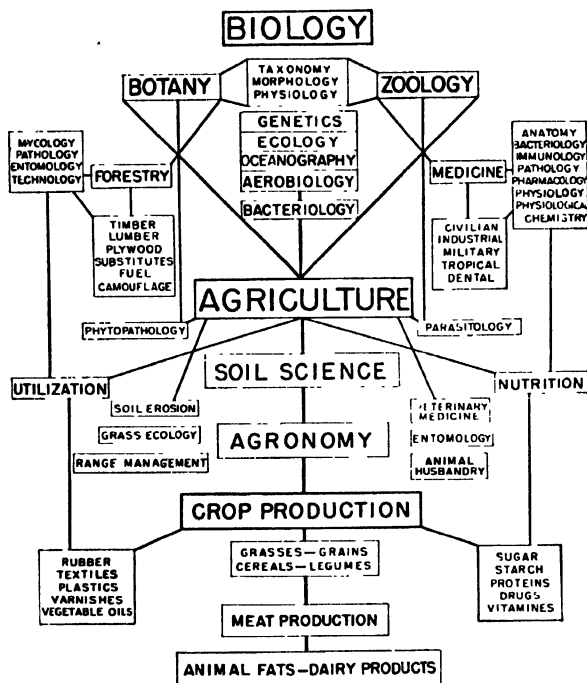


FIG. 325. Chart showing some of the general interrelationships of the biological sciences, with special reference to agriculture. (From Nicholas in the *American Scientist*.)

This intimate food interrelationship of all living organisms, which has been demonstrated by interrelated data accumulated by thousands of biochemical studies, is not only of profound theoretical interest, but also of incalculable practical importance in all problems of soil fertility, including soil composition and maintenance, crop rotation, etc. To coax greater productivity from the soil is a problem of highest importance. One of the most crucial factors in soil productivity is the demand for the economical production of food for plants themselves; in particular, for an adequate supply of nitrogen in a form readily available for the use of cultivated plants. A natural source of nitrogenous plant food is, of course, the nitrogen of the atmosphere, trapped by nitrogen-fixing bacteria, but the artificial conversion of this gaseous element into compounds suitable for fertilizers has taxed to the utmost the ingenuity of chemists. Finally after years of intensive

laboratory study and experimentation, they succeeded in developing industrial processes for accomplishing this result. This has created an enormous industry of world-wide extent and supplied agriculture with a cheaper source of this indispensable nitrogenous food for plants. (Fig. 22.)

Soil investigations involving the cooperation of chemist and biologist lay the foundations for studies on seed planting, germination, and growth, which in turn lead to others on transplanting, grafting, and pruning, and on pollination, hybridizing, and developing new varieties of plants. Nearly every cultivated plant that is important for food or other purposes has been improved. The great body of practical infor-

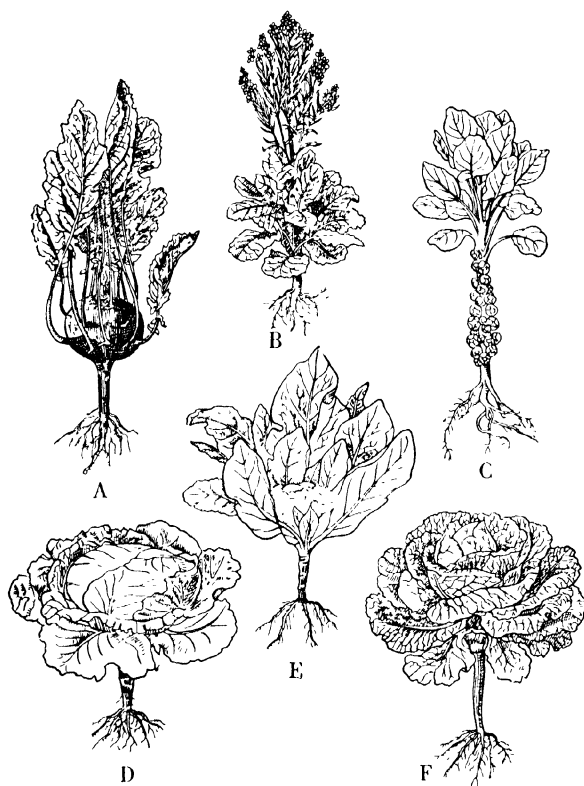


FIG. 326. A, kohlrabi; B, the wild *Brassica oleracea* from which all of the cultivated varieties have been derived; C, brussels sprouts; D, cabbage; E, cauliflower; F, Welsh cabbage. (After Smalian.)

mation which the human race has accumulated from centuries of toil has been multiplied a hundredfold within the past generation, through the intensive work of investigators at agricultural experiment stations, colleges, and universities throughout the world. (Fig. 326.)

INSECTS INJURIOUS TO ANIMALS

A former chief of the United States Bureau of Entomology informs us that insects alone in this country continually nullify the labor of a million men, in spite of the annual expenditure of between two and three hundred million dollars in fighting insects, and if human beings are to continue to exist they must first win the war. This can be accomplished only by the labors of an army of patient and skilled investigators, and the fight will occupy many years, far into the future. This is not only because the insect complex is enormous—there are possibly three million species of which only about six hundred thousand have been described—but also because insects achieved an important place on this globe many millions of years before man came into existence, and today are probably the most perfectly adapted of all creatures to live under all sorts of environmental conditions. If this statement appears extreme, the following examples will serve to make clear some of the cardinal facts which are necessary for an appreciation of the stupendous problems involved. (Fig. 436.)

Among this teeming insect population, probably the botflies, blowflies, fleas, and lice should be considered as major animal parasites. Botflies of various kinds infest domesticated animals but rarely human beings. The female HORSE BOTFLY tries to attach its eggs to the horse's hair in a position where the eggs can be licked off and swallowed. Then the larvae spend nearly a year attached to the lining of the stomach, and if present in considerable numbers cause irritation and serious nutritive disturbances. When full-grown the larvae pass out with the feces, pupate in the ground, and emerge as adult botflies.

Again, the common OX BOTFLY deposits its eggs chiefly on the legs of cattle, and when the larvae, or "cattle grubs," emerge they penetrate the hide, and then remain in the body tissues until the following spring. Finally they come to rest just under the hide of their host, which they puncture to get air. When the larvae are ready to assume the pupal state they burrow out, drop to the ground, and there complete their life history. It is estimated that the monetary loss from the

ox botfly in the United States is more than one hundred million dollars annually. (Fig. 327.)

Fleas and lice of various species are common parasites of the higher animals throughout most of the world. The JIGGER FLEA of warmer climates is frequently a serious human pest because the female flea burrows into the skin when ready to deposit eggs. The cat flea, dog flea, and house flea we usually consider merely nuisances, but they are potential carriers of disease-producing microorganisms. One might think that a life devoted to the study of fleas and lice could be more

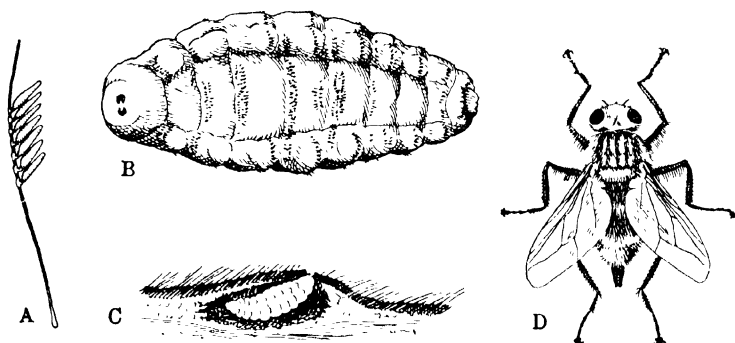


FIG. 327. Ox Botfly, *Hypoderma lineata*. A, eggs attached to hair; B, larva; C, larva just beneath air-hole in skin of ox; D, adult botfly.

profitably spent, until we recall that expert knowledge of these animals was essential to the discovery that trench fever in World War I was transmitted by lice; was essential to make clear that bubonic plague, or "black death," is carried by fleas. (Fig. 328.)

It was long known that rats die in great numbers during a plague epidemic, and accordingly biologists set out to determine whether there is any relation between the disease of the rat and of man. They found that man is infected with the plague bacillus, *Pasteurella pestis*, by being bitten by a flea from an infected rat. Extermination of rats and fleas means the practical eradication of the disease, but in California the ground squirrels have become infected with the bacillus so the problem has become somewhat greater. Bubonic plague is doomed, though it has already taken an incalculable toll of human lives; even during the first four years of the present century it destroyed about two million people in India. Still more recently San Francisco had an outbreak of the plague that in earlier times probably would have

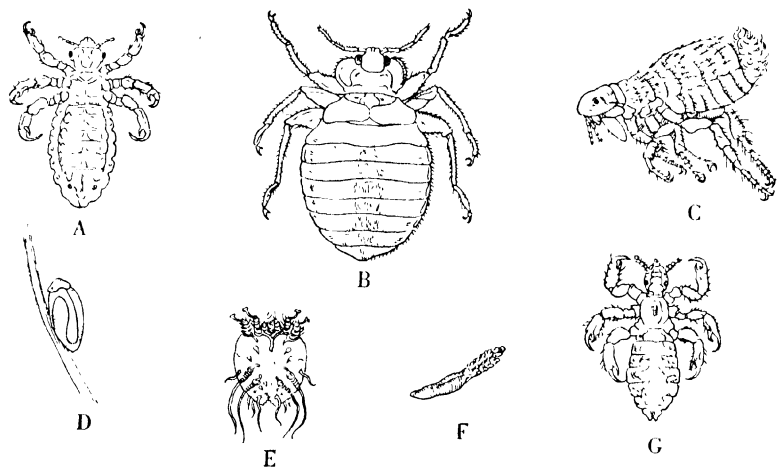


FIG. 328. Human parasites. A, head louse; B, bedbug; C, flea; D, egg of flea attached to a hair; E, mite; F, hair, sheath mite; G, body louse. (From Hegner and various authors. Redrawn.)

developed into a national calamity, but the plague was quickly stamped out with the loss of very few lives.

In brief, numerous parasitic insects not only actually develop at the expense of animal tissue, but others act as the transmitting agents of

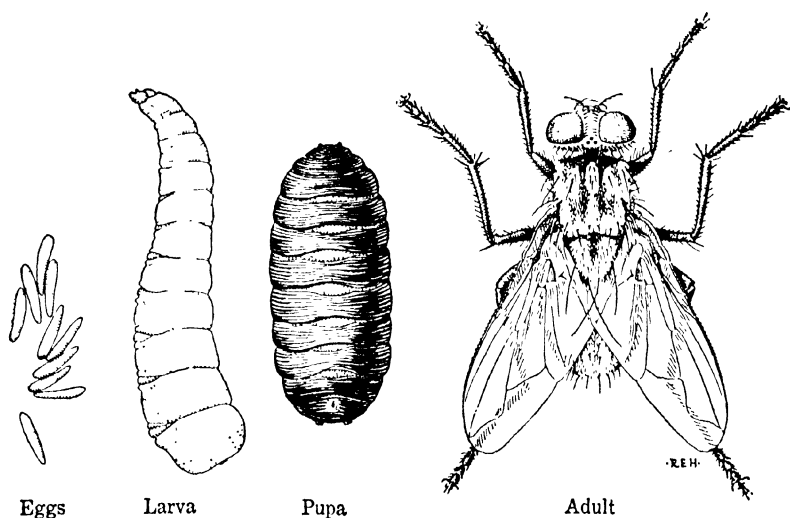


FIG. 329. Life history of the house fly, *Musca domestica*.

bacteria, protozoa, etc., which are the actual parasites, as we have already seen in the case of malaria, yellow fever, and African sleeping sickness. And last, but not least, we know that HOUSEFLIES, which are uninvited guests at our tables, have been shown to carry the germs of typhoid fever, tuberculosis, dysentery, and several other scourges. (Figs. 314, 315, 329.)

INSECTS INJURIOUS TO PLANTS

It has been estimated that it costs the American farmer more to feed his insect foes than to educate his children; in fact, more than is expended for all the educational institutions in the United States, and more than twice the losses by fire. Every kind of plant supports many species of insects, although only certain ones are especially destructive. Oak trees are attacked by no fewer than a thousand species of insect pests, apple trees by about four hundred, and clover and corn by some two hundred insect enemies. A few random examples will suffice for our view of the field.

The ARMY WORM is the larva of a brown moth which sometimes becomes so numerous in regions east of the Rocky Mountains that the caterpillars have to migrate in search of food. Immense armies crawl along, totally destroying the crops over large areas. Fortunately, the pest has its own insect enemies, the chief being certain tachina flies which lay their eggs on the caterpillars, and the larvae of the flies burrow into their bodies and finally destroy them. (Fig. 337.)

Of equal interest is the CABBAGE BUTTERFLY, which was accidentally introduced from Europe into Canada in 1868, and has gradually made the whole of the United States its field, even replacing a related native species. Many of the caterpillars of the cabbage butterfly are destroyed

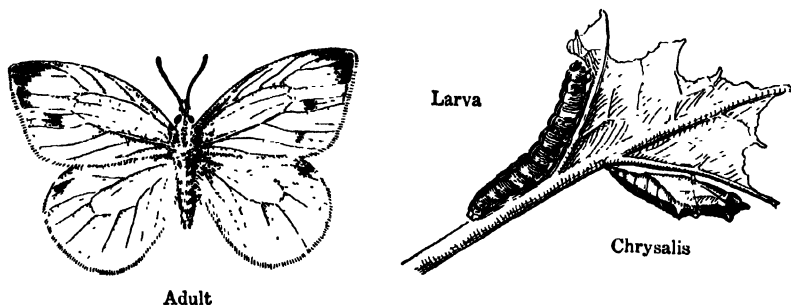


FIG. 330. Life history of the cabbage butterfly, *Pieris rapae*.

by parasites, one being a Braconid fly which was imported from its old home in Europe by entomologists for this special purpose. (Fig. 330.)

The POTATO BEETLE first began to attract attention about a century ago when it transferred its activities from certain weeds in the Colorado region to the recently introduced potato plant, and since that time it has spread all over the United States and has emigrated to Europe to become one of the serious insect pests. Large masses of yellow eggs are deposited by the beetles on the under surface of potato leaves which serve as food for the caterpillars until they are full-grown and ready to pupate in the ground. Two broods of adults are usually produced annually to carry on the depredation. (Fig. 436.)

Among the most destructive parasites of wheat, rye, and barley, nearly the world over, is the HESSIAN FLY which was introduced into America toward the end of the eighteenth century. The life history is especially adapted to the growth of wheat, and two or three broods of the insect develop in one year. Fortunately the fly has numerous parasites of its own that hold it somewhat in check, though in certain regions it is necessary to regulate the planting of wheat according to fly-free dates.

The EUROPEAN CORN BORER has long been distributed over a large part of the Old World and in recent years has reached America. Starting in New England, it has slowly moved westward, is now firmly established in the Middle West, and may well before long infest the entire corn-raising area of the continent. The destructive stage, of course, is the caterpillar which, throughout most of the insect's range, injures or destroys the growing plants, then spends the winter in the stem of the plant, and gives rise to an adult moth early the following summer. Unfortunately, however, in New England there are two generations annually, one of which winters in the larval state. This pest is now causing a loss of millions of dollars annually in the infected areas.

The JAPANESE BEETLE was accidentally introduced into New Jersey from Japan about twenty years ago and since has spread rapidly through many of the eastern States, defoliating trees and shrubs and destroying lawns and truck crops. The larva spends the winter underground, and the adult emerges the following summer.

The destruction wrought by the COTTON BOLL WEEVIL during the first thirty-five years after its invasion of the United States from Mexico

is estimated at upward of three billion dollars, not to mention other immense financial losses due to depreciated land values, etc. Probably each person in the United States pays annually ten dollars more for cotton fabrics than he would if this "evil weevil" did not exist; it is one of nature's methods of reducing the cotton crop. The injury to the cotton plant is caused by both the adults and larvae: the adults by feeding and boring for their eggs, and the larvae by injuring the developing flowers so that they either fail to bloom, or produce seeds with few cotton fibers. (Fig. 331.)

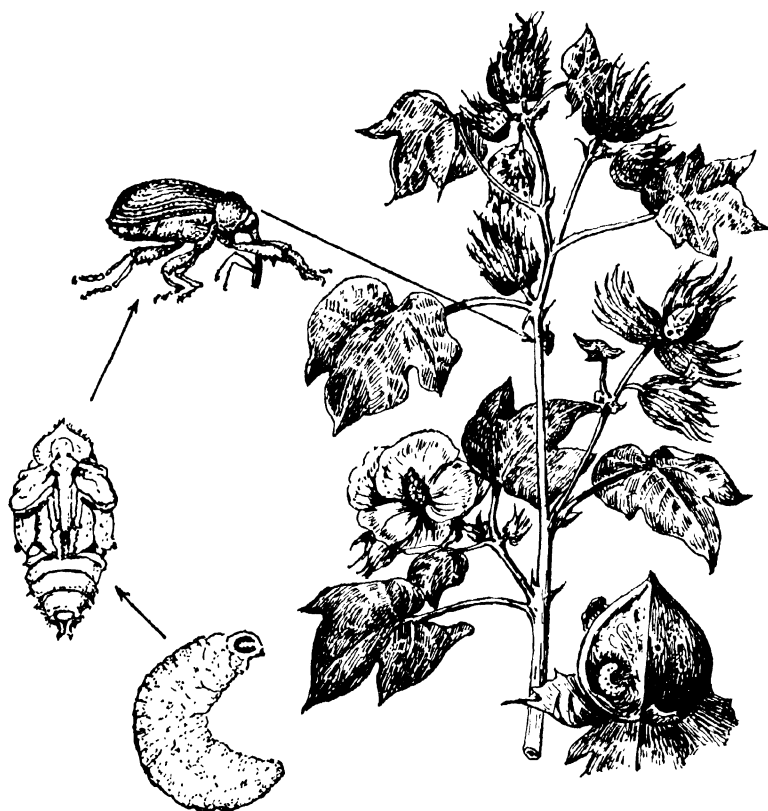


FIG. 331. Life history of the cotton boll weevil. Three stages are shown at left: larva (*lower*); pupa (*center*); adult, as seen from side, (*above*). Adult female lays eggs in cotton boll (*lower right*) which develop into destructive, worm-like larvae, and are followed by pupa and adult stages. (From Metcalf and Flint, after U. S. Department of Agriculture. Redrawn.)

While SCALE INSECTS are so small and obscure that they are only a name to all except specialists, they constitute economically one of the most important groups of the entire insect world. Scale insects infest almost all kinds of trees and shrubs, in some cases doing merely temporary damage and in others actually killing the hosts. Among the myriads of species, the SAN JOSE SCALE is probably the most important, and since being brought to California from China has spread all over the United States. The adult female insect lies permanently attached to the bark, underneath a tiny, waxy scale which it secretes. Here eyes, legs, and antennae are lost, and the saclike creature lives on the plant sap and reproduces. It is estimated that the progeny of a single individual during one season would number thirty million if all were to survive. (Fig. 335.)

About fifty years ago the vineyards of France, and later those of California, appeared to be doomed to destruction by the attacks of a species of minute plant louse, or APHID. The French government offered a large reward for an effective remedy, and many entomologists and botanists devoted all their time to the study of the problem. Eventually it was discovered that certain American wild grapes were naturally immune to the pest. Accordingly by grafting the cultivated grape upon the resistant wild stock a combination was effected which saved the vineyards of both countries. (Figs. 310, 336.)

The MEDITERRANEAN FRUIT FLY, long the bane of fruit growers in many parts of the world, appeared some years ago in certain Florida orchards, but the invasion apparently has been repulsed by the Bureau of Entomology and Plant Quarantine. A defense is also maintained on the Rio Grande against the Mexican fruit fly, and throughout the country against our many native species, though the latter are held in check to some extent by their own insect enemies. However, various species of the genus *DROSOPHILA* have contributed more to our knowledge of genetics than any other animal. Its major diet is yeast and it is

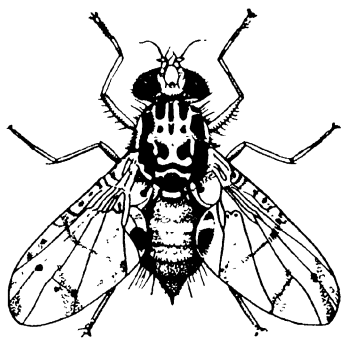


FIG. 332. Mediterranean fruit fly, *Ceratitis capitata*. (From U. S. Department of Agriculture. Redrawn.)

probably guided to its food by the odor of alcohol liberated by the yeast cells. (Figs. 244, 332.)

Another great problem is the preservation of forest and shade trees from native and also imported pests. The enormousness of the loss attributed to this army of silent tree-killers is staggering. They destroy more of the nation's wealth each year than do forest fires—timber equal to one-fifth of the wood produced annually in the United States. So far their march has met relatively little resistance, but controls are not easy when some insects may travel hundreds of miles on the wings of the wind; aviators have trapped them more than two miles aloft. Moreover, airplanes themselves inadvertently transport noxious insects and other pests.

The MOUNTAIN PINE BARK BEEBLE, not content with its invasion of the vast forests of the Northwest, now is threatening those of the Yellowstone National Park. The GYPSY MOTH, accidentally introduced near Boston, has spread throughout a large part of southern New

England, crossed the New York state line, and even started a colony in Pennsylvania. Entomologists have made intensive studies of its European enemies, left behind when it came to America, and the introduction of some of these into New England gives some hope that it may eventually be conquered. In one year alone nearly three million insect enemies, from eight species, were liberated. These two examples may stand as representative of the legions of destructive forest insects. (Fig. 333.)

Finally we should be reminded, if necessary, that our households are not immune to insect marauders that take an immense aggregate toll each year. CARPET BEETLES and CLOTHES MOTHS are all too familiar examples. (Fig. 334.)

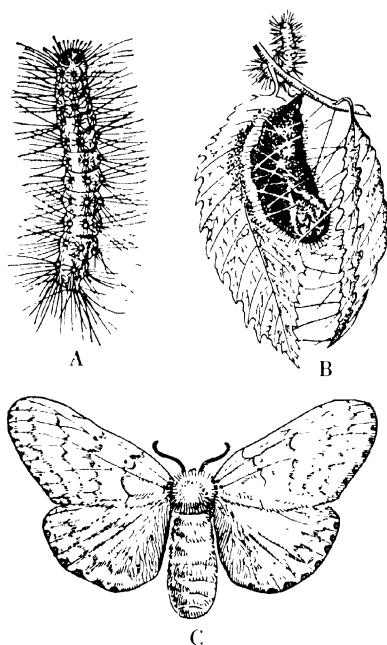


FIG. 333. Gypsy moth, *Porthetria dispar*. A, larva; B, pupa; C, adult female. (From Howard. Redrawn.)

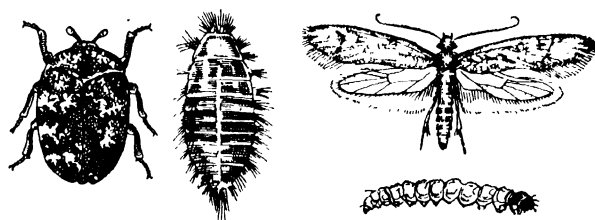


FIG. 334. Adult carpet beetle, *Anthrenus scrophulariae*, left, followed by larva; clothes moth, *Tinea pellionella*, right, with larva, below. (From Riley Redrawn.)

BENEFICIAL INSECTS

Although incidental mention has been made of the importance of certain insects in suppressing other noxious kinds, it would be unfair to the insect world not to emphasize the existence of members which are serviceable to man, those thousands which prey upon our enemies or supply valuable materials. The principal enemies of insects are other insects, and "if they should quit fighting among themselves, they would overwhelm all vertebrate animals." Sometimes, however, long biological investigations are necessary to keep them fighting when we have upset the natural conditions, e.g., moved them to a new environment away from their natural enemies. Thus acacia plants brought from Australia introduced the COTTONY CUSHION SCALE insect which spread to the great California orange and lemon groves and entailed enormous losses. The fruit growers finally sent an expert entomologist to study in Australia the native enemies of the insect. As a result some ladybird beetles were eventually discovered which offered hope of meeting the needs, and these were sent to California and carefully reared until they could be colonized in the infected groves. Here they multiplied and ever since have held the scale in check. (Figs 335, 336, 337.)

When insects destroy weeds or noxious plants we, of course, regard them as beneficial. An impressive example is afforded by the PRICKLY PEAR (*Opuntia*) scourge in Australia. This cactus was accidentally introduced from America and soon became an enormous economic problem by rendering useless some sixty million acres. Cultural, mechanical, and chemical methods of eradication proved impractical, but the study of the insect enemies of the prickly pear led to the introduction of the ARGENTINE MOTHI-BORER, *Cactoblastis cactorum*,

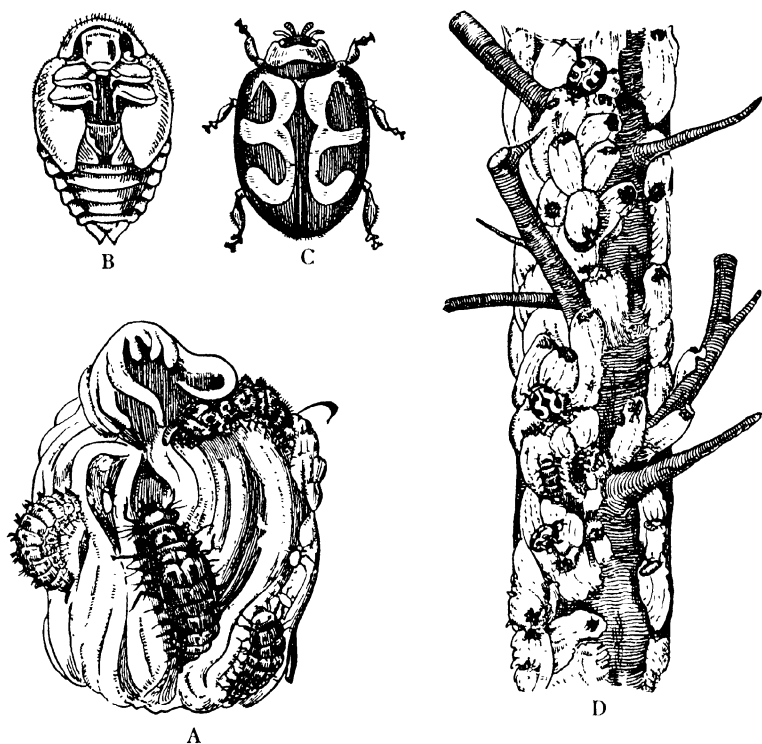


FIG. 335. Australian ladybird beetle, *Rodolia cardinalis*, and cottony cushion scale, *Icerya purchasi*. A, larvae of beetle feeding on secreted scale; B, pupa of beetle; C, adult beetle; D, orange twig showing scales and beetles, as enlarged in A. (From Marlatt. Redrawn.)

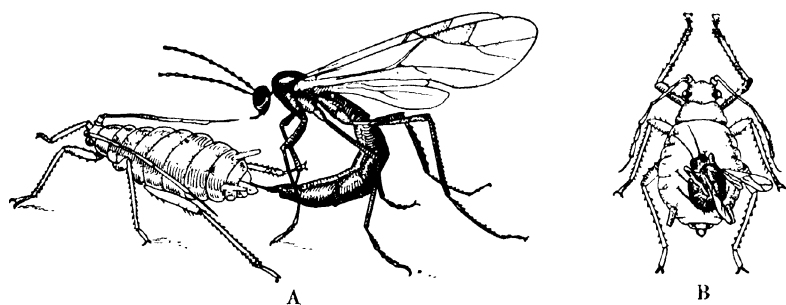


FIG. 336. A, a female Ichneumon fly inserting egg in the abdomen of an aphid; B, emergence from the aphid of the parasite that developed from the egg. (From Webster. Redrawn.)



FIG. 337. Army-worm moth, *Cirphis unipuncta*, and its ecological relationships with other insects. a, adult moth; b, full-grown larva which destroys cereal plants as shown above; c, eggs; d, pupa in soil; e, parasitic fly, *Winthemua*, laying eggs on an army-worm; f, ground beetle, *Calosoma*, preying upon an army-worm, and, at right, *Calosoma* larva emerging from burrow; g, a digger wasp, *Sphex*, carrying an army-worm to its burrow; h, a wasp-like parasite of the army-worm. (From U. S. Department of Agriculture. Redrawn.)

with the result that the menace was brought under complete control within a decade.

Furthermore we must not forget that such insects as the SILKWORM MOTH and the HONEYBEE are really domesticated animals; each is at the basis of an enormous world industry. One of Pasteur's most important studies was on the PEBRINE disease of silkworms, which not only saved the silk industry of France, but also paved the way for the study of infectious diseases in higher animals and man. The cause of pebrine proved to be a protozoan parasite, *Nosema bombycis*. (Figs. 301, 338.)

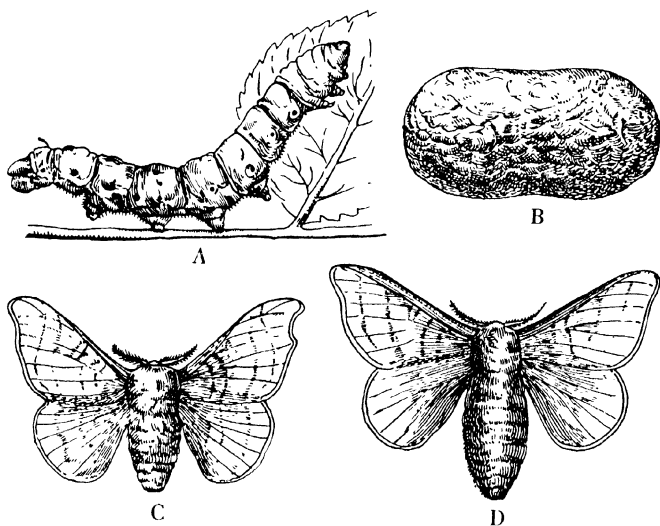


FIG. 338. Silkworm moth, *Bombyx mori*. A, caterpillar; B, cocoon from which the valuable commercial silk is obtained; C, male moth; D, female moth. (From Shipley and MacBride.)

The dependence of many plants upon insects for pollination is well illustrated by the difficulties in establishing the SMYRNA FIG in California. The fruit would not mature, and studies by botanists and entomologists showed that in the plant's native land pollination was effected by a certain tiny insect. Importation and establishment of the insect carrier in California created there the immense fig-growing industry. (Fig. 306.)

As a matter of fact an amazing number of plants that are most highly prized would be unable to reproduce were it not for pollination

by insects; for instance, there would be no pears, apples, peaches, plums, oranges, or strawberries. It is perhaps not unreasonable that an entomologist has asked whether insect depredations may not be regarded as a 20 per cent commission we pay for the invaluable services that "friendly" insects render. It may, but it is economical, if not generous, to reduce the tax to the lowest limit!

Insects affect human affairs in other vital but less direct ways. It will be recalled that Darwin emphasized the importance of earthworms in aerating and plowing the soil; but various insects probably contribute at least as greatly to this indispensable work. Ground-burrowing insects are still more widely distributed than earthworms and in most regions they are more numerous and more active. Moreover, not only do they carry decaying leaves beneath the soil, but also rich nitrogenous plant food such as manure and the dead bodies of animals. (Fig. 337.)

Finally, it is entirely reasonable to wonder how land plants could have arisen without the direct or indirect services of insects. Indeed geological history indicates that land plants did not flourish and flowering plants did not exist before insects became a well-established part of the earth's fauna. (pp. 363-365.)

PLANTS INJURIOUS TO PLANTS

Plants would seem to have enough animal enemies without having to contend with parasitic plants, but as a matter of fact the science of plant diseases, PHYTOPATHOLOGY, is largely devoted to the destructive activities of colorless plants, the bacteria and higher fungi. The life histories of many of the SMUTS, RUSTS, and related parasitic fungi are so complicated that hundreds of specialists are continually employed in ferreting out these pests in order to save the products of farm and forest. Perhaps the WHITE PINE BLISTER RUST, another accidental importation from Europe that threatens our forests, is sufficiently typical to indicate some of the difficulties involved. (Fig. 339.)

This species lives during one stage of its life on the white pine and during another stage on the leaves of the currant or the gooseberry. In common with most of the fungi, it produces spores which are distributed by the wind. When the spores (type one) of a certain stage in the life history fall upon white pine leaves, they enter the stomata, develop, and grow through the tissues. Finally, after several years, the bark swells at the points of infection and sporangia are protruded

which liberate myriads of a second type of spores in the form of a bright yellow powder. For further development, one or more of these spores must be carried by the wind to the leaf of a currant or gooseberry bush. Established here the spore germinates, grows down into the leaf tissue, and in a couple of weeks this new stage in the life history is itself forming spores. Masses of this third type of spore appear as tiny specks on the leaf surface.

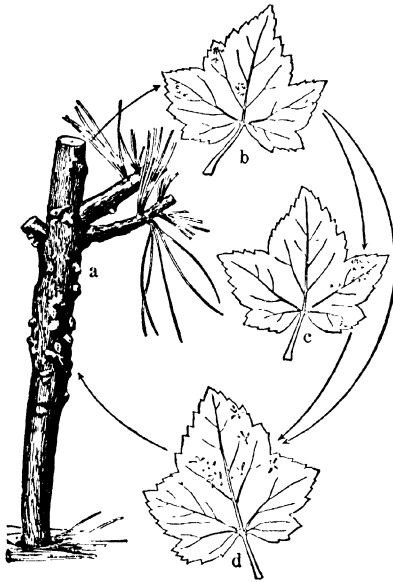


FIG. 339. Diagram of the life history of the white pine blister rust. a, blisters on pine tree in spring, from which the disease spreads to currant or gooseberry leaves and produces the early summer stage, b; thence it may spread to another currant leaf and produce there a second crop of the early summer stage, c, or it may at once produce the late summer stage, d. In the fall this late stage infects the neighboring white pines. (From Smallwood, after Spaulding.)

The third type of spore also develops on the currant or gooseberry and soon another generation of similar spores is produced. Repeating infection may continue every two weeks until autumn when the leaves fall. Then spores of type one appear which can develop only on a white pine. If this transfer is successfully accomplished, the life cycle is completed. Since either the currant or gooseberry acts as the intermediate host, these plants afford a hazard for white pine forests in the vicinity. This life history involving two hosts recalls that of certain animal parasites, such as the malarial organisms.

Enough has been said to indicate the struggle for knowledge which man must maintain in order to cope with the biological forces that would rob him of what he

considers his heritage. But it is only fair to add that some biologists who have given much thought to the problem are by no means certain that the struggle will eventually be successfully terminated; it is possible that insects and allied enemies will gain the upper hand in the warfare for food when the human population has increased beyond a

certain limit. This seems incredible, though it is a conservative statement by men who are specialists and not pessimists. In any event, it is clear that the most urgent need today is more knowledge of the life habits of insects and other destructive organisms. Generous federal and state appropriations must be made so that through research effective methods of control may be developed. Experience has shown that the research dollar is invested in a gilt-edged security that may produce a national dividend almost beyond computation.

CONSERVATION OF NATURAL RESOURCES

We are rapidly awakening to the fact that we have been very short-sighted. Conservation of natural resources has, until relatively recently, received little attention, although it is one of the greatest problems which biologists of the present generation face, and it must be solved soon or it will be too late. What happened in America is being repeated in many other parts of the world. Our forefathers came to a land of fertile soil covered with primeval forests, abounding with large and small birds and mammals, and with waters richly supplied with fish. These they necessarily and rightly drew upon for their livelihood. It was their wealth—nature's generous bonus.

But the apparently inexhaustible supply has already become alarmingly reduced and conservation is now the watchword. This was recognized many years ago as indicated in this statement: "the weightiest problem now before the nation, as nobody can deny the fact that the natural resources of the United States are in danger of exhaustion, if the old wasteful methods of exploiting them are permitted longer to continue." Yet in spite of this, the conditions are still such that a prominent legislator is justified in stating that "it is time that the national conscience be awakened to the necessity of preserving what is left of the outdoor heritage of our fathers, and of restoring some of that which has been destroyed and defiled."

Less than one-eighth of the virgin forest of the United States remains today. Such a condition seems incredible for a civilized nation, but it is only too true. Approximately one-half of our forests are held by the Government, but the remainder has been and still is being destroyed far more rapidly than unaided nature can restore it. And there is nowhere in the world a sufficient supply of the kinds of timber we use to take their place. We have continuously treated our forests, except those under public control, not as a farm on which to produce crops, but as

a mine whose useful product is to be gathered once for all. The axe has held almost unregulated sway, but with ideas of conservation becoming increasingly widespread it may be that hope for a better future for our forests is well founded.

It seems hardly necessary to state that forests are of inestimable value in many ways entirely aside from the lumber they supply. We are, perhaps, prone to forget that under nature's stabilizers of forests, shrubbery and grass, the blowing and washing away of the soil pro-

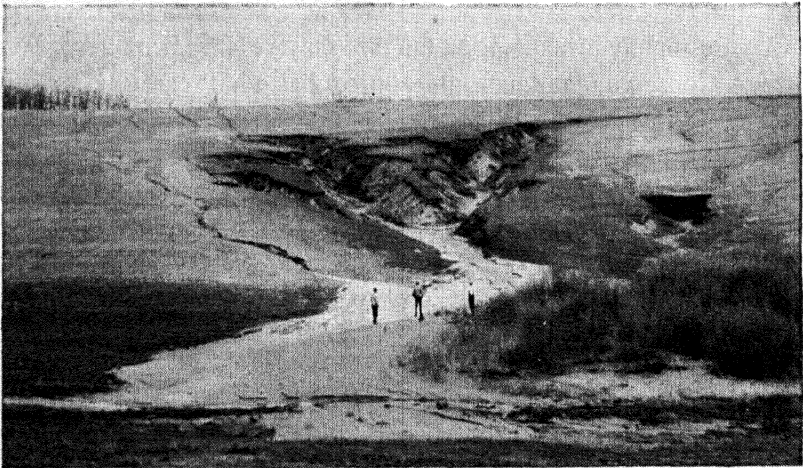


FIG. 340. Erosion culminating in complete destruction of soil by formation of deep gullies, as seen on a middle western farm. (From Stanford, after U.S.D.A. Soil Conservation Service.)

gresses but slowly, while with their removal by man this erosion is increased tremendously. Witness the great dust storms during earlier years in the Southwest. The devastating floods that periodically sweep down the Mississippi, the Ohio, and other American rivers, are in no small part attributable to deforestation. China's affliction from floods is the product of millenniums, ours of little more than a century. Scientific forestry is an essential factor in our future well-being. (Fig. 340.)

Many of the larger animals have been nearly exterminated, and some of the smaller ones are fast approaching the same fate. For instance, the bison is extinct in the United States, except for those sheltered on reservations; the elk is restricted in numbers and range; the elephant seal remains only in one small colony; the two species of

right whales are threatened with extermination; and the beaver has disappeared from most of his former haunts. Only complete protection will save the sea otter from extinction. The demand for fur is estimated to be responsible for the destruction of thirty million mammals throughout the world each year, and this number is nearly doubled if all the wild mammals destroyed for commercial purposes are included. While there is life there is hope, but unless immediate steps are taken to reduce the slaughter, the fur-bearing animals of the world at large are doomed.

Birds are now faring somewhat better owing to the heroic efforts started a generation ago by the Audubon Societies, so that a partial restoration of our former bird population seems probable. Of what use are the birds? Even if usefulness were the only question involved, the answer would still be clear. Experts tell us that without the services of insect-eating and seed-eating birds, successful agriculture would soon be impossible, and the destruction of the greater part of our vegetation would also result. One caterpillar, during its lifetime of less than two months, can consume three-quarters of a pound of leaves, or nearly ninety thousand times its original weight. Birds are "the winged wardens of our farms." Their help is needed in the struggle. (Fig. 341.)

Finally, stream pollution has become an urgent problem. Under normal conditions, protozoa, bacteria, and other small organisms bring about the so-called self-purification of standing and running water. These biological workmen, unseen and unheard, keep our waters unpolluted, and most modern methods of sewage treatment depend to a considerable extent upon their activities. The wide application of our present knowledge of the various factors—biological, chemical, and physical—may even yet return some of our waterways, with their balanced aquatic life, to their pristine purity.

In truth, it is dangerous to upset the intricate balance of the economy of nature by the

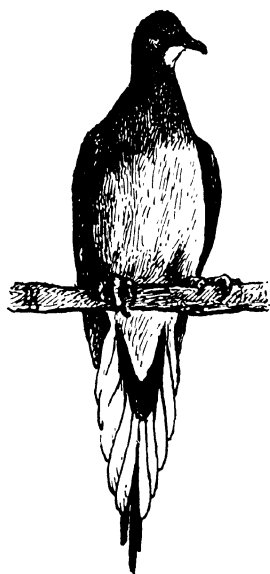


FIG. 341. Passenger pigeon, *Ectopistes migratorius*. Drawing from a photograph of one of the last living individuals of the species. (From Hegner.)

reckless destruction of plant or animal without taking thought for the morrow, without intensive study of the far-reaching consequences which may follow from the breaking of one link in the chain of the interrelationships of organisms. The destruction even of certain protozoa and other microscopic life may seal the fate of animals of great economic value. (Figs. 307, 308, 337, 350, 392.)

CONSTRUCTIVE BIOLOGY

The great living heritage which we have received will be permanently impaired for posterity, even though useless waste is stopped, unless the highly complex problem of conservation is attacked constructively in the light of modern biological knowledge. Merely to hold nature's bonus unimpaired, crucial as that is, will not adequately meet the requirements of increasing populations with the attendant demands of complex civilized life. Few seem to realize that the whole of our business life takes root in nature. All our progress and prosperity is predicated on the abundance of our natural resources and the manner in which we develop them. The methods of raising crops and domestic animals, which were sufficient for primitive communities, are entirely inadequate to satisfy modern conditions.

PLANTS AND ANIMALS

Man's conquest of the plant kingdom has hardly begun, because the number of species already brought into his service is insignificant in comparison with the wealth of available kinds. Relatively few of the nearly two hundred thousand known species of higher plants are cultivated, and many of these in merely an incidental way. There is every reason to believe that many plants not as yet employed possess intrinsic value at least equal to those under cultivation; some neglected plant may one day revolutionize agriculture or medicine—witness the recently discovered properties of the mold, *Penicillium*. Furthermore, the botanist must develop varieties of important plants which not only afford the largest yield, but also are most resistant to unfavorable climatic conditions and to disease; the forester must develop timberland both for the materials it supplies and for the indirect effects on soil erosion and on water conservation for agricultural and other purposes; the entomologist and plant pathologist must devise means for holding in check destructive insects, as well as bacterial and related microscopic parasites of plants. (Fig. 340.)

Indeed, the state of civilization of a people is closely related to its success in developing plants and animals for particular needs. One hears of new "creations," but often fails to recall that man can merely direct the laws of inheritance, and this he can do only by intensive investigations of the principles underlying heredity. Certainly the most important recent contribution of biology is the discovery of the general method of transmission of characters from generation to generation, common to all living things, which has now established the biological science, genetics. Today, as we have seen, biologists the world over are developing and applying these principles in plant and animal breeding. What was impossible a few years ago is now being accomplished almost as a mere matter of routine work in many biological laboratories.

Important as the application of these principles is in the mastery of agricultural problems, a far more profound power remains to be realized when, as nations, mankind becomes awake to the fact that these same basic principles apply equally to human inheritance. If it be true that the human race has not improved in bodily and mental characteristics since the time of the ancient Greeks, the responsibility rests with man himself. He has studied and applied selective breeding of animals and plants. He has in general kept the best for his purposes that nature offered and eliminated the rest. He has depended chiefly on the stock and only secondarily on the environment for permanent improvement. But it has been otherwise with himself. Much of the worst human stock has continued to survive and multiply, and disproportionately so as civilization has advanced. Reliance has been placed almost solely on the improvement of the conditions of life and not on breeding from the best. We may fairly say that humanity is what it is today in spite of the continual violation of many of the biological principles which would improve the race. (Figs. 276, 281, 342.)

This, of course, is merely a statement of fact, not a reproach. Man could not have done otherwise until it had been demonstrated by biological investigation that he is a part of, and not apart from, the rest of living nature—the most profoundly important fact that biology has contributed to human welfare. With this fully grasped, new import is given to the study of general biological principles, and no plant or animal is too insignificant to throw light on life problems. And this has been the chief source of the stupendous potential for biological control which has within less than a century come to mankind. Potential for

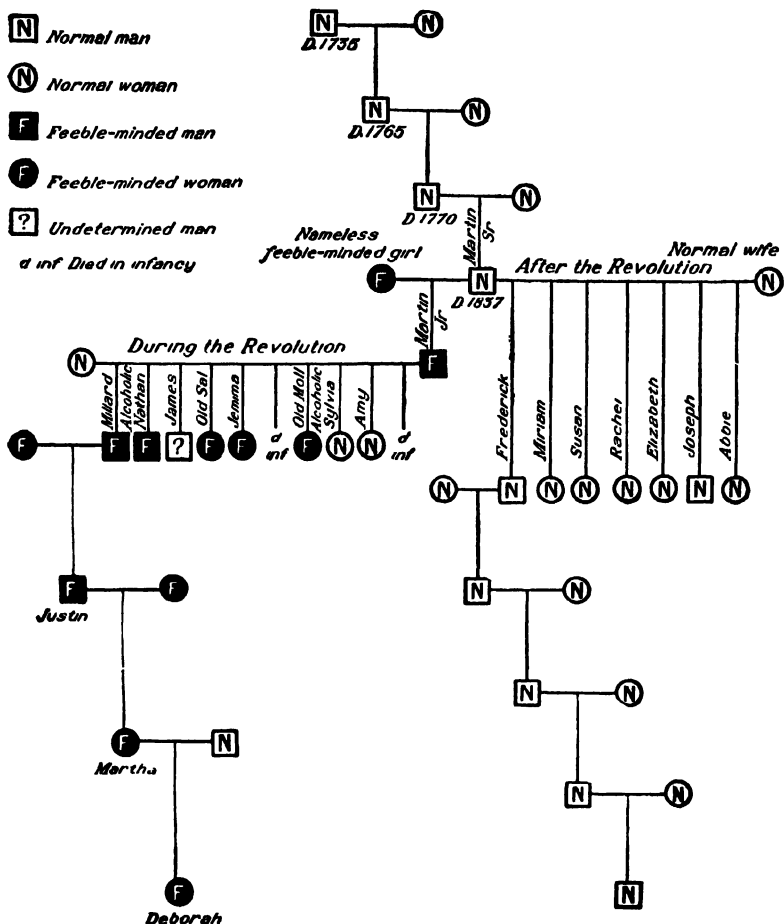


FIG. 342. Diagram showing inheritance in the Kallikak family. A demonstration of the inheritance of feeble-mindedness with its attendant evils, even when it is conceded that an environment of drunkards, thieves, and prostitutes does not foster the best there is in a person.

Of the 480 descendants, in five generations, of the branch shown at the left, 143 are known to have been feeble-minded, 36 were illegitimate, 33 sexually immoral, mostly prostitutes, 24 alcoholic, 3 epileptic, 3 criminal, and 82 died in infancy.

Of the 496 descendants, in five generations, of the branch shown at the right, none were feeble-minded, and all but 2 persons were normal mentally. Two were alcoholic and 15 died in infancy. Thus nearly all were good citizens. Among them were educators, physicians, lawyers, judges, traders, landowners: men and women prominent in every phase of social life. (After Goddard.)

control, we say, because years of research by generations of investigators are still necessary before we shall be prepared to solve the problems which we now face and which the increasing human population will immensely augment. (Figs. 241, 250, 345, 346.)

TIME BY GENERATIONS

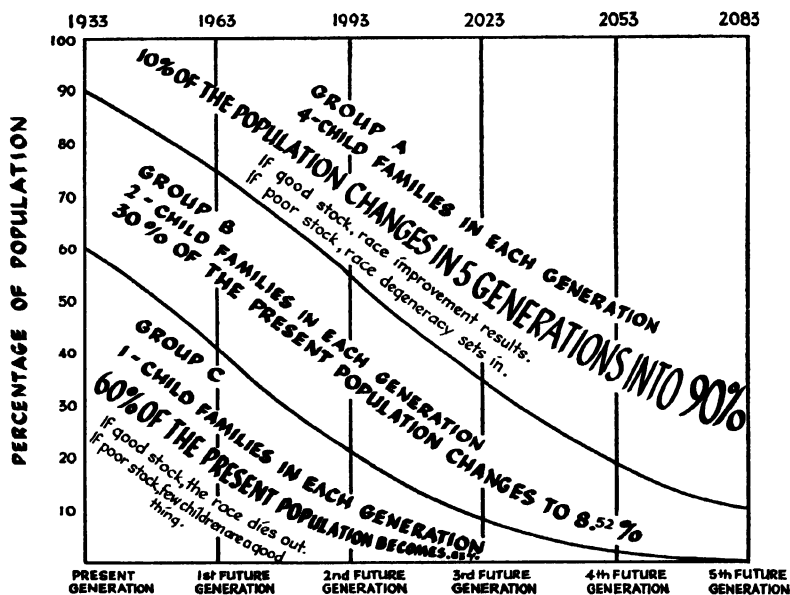


FIG. 343. Effect of differential birth rates on future generations. This chart shows how the shift in character of population is produced by difference in birth rates. Family stocks which are highly fertile, whether desirable or not, soon inherit the nation. (From Stanford, after Laughlin.)

The natural method of securing a healthy, that is, adapted race is, of course, the gradual process of adjustment throughout the ages in response to environmental changes. But mankind has the power, which we believe is denied to the lower animate beings, of conscious response, of choice. Human volition and action can retard or accelerate nature's response. Human volition may decide, within general limits, the response to surrounding conditions, and in addition may frequently directly change the conditions so as to render unnecessary individual or racial adaptation to them. Thoughts such as these make plain the enormous complexity of the situation and reveal the possibility of danger lurking where it may be least expected—danger lest in acting

as we think humane from the point of view of particular individuals, we may be rendering a disservice to the race. While medicine and other branches of the biological sciences are bent upon man's well-being, "social tendencies restrict the breeding of the best and weaklings breed unrestricted and even encouraged by relief."

To state it bluntly, our humanity moves us to try to keep everyone alive, the unfit as well as the fit, and so to permit nearly all to pass on

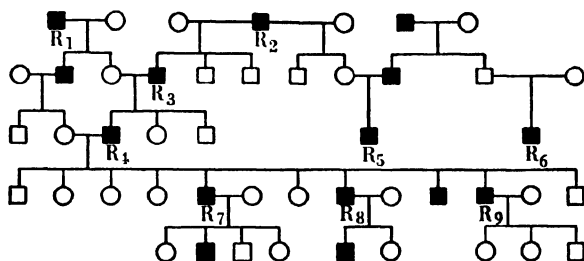


FIG. 344. The Darwin and related families. An indication that heredity rather than environment is chiefly responsible for highly distinguished achievement, even though good heredity has a strong tendency to create good environment. Black squares represent men distinguished for intellectual achievements; including R, members of the Royal Society; R₁, Josiah Wedgwood, founder of the Wedgwood pottery works; R₂, Erasmus Darwin, celebrated physician, scientist, and proponent of evolution in the eighteenth century; R₃, Charles Darwin; R₄, Francis Galton; R₅, George Darwin, astronomer and mathematician; R₆, Francis Darwin, Professor of Botany in the University of Cambridge; R₇, C. G. Darwin, a prominent physicist. The fourth son of Charles Darwin, Leonard Darwin, was president of the first two international congresses of eugenics and president of the Geographical Society. Squares represent males; circles represent females. (From Stanford, after Holmes.)

their genes to their children. Many of the leading geneticists believe that this removal of the influence of natural selection will in time lead to the degradation of the race unless man takes thought for the morrow and consciously supplies a substitute for nature's pruning influence.

Since amazing things have been done with cultivated plants and domestic animals, it may well be asked why the same should not be possible for mankind. The answer is that the problem is vastly more complex on account of the psychological and sociological factors involved that make it exceedingly difficult to control human pedigrees. But assume, for the moment, that the "State" decided to eradicate heritable feeble-mindedness, which is apparently controlled by a recessive gene. It has been estimated that there are about 300,000

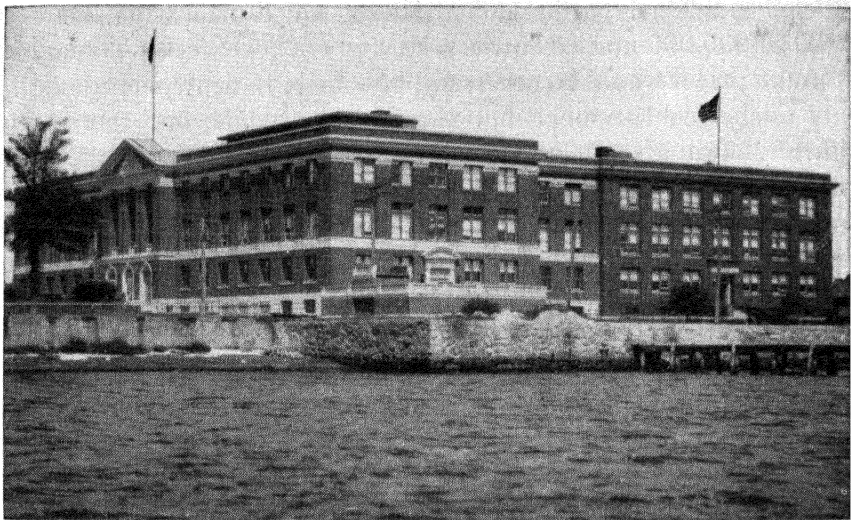


FIG. 345. The Marine Biological Laboratory, Woods Hole, Massachusetts. One of the laboratories where biologists and other scientists spend the summer in research covering many fields of investigation.

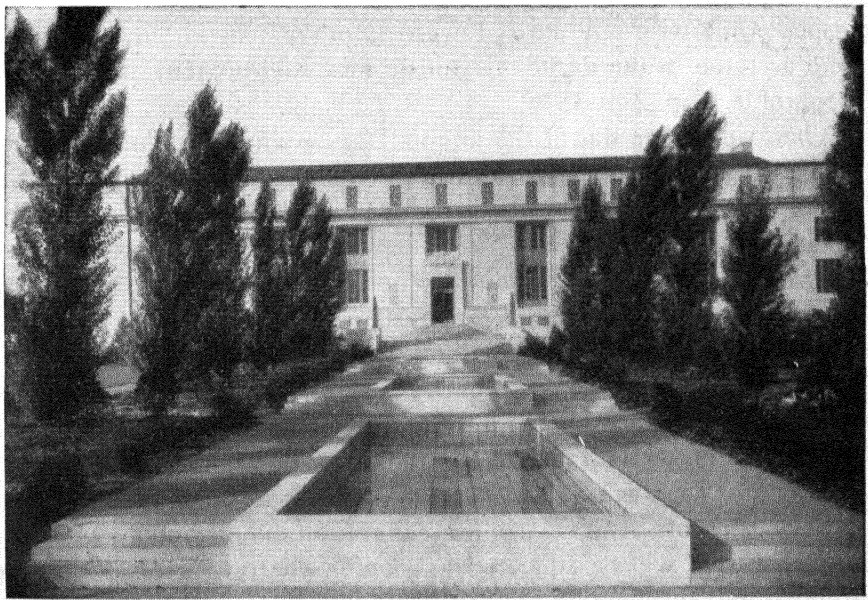


FIG. 346. Home of the National Academy of Sciences and the National Research Council of the United States, in Washington, D. C. The focus of scientific research in America.

afflicted individuals in the United States, which means that there are some 10,000,000 normal carriers. Now to eradicate feeble-mindedness from the race it would be necessary, of course, to deny parenthood not only to the feeble-minded but also to the carriers; and there is the difficulty. But assuming that merely the propagation of all feeble-minded persons was stopped, it has been computed that if the proportion of feeble-minded in the population is one per thousand, to decrease that to one per ten thousand would require about 68 generations, or more than two thousand years. Few would deny that this should be attempted even though it is looking far into the future for practical results. (Fig. 342.)

However, most problems of eugenics, the science of improving the hereditary quality of the race, are problems in genetics so intricately interwoven with those of all the other sciences of human life and relationships that propaganda in eugenics not fundamentally grounded in basic interlocking data from these sciences is not only premature, but fraught with insidious possibilities. Eugenics seeks improvement through nature, euthenics seeks improvement through nurture. Each is a partial view, and before significant progress can be made the proper balance between these two aspects of the one problem must be grasped; otherwise any effort toward improvement is "like trying to carve a statue in the dark." Organism and environment are one and inseparable. (pp. 349-351.)

When we realize that if the infants Darwin and Lincoln, who were both born on the same day, had been exchanged by their parents, it is doubtful if either would have produced epoch-making contributions to science or civilization, it gives us pause. There is a Danish proverb which states that it does no harm to be born in a duckyard if you are laid in a swan's egg—thus emphasizing the basic importance of heredity, though heredity implies not a repetition in kind, but in possibilities. We cannot hope to be born equal, but we may ask to be born with an equal opportunity to develop what is in us. At least it can be said at present, without fear of contradiction, that man owes it to himself to be at least as mindful of his own stock as he is of that of his domestic animals. And we can hope that the time may come when the average citizen will be educated to a point where he can take a constructive part in planning the application of biology to his own problems and those of the community.

From every standpoint the mere pittance man casts to biological

research returns to him manifold in health and wealth, in comfort and power, and most of all in a broader and more appreciative outlook on a congenial world. The walls of ignorance that hem us in may be high, but they can be scaled as generation after generation cuts its niches and gives sure footing to its successor. Far from depriving life of its mystery, biology affords a sublime picture of the interrelatedness of living things and still more inextricably interweaves human life with that of all nature.

CHAPTER XXX

Origin of Life

The mystery of life will always remain. Science is not the death, but the birth of mystery, awe, and reverence.

—Donnan

From the general background of biological facts and principles which has now been established, we are in a position to consider, from an advantageous viewpoint, one of the primary questions in biology, long since asked but never satisfactorily answered: the problem of the origin of life. For its antiquity as well as its universal interest, this question deserves, and still receives, consideration by scientists in several fields.

BIOGENESIS AND ABIOGENESIS

It seems strange, in the face of our present knowledge of the complexities of organisms, that the best minds up to the seventeenth century saw nothing very remarkable in the spontaneous origin of plants and animals of all kinds from inanimate materials, particularly mud and decaying substances. As a matter of fact, even Aristotle, who laid such broad foundations for the science and philosophy of the organism, believed that certain of the vertebrates, such as eels, arose spontaneously.

Similar ideas were voiced repeatedly through more than twenty centuries by scientists and philosophers, poets and theologians. Van Helmont, one of the founders of chemical physiology during the seventeenth century, 'gives particularly specific directions for the experimental production of scorpions and mice, while Kircher actually figures animals that he states arose under his own eyes through the influence of water on the stems of plants. The following ironical reflections, aroused by Sir Thomas Browne's doubts in regard to mice arising by putrefaction, are quite typical of opinion of the time: "So

we may doubt whether, in cheese and timber, worms are generated or if beetles and wasps in cow dung, or if butterflies, shellfish, eels, and such life be procreated of putrefied matter. To question this is to question reason, sense, and experience. If he doubts this, let him go to Egypt, and there he will find the fields swarming with mice begot of the mud of the Nile, to the great calamity of the inhabitants."

Naturally, with the continued increase in knowledge of the complexity of organisms, the belief in SPONTANEOUS GENERATION, or A BIOGENESIS was referred more and more to the lower forms. It remained, however, for Francesco Redi during the latter part of the seventeenth century to question seriously the general proposition, and to substitute direct experimentation for discussion and hearsay. By the simple expedient—it seems simple today—of protecting decaying meat from contamination by flies, he demonstrated that these insects are not developed from the flesh and that the apparent transformations of meat into maggots is due solely to the development of the eggs deposited thereon by flies.

One may imagine that the practical men of affairs at that time scoffed at Redi toiling under the Italian sun with meat and maggots to satisfy a scientific curiosity, and little dreamed that the practical results which germinated from this study would be among the most important factors in twentieth-century civilization. Indeed, it is difficult to overestimate the importance of Redi's conclusion from either the theoretical or practical point of view, for with it was definitely formulated the theory that inanimate matter does not assume the living state, at the present time at least, except from pre-existing living matter.

The influence of Redi's work gradually became evident in scholarly literature. One author during the next century states that "spontaneous generation is a doctrine so generally exploded that I shall not undertake to disprove it. It is so evident that all animals, yea and vegetables, too, owe their production to parent animals and vegetables, that I have often admired the sloth and prejudices of philosophers in taking abiogenesis upon trust." Another writes that he "would as soon say that rocks and woods engender stags and elephants as affirm that a piece of cheese generates mites."

But it is not to be supposed that the time-honored doctrine of spontaneous generation actually had been so easily relegated to the myths of the past, Redi's work and these eighteenth-century opinions

to the contrary. Indeed, the history of the establishment of BIOGENESIS—all life from life—extends down almost to the present time, for no sooner had experiment apparently disposed of spontaneous generation than it arose again with fresh vigor in a slightly different form demanding further investigation.

The difficulties in establishing biogenesis came from two chief sources. In the first place, Redi himself had been baffled by the presence of parasites within certain internal organs of higher animals, such as the brains of sheep. How did they get there if not by spontaneous generation? The answer to this had to await the working out of the marvelously complex life histories of the parasitic worms and allied forms which showed that all types arise from parents like themselves. In the second place, improvements in microscope lenses contributed to the discovery of smaller and smaller living creatures. Countless numbers and myriads of kinds of "animalcules" appearing almost overnight in decaying organic infusions aroused widespread interest and amazement, and proved to be the chief riddle. The plausible explanation seemed to be spontaneous generation. (Figs. 19, 23, 322, 323.)

Among others, Needham studied the problem and believed that he had demonstrated the spontaneous origin of minute organisms in infusions that he had boiled and sealed in flasks. Needham's results attracted considerable attention because the famous French naturalist, Buffon, found support in them for his theory that the bodies of all organisms are composed of indestructible living units, which upon the death of an individual are scattered in nature and later brought together again to form the units of new generations. (Fig. 513.)

Needham's and similar results, however, were shown by Spallanzani and others to be inconclusive because they were obtained by insufficient sterilization and sealing of the flasks containing the infusions. But at this point objections came from another source—the chemists who had recently discovered the importance of free oxygen for life processes and for the putrefaction and fermentation of organic substances. They argued that the treatment to which Spallanzani and other experimenters subjected the infusions might well have changed the organic matter, excluded oxygen, etc., so that it was impossible for life to be produced.

This objection was met by a long series of experiments by various investigators during the first half of the last century; these showed conclusively that thoroughly sterilized infusions never developed living

organisms even when air was admitted, provided the air had been rendered sterile by heat or by having all suspended dust particles removed. The chemists were answered: the infusions possessed all the conditions necessary to support life, but life did not arise. The scientist who contributed most to the establishment of this conclusion was Pasteur. His masterly and comprehensive work was convincing and final, and it also demonstrated the source of the life that so rapidly appeared in infusions exposed to the air. The source is the air. A considerable part of so-called dust consists of microorganisms in a dormant state but ready to resume active life when moisture and other suitable conditions are encountered. Furthermore, these organisms carried in air are not the result, but the cause of decay. Their own activities bring about chemical changes: putrefaction, fermentation, and, in the bodies of higher organisms, disease. This fact is amply attested by the methods now universally used in food preservation and aseptic surgery, to mention but two of the innumerable basic contributions to civilization that have directly followed. (Figs. 347, 348, 497.)

Although highly improbable, it is of course not impossible that simple life is even at the present time arising spontaneously under special environmental conditions. If such living matter is arising, it must be very simple compared with protoplasm as known today. However, when the lowest reaches of known life are studied they descend almost to the realm of the inorganic. Some of the *VIRUSES* that cause disease in plants and animals are smaller than certain large protein molecules. Although the virus particles are referred to as filter-passing, their size can be measured with a considerable degree of accuracy by the technique of ultrafiltration through collodion membranes, the size of whose pores has been previously determined, and also in certain cases directly by the electron microscope. The virus of yellow fever, which is carried by a mosquito, is approximately 22 millimicrons in diameter, whereas the rabies virus is about 125 millimicrons.

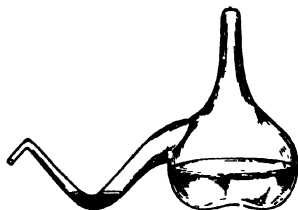


FIG. 347. Drawing of the flask used by Pasteur in his experiments on spontaneous generation. After the contents were poured in, the top of the flask was sealed. The opening at the end was sealed against the entrance of germs, but not against the entrance of oxygen, by the water of condensation that accumulated at the bend. Life did not develop in the sterile contents of the flask.

It may well be asked, what are these almost infinitesimally small particles which fall between the orthodox realms of the bacteria and protozoa and tax our ingenuity in trying to draw a line between the living and nonliving? Recent work shows that at least several, such

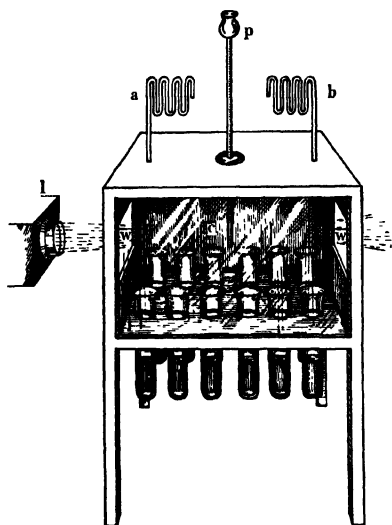


FIG. 348. Apparatus used by Tyndall in his experiments on spontaneous generation. The front and side windows (w, w) of the cabinet are made of glass. Air can enter through the two tubes (a, b). The optical test for the purity of the atmosphere within the cabinet was made by passing a powerful beam of light from the lamp (l) through the side windows. When the atmosphere contained no suspended dust particles, the tubes (c) within were filled, through the pipet (p), with a sterile culture medium suitable for the growth of germs, but none developed. (After Tyndall.)

as the tobacco virus, are chemically single protein molecules. One must ponder on that fact. The behavior of the molecule leads some to regard it as a very primitive type of organism, so primitive, in fact, that it has exhibited, so far, only one of the usually recognized basic functions of life, the power to multiply. The viruses multiply only when in the tissues of the proper host, and the extra units are the direct descendants of the original ones. There is no evidence that they arise spontaneously, though they may vary in some ways. (Fig. 348 A.)

The answers to the many questions raised by the viruses are of the utmost theoretical and practical import. They are of the future, though probably not a distant one. Today this much seems certain. Our well-worn, and well-liked, antithesis between the inorganic and the organic does not exhaust the possibilities. The molecular unit of the nonliving

world approaches the cellular unit of the living, and it is conceivable that an intermediate microcosm, represented by the viruses, will in part bridge the imposing gap between the quick and the dead, and possibly afford a glimpse of life's origin.

Although the borderline between lifeless and living may prove to be intangible, so far as human observation and experiment go, no form

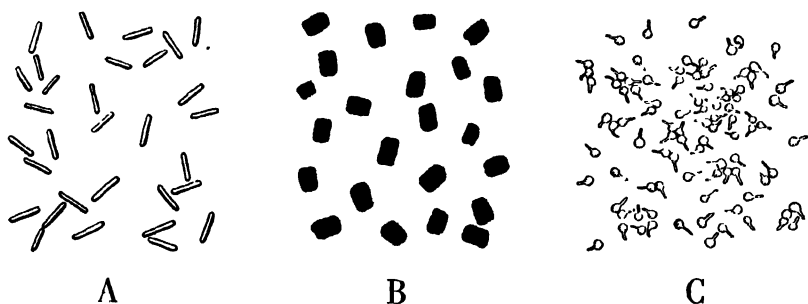


FIG. 348 A. Three types of virus: A, tobacco mosaic virus; B, vaccinia virus; C, bacteriophage which attacks colon bacilli. (Stanley, after Knight, *Science in Progress, Series VI*, Yale University Press.)

of life arises today except by reproduction from pre-existing life. The evidence from innumerable sources converges overwhelmingly to the support of biogenesis. There is no evidence in support of abiogenesis.

ORIGIN OF LIFE ON THE EARTH

The testimony of astronomer and geologist shows clearly that the earth was at one time in a condition in which life could not exist, and so we face the problem of how life came to be established on the earth in the past—the remote past, since the geological record affords convincing proof that life has existed continuously on the earth for many hundreds of millions of years.

Accordingly, unless one ascribes life's origin to SPECIAL CREATION, which at once removes it from the sphere of science and so beyond the present discussion, there are the following alternatives: either life came to this planet from some other part of the universe, or it arose spontaneously from nonliving matter at one period at least in the past as a natural result of the evolution of the earth and its elements. With this in mind, a review may be made of the present state of the problem because it is nearly, if not quite, as important to define our area of ignorance as to extend our area of knowledge.

COSMIC ORIGIN

The establishment of biogenesis and the dawning realization of the unique complexity of the structure of matter in the living state have led several scientists to suggest that life has never arisen *de novo* on

the earth but has been carried here from elsewhere in the universe: the so-called COSMOZOA theory.

On the assumption that some of the heavenly bodies have always been the abode of life, and from the fact that small solid particles, presumably once a part of such bodies, are moving everywhere in space, these particles have been pictured as the vehicles capable of disseminating the simplest forms of life through interstellar space to find lodgment and development upon such planets as afford a suitable environment. From this point of view, life may be as old as the universe itself.

The plausibility of the cosmozoa theory depends on two assumptions: that life exists elsewhere in the universe, and that life can be maintained during the interstellar voyage. Neither assumption has, of course, any foundation of established fact, though the second offers at least something tangible for discussion.

It will be recalled that many of the bacteria and protozoa, especially when under the influence of unfavorable surroundings, have the power of developing protective coverings about themselves and of assuming a dormant condition in which all the metabolic activities are reduced to the lowest ebb. In this spore or encysted state they can endure extremes of temperature and dryness that would quickly prove fatal during active life. For instance, it seems clear that the spores of certain kinds of bacteria can survive a temperature approaching that below which no chemical reactions are known to occur, and others can endure at least as high as 140°C for a short time. The cysts of some relatively highly specialized protozoa can retain their vitality for at least half a century, whereas the seeds of some plants have been found to retain the power of germination for over a century, though statements that grain from ancient Egyptian tombs still maintains its power of growth have been positively disproved. (pp. 399-400.)

The hardships to which living matter would be exposed on its interstellar journey are not to be minimized. Meteors in their fall through the earth's atmosphere become heated to incandescence and, if they are the vehicle of transfer, it would be conceivable for life to survive only far below their surface where the temperature is lower. To avoid this and other difficulties it has been suggested that the radiant pressure of light is sufficient to overcome the attraction of gravitation for particles of the extraordinary minuteness of some of the lower

forms of life, and that isolated germs might make the journey to the earth. But on the assumption that an organism were forced out into space by the mechanical pressure of light waves from the sun of the nearest solar system, it would require many thousands of years for it to reach the earth. However, certain scientists believe that, owing to the exceedingly low temperature and absence of water vapor which must prevail in cosmic space, there is no reason why spores should lose appreciably more of their germinating power in ten thousand years than in six months. Apparently ultraviolet and cosmic rays loom as the chief stumbling-block to this belief. It appears that everywhere in cosmic space living matter would be exposed to so great an intensity of these radiations that there would be hardly any possibility of its survival.

Without further discussion, it is apparent that the cosmozoa theory is one which cannot be proved or disproved. It removes the origin of life to a "conveniently inaccessible corner of the universe where its solution is impossible." So most biologists would agree that, "knowing what we know, and believing what we believe, as to the part played by evolution in the development of terrestrial matter, we are, without denying the possibility of the existence of life in other parts of the universe, justified in regarding cosmic theories as inherently improbable." Accordingly we may turn to ideas regarding the evolutionary origin of life on the earth from inorganic matter.

TERRESTRIAL ORIGIN

It is of basic importance to define as clearly as possible the probable physical conditions under which the advent of living organisms may have occurred, for in this way some ground is provided for rational speculation. Of peculiar significance are the questions relating to the available energy sources of the first organisms and the state of the major biological elements, particularly carbon and nitrogen, at the beginning of the earth's history.

At present it is, of course, the energy from the sun that turns the wheels of living machinery. Some authorities insist that solar energy, particularly the ultraviolet light, which is now absorbed by the ozone layer of our modern oxygen-rich atmosphere, initially supplied the energy for the building up of organic compounds. According to this view, life has been dependent from the beginning on a photosynthetic process, though at first this process would involve the production of

some relatively simple compound, like formaldehyde, by the action of ultraviolet light on water and carbon dioxide, rather than the elaborate utilization of visible light by the chloroplast that is known today.

It would appear that some relevant information can be obtained from the planet Venus, because it has a well-developed atmosphere of carbon dioxide; no oxygen or water vapor is present. Since there is no reason to think Venus more favorably situated than the earth for the development of a carbon dioxide atmosphere, it is reasonable to suppose that carbon existed on the original surface of the earth in the form of CO_2 . Until we know whether free oxygen was also originally present, we cannot tell whether the first step, the formation of formaldehyde photochemically, could take place or not. Balancing all the available evidence, it would seem slightly more probable that oxygen was absent, and that the earth's surface therefore was freely irradiated with ultraviolet.

Less information exists as to the original state of nitrogen than of carbon. Ammonia, however, appears to exist in igneous rocks, so that even if most of the nitrogen of the earth were initially in the atmosphere in a rather inert form, as it is today, enough ammonia might accumulate in the sea, as the result of erosion and volcanic activity, to provide a more active compound to initiate the synthesis of nitrogenous organic compounds. The possibility that cyanogen $(\text{CN})_2$ had been associated, as Pflüger long ago supposed, must not be entirely dismissed; but cyanogen, though cosmically abundant, is unstable in the presence of water and is hardly known in the earth's crust or atmosphere.

Whatever may have been the origin of the first organic compounds, their subsequent history in the presence of water, and probably of metallic compounds acting as catalysts, would be diversified. It has recently been suggested that once a large supply of simple organic compounds existed in the sea, colloidal matter would ultimately be formed by polymerization, and that finally the separation of droplets of colloidal concentrate from the more dilute medium would occur. If so, such droplets may have been the systems from which the first organisms evolved.

It will be noted that the various suggestions, except the cosmozoa theory, assume the chance of assemblage of the various elements of protoplasm: an assumption regarded by some as not unreasonable when the stupendous duration of time and the almost infinite varia-

tions in conditions that were at the disposal of nature are appreciated. It may be significant that the most important components of living matter are the cosmically abundant carbon, hydrogen, oxygen, and nitrogen: elements that would tend to collect in the thin boundary between the solid earth and outer space, which later became the biosphere or region of living organisms.

According to the statistical theory of probability, if one waits long enough anything that is possible, no matter how improbable, will happen—a thought which led Swift to remark that the attempt to advance knowledge by turning a crank has so far failed to produce a single learned treatise! Indeed, Darwin said that “if we consider the whole universe, the mind refuses to look at it as the outcome of chance.” Moreover, it must be emphasized that many modern biologists and physicists insist that the marvelous order of nature cannot be thought of as emerging from the fortuitous.

At all events scientists will agree that it is more profitable to direct attention, as in the previous chapters, to the nature and behavior of protoplasm as seen in the living organisms riotously abundant in the world today, and to dismiss the highly speculative problem of life's origin with the time-tested and enduring statement written nearly three-quarters of a century ago by Huxley: “Looking back through the prodigious vista of the past, I find no record of the commencement of life, and therefore I am devoid of any means of forming a definite conclusion as to the conditions of its appearance. Belief, in the scientific sense of the word, is a serious matter, and needs strong foundations. To say, therefore, in the admitted absence of evidence, that I have any belief as to the mode in which existing forms of life have originated, would be using words in a wrong sense. But expectation is permissible where belief is not; and if it were given to me to look beyond the abyss of geologically recorded time to the still more remote period when the earth was passing through physical and chemical conditions, which it can no more see again than a man can recall his infancy, I should expect to be a witness of the evolution of living protoplasm from not living matter. . . . That is the expectation to which analogical reasoning leads me; but I beg you once more to recollect that I have no right to call my opinion anything but an act of philosophical faith.” (Fig. 502.)

The preceding discussions have been concerned primarily with the universal and interrelated features of structure and function that char-

acterize plants and animals. In the following chapters an attempt will be made to view animate nature, with its prodigious variety of types and innumerable individuals, as a synthetic whole, and thus to develop a more unified concept of the virtually inexhaustible variety of life, dominated by the climax type, *Homo sapiens*.

CHAPTER XXXI

Survey of the Plant Kingdom

From so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved.

—Darwin

The Plant Kingdom, comprising about a quarter million known species, may for convenience be divided into three phyla in which structure and function apparently make the most of the opportunities for variation and specialization: the algae and fungi (Thallophyta); the mosses and kin (Bryophyta); and the vascular plants including ferns and seed plants (Tracheophyta). (p. 695.)

THALLOPHYTES

The division Thallophyta includes a large number of widely divergent plant groups, some unicellular and others with large multicellular bodies. The multicellular body, or thallus, occurs in a multiplicity of forms: filamentous, platelike, and tissue masses. Considerable tissue differentiation is evident in the higher algae types but the root, stem, and leaf of still higher plants with their complex association of tissues are not developed. Some thallophytes have an alternation of generations comparable to that which we are familiar with in higher plants. The Phylum Thallophyta is composed of two major series: the chlorophyll-bearing ALGAE and the FUNGI which lack this pigment.

ALGAE

The seaweeds and their fresh-water allies constitute the immense series of algae, some of the simplest of them presumably similar to the green plants from which all the higher plants have been derived. Although all the algae possess chlorophyll, in many species the green color is masked by special pigments so that there are BLUE-GREEN ALGAE or Myxophyceae, GREEN ALGAE or Chlorophyceae, BROWN ALGAE or Phaeophyceae, and RED ALGAE or Rhodophyceae.

Blue-green Algae. Most of the blue-green algae form "green slimes" on wet rocks and soil, in ponds and puddles, which, when examined under the microscope, reveal single cells or chains and filaments of numerous associated cells. The cells are so simple that there is no clearly differentiated nucleus, and the chlorophyll and other pigments are distributed in the cytoplasm and not confined to chloroplasts. Furthermore, neither motile spores nor gametes are formed, so they are the lowest green plants.

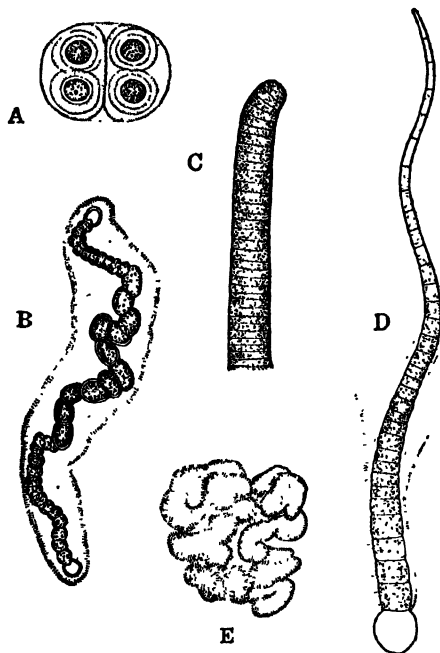


FIG. 349. Blue-green algae. A, *Gloeocapsa*; B, *Nostoc*, single filament; C, *Oscillatoria*; D, *Rivularia*, single filament; E, *Rivularia*, colony. All highly magnified except E which is natural size. (After Engler and Prantl.)

Gloeocapsa, a blue-green alga commonly found on damp rocks, consists of a single cell with a wall which swells to form a sticky jellylike coat, so that cell division results in temporary colonies. Apparently the presence of a gelatinous covering makes it possible for many blue-green algae to thrive in more dry situations than would otherwise be possible. (Fig. 349.)

Oscillatoria, living submerged in shallow water or on damp soil,

serves to illustrate the common filamentous forms—merely a thread of disc-shaped cells. Thus, as each cell divides, it contributes to the elongation of the filament which sooner or later breaks into two. Strangely enough, the filaments have the power of movement: chiefly a feeble creeping or spiral swinging. Other common filamentous forms are *Nostoc* and *Rivularia*. (Fig. 349.)

Although most blue-green algae live in fresh water, *Trichodesmium*, which forms an additional reddish pigment, floats sometimes in immense numbers in marine waters, for instance, the Red Sea, hence the name.

Green Algae. The green algae include an immense and varied assemblage of forms inhabiting both salt and fresh waters; in the latter constituting the dominant algal flora. Some algae are attached, whereas others are free, contributing a large portion to the floating population of microscopic plants and animals known as PLANKTON. In common with some blue-green and brown algae, many species find reservoirs an especially favorable abode and so prove a nuisance in municipal water supplies. However, the moisture of damp soil, shaded rocks, and tree trunks suffices for some species, while others flourish in salt lakes and on the surface of snow. The plant body may be unicellular, filamentous, or a plate of cells. In every case the cells are more highly differentiated than in the blue-green algae, since a definite nucleus and one or more chloroplasts are present.

The green algae are believed to be near the main line of ascent of the higher plants and accordingly have been intensively studied. It will be recalled that we have considered several representatives—for example, the unicellular *Protococcus* and *Sphaerella*, and the filamentous *Ulothrix*, *Oedogonium*, and *Spirogyra*—to illustrate not only the establishment of the simple thalloid plant body, but also the development of motile spores and the origin of gametes and sexual reproduction. *Ulothrix* and *Oedogonium* are commonly found as bright green films on stones in sluggish streams, ponds, and fountains; whereas *Spirogyra* ordinarily float in tangled masses as “pond scum,” buoyed by bubbles of gas, chiefly oxygen from photosynthesis. (Figs. 17, 24, 204-208.)

The unique green *Desmids* are close kin of *Spirogyra*. They constitute an abundant group of somewhat specialized forms, typically unicellular, whose geometrically symmetrical bodies are objects of beauty under the microscope. (Fig. 350.)

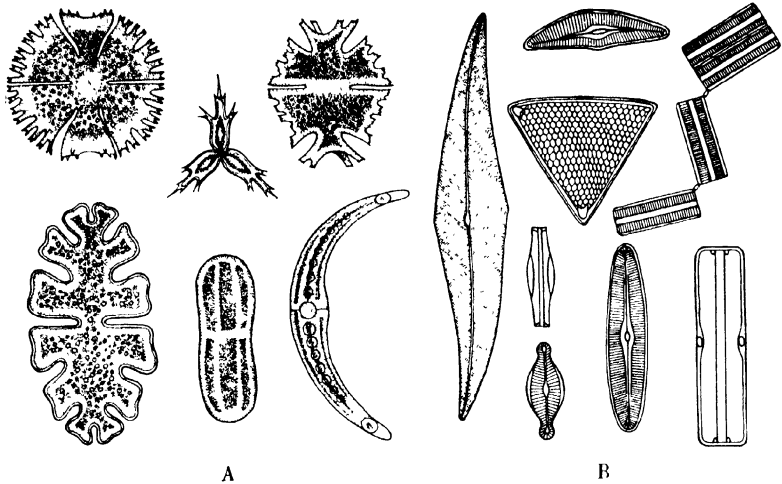


FIG. 350. Representative types of Desmids (A) and Diatoms (B). All are microscopic unicellular algae, but the desmids belong to the green algae, whereas the diatoms are most closely related to the brown algae. Highly magnified. (After Kerner. Redrawn.)

Another interesting group is represented by *Vaucheria*, commonly known as the "green felt," because the branching filaments interlace to form a coarse mat in shallow waters or on wet ground, and even on damp flower pots. Each plant may be regarded as a single very large cell, sometimes several inches long, containing numerous nuclei and chloroplasts. Reproduction occurs by spores and gametes. (Fig. 351.)

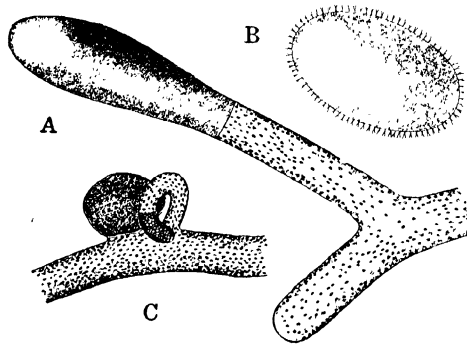


FIG. 351. *Vaucheria*. A, portion of a filament forming a spore at the end of the filament; B, spore; C, portion of filament with gamete-producing organs. (Magnified.)

Although their relationships to other algae are obscure, at this point may be mentioned the stoneworts, so called because some are rendered rough and brittle by incrustations of lime. Representatives are *Chara* and *Nitella* with slender, jointed, branching bodies that rise a foot or more from the bottom of ponds, and bear a superficial resemblance to higher plants. However, the cellular structure is simple, although some of the cells are an inch or more long and exhibit most strikingly protoplasmic streaming. Accordingly *Nitella* is a favorite object of study in biological courses. (Fig. 352.)

Brown Algae. The brown algae are typically marine forms that are conspicuously represented by the kelps and rockweeds of our coasts. They usually have tough, leathery, platelike or ribbonlike thalloid bodies that are anchored by holdfasts and buoyed by air bladders; but some species are delicate, such as *Ectocarpus*. The common kelp, *Laminaria*, may be thirty feet long, while some "giant kelps" attain a length of over 200 feet. Many are differentiated so that the parts of the thallus simulate the structures of higher plants. This occurs also in the gulfweed, *Sargassum*, which forms huge floating masses, such as the so-called Sargasso Sea. Most species reproduce by both spores and gametes, but the gulfweed and the common rockweed, *Fucus*, reproduce only sexually. Rockweed consists of a forking, ribbonlike thallus buoyed by bladders; the swollen tips of the thallus containing small pits in which gametes are produced. Thus most of the brown algae show considerable tissue differentiation and, in general, are more highly specialized than the green algae, but no higher forms appear to have arisen from them. (Figs. 25, 26, 209, 353.)

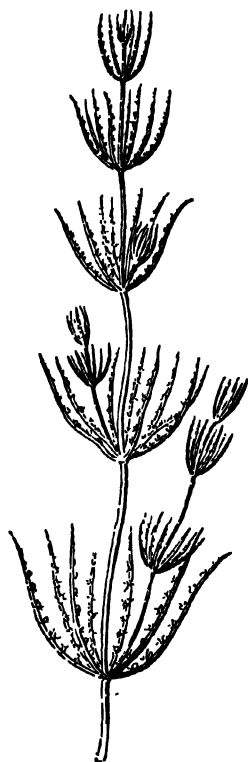


FIG. 352. *Chara*. End of main shoot. (After Strasburger.)

Finally, in passing, mention may be made of a group of unique unicellular forms, known as DIATOMS, whose relationships to other algae are uncertain. They possess a brown pigment, and typically each is

enclosed within a cellulose wall heavily impregnated with silica. Their beautiful glassy cases, in some species so regularly sculptured that they are employed to test the quality of microscope lenses, accumulate at the bottom of lakes and seas, such deposits during the geological past forming the "diatomaceous earth" that is the basis of some commercial polishing powders. Though diatoms are microscopic in size, their immense numbers make them of great importance in the synthesis of food for aquatic animal life. (Figs. 307, 350.)



FIG. 353. Gulfweed (*Sargassum*) showing the "stem," "leaves," and the berry-like floats of the thallus. (From Coulter, Barnes, and Cowles.)

Red Algae. The great majority of red algae are marine forms that are anchored by holdfasts, some species in the deepest waters that algae inhabit. It is probable that their characteristic reddish pigment, which masks the chlorophyll, is an adaptation to the lower illumination available in their environment for photosynthesis, and their typically graceful form and delicate texture to their usual abode below tide level. However, not all are red and some have a leaflike or leathery thallus; indeed, it may become incrustated with lime and so contribute to the formation of coral reefs, atolls, etc. (Fig. 354.)

Among the important characteristics of the red algae are the presence in most species of broad protoplasmic bridges between adjacent cells of the thallus, the absence of motile spores and gametes, and the

development of a highly specialized type of sexual reproduction—features that make the origin of the class obscure.

Well-known products of the red algae are agar-agar, extensively used as a culture medium in bacteriological work, and the abundant Irish moss of the North Sea and Atlantic Ocean which is collected in



FIG. 354. Red alga, *Polysiphonia*. Portion of thallus with club-shaped antheridia. (From Smith and others.)

large quantities and used in the preparation of jelly. Some are extensively cultivated for food, such as *Porphyra* which forms the “laver” of Japan, China, and Hawaii. In fact the algae in general are used in myriads of ways in agriculture, industry, medicine, photography, and even in cosmetics.

So we leave the algae, the great basic group of green plants, noting that these organisms accomplish the transition from the unicellular condition to the multicellular thalloid body, the beginnings of tissue

differentiation, and the establishment of reproduction not only by motile spores but also by gametes, and so introduces the origin of sex and alternation of generations in plants.

FUNGI

The thallophytes include also the fungi, an immense and widely distributed assemblage of diverse colorless plants which may be variously colored, but since they lack chlorophyll are never leaf-green. Being without chlorophyll, fungi, as shown earlier, cannot manufacture their food but must secure it either as parasites from living plants or animals, or as saprophytes from the products of living or dead bodies. Some fungi are either saprophytic or parasitic as occasion demands.

It is probable that most of the fungi are descendants from algae which have lost chlorophyll, while some have arisen from simple unknown forms without chlorophyll which are ancestral to all plants. Although a satisfactory classification of the group is difficult to establish, for practical purposes we may consider four subdivisions: the BACTERIA or Schizomycetes, the ALGALIKE FUNGI or Phycomycetes, the SAC FUNGI or Ascomycetes, and the CLUB FUNGI or Basidiomycetes. (p. 695.)

Bacteria. The Schizomycetes, or bacteria, include the smallest unicellular organisms revealed by the microscope, but in spite of their size they apparently have ruled the world since it was young, and today their study constitutes the immensely important science of bacteriology. However, we may summarily dismiss the bacteria at this point because they have already been considered as a factor in the circulation of the elements in nature, as well as from the standpoint of their relation to certain diseases of plants, animals, and man. (Figs. 19, 22, 284; p. 437.)

Algalike Fungi. Common examples of the algalike fungi, or Phycomycetes, are the black molds that form furry growths on damp bread, preserved fruit, etc., the water molds, and the blights that cause very destructive plant diseases. The plant body consists of an extensive branching mass, or MYCELIUM, of colorless filaments, or HYPHAE, which permeate the nutritive material and function as digestive and absorbing organs. Certain specialized hyphae give rise to spores or gametes.

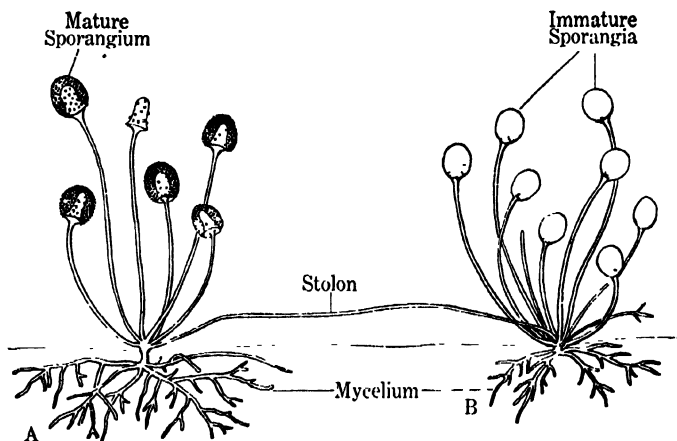


FIG. 355. Bread mold, *Rhizopus*. Older plant (A) has given rise to another plant (B) by growth of stolon. The mycelium permeates the bread. See Fig. 356. Magnified.

The bread mold (*Rhizopus*), one of the black molds, liberates clouds of nonmotile spores that are widely distributed by air currents, as is attested by its almost universal distribution. Also under certain conditions a nonmotile gamete is formed by a hypha when it comes in contact with one from another plant, presumably of the opposite sex. (Figs. 355, 356.)

Closely related to the black molds is *Empusa*, which kills the housefly, a halo of its hyphae often being seen in the autumn about dead flies on window panes. The mycelium of the common water mold, *Saprolegnia*, develops in the tissues of dead aquatic insects, though certain related species frequently cause serious depredations among fish in aquaria. Some water molds find sufficient moisture for their existence on dead organisms in the soil. Reproduction occurs by motile spores and by gametes.

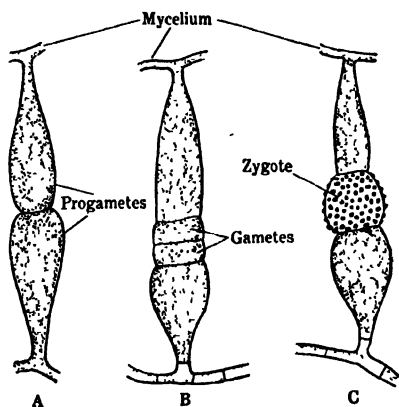


FIG. 356. Bread mold, *Rhizopus*. Formation of gametes and fertilization, after contact of progametes of hyphae of two strains. Highly magnified.

Representative of the blights are the blister blight of the shepherd's purse and radish, the potato blight, and the downy mildew or blight of the grape. All these species form extensive mycelial growths in the tissues of their hosts, and are propagated by externally produced spores known as CONIDIA. The spores are distributed by the wind, but become motile on reaching the moist surface of a prospective host. Gametes also arise and fertilization results in a resting zygote which forms motile spores ready to infect another host.

Sac Fungi. Nearly everyone is familiar with the blue, green, and yellow molds so common on fruit, damp leather, and cheese. Indeed,

the characteristic flavors of some cheeses are due to particular molds. Recently it has been found that certain chemical products of molds, such as *Penicillium* and *Aspergillus*, are highly effective inhibitors of bacterial reproduction and at the same time apparently harmless to human tissues. Accordingly they are of great value in the treatment of many infections. One of the most widely used antibiotic, known as penicillin, is secured chiefly from *Penicillium notatum*. (Fig. 357.)

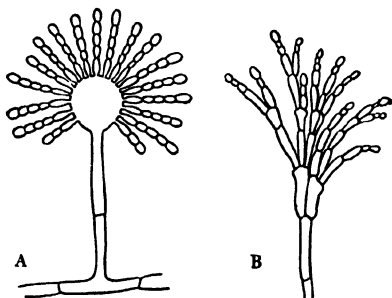


FIG. 357. A, *Aspergillus* (green or yellow mold); B, *Penicillium* (blue mold). Hyphae bear chains of air spores, or conidia. Highly magnified. Redrawn.

Other common sac fungi are the powdery mildews, such as *Microsphaera* which is found on lilac leaves. Dissemination is by conidia and by ASCOSPORES that develop in unique spore sacs, or asci; hence the name Ascomycetes. In many species, sexual phenomena precede the development of ascospores.

Still other examples of sac fungi are the edible truffles and morels, and the various species that produce diseases known as the "black-knot" of the plum and cherry, the "ergot" of rye, and the "peach-curl." The yeasts are generally included as specialized or degenerate sac fungi that do not develop a mycelium. Yeast cells typically reproduce by budding, but under adverse conditions resort to the formation of ascospores. The metabolism of yeast has already been considered. (Fig. 283; p. 398.)

Club Fungi. Here the most highly organized of the fungi are assem-

bled, constituting the Basidiomycetes: the rusts and smuts and the mushrooms or toadstools. The former are chiefly parasitic plants, whereas the mushrooms and toadstools are for the most part harmless saprophytes, though including a few parasites. Reproduction is typically by BASIDIOSPORES, so called because they arise from a characteristic reproductive structure, the BASIDIUM. Sexual processes are obscure.

The rusts and smuts comprise a large group of very destructive parasites of higher plants. Well-known are the cedar and apple rust, the wheat and barberry rust, and the white pine and gooseberry rust, each with an amazingly complex life history including several types of spores. The smuts are particularly injurious to cereals, producing in wheat, barley, corn, oats, etc., the diseases known as smuts from the appearance of the masses of dark-colored spores. (Fig. 339.)

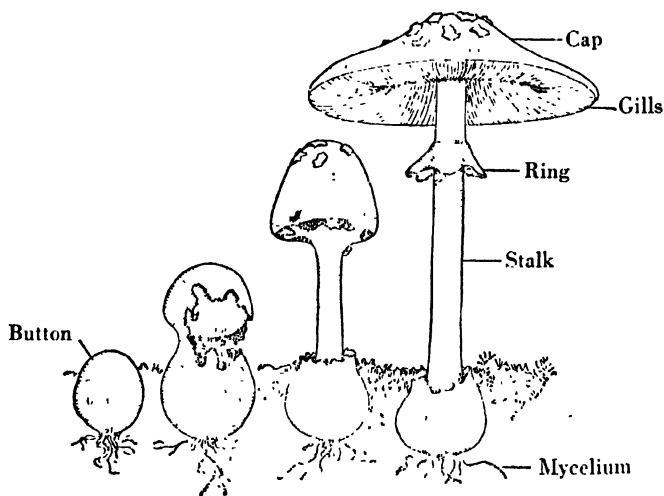


FIG. 358. Mushroom, *Amanita* (poisonous), showing stages in the development of the plant body and the spore-bearing gills from the underground mycelium. (From Ganong, after Gibson.)

The common field mushroom, *Psalliota campestris*, so widely cultivated for its edible qualities, is representative of the group, though many mushrooms, such as various species of *Amanita*, are highly poisonous. The plant body consists of an extensive tangled mass of branching mycelial filaments that spread through the substratum and give rise to large, fleshy spore-bearing structures, the conspicuous

mushrooms. The spores of *Psalliota* are formed on platelike gills on the under surface of the expanded cap of the mushroom, but in some genera tiny tubes are formed through which the spores are released. (Fig. 358.)

Closely related to the mushrooms are the common parasitic bracket fungi that form shell-like outgrowths on trees and stumps, the coral fungi resembling branching corals, the puffballs, earthstars, and others—all the large spore-bearing structures with hidden mycelia.

This completes our survey of the fungi and also of the heterogeneous group, the thallophytes; but, in passing, mention must be made of the LICHENS which are composites of algae and fungi in symbiotic relationship; each contributes to the welfare of the other partner. The fungus, usually one of the sac fungi, makes up the bulk of the body with its interwoven mycelium, and in this the unicellular algae, either green or

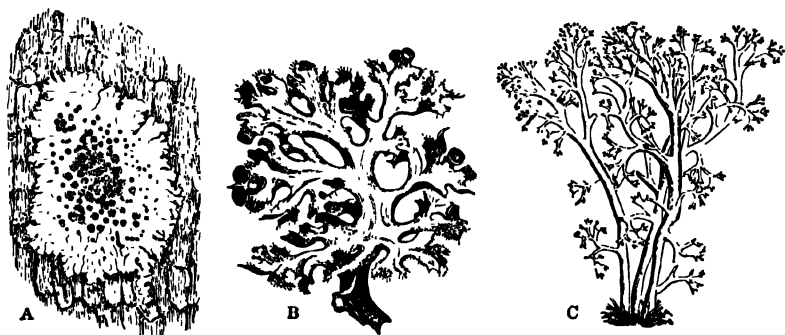


FIG. 359. Lichens. A, crustose type, *Physcia*, growing on bark of tree trunk; B, foliose type, *Cetraria*; C, fruticose type, *Cladonia*. See Fig. 311. (From Ganong.)

blue-green, are enmeshed. There are three chief types of lichen bodies: the CRUSTOSE in which the thallus forms an incrustation on trees, rocks, or soil; the FOLIOSE, comprising leaflike lobes attached at one or more points to the substratum; and the FRUTICOSE with filamentous bodies, branching like shrubs, and either prostrate, pendent, or erect. (Figs. 311, 359.)

Lichens are of particular interest for their exhibition of symbiosis, and also for their contributions to the soil. Certain crustose forms dissolve and disintegrate rocks and so provide a footing for other plants. Moreover lichens such as the so-called Iceland moss and reindeer moss are of some importance as animal food, the rock tripe may serve in an

emergency as human food, and the bread of heaven may well be the manna of the Israelites.

BRYOPHYTES

The mosses and their allies, or Bryophyta, form a relatively unimportant phylum of inconspicuous green plants which are somewhat intermediate between the thallophytes and the tracheophytes, but their relationships with these groups are not clear. Although a few bryophytes are aquatic, most of them are land dwellers and afford a glimpse of a plant type which arose from the algae and emerged from the water, but rather falteringly made the land its abode; the conquest of the land was reserved for the better adapted tracheophytes. (pp. 292-295; 695.)

The bryophytes differ from their algal ancestors chiefly by usually possessing a more complex body and reproductive structures, in particular archegonia, and by the further specialization of the alternation of generations so that the sporophyte is dependent upon the gametophyte. It will be recalled that the gametophyte is the dominant generation in the life history of bryophytes: the moss is a gametophyte. (Figs. 210, 211.)

The bryophytes include two classes: the relatively little-known LIVERWORTS, or Hepaticae, and the true MOSSSES, or Musci, familiar to nearly everyone.

Liverworts. The majority of the liverworts are moisture-loving plants, some floating on the water but more growing on damp ground, rocks, or the bark of trees. The body of the gametophyte generation is a prostrate thallus that may have leaf-like structures similar to those of true mosses. The ventral surface is provided with rhizoids for attachment and perhaps for absorption, while the dorsal surface exposes chlorophyll-bearing cells to the sunlight. Apparently there have been three main lines of liverwort evolution, well represented by *Marchantia*, *Porella*, and *Anthoceros*.

In *Marchantia* and its kin the body is essentially a remarkably complex

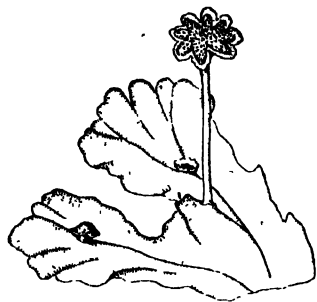


FIG. 360. *Marchantia*. Thallus with an erect receptacle, bearing antheridia, and two surface bud cups. (From Ganong, after Kny.)

thallus, owing to a thickening and differentiation of its component cells into tissues. (Fig. 360.) Reproduction occurs asexually by buds that develop in tiny cups on the dorsal surface and, sooner or later, fall off and form new plants, and also sexually by gametes that arise on characteristic upright structures known as male and female receptacles. Sperm discharged from the antheridia fertilize eggs in the archegonia, and then each zygote, *in situ*, develops into a simple sporophyte. Subsequently the latter liberate spores that give rise to gametophytes, and so the alternation of generations is completed.

Porella and its allies constitute the greatest group of liverworts. They are typically delicate plants growing either in damp situations or on rocks and tree trunks, and bear little resemblance to Marchantia. Commonly they are called scale mosses or leafy liverworts and are mistaken for true mosses because the gametophyte body usually consists of a stem bearing three rows of small, simple leaves. (Fig. 361.)

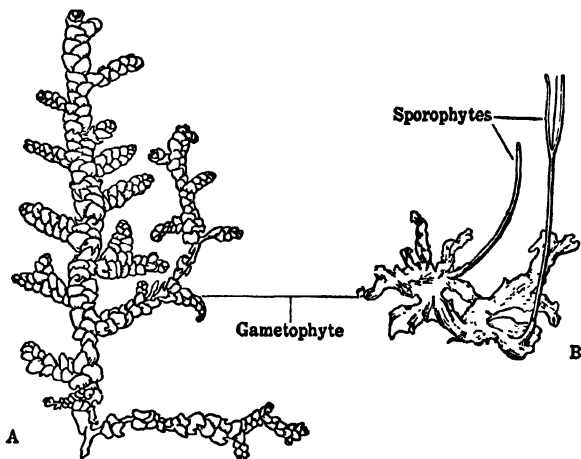


FIG. 361. A, *Porella*, gametophyte; B, *Anthoceros*, gametophyte bearing sporophytes. (From Smith and others.)

Anthoceros forms are few and inconspicuous, but of particular interest because, in contrast to other liverworts, the gametophyte is simple while the sporophyte is considerably more complex and bears chlorophyll. Thus, although the sporophyte is dependent upon the gametophyte for water and solutes, it carries on photosynthesis and so is prophetic of the gradual ascendancy in prominence of the sporophyte as plant evolution progresses. (Fig. 361.)

Mosses. The true mosses, or Musci, are adapted to nearly all habitats from actual submergence to great dryness. The peat moss, *Sphagnum*, often fills ponds with a dense growth that flourishes above the surface and dies below, with the final result that the lower layers frequently become transformed into peat, a low-grade fuel. Incidentally, the high absorptive capacity of *Sphagnum* commends it as an emergency surgical dressing and as a material for packing live plants. (Fig. 362.)



FIG. 362. Peat moss, *Sphagnum*. Gametophyte plant with sporophytes at the tip of the stem. Redrawn. (From Bergen.)

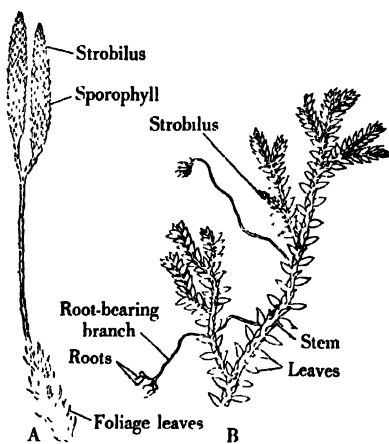


FIG. 363. A, *Lycopodium*; B, *Selaginella*. Portions of mature sporophytes. Redrawn. (From Smith and others.)

But by far the most numerous and common mosses form the abundant carpet vegetation of many of the drier places of the earth, and presumably are related to the original green plants which covered the uplands before the more successful tracheophytes had arisen.

Since the general structure of the body, with simple upright branch and leaves, and the clear-cut alternation of generations exhibited by mosses have already been considered, we can leave them, and the bryophytes in general, at this point. We may note, however, that the mosses have made significant advances upon the foundations afforded by the thallophytes, though they are not believed to be the direct ancestors of higher plants. (Figs. 210, 211.)

TRACHEOPHYTES

The immense assemblage of plants exhibiting a specialized system of vessels for the conduction of materials through the body is known as the Tracheophyta, and the group includes all the higher members of the plant kingdom: the ferns and their kin and the seed plants. They are *vascular plants*, in contrast to the nonvascular thallophytes and bryophytes. Indeed, the development of a vascular system in the independent sporophyte generation constituted an epoch in plant evolution because it made possible a larger and more complex body with highly differentiated tissue systems. So some of them found a free field and flourished as the first forests of the earth, notably during the Carboniferous period. (Fig. 265; pp. 522, 695.)

Three great classes of the tracheophytes are the CLUB MOSSES (Lycopsidea), the HORSETAILS (Sphenopsida), and the FERNS and SEED PLANTS (Pteropsida).

CLUB MOSSES

The best-known club mosses are the so-called ground pine and running cedar, the latter widely used for Christmas greens. Both are members of the genus *Lycopodium* and have slender branches entirely covered with small, elongated leaves. (Fig. 363, *A.*) Many of the erect branches terminate in a conspicuous STROBILUS, a compact group of highly modified leaves (sporophylls) that bear spores. A smaller club moss, *Selaginella*, is of particular interest because it produces two kinds of spores (heterospory) and, therefore, male and female gametophytes. These are dependent upon food stored in the spores and so upon the parent sporophyte generation, a complete reversal of the relations in the bryophytes. In fact *Selaginella* closely approaches seed formation. (Fig. 363, *B.*)

HORSETAILS

Some three dozen species of horsetails, all members classified in the genus *Equisetum*, are relatively inconsequential relics of the geologic yesterday when horsetails were tree-like. The sporophyte of *Equisetum* consists of a creeping stem from which arise green branches that are typically hollow, markedly jointed, and abundantly provided with silica—the latter suggesting their use for scouring and the name “scouring rush.” At each joint of the branches there is a whorl of tiny

scalelike leaves, but photosynthesis is chiefly performed by chlorophyll in the branches. Spore-bearing strobili develop either at the tips of the vegetative branches or of special ones devoid of chlorophyll. Existing horsetails are homosporous, but some of the ancient species were heterosporous. (Fig. 364.)

FERNS AND SEED PLANTS

The true ferns, or Filicineae, are today the most numerous and representative of the plant group commonly called the Pteridophytes. They flourish in temperate regions, but their fullest development is reached in the tropics where they are a prominent feature of the vegetation, and vary from low forms, with either delicate and filmy or broad leaves, or *fronds*, to trees rising some forty feet and crowned with leaves thirty feet long. (Figs. 48, 211, 212, 365.)

The structure of ferns suggests in various ways the anatomy of the seed plants. The fibrovascular tissue of certain species forms a hollow cylinder of xylem and phloem which separates the basic tissue of the stem into an inner pith and outer cortex. In fact, in some of the larger ferns there may be several concentric rings of vascular bundles. The spores of some species are formed on special leaves, or sporophylls.

Ferns have already been considered with particular reference to alternation of generations, so we may dismiss them with a passing reference to the small group of water ferns. They bear little superficial resemblance to the common ferns, as is attested by Marsilea. This little clover-leaf fern is of much interest, not only because it is heterosporous, but also because the male and female gametophytes are so greatly reduced that they essentially consist of only reproductive structures (antheridia and archegonia) which develop within the respective spores: a reduction that is prophetic of the condition in higher plants. Clearly the great group of pteridophytes, with

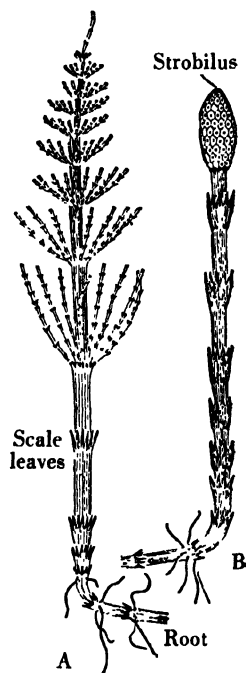


FIG. 364. Horsetail *Equisetum*. Sterile (A) and fertile (B) aerial branches of sporophyte. Redrawn. (From Smith and others.)

the development of a complex dominant sporophyte generation with vascular tissues, large foliage leaves, and, in some cases, sporophylls, heterospory, and attendant phenomena, carries on apace to the conditions found in the seed plants. However, the evidence indicates that the modern ferns are not the ancestors of the seed plants. (Figs. 214, 215.)

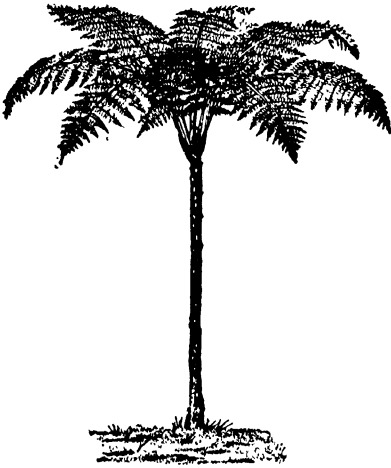


FIG. 365. Tree fern (*Alsophila*).
(From Martin.)

The seed plants, or technically Spermatophytes, are the modern plants that have successfully dominated the vegetable world, probably largely by virtue of seed formation. They are by far of most economic importance. In fact, to most people seed plants and botany are essentially synonymous, although, of course, any real understanding of seed plant structure and life history is impossible without a knowledge of the lower plants. This is particularly true of their most characteristic feature, seed formation: the partial development of the new sporophyte generation within the tissues of the

previous sporophyte generation, and then its release, with a food supply and a protective coat, as a seed. (Figs. 27, 219, 221, 222.)

Since previously we have had occasion to survey the structure and life history of seed plants, and also the development and significance of flower and seed, our present attention may be confined chiefly to an outline of their classification. (Chaps. V, VI, XXI.)

There are two remarkably independent lines of seed plants: the GYMNASPERMS that bear seeds exposed on sporophylls arranged in the form of a strobilus, or CONE, and so are without flowers in the popular sense, and the ANGIOSPERMS that produce seeds enclosed within the base of a flower—the typical flowering plants.

GYMNASPERMS

The gymnosperms include the tropical CYCADS, the GINKGO, and the familiar CONIFERS, commonly represented by the pines, firs, spruces,

hemlocks, cedars, redwoods, etc. About five hundred species are living today, but in the geological past the gymnosperms were the dominant seed plants and flourished in association with giant club mosses, horse-tails, and related forms.

Cycads. The cycads, a very small remnant of a once important group, bear a superficial resemblance to ferns, and apparently have arisen from an ancient and now extinct group known as seed ferns. The stem is either a stout columnar shaft, or like a great tuber crowned

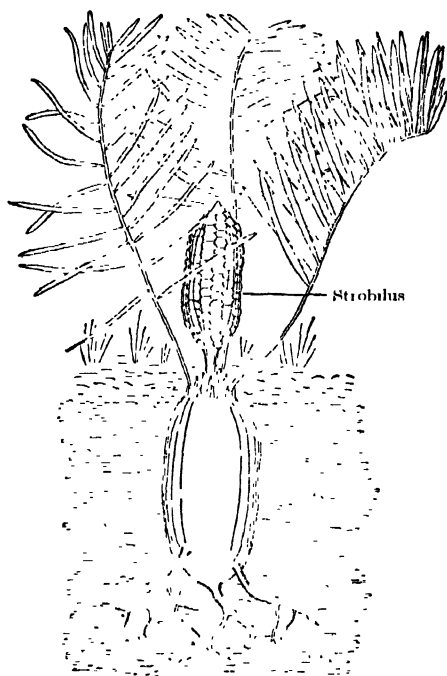


FIG. 366. A cycad, *Zamia*. Mature sporophyte bearing a central carpellate strobilus. (From Smith and others.)

with a rosette of large leaves as in the well-known *Zamia* of Florida. It is of much interest that the cycads, and the related ginkgo, produce motile sperm, a function that has been lost by the male gametes of all other seed plants. (Fig. 366.)

Ginkgo. There is only a single living species of the Japanese maiden-hair tree, *Ginkgo biloba*. The leaves resemble in venation the leaflets of some ferns. The plant is not known in the wild state but fossil

species, very similar to the living species, are of widespread occurrence, beginning in the early Mesozoic.

Conifers. The representative gymnosperms in temperate regions are the conifers with their characteristic groups of sporophylls, or cones, and scale or needle leaves: a leaf form adapted to endure severe conditions. Conifers either have no regular period of leaf falling or shed their leaves every two years, and so are "evergreen." However, the larch and bald cypress lose their leaves annually. (Figs. 367, 368.)

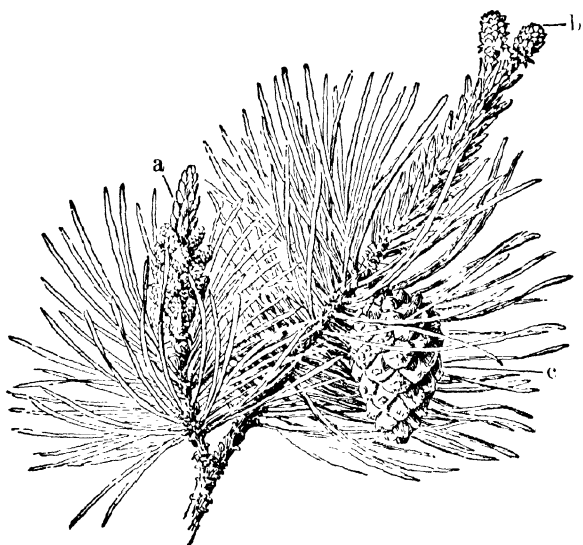


FIG. 367. Scotch Pine, *Pinus sylvestris*. Twig showing: a, staminate cones; b, young carpellate cones; c, mature carpellate cone. (From Bergen.)

ANGIOSPERMS

The most numerous, conspicuous, and important group of the vegetable kingdom comprises the angiosperms: a relatively modern array, apparently still in active evolution, that has gradually displaced the gymnosperms in dominance. Angiosperms are the familiar flowering plants, and the development of true flowers has involved the elaborate interrelationships with insects by which pollination is effected. It is true that some angiosperms depend on the wind for pollen distribution, as do all conifers; nevertheless insects appear to be largely responsible for the great variety of floral structure. (Figs. 219, 306, 368.)

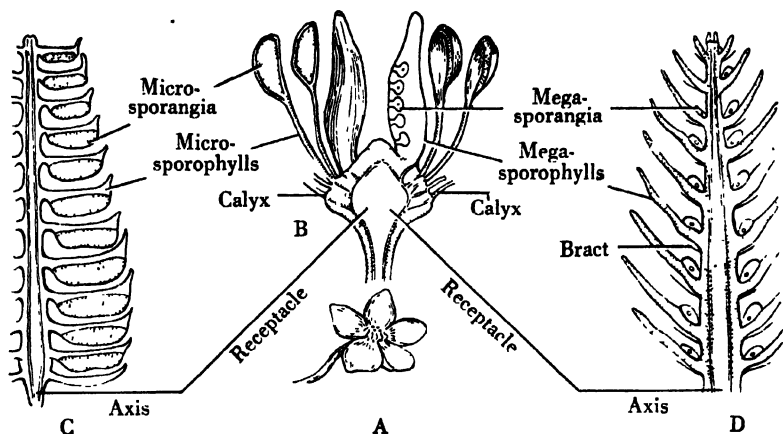


FIG. 368. Diagrams to illustrate the corresponding parts of the strobili of the spruce and the flower of the marsh marigold. A, flower of the marigold; B, section of the flower; C, median longitudinal section of the staminate strobilus of the spruce; D, similar section of the carpellate strobilus of the spruce. See Fig. 373. Redrawn. (From Densmore.)

It will be recalled that the typical flower is a modified branch bearing sporophylls (carpels and stamens) and a perianth of sepals and petals. In the club mosses, horsetails, and some ferns, and in the gymnosperms, the flower consists of a cluster of sporophylls, the strobilus or cone, but a perianth is absent. The diversities of floral structure, as well as the arrangement of the flowers (either singly or in different

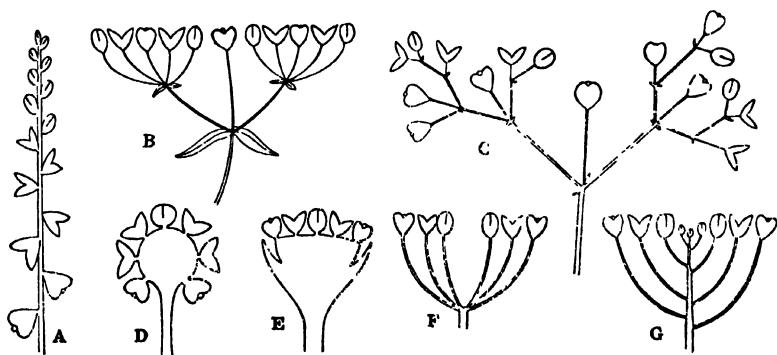


FIG. 369. Diagrams showing the arrangement of flowers in some common types of inflorescence. A, spike; B, cyme (compound); C, fascicle; D, head (clover type); E, head (composite type); F, umbel; G, corymb. (After Stevens.)

types of clusters, termed INFLORESCENCE), are usually departures from a more or less typical plan and thus afford the characteristics which are largely depended upon in the classification of angiosperms. (Figs. 216-218, 369.)

There are two great classes of angiosperms, quite distinct but somewhat parallel: the DICOTYLEDONS, represented by over one hundred and fifty thousand species, and the MONOCOTYLEDONS, by about fifty thousand species. The typical contrasting characters of these groups are as follows:

Dicotyledons. The embryo sporophyte in the seed has two lateral cotyledons (seed leaves); the vascular bundles of the stem usually have cambium and form a hollow cylinder, permitting an annual increase in diameter and in branching; the veins of the leaves form a conspicuously netted system; and the floral parts are typically in multiples of five. (Figs. 40; 41; 370, A.)

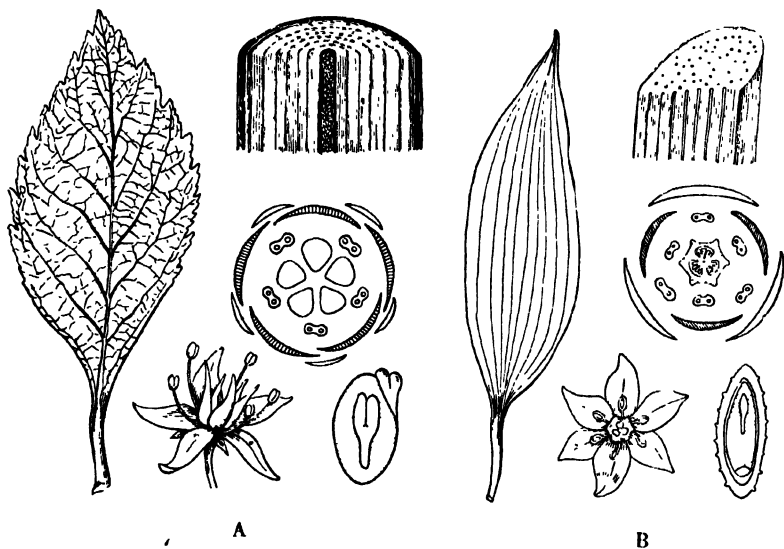


FIG. 370. A, diagrams of characteristic structures of dicotyledonous seed plants. Left, leaf, netted-veined; above, stem with vascular bundles arranged so that wood forms annual rings; center, flower with parts usually in 5's (transverse section); below left, flower; below right, section of seed having embryo with *two* cotyledons. B, diagrams of characteristic structures of monocotyledonous seed plants. Left, leaf, parallel-veined; above, stem with vascular bundles scattered through the pith; center, flower with parts in 3's (transverse section); below left, flower; below right, section of seed having embryo with *one* cotyledon. (From Gager. Redrawn.)

Monocotyledons. The embryo in the seed has a single lateral cotyledon; the vascular bundles of the stem are without cambium and are irregularly scattered so that usually no annual increase in diameter or extensive branching occurs; the veins of the leaves are parallel; and the floral parts are in multiples of three. (Figs. 43; 370, *B.*)

DICOTYLEDONS

The commanding position among the vegetation of the earth today is held by the dicotyledons: herbs, shrubs, and trees displaying almost every conceivable variety in size, form, and habitat. There are about 8000 genera arranged in nearly 225 families, from which the following may be taken as representatives:

Willow Family. The willows and poplars, widely distributed woody shrubs or trees, are among the most primitive dicotyledons, as is indicated by their very simple flowers without sepals and petals. These are in clusters, known as CATKINS, which comprise either carpellate or staminate flowers, which are borne on separate plants. The fuzzy catkins of the pussy willow are eagerly sought in early spring. Closely related families are represented by the walnuts, birches, beeches, and oaks. (Fig. 371.)

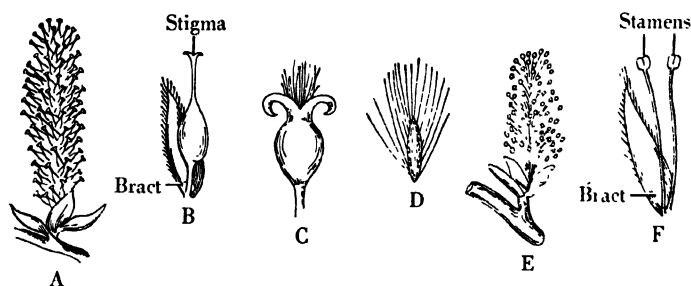


FIG. 371. Flower parts of the willow. A, carpellate catkin, or flower group; B, carpellate flower; C, fruit; D, seed; E, staminate catkin; F, staminate flower. Redrawn. (From Smith and others.)

Nettle Family. This is a rather diversified group of herbs, shrubs, and trees with slightly more complex flowers possessing sepals. Most of the plants are tropical, but well known are the elms, mulberries, figs, hops, hemsps, and nettles. Many members of the family contain a milky juice, or LATEX: that from certain species being used as a beverage or as a source of rubber. (Fig. 372, *A.*)



FIG. 372. A, elm twig bearing flowers and fruit; B, inflorescence of sweet william, a member of the pink family. (From Smith and others.)

Pink Family. This family consists chiefly of herbs with relatively conspicuous flowers, usually provided with both sepals and petals. Widely known are the carnations, sweet williams, and chickweeds. (Fig. 372, B.)

Buttercup Family. The common buttercup is fairly typical of this family, which includes many species with showy flowers due to prominent sepals or petals. Some of the best-known near relatives of the buttercup are the anemones, hepaticas, marsh marigolds, peonies, and columbines. (Fig. 373.)

Mustard Family. Representative of this family are large numbers of herbs, often with acrid substances such as the familiar mustard. The flowers have a characteristic cross-shaped corolla and are arranged in a **RACEME**, as is well seen in the shepherd's purse. Other common examples are the radish, turnip, and water cress, as well as the variations of a species of *Brassica* such as the cabbage, Brussels sprouts, and cauliflower. (Figs. 326, 374.)

Rose Family. This is a very large and diversified assemblage of herbs, shrubs, and trees, and includes many of the most important economic and ornamental plants. Representatives of several sections

of the family, each characterized by a special type of flower and fruit, are the apple and hawthorn, the strawberry and cinquefoil, the raspberry and blackberry, the roses, and the plum, cherry, and peach. (Figs. 37, 224, 375.)

Cactus Family. The plants most highly adapted to withstand the extreme heat and dryness of desert areas are some thousand species of shrubs and trees that form the exclusively American cactus family.

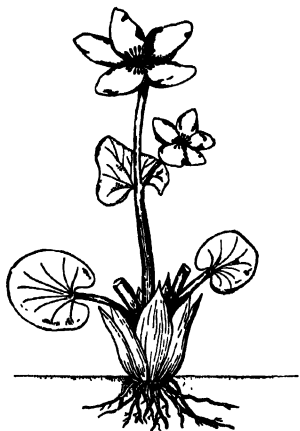


FIG. 373. Marsh marigold. Redrawn. (From Densmore.)



FIG. 374. Shepherd's purse; a plant (*below*) and a raceme bearing flowers on its upper portion and fruits below. (From Smith and others. Redrawn.)

To conserve water most cacti have dispensed with leaves, and the stem and branches have taken over the photosynthetic function. Spines are profusely developed and serve as a needed protection since succulent vegetation is rare in the typical habitat of these plants. In spite of their unorthodox body form, most cacti bear beautiful cup-shaped or funnel-shaped flowers of variegated colors—sometimes only for a few hours, or for one night as is the case of the famous night-blooming *Cereus*. Common types of cacti include the prickly pears (*Opuntia*),

barrel, organ pipe, suharo, and hedgehog cactus. One species of prickly pear occurs sparingly in New England. (Fig. 376.)

Pulse Family. The peas, beans, and peanuts are members of an immense family which is characterized, in general, by bilaterally symmetrical flowers and fruit in the form of a pod, or **LEGUME**. In the

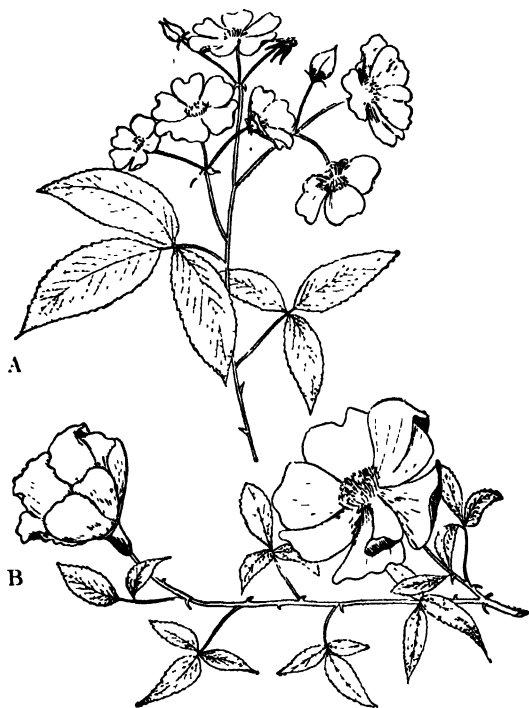


FIG. 375. A, Cherokee rose; B, tea rose. (From Hylander.)

temperate zone a few are trees, such as the locusts, but in the tropics trees are abundant, supplying lumber, gums, drugs, and dyes. It will be recalled that certain plants of this family, such as beans, clovers, soybean, and alfalfa, have symbiotic relations with nitrogen-fixing bacteria, and so are important for the nitrogen supply of soils. (Figs. 22, 377.)

Parsley Family. Characterized by small flowers arranged in an **UMBEL**, this family is commonly represented by herbs that secrete volatile, odorous substances. Parsley and celery, parsnip and carrot

are edible species and so quite unlike the poison hemlock and the wild carrot and wild parsnip. However, the production of volatile oils is even more characteristic of the large *Mint Family*, which includes the peppermint, spearmint, and catnip. (Figs. 369, 378.)

Nightshade Family. Representatives of this group of herbaceous plants with radially symmetrical flowers are known to nearly everyone by the tobacco, potato, tomato, and red pepper. Many of the fruits contain substances used as drugs; indeed, a "greened" potato may develop a virulent poison. (Fig. 379.)

Gourd Family. Strange to say, the flowers of this family are either staminate or carpellate as in the primitive willow family, though otherwise they show characteristics that justify their advanced position among the dicotyledons. Most species are natives of tropical or semi-tropical regions, but many, such as the squash, muskmelon, pumpkin, cucumber, watermelon, and gourds, prosper under cultivation farther north. (Fig. 380.)



FIG. 376. Barrel cactus. (From Bergen.)



FIG. 377. Legumes: soy bean (left), alfalfa, and vetch. (From Hylander.)

Composite Family. The dicotyledons culminate in the great Composite Family, which alone comprises about twenty thousand species, nearly one-sixth of all seed plants, and has an immense geographical distribution due largely to the many devices by which its seeds are

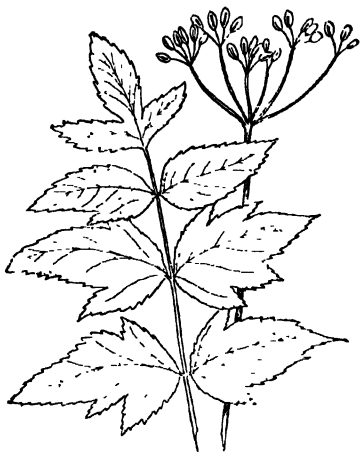


FIG. 378. Wild parsnip. Compound umbel composed of several simple umbels. (From Hylander.)

widely disseminated. The most notable feature of the family, well represented by the daisy, is the characteristic composite head, or flower cluster, in which the numerous individual flowers are usually differentiated into showy RAY flowers about the edge of the head and relatively inconspicuous DISC flowers within. Thus the individual flowers are subordinated to the cluster which superficially has the appearance of a single flower. Practically all composites are herbs, some of economic and many of ornamental value, but there are plenty of weeds. Chrysanthemums, asters, sunflowers, goldenrods, yarrow, dandelions, ragweeds, thistles,

sagebrush, and burdock are other composites typical of this most successful plant group. (Figs. 369, 381.)

MONOCOTYLEDONS

The monocotyledons are believed to have their origin in a very primitive dicotyledonous stock and then independently evolved complexities of floral structure along lines broadly parallel. They are mostly herbaceous plants, distributed in some 1200 genera and 42 families. Conspicuous among the latter are the following.

Cattail Family. This is one of the most primitive families and is well represented by the common cattails of marshes with their long-lived branching stem in the mud and annual aerial branches ensheathed with long leaves. The tiny flowers are without sepals and petals, and so remind one of the condition in the willow family, the simplest of the dicotyledons. The flowers are closely grouped in a cylindrical SPIKE, the lower flowers being carpellate and the upper staminate, and soon

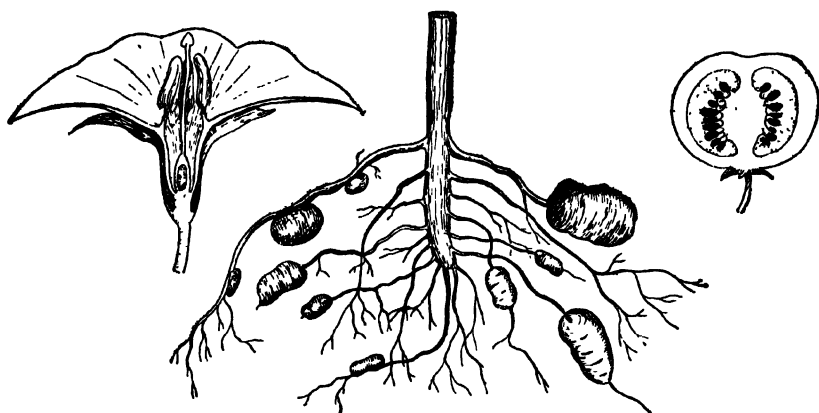


FIG. 379. Potato. Flower section (*upper left*), underground tubers, and section of fruit (*upper right*). (From Hylander.)

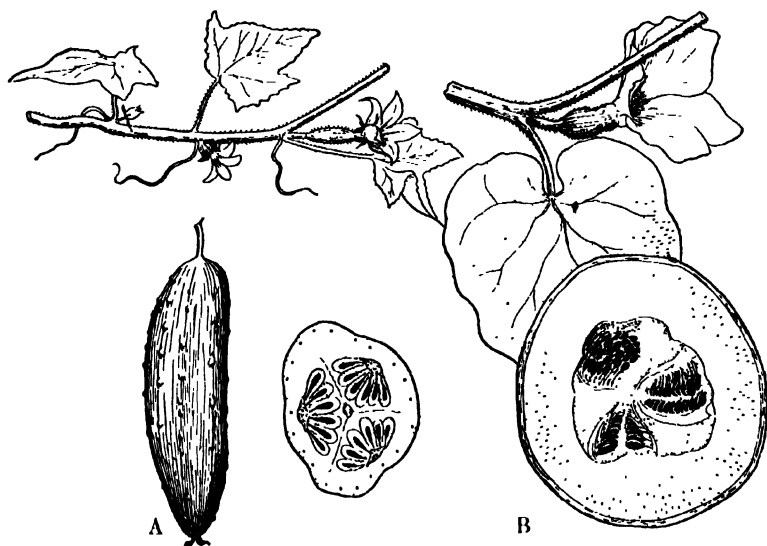


FIG. 380. Flowers and fruit of A, cucumber; B, muskmelon. (From Hylander)

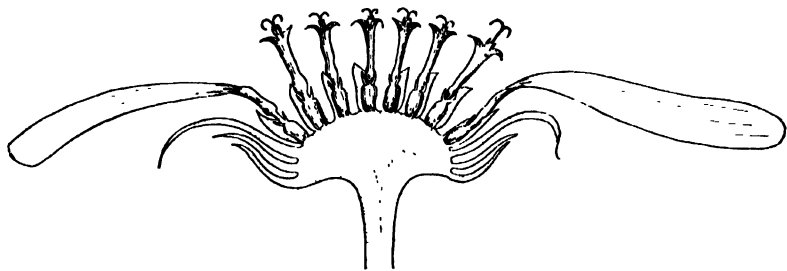


FIG. 381. Vertical section of entire flower head of the sunflower, showing bracts, two ray flowers, and six disk flowers (*center*). (From Hylander.)

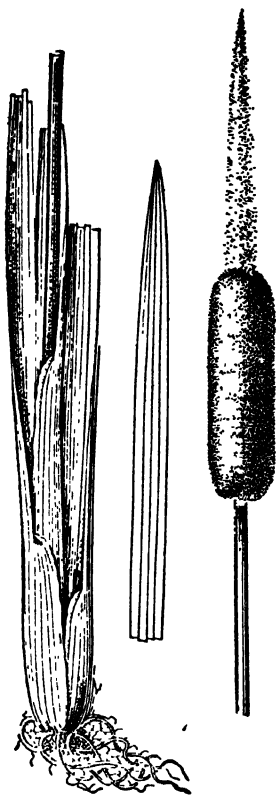


FIG. 382. Cattail. An aerial branch (*left*), a single leaf, and a spike, or flower cluster. (From Smith and others.)

after pollination the latter wither and disappear, leaving the characteristic cattail. (Figs. 369, 382.)

Grass Family. This is the most important of all plant families from the standpoint of usefulness to man. Grasses constitute a large, rather sharply defined group with simple, small flowers that lack a typical calyx and corolla and are usually arranged in a more or less compact head or spike above the leaves, as in wheat. Sometimes stamens and carpels are in separate flowers as, for instance, in Indian corn where the ear is a carpellate flower cluster and the tassel a staminate cluster. The stem typically is jointed, and by interlacing rootstocks may produce annual shoots, forming a turf. Other examples are the grasses of our lawns, oats and barley, as well as bamboo and sugar cane. Closely related to the grasses are the sedges—so-called rushes and marsh grasses. (Figs. 383, 384.)

Palm Family. Palms afford a conspicuous display in tropical vegetation, with their columnar stems crowned by immense leaves. Unlike most other monocotyledons, they usually have woody stems, and some are trees. The flowers are arranged in

spikelike clusters and possess a very simple perianth. Well-known representatives are the coco and date palms. The rattan palm is a climbing plant. (Fig. 385.)

Lily Family. This familiar assemblage comprises chiefly perennial herbs with well-developed bulbs or rootstocks and beautiful flowers. Usually the leaves of the calyx and corolla are similar in color, and

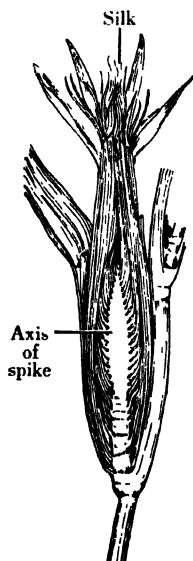


FIG. 383. Corn. A carpelate flower cluster, or ear, before fertilization. The axis of the spike is the cob, and the tip of each corn silk is a stigma. (After Sargent. Redrawn.)

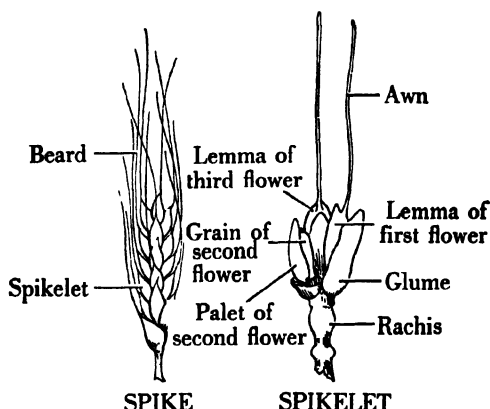


FIG. 384. Wheat inflorescence. Spike shows the complete flower bearing numerous spikelets. (From Mavor. Redrawn.)

often united at the base to form a tube. Many are garden favorites, such as the lilies, tulips, hyacinths, and so on to asparagus, onion, and garlic. Common wild forms include trillium and Solomon's Seal. (Figs. 38, 46, 386.)

Orchid Family. The orchids form not only the largest—over fifteen thousand species—but also the most specialized group of monocotyledons, with characteristic bilaterally symmetrical flowers exhibiting bizarre variations of sepals, petals, and other floral parts in adaptation to insect visitors that ensure cross-pollination. Curiously enough,

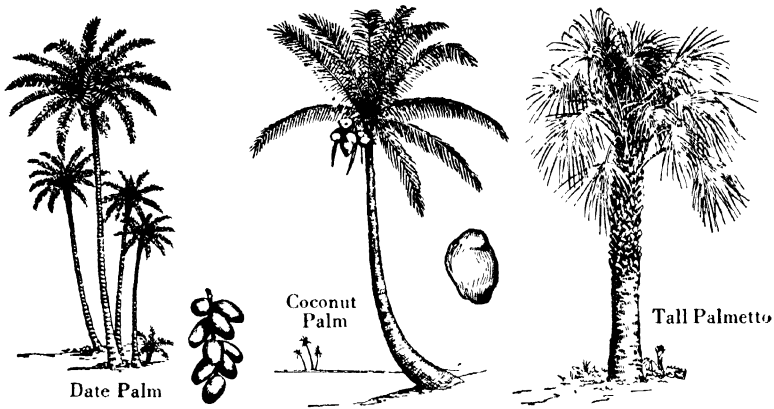


FIG. 385. Three economically important types of the monocotyledon Palm Family: the date palm for food; the coconut palm for food and for commercial fat (copra); the palmetto for fibers (raffia). (From Palmer.)

many of the flowers have a fanciful resemblance to "insects and their relatives, with spidery petals and sepals and variegated bodies which are the lips of the flowers." Orchids are chiefly tropical plants, many of them growing high up in trees as epiphytes, and some without chlorophyll living as saprophytes, but none as parasites. It is an interesting fact that intimate mycorrhizal and similar relationships are particularly well illustrated in the orchids.



FIG. 386. Flowers of the Turk's cap lily. (From Hylander.)

Apparently they do not thrive in the absence of symbiotic association with the mycelial filaments of fungi, and their microscopic seeds even fail to germinate unless they are in relation with a specific fungus. Some orchids are of economic value, including the widely cultivated climbing vanilla which supplies the vanilla bean, and their beauty and their rarity in temperate regions give them an aesthetic attraction for all plant lovers, as is attested by the well-known lady's-slippers. (Figs. 306, 387; pp. 424-425.)

This completes a systematic survey of the plant kingdom. The monocot-

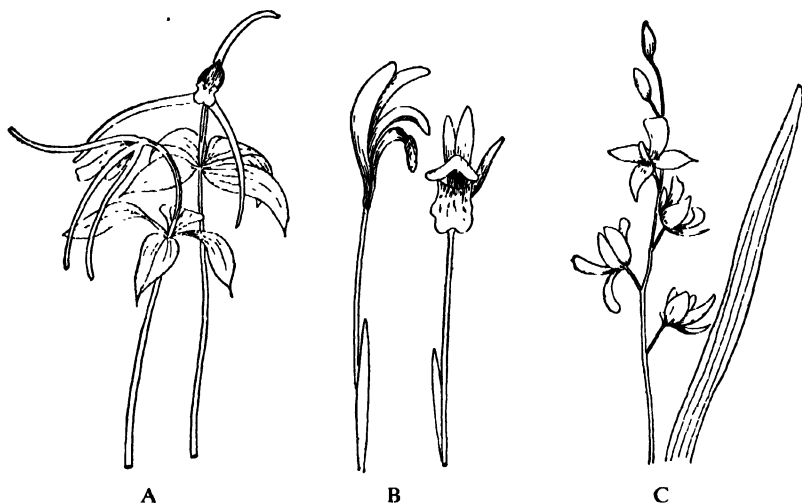


FIG. 387. Flowers of orchids: A, whorled pogonia; B, wild pink, and C, grass pink. (From Hylander.)

yledons culminate in the orchids, and the dicotyledons in the composites; the two groups representing the present acme of plant evolution—a long way from the simple unicellular algae near the beginning of the pageant of plant life.

PLANTS OF THE PAST

The plants that have been considered are evidently only a small remnant of those which flourished and became extinct during the immensely long past of geologic history. This much we know from fossil plants that have been discovered, though of course there are great gaps in our knowledge, in part owing to the necessarily incomplete fossil record. Even so, certain facts stand out so that with reasonable assuredness one can picture in bold strokes some of the most significant progressive steps in the evolution of the plant kingdom.

Although the first plants are completely unknown, it seems certain that they must have been aquatic forms that were able to synthesize their food from inorganic materials by some simpler means than the chlorophyll apparatus of today; probably by one somewhat similar to the autotrophic method of nutrition of some of the bacteria. Doubtless these earliest organic synthesizers were below cellular grade, without the protoplasmic physiological division of labor represented by nucleus

and cytoplasm. Then came cellular complexity, followed by the multicellular body with its attendant differentiation of tissues and organs. And probably very early in this evolution sexual phenomena and alternation of generations were established. (pp. 397-398.)

All this and more came to pass before the fossil record is of much assistance. The earliest fossils show bacteria and blue-green algae in the Proterozoic era and all of the great groups of algae on the shores of the early Paleozoic seas. Therefore plant life undoubtedly began in the sea, and the thallophytes with unicellular or thalloid bodies are well-adapted for an aquatic habitat. The relatively uniform environment of the sea gave place to conditions much more diverse, affording wider scope for variation and evolution. Invasion of the land presented new problems and a wide field for the successful pioneer.

On dry land it is necessary to form an attachment (root) with the source of water, and at the same time an extensive surface (leaf) for photosynthesis, adequately waterproofed to prevent unduly rapid evaporation. Moreover, the leaves must be advantageously exposed to light—separated from one another on a mechanically strengthened axis (stem). And since the points of intake and outgo of water are now far apart, the stem must be provided with a conducting system (vascular bundles).

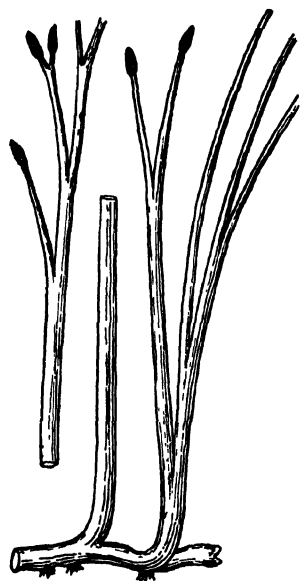


FIG. 388. *Rhynia major*, one of the fossil Psilophytales, with aerial, leafless branches, tipped with sporangia, arising from a rhizome. (After Kidston and Lang. Redrawn.)

Accordingly, the most highly successful land invaders were the vascular plants, or tracheophytes, which forsook, as it were, the thalloid body and developed true root, stem, and leaf in Devonian time. The earliest known and most primitive vascular plants are the Psilophytales which probably evolved from an Anthoceroslike ancestor, and not through the bryophytes proper which, without a vascular system, somewhat falteringly essayed a land habit. The Psilophytales are small forms with erect stems arising from a creeping or underground rhizome and terminating in cone-like clusters of sporangia. From this group

of plants there probably arose by different lines of descent the ferns and the seed plants of today. (Figs. 361, 388.)

The first known seed plants appeared late in the Devonian period and are represented by the most primitive order of the gymnosperms, the Cycadofilicales or seed ferns, now long since extinct. Angiosperms are not known before the Cretaceous period and thenceforth they rose relatively rapidly to the position of supremacy that they still maintain. In fact, many existing genera of flowering plants, such as the poplar and sassafras, are represented by fossil species that lived long before birds and mammals arose. (Fig. 265.)

The seed plants constitute the dominant element in the modern flora, largely, it is believed, by virtue of seed formation. This eliminates many of the disadvantages attendant upon the method of spore distribution exhibited in lower plants, abolishes the delicate, free-living gametophyte, removes the water hazards of free-swimming sperm by developing pollination, provides with greater surety for the protection and nourishment of the embryo within the parent tissues, and then distributes this endowed embryo as a seed. No wonder seed plants today hold the place they do in the sun. (Figs. 220, 222, 225, 226.)

PLANT DISTRIBUTION

The review of the plant kingdom has necessarily neglected the interrelationships of the plants with their organic and inorganic surroundings as illustrated by their distribution. There are, of course, PLANT COMMUNITIES characteristic of relatively local physical environments, and also of the wider geographical areas of continents. (pp. 419-422.)

Many complex problems are involved in the distribution of vegetation, including factors that are in part hereditary and in part environmental. The latter are the more obvious and include moisture, temperature, and other factors that determine the CLIMATE, and the chemical and physical composition of the SOIL.

Some plants, such as the ubiquitous dandelion, ragweed, and goldenrod, have a heritage sufficiently versatile so that they thrive from low to high altitudes and under wide variations in soil, but the great majority are confined to a more restricted habitat—in many cases a single factor rendering a region untenable or favorable. Thus cranberries are adapted to acid bogs, cacti to arid wastes, hemlock seedlings to deep shade, poplar seedlings to high illumination, palms

to above-freezing temperatures, redwoods to foggy mountain slopes, and edelweiss to Alpine meadows. Many plants are found only on limestone soils, while others are characteristic of serpentine areas.

Such factors and many more present a complex of interacting conditions that in the final analysis determine the FLORA of a region. This

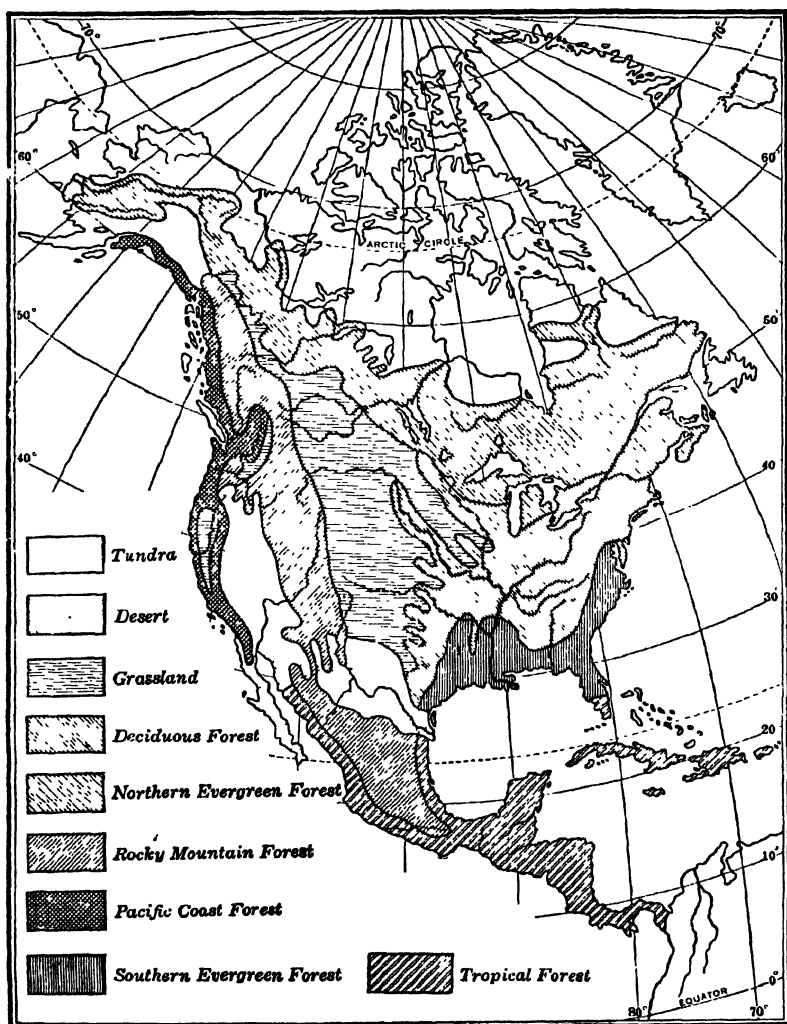


FIG. 389. Map showing general regions of vegetation in North America. (After Smith.)

may be illustrated broadly by the general regions of vegetation in North America: the forests, grasslands, deserts, and tundra. (Fig. 389.)

The great FORESTS of the continent are designated the northern, the southern, and the western evergreen forests, the deciduous forest, and the tropical forest.

The *northern evergreen forest* extends across the continent from ocean to ocean, its northern boundary being an area transitional to the treeless arctic regions, and its southern boundary, in general, the northern tier of states northwestward to the Rocky Mountains and to Alaska. It broadly follows glaciation, being mostly north of the ancient glacial limits. As the name indicates, the predominant trees are evergreens, chiefly conifers, such as spruces, firs, hemlocks, and pines.

Another large tree belt, the *southern evergreen forest*, extends over the coastal plain from eastern Virginia to Texas and includes such well-known species as the longleaf and shortleaf yellow pines and the bald cypress.

Again, on the Pacific coast there is the *great western evergreen forest*, extending from Alaska to southern Mexico. This comprises the so-called Rocky Mountain forest extending along the slopes of the Rockies from northern British Columbia to southern Mexico, and the Pacific coast forest covering the slopes of the coastal mountains from southern Alaska through California. The former is characterized by the western yellow pine and lodgepole pine, and the latter by the Sitka spruce and Douglas fir and a narrow belt of the famous giant redwoods, or sequoia.

Thus evergreen trees form the dominant stands over an immense part of North America and are of enormous economic importance.

The great *deciduous forest*, composed of trees that annually shed their leaves, merges on the northeast with the northern evergreen forest and extends from central New York along the Appalachian Mountains to Texas. Its boundary on the west passes from Wisconsin down to eastern Oklahoma. The most characteristic development of this forest is in the southern Appalachians, with stands of such trees as oaks, maples, hickories, birches, walnuts, ashes, and elms.

The *tropical forest* region comprises southern Florida, the coastal plain of Mexico, and all of Central America as well as the West Indies. A tropical forest in full development as seen in certain parts of Central America is an astounding display of vegetation. Under the canopy

formed by tall trees there is usually a dense undergrowth, favored by moisture and warmth, while the trunks and branches of the trees are entwined with woody vines, or LIANAS, which afford a place in the sun for a profusion of lichens, mosses, ferns, orchids, and other EPIPHYTES. And the fauna of such a forest canopy is a world in itself. Indeed, an experience never to be forgotten is a visit to the tropical rain forest encompassing the Barro Colorado Island Biological Station in the Canal Zone.

Turning from the forests, we find the GRASSLANDS of the continent covering an immense area with its eastern boundary extending approximately from Manitoba to the middle of Texas, and its western border among the approaches to the Rockies from Alberta to New Mexico. The eastern portion is the so-called PRAIRIE, and the more western is the GREAT PLAINS; both apparently are the result of a light annual rainfall and high evaporation that is unfavorable for the growth of tree seedlings.

From grassland to desert the transition may not be abrupt. Large desert areas include most of Nevada and Arizona, parts of southern California, New Mexico, Texas, and northern Mexico, as well as a considerable portion of Lower California. The so-called Great Basin between the Rockies and the Sierras, characterized by sagebrush and other shrubs of similar appearance, except for rapidly maturing herbs after the seasonal rains, merges toward the south into a region of intense heat and drought which is remarkable for many XEROPHYTIC plants—cacti, yuccas, agaves, and the leafless “creosote bush” adapted to aridity.

Quite different conditions, though no less rigorous for vegetation, occur along the northern border of the continent from Labrador to Alaska. Here, forming the TUNDRA, are only the most hardy plants—chiefly lichens, mosses, grasses, and certain low shrubs that withstand the intensely cold, dry air, strong winds, and soil that, in general, thaws to a depth of only a few inches. Many of the herbaceous species make the most of this favorable period to display masses of conspicuous flowers.

Such a synoptic view of the several great regions of vegetation in North America can do little more than suggest the interest and importance of the immense field of plant geography, an aspect of ecology.

CHAPTER XXXII

Survey of the Animal Kingdom: Invertebrates

It seems as if Nature had essayed one after the other every possible manner of living and moving, as if she had taken advantage of every permission granted by matter and its laws.

—Gide

Wide as are the diversities in structure exhibited by plants, they are exceeded manyfold by animals, so zoologists have even more difficulties than do botanists in attempting to develop a natural classification. Indeed, there is considerable difference of opinion even in regard to the number of main divisions, or phyla, and, in some instances, to the sequence in which they should be arranged. In this brief survey, however, it is necessary only to emphasize the chief phyla and, of course, to study them serially; however, the series must not be regarded as invariably indicating the genetic relationships. To attempt to express these relationships, it would be necessary to resort to a branching "phylogenetic tree"; the details of such a scheme would show considerable variation made by different zoologists. Thus forewarned in regard to some of the uncertainties of present-day systems of classification, we may proceed to a synoptic view of the animal kingdom. (Fig. 441.)

PROTOZOA

The first phylum is the Protozoa, which includes the most primitive forms of animal life, each individual consisting typically of a single cellular unit of living matter, as described earlier. Some Protozoa, however, exhibit a complexity of structure within the confines of a cell that probably is not exceeded in the cells of higher animals. The Protozoa are the simplest, but by no means simple animals, and their study forms the science of PROTOZOOLOGY. There are plenty of kinds

of Protozoa. Although only about 20,000 species have so far been described, apparently there are more protozoan species than in all the rest of the animal world because every higher animal that has been carefully studied has been found to harbor one or more species of Protozoa specialized to live in it. (Fig. 317.)

The Protozoa, as single cells, demand for active life a more or less fluid medium, and so are aquatic animals. However, different species exhibit all gradations of adaptation to variations in moisture, from those that thrive in oceans and lakes, or pools and puddles, to those that find sufficient the dew on soil or grass blade, or the fluids within the tissues and cells of higher plants and animals.

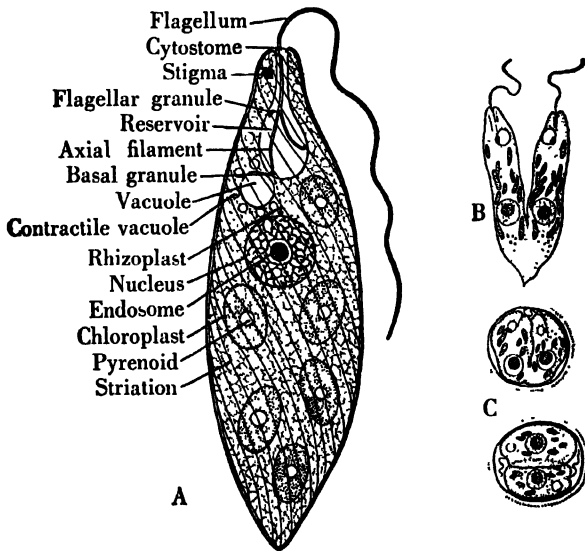


FIG. 390. *Euglena*. A, active individual showing details of structure (from Hegner); B, reproduction of euglena by longitudinal binary fission; C, two stages of binary fission within a cyst. Various magnified.

The phylum Protozoa is divided, largely on the basis of the locomotor organs, into four classes: the Flagellata, Rhizopoda, Sporozoa, and Ciliata. The flagellates, such as *Euglena*, move by means of flagella; the rhizopods, as amoeba, by pseudopodia; and the ciliates, as *Paramecium*, by cilia. The Sporozoa, all of which are parasitic, such as the organisms causing malaria, possess no characteristic type of organ for

locomotion though all are motile at some stage in their life history. (Figs. 10, 13, 16, 390, 396.)

Flagellata. The great class of flagellated Protozoa, sometimes called the Mastigophora, comprises the most primitive animals. However, no hard and fast line can be drawn between the plant and animal kingdoms; one merges into the other when the simplest forms of life are

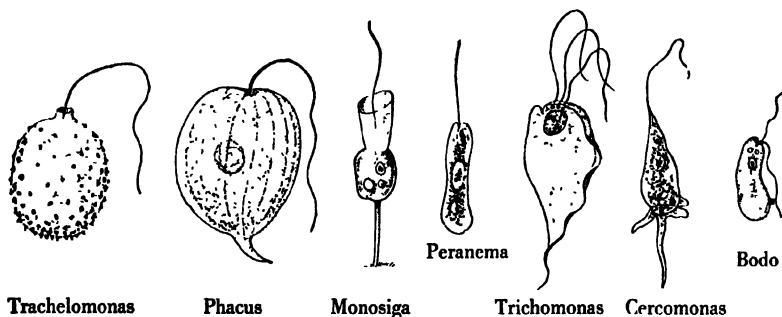


FIG. 391. Seven types of common flagellated Protozoa. Highly magnified.

approached. Indeed, botanists, with considerable justice, claim many of the flagellates, chiefly because they possess chlorophyll and are able to manufacture their own food. But in the absence of sunlight many chlorophyll-bearing forms, such as *Euglena*, are able to utilize food material in solution and are similar in structure to other species without chlorophyll that are typically holozoic. Moreover it is not possible to draw a sharp line between the flagellates and the amoeboid rhizopods because certain organisms possess both flagella and pseudopodia during various phases of their life. (Figs. 391, 392.)

Flagellates are very widely distributed in sea, pond, and infusions of organic matter. An immense group, the DINOFLAGELLATES, constitutes a large part of the microscopic life of the sea, competing with certain rhizopods and microscopic plants in variety of species and number of individuals—numbers so immense that wide areas of the sea may become discolored or appear phosphorescent.

Many flagellates have invaded the field of

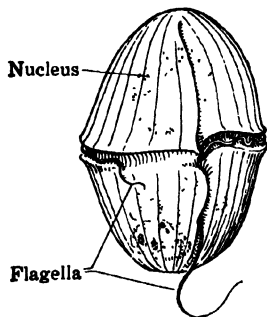


FIG. 392. A marine dinoflagellate, *Gymnodinium*. Highly magnified.

parasitism, living in the digestive tract and blood stream of higher animals: some TRYPANOSOMES being among the most destructive blood parasites of man and beast in certain tropical regions. In the United States, the frogs, newts, rats, and cattle, for example, may each harbor their own particular species of trypanosome, apparently without ill effects. (Figs. 315, 392.)

The versatility of the flagellates in mode of life and nutrition apparently implies a high potential of adaptation and evolution. Indeed,

it is among them and some unicellular algae that certain interesting associations, or COLONIES, of individuals occur that suggest a possible method of origin of the multicellular body. (Figs. 8, 9.)

Rhizopoda. Amoeba, which we have already studied, may be visualized as the type of the rhizopods since all members of this class are, broadly speaking, amoebae, but there are numerous species of the genus *Amoeba* itself. The common, relatively large fresh-water species, *Amoeba proteus* and *Amoeba dubia*, have as associates many other fresh-water and salt-water species. Again, numerous species, such as those comprising the genus *Endamoeba*, live within the bodies of man and other animals. Furthermore, there are

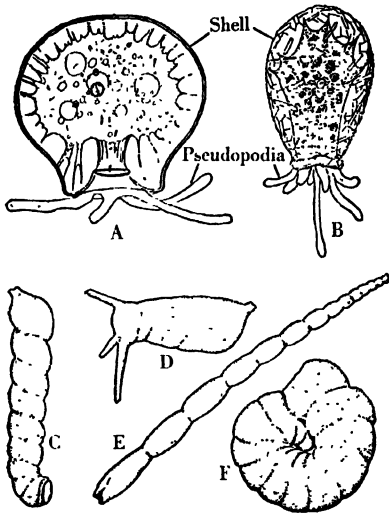


FIG. 393. A, *Arcella* showing the protoplasm through the transparent shell and also protruding below as pseudopodia; B, *Diffugia* showing the same condition as A; C, D, E, F, shells of four species of Foraminifera. Various magnified.

many common fresh-water genera, such as *Arcella* and *Diffugia*, that have resistant protective coverings, or shells. The shells have an opening through which the pseudopodia are protruded so that locomotion, securing of food, etc., can be performed. But all of these animals, whether free-living or parasitic, naked or provided with a shell, are creeping cells with more or less broad or blunt finger-form pseudopodia and comprise a group of the rhizopods usually known as the LOBOSA. (Figs. 7, 13, 16, 316, 393; pp. 42-45.)

An immense group of chiefly marine rhizopods is the FORAMINIFERA. Most species have quite complex shells of calcium carbonate, with one or many openings through which threadlike pseudopodia emerge, branch, and flow together so that the shell becomes essentially an internal structure. The almost incalculable number of Foraminifera constitutes an important source of marine food for small animals which, in turn, are the food of economically important fishes. The more resistant shells of the Foraminifera sink to the sea bottom and cover vast areas totaling, perhaps, one-third of all the sea bottom and an even larger proportion of the North Atlantic ocean. This so-called Globigerina ooze is reported to be accumulating at the rate of about one-tenth inch a year on submarine telegraph cables. Similar deposits during the past ages are represented today by limestone deposits thousands of feet thick. The Pyramids and the Sphinx are built of foraminiferous rock. (Figs. 393, 394.)

Two other groups of the Rhizopoda, known as the HELIOZOA and RADIOLARIA, typically have unbranched, radiating pseudopodia, each supported by a core of more dense protoplasm. Most species are floating, spherical forms, and the pseudopodia, protruding from the entire surface of the cell, give the appearance of the conventional figure of the sun. Accordingly the fresh-water forms are commonly called sun animalcules, or Heliozoa. The Radiolaria are all marine and are more complex than the Helio-

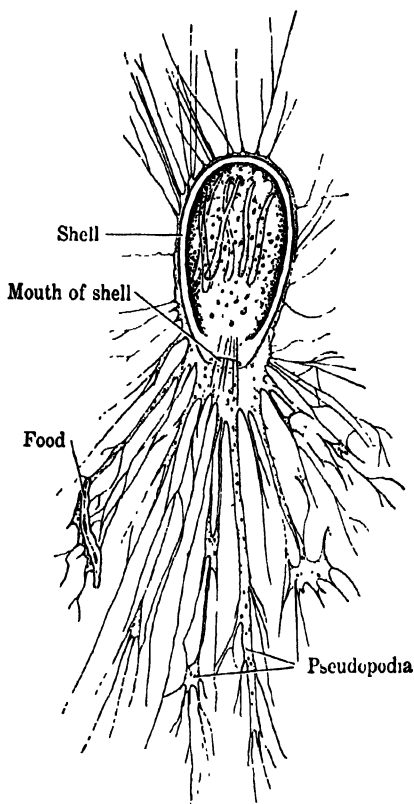


FIG. 394. *Allogromia*, one of the few fresh-water Foraminifera. Note the pseudopodial mass emerging from, and surrounding the shell. Highly magnified. (After Cambridge Natural History.)

zoa, the protoplasm being differentiated into several layers, enclosing a dense, perforated CENTRAL CAPSULE, and usually supported by an elaborate skeleton of silica. The Radiolaria vie in numbers and importance with the Foraminifera in the economy of the sea; the deposits of their siliceous skeletons forming the Radiolarian ooze, widely distributed in the tropical Pacific and Indian oceans. Certain immense rock strata are contributions to the earth's surface made by the Radiolaria during bygone ages. (Fig. 395.)

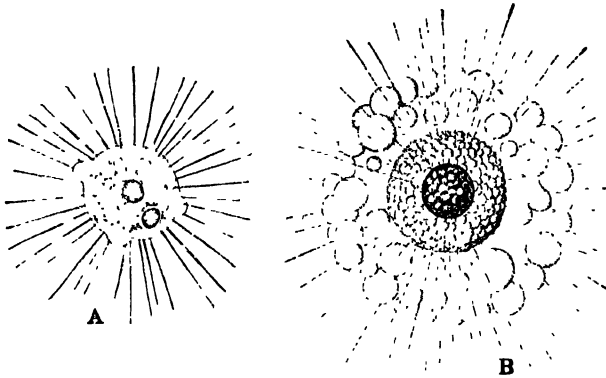


FIG. 395. A, Heliozoön, *Actinophrys sol*; B, Radiolarian, *Thalassicolla nucleata*. Highly magnified. (From Kudo.)

Probably related to the Rhizopoda are the MYCETOZOA, though they have certain characteristics of fungi and so are frequently called slime molds. A prominent phase in their life history is typically a multinucleate amoeboid sheet of protoplasm that may be several inches in diameter as it flows along on a decaying log.

Sporozoa. Although parasitic species are found in all four classes of Protozoa, the Sporozoa have the distinction of living solely at the expense of other organisms, their HOSTS, in which they create disturbances of more or less severity which frequently result in disease. The parasite's ability to get a living with little expenditure of energy has in the Sporozoa, as elsewhere in the animal kingdom, resulted in a degeneration of structures necessary for a free life, and in an elaboration of the reproductive processes to ensure that the parasite secures access to the proper host. For, in general, each sporozoan is adapted to live in one or two particular species of animals; probably every species of higher animal has at least one sporozoan specially fitted to live in it.

Monocystis is a parasitic sporozoan that spends its entire life in the tissues of an earthworm. The adult Monocystis is an elongated cell living in the seminal vesicles and securing its nourishment from the developing germ cells of the worm. Here food is plentiful, and accordingly much is stored for use during the complex reproductive changes which terminate in the production of resistant SPORES. These eventually are discharged from the body of the worm and trust to chance that entrance may be gained to the body of another worm in order that the life cycle may be continued. (Fig. 396.)

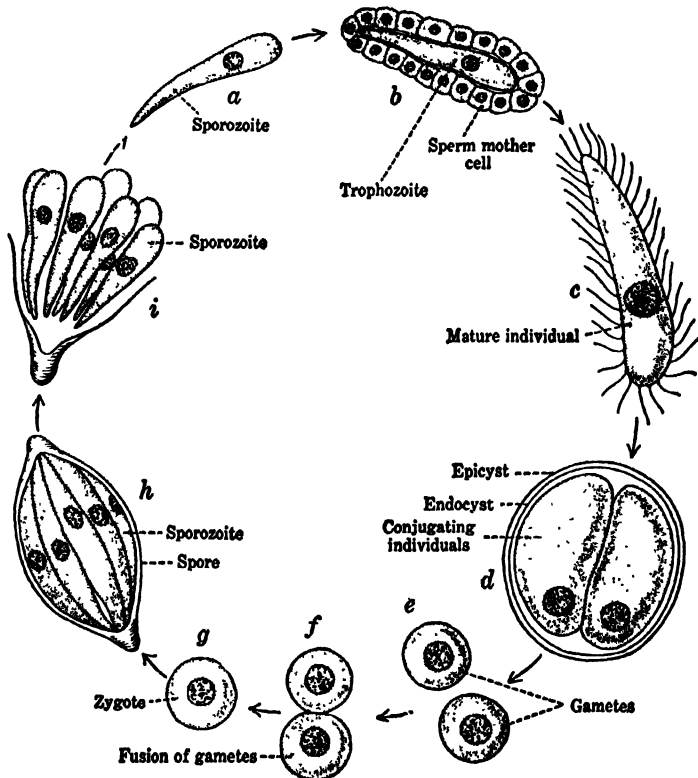


FIG. 396. Monocystis, a sporozoan of the order Gregarinida that occurs in the seminal vesicles of the earthworm. *a*, sporozoite. *b*, trophozoite within a bundle of earthworm sperm-mother cells. *c*, trophozoite with tails of degenerate earthworm spermatozoa attached. *d*, cyst containing two conjugating trophozoites. *e*, two gametes produced by *d*. *f*, union of two gametes. *g*, zygote. *h*, spore containing 8 sporozoites. *i*, sporozoites escaping from sporocyst. All highly magnified but not drawn to scale. (From Hegner.)

Malaria is transmitted to man solely by infected female mosquitoes that inoculate into the blood stream Sporozoa of the genus *Plasmodium*. Once in the human blood, the parasites pass to certain tissues where they multiply. Then the progeny return to the blood stream and enter red cells where further reproduction takes place until millions of these cells are infected and destroyed. In order to complete their life history the parasites must again be taken into the body of a mosquito by the mosquito's withdrawing blood from an infected person. (Figs. 314, 315, 318-319.)

Ciliata. The ciliated Protozoa, constituting the class Ciliata, probably represent the most complex development of the unicellular plan of animal structure. This is well shown by *Paramecium*, which has already been considered in some detail as an example of protozoan organization. At this point, then, it is necessary only to emphasize certain general facts about the class. (pp. 89-96.)

Ciliates are to be found nearly everywhere: as teeming populations in puddle, pond, and sea; in the moisture of the soil and on vegetation; and sometimes in the fluids within the bodies of higher animals; there is a highly complex fauna in the digestive tract of sheep and cattle. Even the air is inhabited, since dormant, encysted stages of various

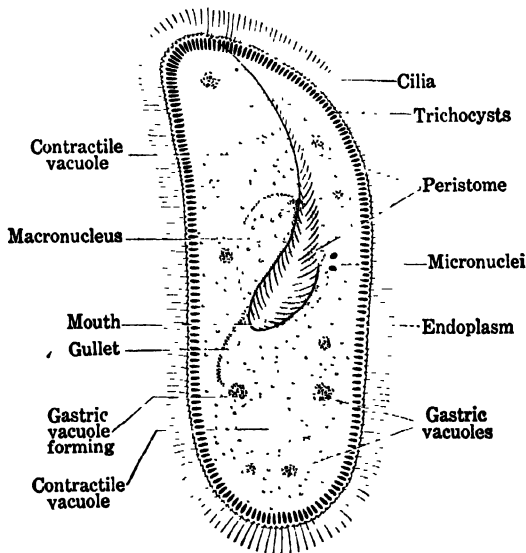


FIG. 397. *Paramecium culikinsi*. Highly magnified.

species are wafted aloft, ready to become activated if they fall upon moisture. Incidentally, *Paramecium* apparently is unable to encyst. (Figs. 10, 397, 398.)

The classification of the group is based chiefly on the distribution and modification of the cilia. For example, it will be recalled that *Paramecium* is completely coated with cilia that are all essentially alike, and in this feature it resembles other species. But in other forms, the ciliary coat is restricted to certain parts of the cell, and the cilia vary

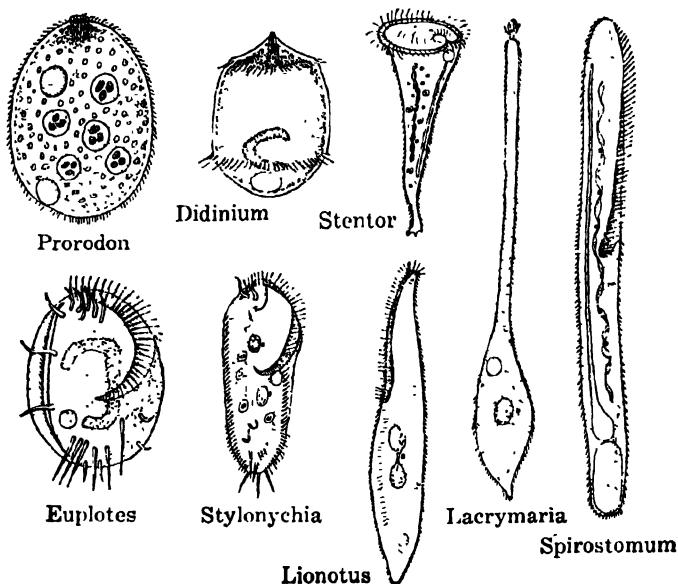


FIG. 398. Eight common types of ciliated Protozoa from fresh water. Various magnified.

in many ways. Frequently in the oral region they unite in series to form MEMBRANES that undulate. This is readily seen in *Colpidium*, *Blepharisma*, and the various stalked species of *Vorticella* (Fig. 23). Again, the cilia may be restricted almost solely to the ventral surface where many fuse to form stout bristles, or CIRRI, which enable the animals to crawl about, as do *Stylonychia* and related species. The members of one large subdivision, the SUCTORIA, have no cilia in the adult forms, these locomotor organs being confined to the young cells that are budded off from the parent, swim about for a time, and then

settle down for life and develop tentacles for capturing prey. (Fig. 398.)

Next to the possession of cilia, the most important characteristic of the class is the distribution of the nuclear material in two parts: a large macronucleus and one or more smaller micronuclei. The latter play the active part in sexual phenomena and make possible the unique mutual fertilization during conjugation.

In this necessarily brief survey of the Protozoa, at least one major point must be forced upon our attention: the versatility of form and function exhibited by these unicellular animals—their ADAPTATION to many and varied modes of life in the most diverse environmental conditions. But their unicellular plan of structure, permitting only cytological differentiation, has obvious inherent limitations which adaptation cannot surmount, while the multicellular type of organization characteristic of all other animals affords opportunities almost transcending imagination. Multicellular organization makes possible both cytological and histological (tissue) differentiation. However, the potential of evolution of the protozoan type did achieve expression it is believed, when it gave rise in the geological past to the stock from which the higher animals have developed. This allowed the powers of adaptation pent up, so to speak, in the single cell to find expression in specialization and cooperation in the individuals of another and higher order, the Metazoa, which multicellular animals represent. (Fig. 441; p. 696.)

METAZOA

Just how the Metazoa evolved from the Protozoa is, of course, not known, but it seems reasonable to believe that they arose from flagellates because of the versatility and adaptability of these protozoons and the wide distribution of flagella in the animal kingdom, notably as the locomotor organs of sperm. It is intriguing to think that a colonial flagellate, in a general way comparable to *Volvox*, developed an internal cellular layer, devoted primarily to digestive functions, in which the germ cells became located. Such a two-layered organism, theoretically at least, would form the point of departure for the evolution of the Metazoa. The important problem, however, is not how multicellular animals arose, but how they profited by their endowment. (Fig. 9.)

The multicellular animals constituting the invertebrates present a bewildering array of forms adapted to nearly every conceivable environ-

ment. Some are smaller than many of the Protozoa and others much larger than certain vertebrates. Some are aquatic, others are terrestrial, and still others spend most of their life in the air. The great majority possess the power of locomotion, but many are fixed, or sessile, and not a few are obligatory parasites in or on the bodies of other animals.

The fact that there are nearly a million known species, and probably twice as many yet to be discovered, at once suggests that this survey must be confined to a relatively few representatives from each of the major invertebrate phyla—just enough to place the forms selected for special study, in proper perspective. (Chap. VII; Figs. 63, 73, 76.)

SPONGES

It is not surprising that the sponges, which constitute the PORIFERA, the lowest phylum of multicellular animals, show certain relationships with the Protozoa. Specialization of cells and physiological division of labor, though carried far beyond that shown by the most complex colonial Protozoa, nevertheless have not suppressed the individualities of the cooperating cells to the extent that occurs in higher forms. Witness the fact that when certain sponges are gently squeezed through the meshes of fine silk cloth, so that the tissues are changed to separate cells, these cells will soon assemble in small groups and each group will grow into a sponge. Moreover, if the disassociated cells of different species are intermingled, they will sort themselves into their respective species: a remarkable example of the power of regulation so generally exhibited by living organisms. In brief, the sponge is an individual animal, but its organization is loose and the dependence of one cell upon another is relatively slight.

From casual observation one would not recognize sponges as animals; in fact it was only during the past century that their animal nature was demonstrated. For example, the common *Leucosolenia* of the New England coast has a tiny vase-shaped body permanently attached by its base to a rock or other support just below low-tide mark. It is without the power of locomotion and does not visibly respond in any way when touched. However, when examined under a lens, it will be found that the whole surface of the saclike body is dotted with innumerable tiny pores, or OSTIA, that give the name Porifera to the phylum. Through these pores water is drawn into the large central GASTRAL CAVITY and passed on out through an opening, or OSCULUM, at the narrowed top. The ostia and the osculum are surrounded by contractile cells that

regulate the size of the openings, but no sensory cells or nerve fibers are present, accordingly the contractile cells must necessarily respond to direct stimulation.

A section of the body wall of *Leucosolenia* shows that it consists of two fairly definite layers of cells: an outer DERMAL EPITHELIUM and an inner GASTRAL EPITHELIUM, separated by a gelatinous MESENCHYME layer containing many kinds of amoeboid wandering cells, including germ cells. The body is supported by a skeleton composed of a network of three-pronged SPICULES of calcium carbonate, formed and embedded in the mesenchyme. (Fig. 399.)

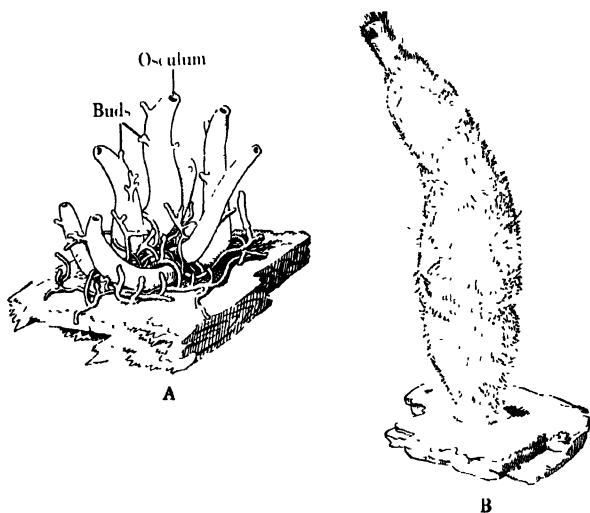


FIG. 399 A, small colony of *Leucosolenia*. See Figs. 400, 401; B, *Sycon*. Not drawn to scale.

The gastral epithelium is of particular interest because it consists chiefly of a layer of COLLAR CELLS, each provided with a flagellum and resembling certain flagellated Protozoa. (Fig. 400.) It is the constant lashing of the flagella that creates the current of water, laden with food and oxygen, through the pores into the gastral cavity, and on out through the osculum, bearing waste materials. Thus although sponges are static there is seething activity within; it has been estimated that some five gallons of water may be drawn during a single day through the canal system of a sponge 10 cm high and 1 cm broad. It is also the collar cells that capture, engulf, and in part digest particles of food in

typical unicellular fashion (intracellular digestion) and pass the products on to the other cells. Apparently the amoeboid wandering cells also ingest and store food. Similarly, respiration and excretion are carried on by the individual cells.

Such is the essential plan of structure of a simple sponge, but there are many more complex forms which, in general, can be derived from this so-called ASCON type by a thickening of the body wall, and then either the restriction of the collar cells to canals embedded in it in close proximity to the gastral cavity (SYCON type), or their segregation in tiny cavities more remotely situated in the tissues but still in communication with the gastral cavity by long canals (LEUCON type). In

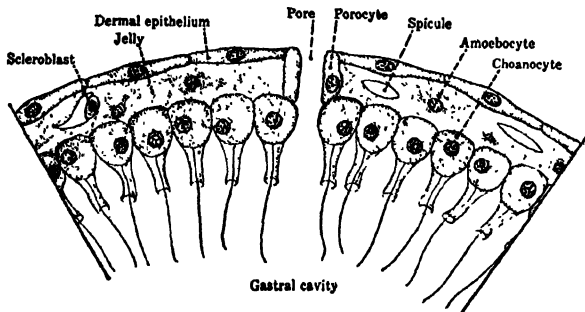


FIG. 400. Diagram of the body wall of an ascon sponge, *Leucosolenia*. Highly magnified. (From Hegner.)

the last type the functioning surface of both the dermal and gastral epithelium is enormously increased. Obviously the elaboration of canals makes possible the massive types of sponges, since it serves, in general, the purpose of a circulatory system. No wonder, then, that the great majority of sponges are built on the leucon plan. The sycon type is represented by *Scypha* and *Grantia* and the leucon type by the common fresh-water sponge, *Spongilla*, and the bath sponge, *Spongia*. (Fig. 401.)

But one must not gain the idea that all sponges are quite similar in appearance. Some are no larger than a pinhead, others are six feet or more tall. Some are branched, fan-shaped, cup-shaped. Most are white or gray though many contribute brilliant colors to the picture presented by the sea floor. All are included in three large groups. The class CALCISPONGIAE comprises the species with skeletons composed

of calcium carbonate. They are comparatively simple marine forms, living in shallow water, and well represented by *Leucosolenia* and *Scypha*. The members of the class HYALOSPONGIAE have silicious spicules that sometimes form a continuous skeleton resembling spun glass, as in the well-known Venus's-flower-basket, *Euplectella*. Most are deep-sea inhabitants. The final and present-day dominant array of sponges constitute the class DEMOSPONGIAE. Some species have no skeleton, but when present the sponge skeleton consists of silicious spicules or spongin fibers or a combination of both. The animals inhabit various ocean depths, excepting the members of one family which live in fresh water. Representatives of the Demospongiae are the bath

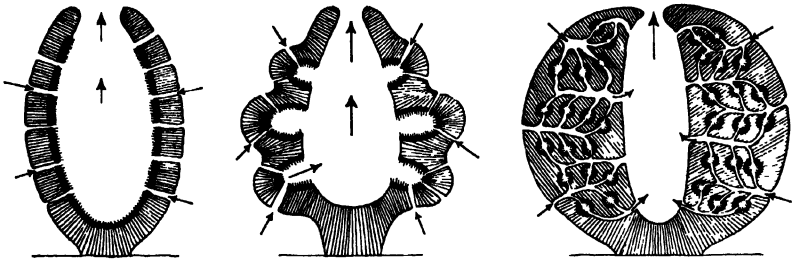


FIG. 401 Types of canal systems of sponges. Ascon type (*Leucosolenia*), left; Sycon type (*Grantia*, *Sycon*), center; Leucon type (*Spongilla*, *Euspongia*), right. The arrows indicate the direction of the current of water. Solid black represents the gastral layer with collar cells. (After Johnson and Snook. Redrawn.)

sponge (*Spongia*), the finger sponge (*Haliclona*), the boring sponge (*Cliona*), and the fresh-water sponges (*Spongilladae*).

Among all this variety of sponges, certain species, chiefly of the genus *Spongia*, stand out as of high economic importance because their flexible, fibrous skeletons of SPONGIN, when cleaned and dried, become the familiar bath sponges of commerce. These have long been gathered by diving and now are also cultivated with success. Live sponges are cut into very small pieces, wired to cement plates, and then sunk to places favorable for sponge growth. Some years later the pieces will have matured sufficiently to produce a marketable sponge crop.

Although but few species of sponges are useful to man, they have an important function in the economy of many marine animals. On account of their sessile habit and porous structure sponges are widely used as an anchorage and safe harbor by other animals, notably worms and crustaceans. Certain species of shrimps regularly inhabit the in-

terior of sponges, many thousands in one large sponge. In fact, shrimps of one genus in particular (*Spongicola*) live in pairs in the gastral cavity of such sponges as *Euplectella*; and there they stay because, entering when small, they soon become too large to make an exit through the osculum. "Glass sponge skeletons with an imprisoned pair of shrimps are said to be used in Japan as wedding gifts to symbolize marriage until death." Certain sponges regularly, and apparently of necessity, grow on snail shells inhabited by hermit crabs, until they completely enclose shell and crab except for the shell opening. The shell finally disintegrates and only the sponge remains as a protective case for the crab while the sponge itself secures transportation. These examples will suffice to indicate the intimate associations in which sponges are found on the sea floor.

Sponges reproduce both asexually and sexually. Asexual reproduction is by BUDS, which may remain attached and form a colony as in *Leucosolenia*, or become separated as distinct individuals; and also in many cases by the liberation of groups of cells, called GEMMULES, possessing the power to form new individuals. Some species under adverse conditions collapse and disintegrate into rounded cell masses that later regenerate to normal form. Sexual reproduction is by egg and sperm, both being formed in the same hermaphroditic individual. The zygote develops into a tiny ciliated embryo which, after a short free-swimming existence effecting the dissemination of the species, settles down, becomes permanently attached, and soon attains the adult structure.

The relationship of the Porifera to other invertebrates raises an interesting problem. The tissues of sponges are, as we have seen, too complex to be considered colonies of Protozoa, but they also are much less complex than those of the higher multicellular animals. Furthermore, they are organized in a radically different way—without organs and organ systems, without mouth and enteron, and with two primary cell layers that are not homologous with the ectoderm and endoderm of higher animals. All considered, sponges probably represent a side branch of the animal kingdom that went up an evolutionary blind alley, so to speak, and remained only sponges (Fig. 441.)

COELENTERATES

With the large group of aquatic animals comprising the COELENTERATA—the polyps, jellyfish, sea anemones, and corals—we reach a

basic phylum of the invertebrates, because, with ectoderm and endoderm definitely established, with a mouth opening into a digestive cavity, and with specialized body parts coordinated by a simple nervous system, the coelenterates institute a plan of structure that proves to be fruitful for the derivation of certain features exhibited in higher animals. This review of the phylum will serve merely to indicate some of the chief forms assumed by the POLYP type of individual, already studied in hydra, in the highly diversified classes known as Hydrozoa, Scyphozoa, and Anthozoa. (p. 696.)

Hydrozoa. The life history of the common polyp, hydra, one of the few coelenterates inhabiting fresh water, is not typical of the many kinds of marine Hydrozoa that grow on submerged objects, such as the piles of piers, because most of them consist of large colonies of hydralike individuals organically connected, somewhat as though a hydra formed many buds that remained attached. Moreover, the colony is only one phase of the life history of a hydroid, for it develops special buds, known as MEDUSAE, which become separated from the colony as independent free-swimming individuals. At first glance a medusa bears little resemblance to a polyp, though it is essentially a sexual polyp that has been produced on the colony by budding and then liberated. Accordingly the complete life history of a typical hydroid involves an ALTERNATION OF GENERATIONS consisting of the asexual colony and the sexual medusae that swim away and disseminate the species. Hydra is apparently a specialized form in which the medusa generation is suppressed; this is just opposite to the condition in a common medusa, *Gonionemus*, of the Atlantic coast, which is a hydromedusa with the hydroid generation reduced nearly to the vanishing point. (Figs. 402, 404.)

The hydroid colonies exhibit some interesting examples of physiological division of labor between the component individuals. Thus in *Bougainvillea* there are two kinds of polyps: the typical feeding polyps, or HYDRANTHS, and the MEDUSOID polyps which later, with some structural changes, are set free. Again in *Obelia*, another common hydroid, there are also highly modified individuals, or GONANGIA, specialized to produce the medusa generation by budding. In still other Hydrozoa POLYMORPHISM is even further developed. For instance, *Physalia*, the Portuguese man-of-war, is a floating hydroid colony consisting of an air-filled contractile sac, or float, with a sail-like crest, from which are suspended a large number of individuals. These are very diverse:

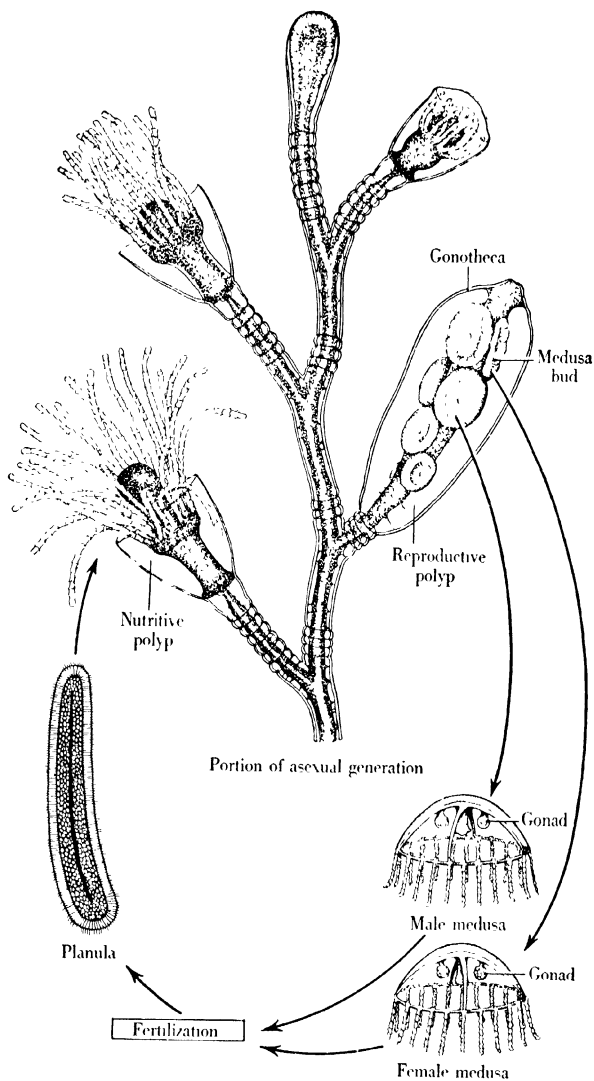


FIG. 402. Life history of a hydroid, *Obelia*. Portion of the asexual colony, above, showing several hydranths and a gonangium; free-swimming sexual medusa, side view, below; ciliated larva, planula, left. Various magnifications. (After Buchanan.)

some are nutritive, others are tactile, and still others bear long "fishing" tentacles with batteries of nematocysts that can inflict severe pain. Furthermore, there are male reproductive individuals and others that are released as free-swimming female medusae. Obviously an animal such as *Physalia* suggests that in many of the lower forms the indi-

vidual is not so sharply defined, and is more difficult to define, than in the higher animals. (Fig. 403.)

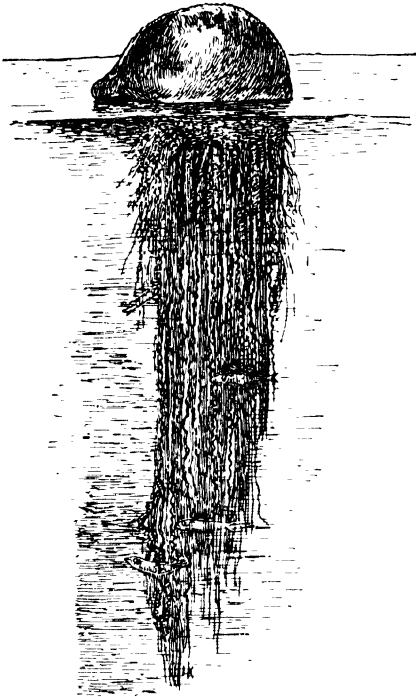


FIG. 403. *Physalia pelagica*, the Portuguese man-of-war. Drawing of a model showing the gas-filled float with various types of polyps attached. (American Museum of Natural History. Redrawn.)

Scyphozoa. The second great class of the coelenterates comprises chiefly large medusae, such as the common saucer-shaped *Aurelia* of the Atlantic coastal waters or its giant relative, *Cyanea*, which may attain a diameter of eight feet: each appropriately called jellyfish, since their soft tissues are about 96 per cent water.

The structure of *Aurelia* is basically the same as that of the medusa generation of the hydroids, the most obvious difference being an excessive development of the mesoglea between ectoderm and endoderm so that the body wall is relatively thick. Moreover, the gelatinous mesoglea contains scattered cells, so that it may be regarded as a mesenchyme layer, though not a third cell layer. (Fig. 404.)

The mouth is in the center of the under (oral) surface and opens into a large enteron. The latter branches into RADIAL CANALS that run to the circumference, or rim, where they merge into a CIRCULAR CANAL. Thus digested food is carried directly to all parts of the animal without the necessity of a special circulatory system. Surrounding the mouth are four ribbonlike ORAL ARMS which, together with the fringe

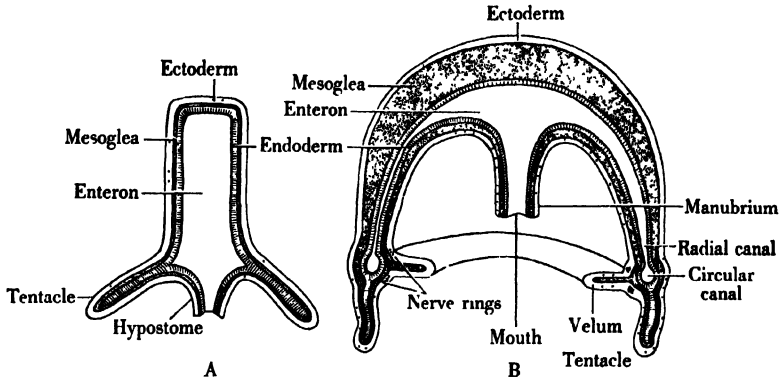


FIG. 404. Diagram showing the fundamentally similar structure of Hydra (A) and of a medusa (B). (From Parker. Redrawn.)

of tentacles about the rim of the animal and certain filaments in the radial canals, are well supplied with nematocysts for stinging the prey. (Fig. 405.)

Among the tentacles on the rim are SENSE ORGANS which control, through the underlying nerve cells and muscle bands, the movements of the animal. Contraction of the rim of the bell, slowly and rhythmically, presses the water within the bell against that without and so forces the animal along. However, Aurelia is largely at the mercy of wind and wave, few being destined to reproduce before dissolution and none to survive the winter.

The reproductive organs of Aurelia consist of four large U-shaped GONADS which shed their products, either eggs or sperm, into the radial canals and so to the outer world through the mouth. Fertilization takes place in the open water and forms a zygote that develops into a free-swimming larva. This soon settles to the bottom, becomes attached, and assumes a polyplike form which feeds and buds and is comparable to the hydroid generation of the Hydrozoa. During the winter this fixed individual, now known as STROBILA, becomes, as it were, sliced

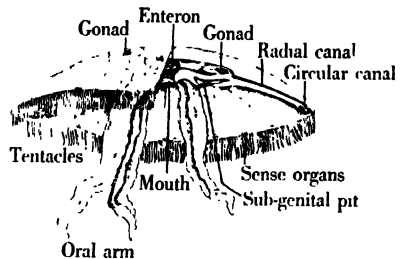


FIG. 405. A common jellyfish, *Aurelia*, showing lateral view; one quadrant is shown in section. See Fig. 406, I. (After Parker and Haswell. Redrawn.)

in orderly fashion into a series of saucerlike embryo medusae, called EPHYRAE, which separate, one by one, and swim away to attain eventually the form of the adult sexual Aurelia. The remaining part of the strobila again assumes the typical polyp form and, after feeding and budding, may strobilate anew the following winter. (Fig. 406.)

Anthozoa. The final class of the coelenterates, the Anthozoa, presents another array of polyp-like animals, comprising the sea anemones and the corals.

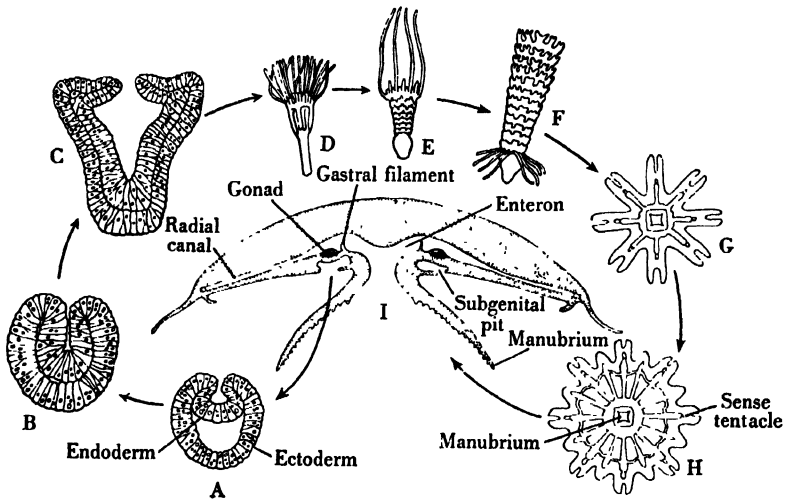


FIG. 406. *Aurelia*, life history. A, B, C, longitudinal sections through gastrula stages; D, scyphistoma; E, F, strobila; G, H, ephyra; I, vertical section through adult. A, B, and C are more highly magnified than the other figures. (From Hegner, after Kerr. Redrawn.)

Metridium, a well-known sea anemone of the North Atlantic coast, is common in tide pools or attached to piers of wharves, its slight powers of creeping seldom being exerted. It is a ruggedly built polyp, nearly cylindrical in form, with the upper end disclosing the mouth in the midst of a crown of numerous tentacles. The mouth opens into a large gullet which leads down into the enteron. The enteron is quite complex because its walls give rise to several series of vertical, radially arranged partitions (MESENTERIES), thereby increasing the functional digestive and respiratory surface. Pores, or OSTIA, make possible the passage of water through the mesenteries. Also within the enteric cavity are long, coiled, nematocyst-bearing filaments that can be pro-

truded in profusion through both the mouth and numerous pores in the body wall, and so are efficient offensive and defensive weapons. (Fig. 407.) Furthermore, the solid tentacles of *Metridium* are well supplied not only with nematocysts, but also with a coat of cilia that plays the chief part in the ingestion of food. Once the prey has been paralyzed by the discharge of the nematocysts, the tentacles bend inward and over so that ciliary action sweeps the food slowly but surely

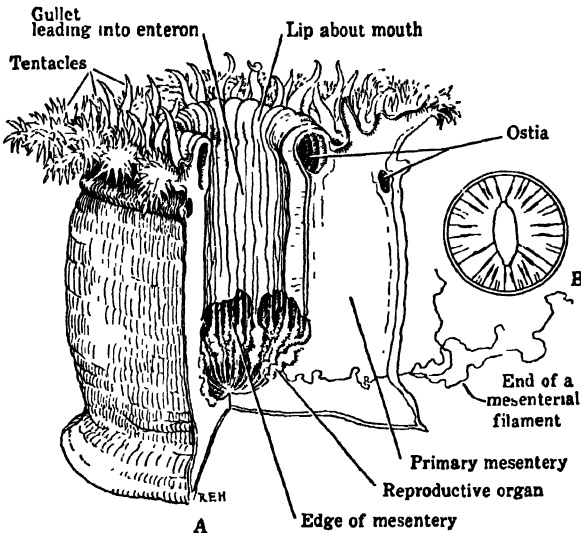


FIG. 407. Sea anemone, *Metridium marginatum*. A, view of polyp with one quadrant removed; B, diagram of transverse section showing mesenteries.

toward the mouth. Here other cilia, in particular those in two or more long grooves known as SIPHONOLYPIHS, aided by muscular contractions, carry it on down into the enteron.

Metridium typically reproduces sexually, though asexual reproduction by budding may also occur. The reproductive organs are located within the enteron where, in the case of females, the eggs are fertilized and the embryos develop into ciliated larvae before making their exit to settle down and assume the adult characters.

Metridium, then, illustrates the general type of polyp structure exhibited by the Anthozoa, and it is only necessary to note that the corals are essentially *Metridium*-like polyps that secrete, under and about themselves, more or less complex skeletons, chiefly of carbonate of

lime. As the polyp continues to secrete the coral, it actually pushes itself farther and farther away from the surface to which it became attached. This growth process, together with multiplication by budding, gradually builds up considerable masses of coral about larger and larger colonies of polyps, the arrangement of the polyps and the disposition of the coral being characteristically different in the numer-

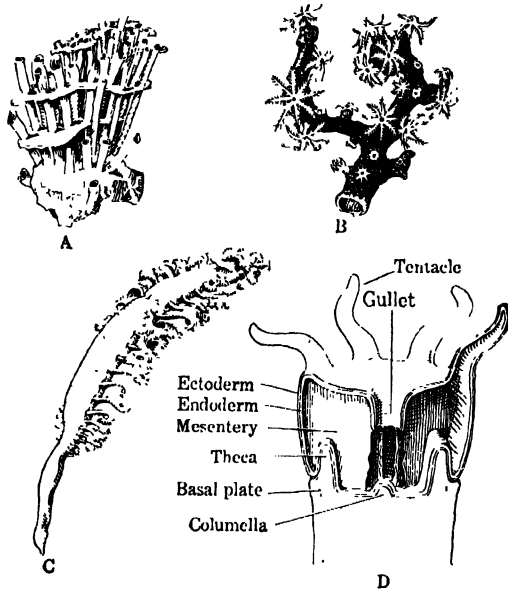


FIG. 408. Corals. A, skeleton of a young colony of organ-pipe coral, *Tubipora musica*; B, small branch of red coral, *Corallum rubrum*, showing living polyps; C, sea pen, *Pennatula phosphorea*; D, diagrammatic section of a single coral polyp. Various magnifications.

ous species of coral animals. Certain kinds of coral, acting through long periods of time, are chiefly responsible for building not only atolls and islands but also fringing reefs and barrier reefs; the Great Barrier Reef of Australia is over a thousand miles long and fifty miles broad. (Fig. 408.)

The polyp type of individual obviously is successful in its way, but our present interest lies chiefly in the fact that it is the stem, or near the stem, from which higher forms started along their main path of ascent. (Fig. 441.)

FLATWORMS

Omitting a small phylum of marine coelenterate-like animals, the CTENOPHORA, popularly called sea walnuts and comb jellies, which have apparently made an abortive attempt to establish a body on the basic three-layer plan, we come directly to the first great group of animals with a definite mesoderm, the flatworms, constituting the phylum PLATYHELMINTHES. (Fig. 409.)

On the lower surface of submerged stones near the edges of ponds are often to be found tiny black, gray, or white flatworms, creeping by cilia; these worms are known as Planaria. They are obviously radically different in structure from a polyp since they exhibit bilateral symmetry, involving both anteroposterior and dorsoventral differentiation. They have a broader anterior end with simple eyes and brain, and a narrower posterior end, and so have right and left sides—a fundamental characteristic.

However, the mouth is situated not in the head, but behind the middle of the ventral surface of the body, and functions both for

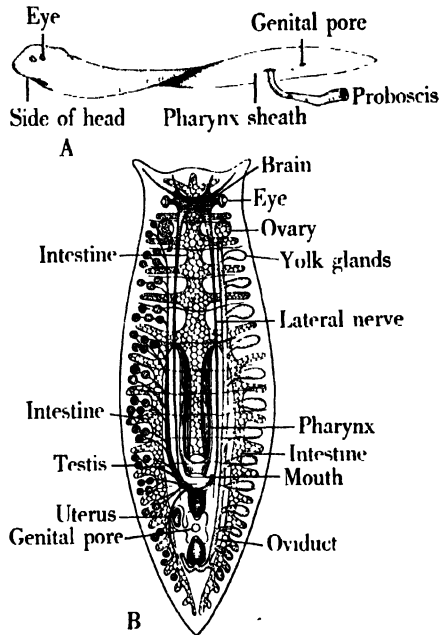


FIG. 409. A, *Planaria polychora*, a fresh-water flatworm; B, diagram of internal organs of a flatworm. Magnified. (After Shipley and MacBride, and von Graff. Redrawn.)

the intake of food and the exit of waste. Moreover, instead of opening into a saclike enteron, the mouth leads into a long, protrusible pharynx, which, in turn, leads into an extremely branched intestine extending throughout the body. The excretory system, the male and female reproductive systems, and the weblike nervous system extend through the body somewhat similarly, each and all embedded in a continuous mass of mesenchyme tissue, which is derived from the third primary germ layer, the mesoderm. Thus the organ systems do not actually lie in a

definite body cavity. Since nearly every organ system extends throughout the body, no special circulatory system is required, and apparently oxygen sufficient for the animal's need can diffuse through the tissues. (Figs. 163, 165, 166, 410.)

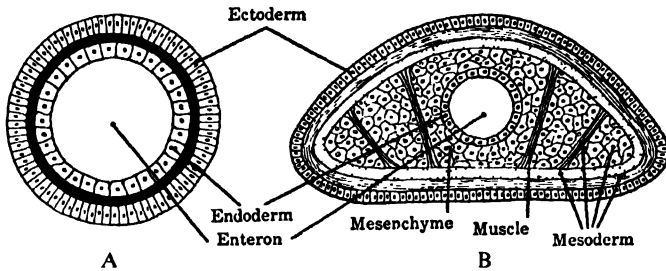


FIG. 410. Diagram of cross sections of the body of a coelenterate (A) and a flatworm (B). Note the mesoderm between the ectoderm and endoderm in the latter. The mesenchyme here occupies the coelomic cavity of higher forms. (From Hegner.)

The genus *Planaria* is a member of the first class of the phylum, known as the **TURBELLARIA**, the other classes being the **TREMATODA**, or flukes, and the **CESTODA**, or tapeworms. Both of the latter classes have superficially departed somewhat widely in structure from the free-living planarians, and also have developed extraordinarily complex life histories, involving alternation of generations, in becoming adapted to various parasitic modes of life. The study of flukes and tapeworms, as well as of the roundworms considered below, constitutes an important part of the science of **PARASITOLOGY** because many species inhabit man and beast and produce disease. The life histories of these forms have already been studied as a phase of the relation of biology to human welfare. (Figs. 321-323.)

ROUNDWORMS

If either the number of species or the number of individuals were the sole criterion of a phylum's importance, unquestionably the lowly **NEMATHELMINTHES**, or roundworms, most of which are members of the class **Nematoda**, would rank high in the animal kingdom. They live literally everywhere from hot springs to Arctic ice, from desert sand to bottom mud of lakes and seas, from the roots of plants to the blood of man. A thimbleful of soil may contain hundreds, even thousands, of individuals. "If all the matter in the universe except the

nematodes were swept away, our world would still be dimly recognizable, and if, as disembodied spirits, we could then investigate it, we should find its mountains, hills, vales, rivers, lakes, and oceans represented by a film of nematodes. The location of towns would be decipherable, since for every massing of human beings there would be a corresponding massing of certain nematodes. Trees would still stand in ghostly rows representing our streets and highways. The location of the various plants and animals would still be decipherable, and, had we sufficient knowledge, in many cases even their species could be determined by an examination of their erstwhile nematode parasites." (Cobb.)

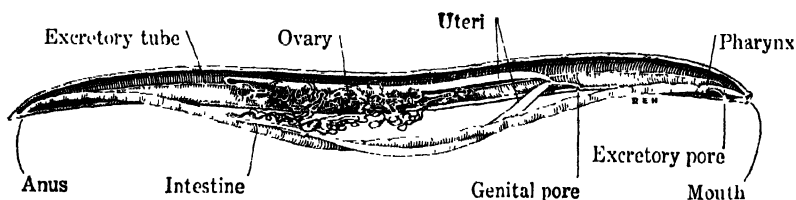


FIG. 411. A common roundworm, *Ascaris lumbricoides*. Diagram of dissection from right side. Reduced.

The roundworms are slender, cylindrical worms, as is indicated by their other common names, such as threadworms, hairworms, and eelworms. The vinegar eel, found in cider vinegar, is a form readily available for study at any season of the year. The nematode body plan shows considerable advance over that of the flatworms because the simple intestine has two openings to the exterior, mouth and anus; the nervous system consists of a ring around the pharynx which sends large nerves throughout the length of the body; the excretory system is well developed; and the male and female reproductive systems are usually in separate individuals. Furthermore the various organs lie in a spacious cavity. However, there are no special circulatory or respiratory systems. (Figs. 411, 412.)

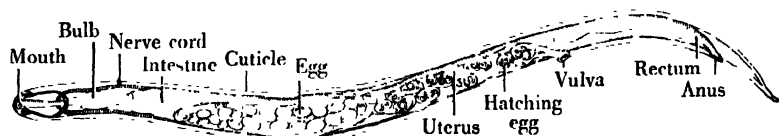


FIG. 412. Vinegar eel, *Turbatrix aceti*. Diagram of a female showing parts of the nervous, digestive, and reproductive systems. Magnified. (From Hegner. Redrawn.)

Naturally the roundworms that have been studied most are parasites of man and domestic animals. The guinea worm, probably the "fiery serpent" of Moses, is sometimes more than three feet long and spends its adult life just under the human skin and its youth in a water flea, Cyclops. The various species of *Ascaris*, best known in man, horse, and pig, are relatively large intestinal worms, the females often attaining a length of more than a foot and producing some 15,000 eggs a day. Related ascarids are common parasites in puppies and kittens. Two of the most dreaded human parasites are the tiny *Trichinella*, the cause of the often fatal TRICHINOSIS contracted by eating infected pork, and *Necator*, notorious as the hookworm. And the common gall worm which infects most of our crop plants is one of the worst pests known to agriculture.

All considered, the roundworms are hardly second to the flatworms from the standpoint of medical zoology and, like them, test the ingenuity of biologists who must ferret out their complex reproductive processes and life histories, which have been evolved to ensure a favorable abode in a specific host. (Figs. 323, 324.)

ROTIFERS, BRYOZOANS, AND BRACHIOPODS

At this point a passing glance may be taken at representatives of three small phyla that contribute relatively little of theoretical or practical importance.

The ROTIFERA, or wheel animalcules, constitute a group of tiny animals commonly found in fresh and salt water, in association with the Protozoa. Although rotifers are the smallest Metazoa, they possess a highly complex series of internal organs, in spite of which some species can withstand slow drying in mud. In this desiccated condition they may be blown about until moisture is again encountered, whereupon they gradually swell up and assume active life and reproduction. (Fig. 413.)

The BRYOZOA are frequently referred to as moss animals because most of them form matlike fixed colonies growing on submerged objects in sea or pond. A superficial examination of the common freshwater *Plumatella*, for example, might suggest that it is a hydroid, but closer scrutiny reveals a very different structural plan, including complex internal organs. In addition to reproducing sexually and by typical budding, *Plumatella* develops peculiar internal buds, or STATOBLASTS, each enclosed in a chitinous shell. In the event that the pond

dries up or the colony is frozen, the resistant statoblasts survive to start a new colony upon the return of favorable conditions. (Fig. 414.)

The BRACHIOPODA, or lampshells, look like clams at first glance, and so bear no obvious resemblance to the colonial Bryozoa. However, brachiopods possibly are related to the Bryozoa because their internal structure resembles in certain ways that of *Plumatella*. Brachiopods represent one of the older marine groups, their shells constituting conspicuous and characteristic fossils in the more ancient rock strata.

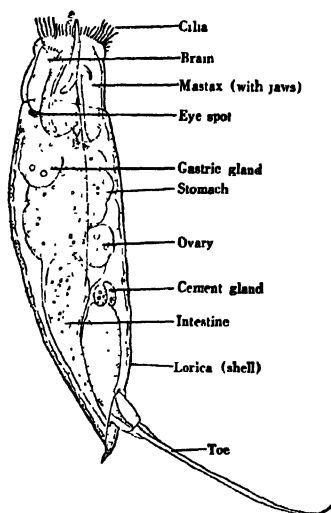


FIG. 413. A rotifer, *Trichocerca rosea*. Highly magnified. (From Edmondson.)

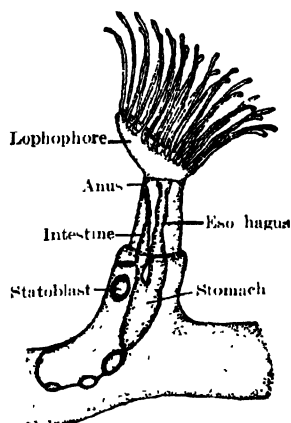


FIG. 414. A single individual of a colony of *Plumatella*. Highly magnified. (After Brown.)

Those living today are merely little-changed survivors of a successful group of yesterday—perhaps nearly half a billion years ago in the early Paleozoic seas. “The everlasting hills are the type of venerable antiquity, but the genus *Lingula* has seen continents grow up, and has maintained its integrity unmoved by the convulsions which have given the crust of the earth its present form.” (Fig. 415.)

ANNELIDS

The segmented worms constitute a relatively straightforward phylum, the ANNELIDA, which carries us on apace in the development of the more complex animal body, conspicuously by definitely intro-

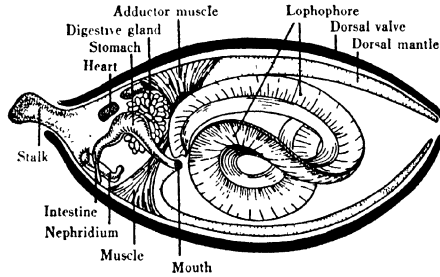


FIG. 415. Brachiopod. Diagram of a vertical section through the body. (From Hegner.)

ducing the principle of segmentation. Well-known representatives are the marine sandworms of the class POLYCHAETA; the earthworms of the OLIGOCHAETA; and the leeches of the HIRUDINFA. (Figs. 72, 73, 77.)

The principle of segmentation, as already emphasized in our discussion of the earthworm, is probably the most significant advance made by the phylum. At all events, it is the plan exemplified by the most successful of the higher groups: the arthropods and vertebrates.

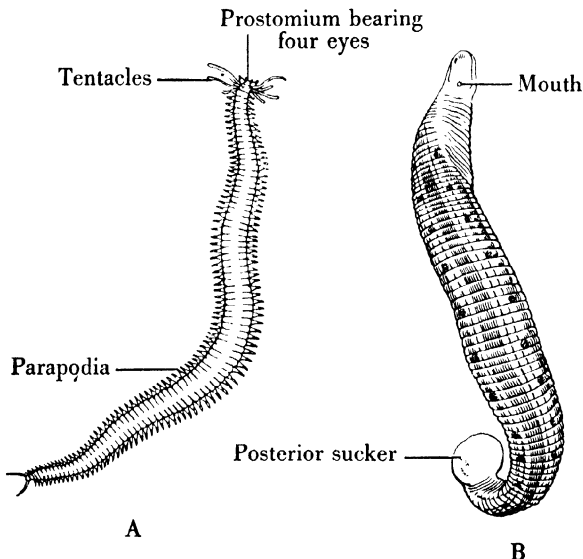


FIG. 416. A, the common marine annelid, the sandworm, *Nereis virens*. See Fig. 417; B, the medicinal leech, *Hirudo medicinalis*.

Apparently the segment is an adaptable unit of organization that makes possible local specialization. Moreover in annelids the coelom first attains high structural significance and affords ample space for more elaborate organ systems. With these facts and the general anatomy of the earthworm in mind, the three most important classes of the phylum may be considered. (pp. 100-110; 696.)

Polychaeta. This class comprises a large number of species of marine worms, most of which burrow in sand or mud at tide level and so are rightly called sandworms. A common and representative genus is

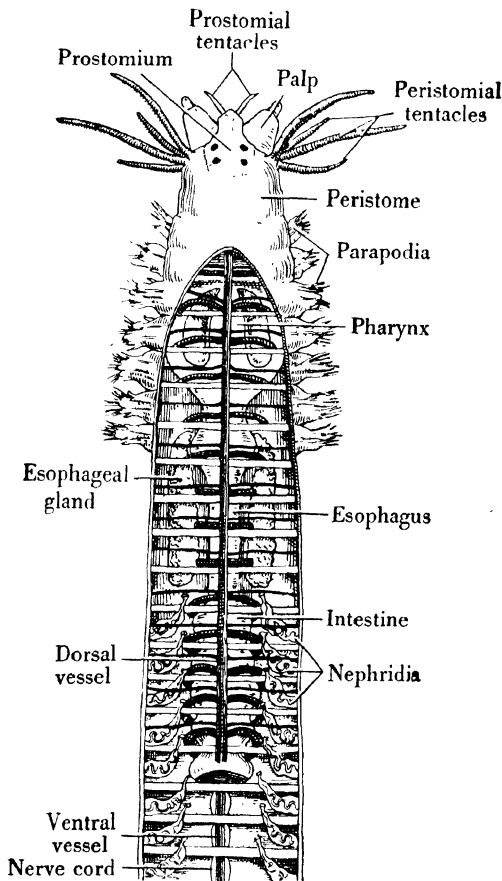


FIG. 417. *Nereis*. Dissection of the anterior end of the body; dorsal body wall removed. (After Parker and Haswell. Redrawn.)

Nereis, although marked modifications of the external features of the body of Nereis are exhibited by many other genera, such as the tube-worms in specially constructed tubes that are permanently attached.

The body of Nereis consists of a linear series of some fifty segments and may attain a foot in length. Several of the anterior segments form a head with mouth, chitinous jaws, and sense organs—notably rather complex eyes; while most of the remaining segments are provided with paddlelike, bristled appendages, or PARAPODIA, that act as both respiratory and locomotor organs. The general plan of the internal organs, with the exception of the reproductive system, is the same as in the earthworm. (Figs. 416, 417.)

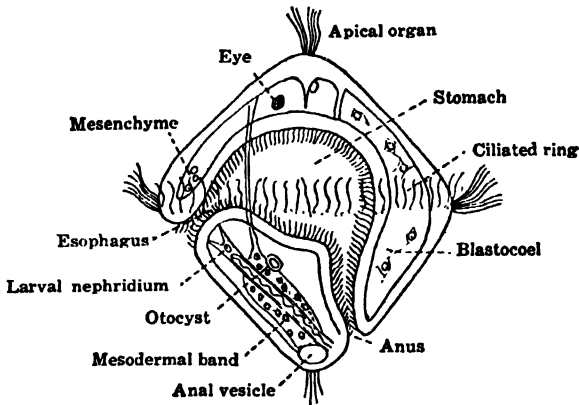


FIG. 418. Diagram of the trochophore larva of a polychaete worm. Side view. (From Hegner, after Shearer.)

The sexes are separate in Nereis, and from the fertilized egg arises a free-swimming larval stage, the TROCHOPHORE, which finally develops into the adult worm. A trochophore, or similar larva, occurs in the development of members of several other phyla of invertebrates, for example the Mollusca, and some zoologists believe this to be an indication that the phyla involved have all descended from a common ancestor. (Figs. 418, 441.)

Oligochaeta. Earthworms and closely related fresh-water worms constitute the second great class of annelids. They show a simplification of the external structures exhibited by Nereis, for the head is greatly reduced and attendant specialized sense organs are absent. Furthermore, the setae are all that represent the parapodia. Apparently

the sluggish, underground life of earthworms renders highly developed locomotor, respiratory, and sense organs unnecessary. However, in some of the more active fresh-water oligochaetes, projections of the body serve as gills, and simple eyes are present. It will be recalled that earthworms are hermaphroditic and that the zygote develops directly into a small worm without an intervening larval form as in the polychaetes.

Some idea of the importance of the many species and enormous numbers of earthworms may be gathered from Darwin's estimate that in many soils these creatures annually bring to the surface as castings some eighteen tons of earth per acre. Thus the earthworms, unseen and unheard, gradually effect radical transformations of the surface soil, and so are very important in loosening and aerating the soil. (Fig. 419.)

Hirudinea. The best-known member of the class is the medicinal leech, *Hirudo medicinalis*, so much used when bloodletting was in vogue that physicians were dubbed "leeches." The members of this species are about four inches in length but capable of great change in form. The body is somewhat flattened and comprises about thirty segments. There are two suckers, one at either end of the animal, but no setae or parapodia, and the coelom is greatly reduced. The chief food of most leeches is the blood of vertebrates, which is sucked into the large branched dilation of the alimentary canal where it is stored. Then during a period of months, the blood is gradually passed to the stomach for digestion. Clotting of the blood is prevented by the secretion of an anticoagulant. (Fig. 416.)

Leeches are hermaphroditic and the reproductive process is similar to that in the earthworms. The medicinal leech is a fresh-water form, but many species are marine and even more are terrestrial.

MOLLUSCA

The immense phylum MOLLUSCA, which includes such well-known edible shellfish as the clams, oysters, scallops, snails, and abalones, and also the cuttlefishes, nautili, etc., exhibits a considerable departure in body plan from that exhibited by the segmented worms. However,

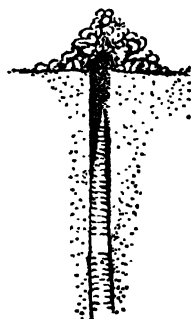


FIG. 419. Diagram showing an earthworm in its burrow, with castings piled at the surface. (After Walton, Redrawn.)

it seems clear from certain structural features exhibited by the lowest class, the AMPHINEURA represented by the chitons, and also from the developmental stages, such as the trochophore of various mollusks, that the phylum has arisen from a wormlike ancestral type. This form, instead of adopting segmentation, became otherwise specialized to give rise to the unique and highly successful molluscan group that is rivalled among invertebrates only by the insects. (Fig. 420.)

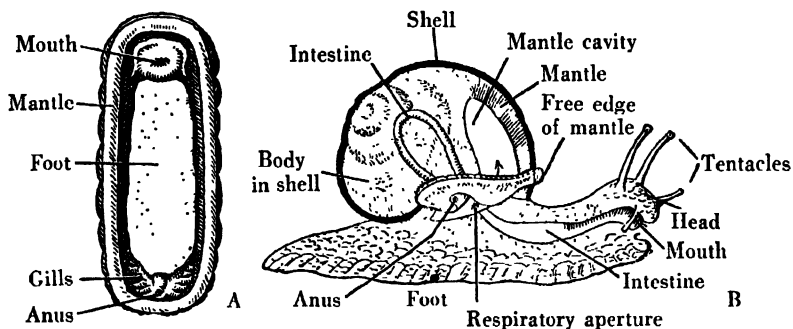


FIG. 420. A, chiton, ventral view; B, snail, diagrammatic side view, showing parts of the internal structures.

The most characteristic structures of mollusks are an external skeleton, the **SHELL**; a fleshy muscular organ, the **FOOT**, typically for locomotion; and a **MANTLE CAVITY** between the main body and an enclosing envelope, the **MANTLE**, that secretes and lines the shell. Among the five classes of mollusks three are of commanding interest: the *Gastropoda*, *Pelecypoda*, and *Cephalopoda*. (pp. 696-697.)

Gastropoda. One usually thinks of mollusks as sea-dwelling animals, but among about sixteen thousand species of snails, slugs, and other similar gastropods, more than one-third are terrestrial. Everyone is familiar with the spirally coiled shells of the garden and pond snails and of the periwinkles of the seashore, into which the animals can completely retire when disturbed. However, many close relatives, such as the limpets, commonly represented by the marine boat shells (*Crepidula*) and abalones, have shells that are relatively simple, flattened cones, while most of the slugs have no shell at all. (Fig. 421.)

The common snails and slugs glide along on a path of slime by wavelike muscular contractions of the foot, which forms the entire ventral part of the body, but some of the marine species actively swim

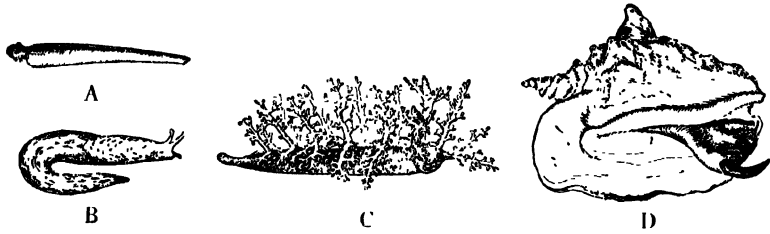


FIG. 421. Gastropod types. A, *Dentalium*, tooth shell; B, garden slug; C, *Dnurdonotus*, a nudibranch; D, conch. Not drawn to scale. (After Hegner. Redrawn.)

by means of delicate, undulating expansions of the foot. Many of these are the unique sea butterflies, or pteropods, that spend their time on the ocean surface, often in such untold multitudes as to form an important food for whales.

Snails and their allies have a well-developed head with tentacles, eyes, and a mouth supplied with a rasping tongue-like organ, the *RADULA*. Indeed, the oyster drill uses this organ to bore holes through oyster shells so it can secure the contents. The mouth leads into a complicated digestive tract. Add to this the complex circulatory, respiratory, excretory, nervous, and reproductive systems, and it becomes evident that even the lowly garden slug belies its soft, slimy body. Most of the terrestrial and many of the freshwater gastropods breathe by a lunglike sac instead of gills. (Fig. 420.)

Pelecypoda. The Mollusca is a phylum of surprises, for the Pelecypoda is a class of headless animals that, for the most part, have taken to a sedentary life within a calcareous shell composed of two valves hinged together; they are bivalves. The adult oysters are permanently attached and therefore footless; the clams and mussels are sluggish, sand-burrowing creatures; the shipworms riddle wharves with their tunnels; and the scallops swim by rapidly opening and clapping together the valves of the shell to eject a stream of water. (Figs. 422, 423.)



FIG. 422. Pelecypod types. A, clam, *Yoldia*; B, scallop, *Pecten*; C, soft-shell clam, *Mya*, with siphon extended. (After Hegner. Redrawn.)

The most distinctive feature of the bivalves, aside from the shell, is their peculiar method of securing food from a current of water that is kept in motion by the activity of cilia on the gills, mantle surface, and LABIAL PALPS about the mouth. In brief, water laden with oxygen and microscopic animals and plants is drawn through an opening, the INHALENT SIPHON, into the lower part of the mantle cavity, known as

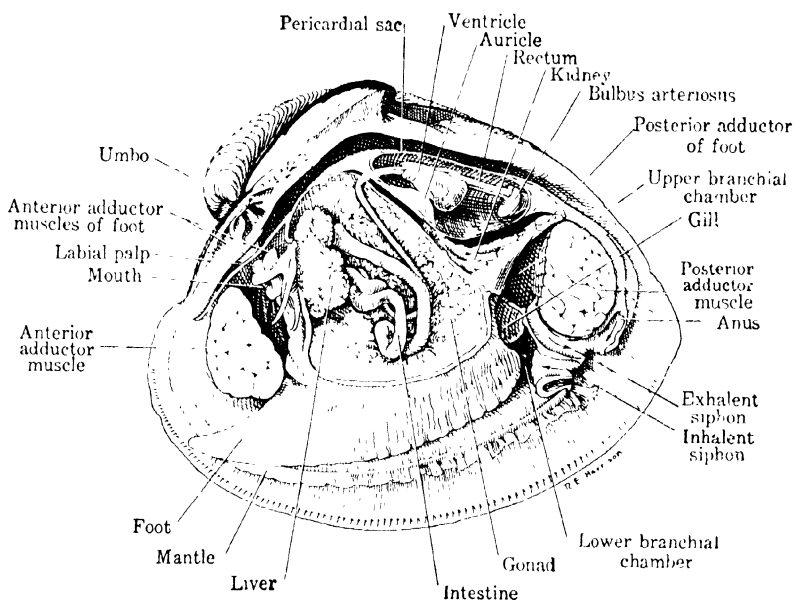


FIG. 423. Hard-shell clam, or Quahog, *Venus mercenaria*. Dissection showing structures which are visible when left valve, mantle, and gills are removed

the INFRABRANCHIAL CHAMBER, where the sievelike gills are suspended. As it passes through the gills, the food is carried by ciliary action to the mouth, while at the same time the blood in the gills is aerated. From the gills the water current passes into the SUPRABRANCHIAL CHAMBER and then on out through the EXHALENT SIPHON, carrying with it various waste products.

The mouth opens into the esophagus, thence to the stomach, which is provided with two large digestive glands, the liver. Strange to say, the long, coiled intestine passes through the heart before it proceeds above the POSTERIOR ADDUCTOR muscle to discharge waste into the exhalant siphon. (Fig. 423.)

The circulatory system comprises a heart, dorsally situated in the PERICARDIAL SAC, and a system of blood vessels and spaces, or sinuses, that deliver the blood throughout the body. The nervous system is rather complex and consists chiefly of three pairs of large ganglia and nerves connecting them. Several types of simple sense organs occur, the sensory cells on the edge of the mantle probably being responsive to light and contact.

The reproductive process varies considerably in different bivalves. In most species the sexes are separate, but in some the individuals are hermaphroditic. Indeed, a periodical change in sex is not rare. Oysters spawn in the spring, liberating the sperm and eggs, and the zygotes develop into microscopic free-swimming SPAT. Within a week these sink to the bottom and become attached to whatever object they happen to touch and, if fortunately located, develop into adult oysters. Fortunate, because it is estimated that a larva has less than one chance in a million of surviving to maturity and attaining the qualities that appeal to the human palate. However, one female may liberate nearly half a billion eggs.

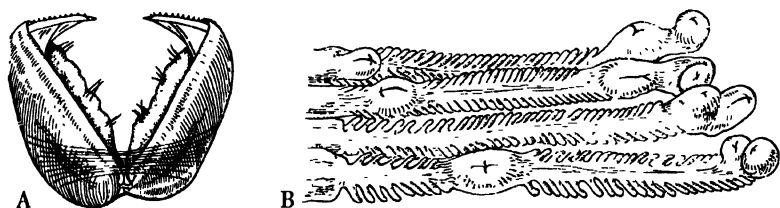


FIG. 424. A, glochidium of a fresh-water mussel; B, gill filaments of a fresh-water fish with many embedded glochidia, which live for a time as parasites. (After Lefevre and Curtis. Redrawn.)

The eggs of the fresh-water clams or mussels are fertilized by sperm entering the mantle cavity with the inhalent water current, and the larvae develop in the gills which act as temporary brood pouches. Eventually the embryos, known as GLOCHIDIA, escape, settle on the bottom of the pond or river, and die unless they come into contact with a fish. In this event each glochidium attaches itself to a fish and as a parasite obtains free food and transportation for several weeks until it has developed sufficiently to drop off, settle to the bottom, and shift for itself. (Fig. 424.)

The economic importance of the bivalves hardly need be mentioned. Oyster farms in America produce an annual crop valued at many

millions of dollars; fresh-water mussels are the basis of the important pearl button industry of the Mississippi Valley; and pearls produced by the irritated mantle tissue of several species of bivalves are among the most highly prized and priced jewels.

Cephalopoda. The squids, cuttlefishes, octopi, and nautili exhibit in many ways a marked contrast to the rest of the mollusks, being relatively active, aggressive marine animals which have achieved a highly specialized head by combining head and foot: hence the name *Cephalopoda*. Most species are shell-less or have merely an internal remnant such as the "pen" of the squid, or the cuttlefish "bone" favored as food by caged canary birds. Squids depend upon their activity, or rapid changes in color, or emission of a cloud of ink, or all combined, in order to escape an enemy. However, the pearly, or chambered, nautilus is without an ink sac, and lives in the largest and terminal chamber of a shell coiled in a flat spiral. (Figs. 425, 426, 427.)

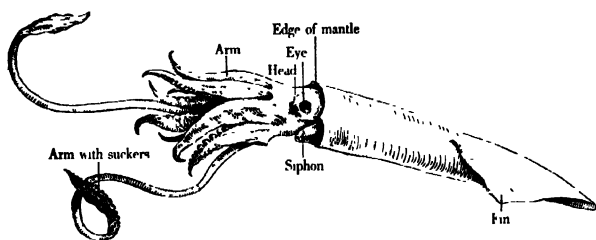


FIG. 425. The squid, *Loligo*, as seen from left side. X $\frac{1}{3}$. Drawn from laboratory specimen.

The head of cephalopods is provided with a parrot-like beak and rasping tongue, as well as with a rather large brain, and efficient eyes that superficially are very like those of fishes. Extending from the head is a circle of muscular, mobile ARMS with suckers used for capturing prey. And usually near by there is a flexible tube-like SIPHON, through which are forced jets of water that aid in propelling and steering the animal.

Cephalopods are in some respects more capable than some of the lower vertebrates. They apparently exhaust the possibilities of the molluscan body plan both in complexity and in size. Indeed the giant squid is one of the largest invertebrates; measured to the tip of the extended arms it exceeds in length any vertebrate except the largest whales.

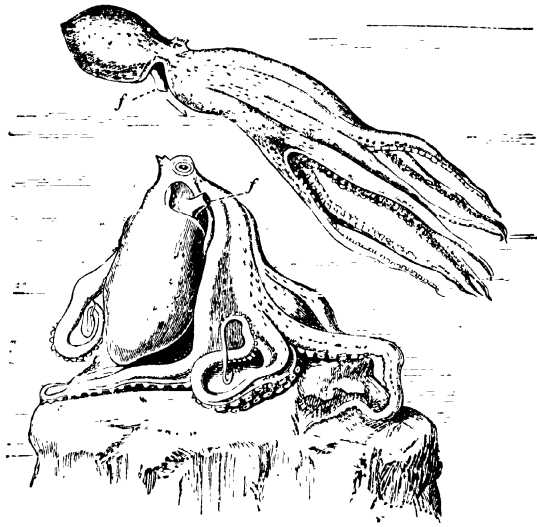


FIG. 426. Octopus, at rest (*below*), and in motion (*above*): *f*, siphon (From Hegner, after Merculiano and Williams.)

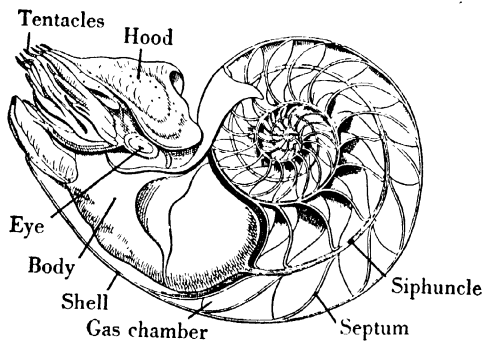


FIG. 427. *Nautilus pompilius*, the chambered, or pearly, nautilus. Part of the shell removed to show the animal-body and the many gas-filled chambers. (From Hegner. Redrawn)

ECHINODERMS

Everyone who has spent a summer at the seashore should be familiar with the starfishes and sea urchins, common examples of the marine phylum of spiny-skinned animals, the ECHINODERMATA. All members of the group have radially symmetrical bodies, a condition not seen since we left the Coelenterata. However, this symmetry indicates no direct relationship with the coelenterates: during early embryonic life an echinoderm is actually bilaterally symmetrical, and the radial form is only secondarily assumed, masking the basic structure.

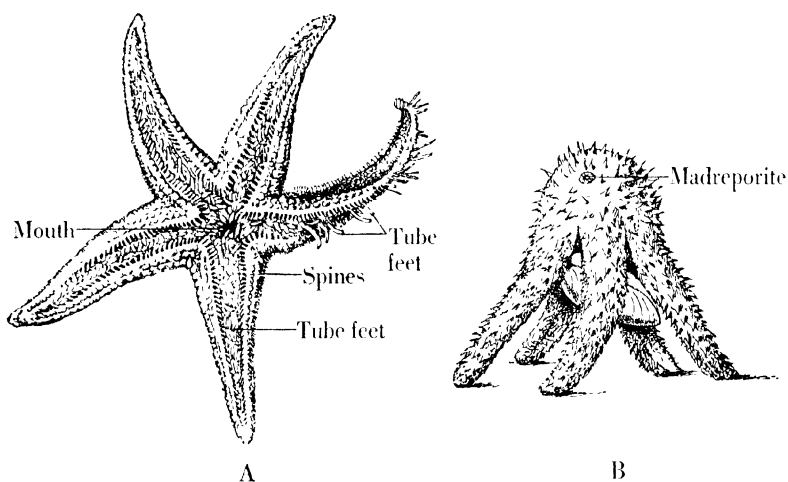


FIG. 428. Starfish, *Asterias*. A, oral view; B, devouring a clam. See Fig. 429. (From Cambridge Natural History. Redrawn.)

Indeed "Nature's pentagonal experiment" has produced a series of bizarre forms that have been successful from early geologic time to the present, though they bear little resemblance to other animals. Witness the structure of a common starfish representing the class Asteroidea. (Fig. 428.)

Asteroidea. The body of a starfish consists of a CENTRAL DISC from which radiate five or more ARMS. The entire animal is protected by an exoskeleton consisting of calcareous plates, embedded in the tissues, and short blunt spines. Surrounding the bases of the latter are many specialized spines, or PEDICELLARIAE, which are tiny pincers operated by muscles. The pincers serve to keep the surface of the animal free

from debris and protect the delicate, protruding DERMAL BRANCHIAE.

The mouth, situated on the ventral surface of the disc, opens into a large stomach that leads into the PYLORIC SAC from which large, glandular PYLORIC CAECA extend into each arm. Above the stomach is a small rectum that continues to the tiny dorsal anal opening, but all waste materials are ejected through the mouth. The nervous system is essentially a nerve ring encircling the mouth, with a branch extending into each arm. There is no central, dominating nerve mass that is comparable to a brain, and only very primitive sense organs are present. The functions of a circulatory and respiratory system are carried on by the coelomic fluid—mostly sea water in which amoeboid cells float—that fills the large body cavity, or coelom, circulates through the dermal branchiae, and bathes all the organs, including the male or female reproductive organs.

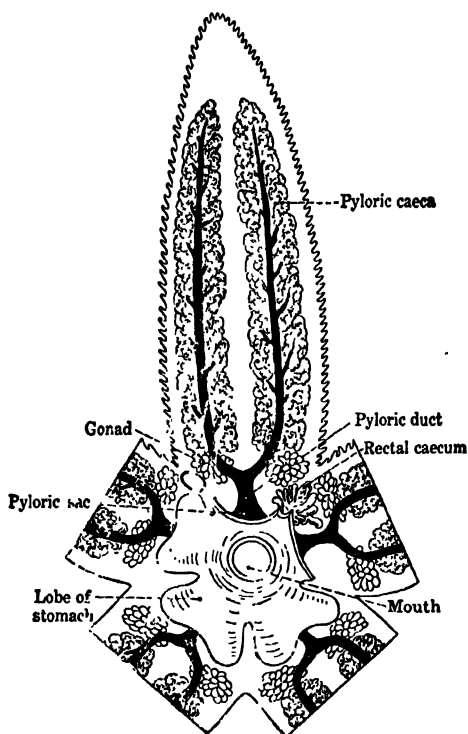


FIG. 429. Starfish. Diagram showing part of internal anatomy from oral side. Four arms have been cut off. See Fig. 430. (After Hegner.)

On the dorsal surface of the disc, near the anus, there is a small porous plate, the MADREPORITE, that admits water to a series of tubes, the WATER-VASCULAR SYSTEM, terminating in myriads of TUBE FEET, the unique hydraulic locomotor and food-capturing organs. The tube feet project from a groove on the ventral surface of each arm. When the feet are pressed against an object and the water in them is withdrawn to the reservoirs in the system, they cling by suction to the object, and when the water is again forced into the feet, suction ceases and they are released. (Figs. 428, 429, 430.)

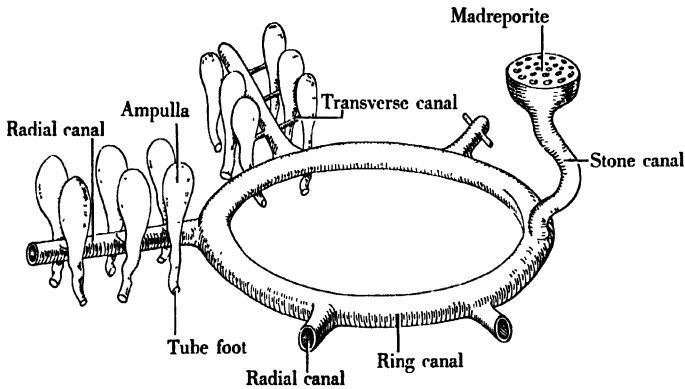


FIG. 430. Starfish. Diagram of part of water-vascular system; three of the radial canals are cut off at the base and the other two near the base. (From Heger. Redrawn.)

Starfish are voracious, carnivorous animals with, unfortunately, a predilection for oysters and clams. A steady and prolonged pull exerted by a multitude of tube feet, working in relays, exhausts the adductor muscles of the mollusk so that the shell gapes. Then the stomach of the starfish is everted to surround and digest the inhabitant.

The various species of starfish differ considerably in external appearance; some have numerous arms, usually in multiples of five, others have very long arms, and still others such short arms that the general outline of the animal is almost pentagonal.

Ophiuroidea. Most similar to the common starfish are the brittle stars and basket stars of the class *Ophiuroidea*; the former typically with five long, mobile arms that are easily lost and as easily regenerated, and the latter with each arm branched many times so that there may be thousands of active terminal twigs. Tube feet serve solely as

tactile and respiratory organs since locomotion is effected by contractions of the arms.

Echinoidea. The sea urchins, of the class Echinoidea, are without arms, the body being enclosed within a hard, globular shell composed of rows of small, closely fitted calcareous plates, and covered with a forest of spines for protection. Protruding tube feet serve in locomotion. Exposed on the oral, or ventral, surface are five white teeth that form a part of a complicated internal apparatus, known as Aristotle's lantern, which is associated with the intake of food. Sand dollars are essentially greatly flattened sea urchins covered with so many tiny, short spines that the surface feels like velvet. (Fig. 431.)

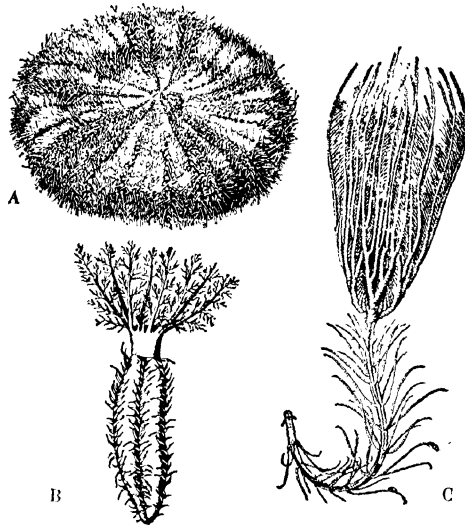


FIG. 431. A, sea urchin, *Asthenosoma*, oral view; B, sea cucumber, *Cucumaria*; C, sea lily, *Metacrinus*. (From Thomson, Ludvig, and Carpenter. Redrawn.)

Holothuroidea. The sea cucumbers, forming the class Holothuroidea, are elongated, muscular, flexible sacs with the mouth at one end surrounded by contractile tentacles, representing modified tube feet. The animals seem to be little inconvenienced if they are irritated to eject most of their internal organs, because a period of rest suffices for the regeneration of the lost tissues. (Fig. 431.)

Crinoidea. Finally, the sea lilies, of the class Crinoidea, are apparently the antithesis of the sea cucumbers. They are usually tempo-

rarily or permanently attached by a jointed stalk, and extend their numerous much-branched arms in plumelike fashion; so some species are called feather stars. (Fig. 431.)

Even with all this diversified array exhibited by some 5,000 species of echinoderms, it is certainly true that all are basically similar in structure and development; they have almost surely been derived in a roundabout way from a primitive wormlike ancestor. Many zoologists place them as the final phylum of invertebrates and regard them as nearest to the stem from which the chordates arose. (Fig. 441.)

ARTHROPODS

We now turn to the more orthodox (because dominant) phylum of segmented invertebrates with jointed appendages, the ARTHROPODA. The most important classes are the Crustacea, Myriapoda, Insecta, and Arachnida; the first chiefly aquatic and breathing by means of GILLS, and the rest typically terrestrial with TRACHEAE or equivalent air-breathing organs. (Fig. 111.)

The arthropod body, as already indicated in the study of the crayfish, is built on the plan of a chain of segments, several of the anterior segments constituting the head, with the mouth, and the posterior segment containing the anus. In the simplest arthropods there is relatively little differentiation either among the segments or among the characteristic pairs of jointed appendages that each bears. In more complex forms, however, there is a progressive union and specialization of segments in certain regions of the body and a shifting and transformation of their appendages for one function or another. As a matter of fact, it seems that all the possible changes are rung on the pervading segmental chain. (Figs. 75, 76; pp. 110-120.)

Another conspicuous feature of the phylum is the presence of a hard, unyielding, external armor, or exoskeleton, with flexible joints, moved by attached muscles. This skeleton hampers the increase in size of the inhabitant, so periodically the shell is shed; the animal molts. Seizing the opportunity, so to speak, the animal rapidly increases in size at the expense of material stored for this purpose, and also secretes a new skeleton. A "soft-shelled" crab is one which has recently molted and has been taken at a disadvantage before the newly secreted skeleton has had time to harden.

The life history of many of the arthropods is surprisingly complex and involves radical form changes that constitute a METAMORPHOSIS.

The embryo of certain Crustacea develops from the egg as an unsegmented larva, then after molting assumes a segmented larval form, and so on until the adult state is attained. In other Crustacea one or more of these stages may be briefly summarized, as it were, in the egg before hatching. Finally, animals like the crayfish hatch with essentially the adult form. This series of in metamorphic stages in the development of the higher Crustacea is of considerable theoretical interest because the stages are very similar to the larval or adult forms of certain other Crustacea that are regarded as more primitive in organization. Thus it appears that individual development in the higher Crustacea very broadly and incompletely summarizes, or RECAPITULATES, their ancestral, or evolutionary, history. (Fig. 432.)

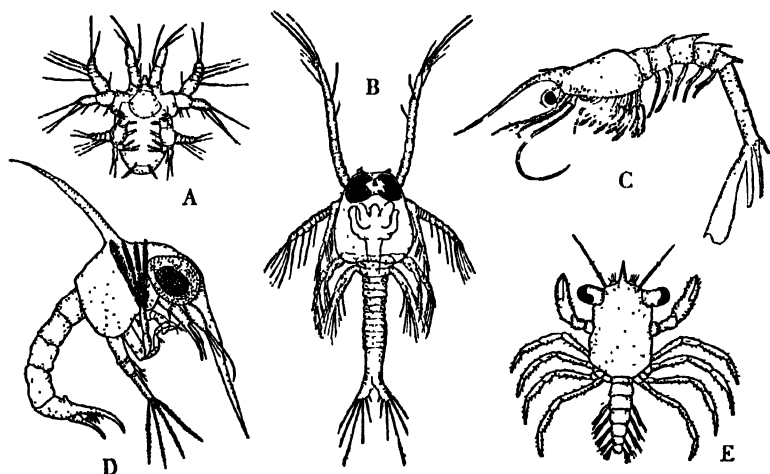


FIG. 432. Larval stages of crustacea to illustrate the recapitulation theory. A, Nauplius stage (*Cyclops*); B, Zoea stage (*Pendaeus*); C, Mysis stage (*Pendaeus*); D, Zoea stage (*Carcinus*); E, Megalops stage (*Carcinus*). (After Deitrich, Claus, Faxon, and Bate.)

However, metamorphosis is probably called to our attention more prominently in the insects. It is common knowledge that caterpillars are the larval, wormlike, feeding stages of butterflies and moths. The winged condition is attained after a final molt. This takes place while the larva is in a resting condition, the PUPA, necessitated by the great structural changes involved. In many other insects there is a similar metamorphosis, but in some it is less radical. Thus the young locust,

or grasshopper, is similar in form to the adult, but after each molt it is larger than before, and finally is a mature winged adult. Such a transformation not involving a pupal stage is frequently referred to as incomplete metamorphosis. (Figs. 327-338, 433.)

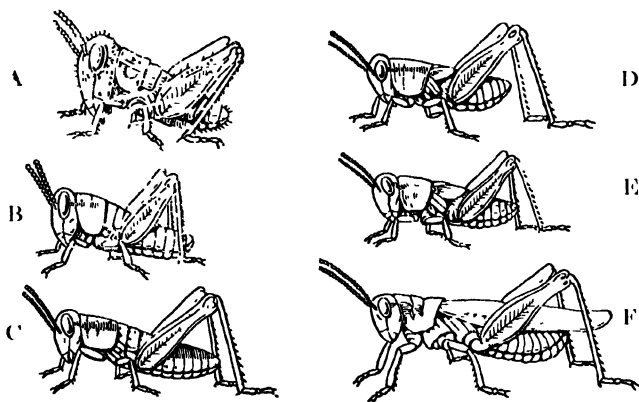


FIG. 433. Partial, or incomplete, metamorphosis of a locust, showing the five nymph stages (A-E), and the adult (F). Not drawn to scale. Note the gradual growth of the wings which are first visible in D. (After Packard.)

In the light of these general facts, representative types of the Arthropoda may be reviewed.

Crustacea. A varied multitude of marine and a somewhat smaller number of fresh-water animals constitute the class Crustacea. Among approximately twenty thousand species, probably the best-known (because they are among the largest and some are edible) are the lobsters, crayfishes, and crabs. The crabs appear unique because the abdomen is permanently bent forward under the cephalothorax. Then at the other extreme of crustacean types are the wood lice, or pill bugs, that live in damp places, even in our gardens. All of these and their many close relatives form one of the two crustacean subclasses, the MALACOSTRACA. The other great subclass, the ENTOMOSTRACA, includes even greater diversity of structure. There are the Cirripedes, or barnacles, which early in their life settle down permanently to a sedentary existence and thereby foul the hulls of ships and encrust driftwood and stones on the seashore. Then, unrecognized by other than specialists are the many kinds of microscopic crustaceans, such as *Daphnia*, *Cyclops*, and their allies. These so-called water fleas vie in numbers with the Protozoa and microscopic plants in the vastness of open

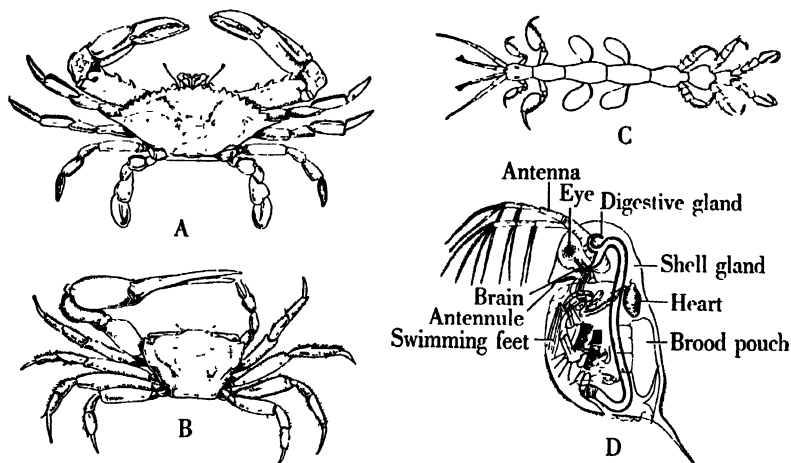


FIG. 434. Crustaceans. A, edible blue crab, *Callinectes*; B, fiddler crab, *Gelastus*; C, *Caprella*; D, *Daphnia*, a water-flea. Not drawn to scale. (From Paulmier, and Claus. Redrawn.)

seas as well as in many lakes. They form a crucial part of the food of larger animals, including fishes, and so indirectly of man. (Figs. 76, 78, 285, 434.)

Myriapoda. Passing to the Myriapoda we reach the terrestrial arthropods with long serpentine bodies, such as the more or less flattened centipedes, or chilopods, and the rounded millipedes, or diplopods; the latter have the body segments united in pairs so that there seem to be four legs on each segment. As their names indicate, legs are plentiful, reaching nearly two hundred in some millipedes. Centi-

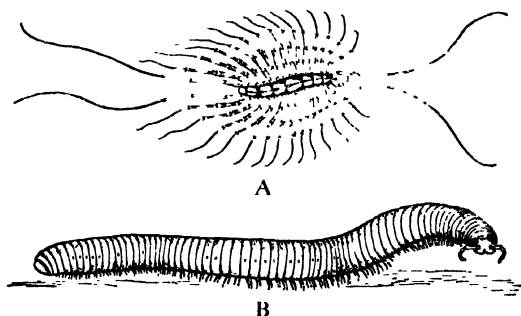


FIG. 435. A, centipede, *Scutigera forceps*; B, millipede, *Julus virgatus*.

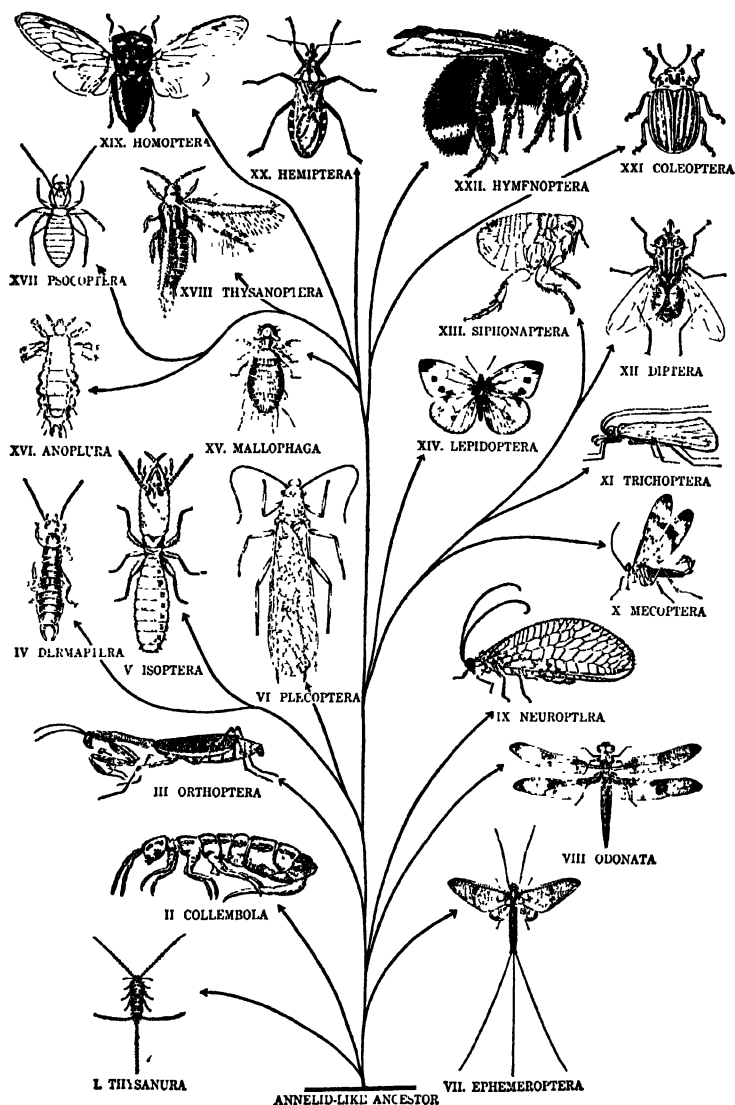


FIG. 436. General relationships of the chief orders of the class Insecta. I, silverfish; II, springtail; III, praying mantis; IV, earwig; V, termite; VI, stonefly, VII, mayfly; VIII, dragonfly; IX, lacewing-fly; X, scorpion-fly; XI, caddice-fly, XII, stable fly; XIII, flea; XIV, butterfly; XV, bird louse; XVI, body louse. XVII, book louse; XVIII, thrips; XIX, cicada; XX, triatom bug; XXI, potato beetle; XXII, humble bee. In general, the classification is based on the presence or absence of wings, structure of mouth parts, and the life history. (From Hegner.)

pedes are swift-moving carnivorous forms with poisonous jaws, represented, for example, by members of the genus *Scolopendra* of the tropics, which may be nearly a foot in length and sometimes dangerous to man. The common house centipede, *Scutigera forceps*, feeds on insects but is harmless to man. Millipedes, on the other hand, are slow-moving vegetarians which, in many cases, are highly destructive to plants. (Fig. 435.)

Insecta. Everyone knows various members of the *Insecta*, familiarly represented by that most domestic of animals, the housefly, but probably few realize that the species of insects outnumber all the other species of animals except the Protozoa. (Figs. 329, 436; p. 697.)

A typical insect is characterized by a body divided into three major parts: head, thorax, and abdomen. The head bears a pair of compound eyes, usually one to three simple eyes, or OCELLI, a pair of feelers, or ANTENNAE, and the mouth parts: the LABRUM, MANDIBLES, MAXILLAE, and LABIUM. (Figs. 111, 302, 437.)

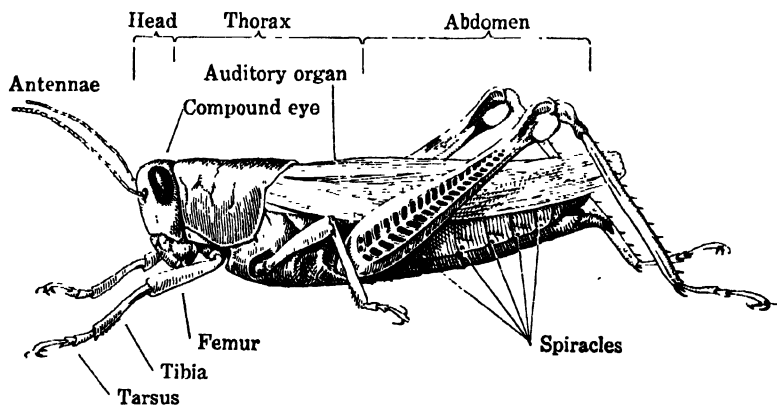


FIG. 437. Grasshopper, or locust, *Melanoplus differentialis*.

The thorax is composed of three segments, each of which bears a pair of legs. The legs of insects in most cases perform many functions in addition to locomotion; they are really a set of tools, as has been seen in the legs of the honeybee. (Fig. 303.)

Usually two of the three thoracic segments each bears a pair of wings, but the housefly, of course, has but one pair and the flea none, though the fly's balancers (halteres) are remnants of its missing pair. In origin and structure the wings of insects are entirely different from

the legs, and therefore bear no relation to the paired appendages of other arthropods. Wings are new structures that confer upon insects the honor of being the only invertebrates to conquer the air. Indeed, the adaptive radiation of insects to all sorts of habitats and modes of life exhibits a versatility that somewhat parallels that of the highest vertebrates, the mammals. (Figs. 293, 299.)

Furthermore, certain insects surpass all the rest of the living world, excepting man, in the remarkable development of communal organization. In insects this involves specialization of individuals for definite contributions to the economy of the social units, such as termite and ant nests and beehives. (Fig. 438.) The termites, for instance, have

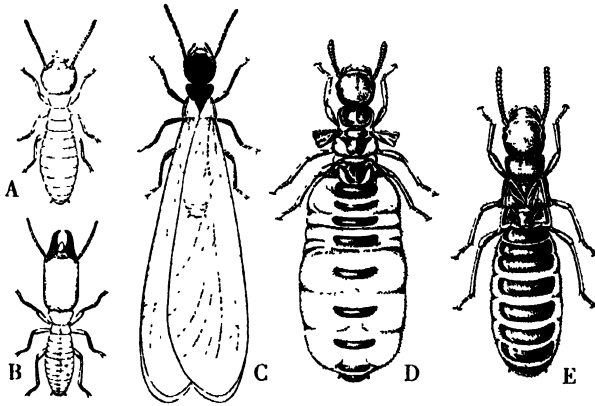


FIG. 438. Termite, *Reticulitermes flavipes*. A, worker; B, soldier; C, winged form; D, female, or queen, distended with eggs; E, male, or king. (After Snyder, and Herms. Redrawn.)

developed a highly complex system of division of labor. Each colony consists of various kinds of individuals, or castes, especially fitted by form and instinct to carry on diverse activities. There are usually three castes: male and female reproductive individuals, soldiers, and workers. The workers gather food, feed the king, queen, soldiers, and young, and also build the tunnels, mounds, nests, and fungus gardens which various species of termites make.

With these brief statements we may leave the insects, since they have already been discussed in relation to the numerous biological problems with which they are associated. (pp. 413-418; 453-465.)

ARACHNIDA

The phylum Arthropoda also includes the class Arachnida, which comprises the spiders, ticks, mites, scorpions, and their close relatives. These are frequently confused with insects, but the more common forms, such as the spiders and ticks, are readily distinguished by the possession of eight legs. (Fig. 439.)

Spiders are carnivorous animals that capture their prey in elaborately constructed webs, or by stalking and pouncing upon it. Some spiders are poisonous, and the reputation of these has served to malign their many harmless relatives. The scorpions, however, are in general poisonous, and the mites and ticks are injurious to man in many ways. Some bite and others burrow into our bodies and those of domestic animals; the common rabbit frequently harbors several thousand ticks. Even garden crops and forests suffer. Unfortunately certain species infect their hosts with various bacteria and Protozoa and so produce

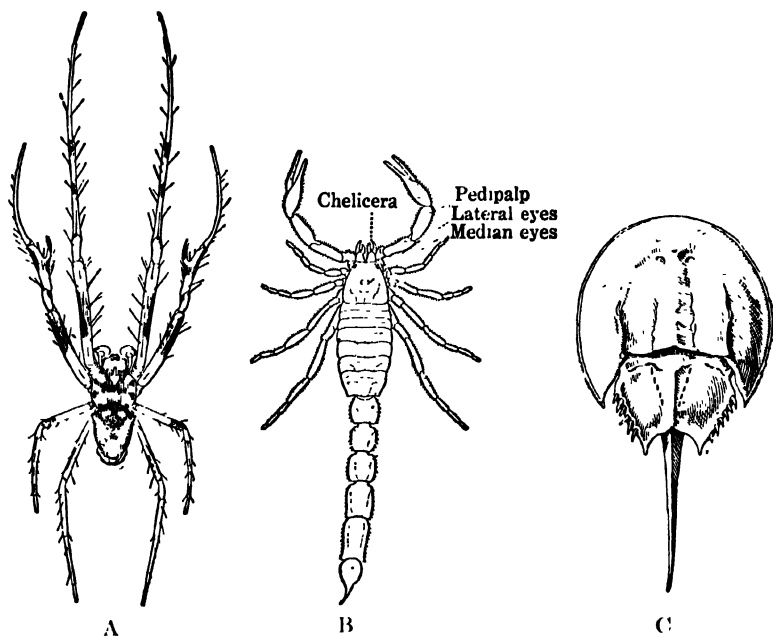


FIG. 439. A, spider, *Epeira verrucosa* (from Emerton); B, scorpion, *Buthus occitanus* (from Krapelin); C, king-crab, *Limulus polyphemus*. Not drawn to scale.

serious diseases. But there are many harmless forms, represented by the well-known red harvest mites.

Appended to the Arachnida is the peculiar marine king crab or horseshoe crab, *Limulus polyphemus*, of the Atlantic coast. It is of considerable theoretical interest to students of evolution because it shows certain resemblances to the great group of extinct arthropods known as trilobites. (Fig. 439.)



FIG. 440. *Peripatus*, *Peripatopsis capensis*. About natural size. Redrawn. (From Sedgwick.)

Finally, mention should be made of a unique group, the Onychophora, that is usually regarded as a class of the Arthropoda. It comprises only a few genera and species, commonly called Peripatus, whose sole importance is that they seem to link the Arthropoda with the Annelida by exhibiting characters of both phyla. The chief organ systems are, in general, like those of the annelids, but jaws, paired appendages, tracheae, and a hemocoel are present. These animals, now found in widely separated parts of the earth, probably are the remnants of a population, once continuous, that has departed but little from the arthropod stem. (Fig. 440.)

The arthropods, judged by the stupendous number of species and individuals, or by variety of form, or by sheer success in competition with other animals in air, water, and on the ground, are "Nature's most successful invertebrate experiment." The segmental plan begun in a small way in some of the lower forms, is definitely established in the annelids, and is made the most of in the arthropods.

However, arthropods are hampered by inherent structural limitations. The hard, dead, external skeleton imparts certain mechanical restrictions on size and freedom of action that are relieved in vertebrates by the substitution of an internal living skeleton. Furthermore, small size precludes a constant body temperature greater than the surroundings, so that arthropods cannot achieve the constancy of living possible to the warm-blooded birds and mammals. Nevertheless it has

been suggested as not beyond the range of possibility that insects may yet dominate the earth! (Fig. 441; pp. 453-465.)

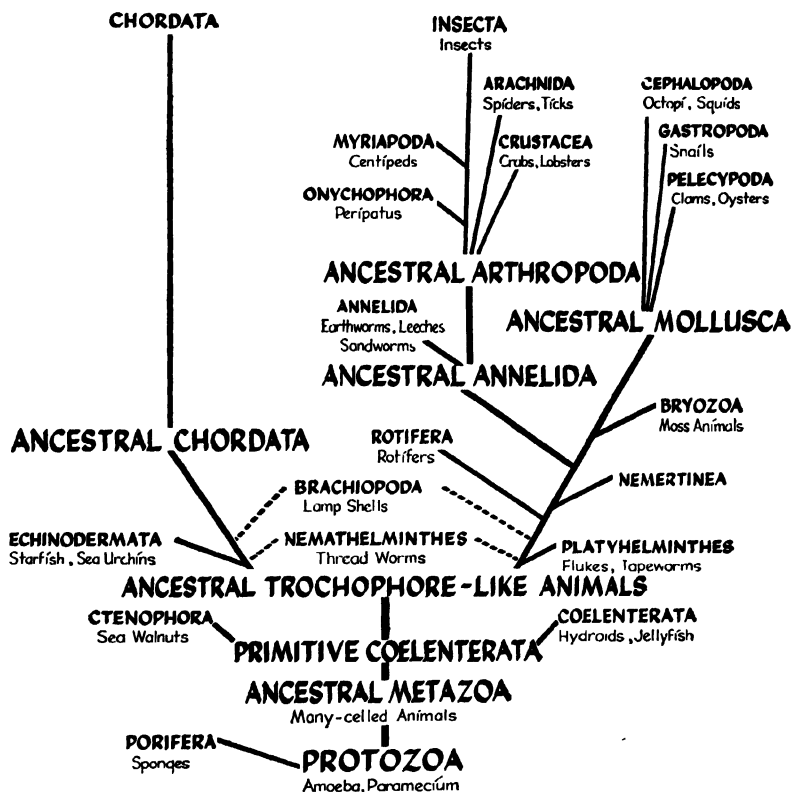


FIG. 441. Genealogical tree showing probable relationships of the principal groups of invertebrates. (From Newman, after Sigerfoos and Allee. Redrawn, slightly modified.)

CHAPTER XXXIII

Survey of the Animal Kingdom: Vertebrates

In the course of the age-long struggle for existence, Nature has discovered the mechanisms most apt for each species to meet the conditions of survival.
—Lillie

Now that the important phyla of the invertebrates have been described, it remains to survey the highest and concluding phylum of the animal world, technically known as the CHORDATA, a word which for all practical purposes is synonymous with the VERTEBRATA. The only chordates that are not vertebrates, or backboned animals, are a few lowly creatures, the PROTOCHORDATES, apparently having invertebrate and certainly vertebrate affinities, the latter chiefly evidenced by the presence of a notochord which is the forerunner of the backbone, a dorsal nerve tube, and gill slits. (Figs. 82, 83, 442-444.)

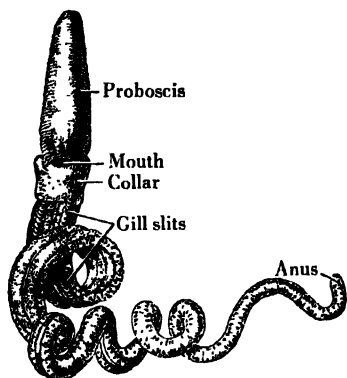


FIG. 442. *Dolichoglossus kowalevskii*, a species of primitive chordate that lives on sand flats from Massachusetts Bay to Beaufort, N. C. Natural size, about seven inches long. (After Agassiz. Redrawn.)

brate and certainly vertebrate affinities, the latter chiefly evidenced by the presence of a notochord which is the forerunner of the backbone, a dorsal nerve tube, and gill slits. (Figs. 82, 83, 442-444.)

The protochordates include three quite distinct subphyla, the Hemichorda, Urochorda, and Cephalochorda. In the Hemichorda, well represented by the worm-shaped *Dolichoglossus*, the notochord is a short rod of cells lying above the anterior end of the alimentary canal which is perforated by small gill slits. A short section of the dorsal nerve cord is tubular. In the Urochorda, which includes the tunicates,

or sea squirts, a clear-cut notochord and nerve tube, both confined to the tadpole-like larval stages, is accompanied by a large pharynx, perforated by a multitude of gill slits. These persist in the sessile adult. Finally in the Cephalochorda all three chief chordate characteristics attain full development. The little sand-burrowing amphioxus is of especial interest because it epitomizes the general type from which the higher animals probably have been derived. In addition to the noto-

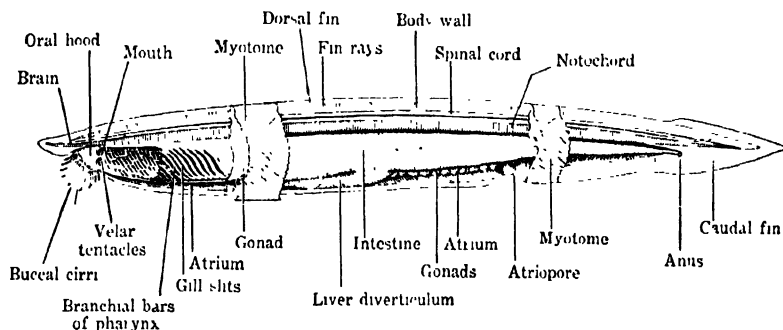


FIG. 443. The general anatomy of a primitive chordate, amphioxus, or the lancelet (*Branchiostoma lanceolatus*), a near relative of the lowest vertebrates. Lateral view with most of the left body wall removed. Nearly twice natural size.

chord, gill slits, and dorsal nerve tube, amphioxus exhibits a segmental arrangement of the muscles, a circulatory system with the blood flowing posteriorly in the dorsal vessel and anteriorly in the ventral vessel, and a liver-like diverticulum of the alimentary canal—all prophetic of the condition in the vertebrates, which constitute all the rest of the chordates. (Fig. 444; p. 697.)

The vertebrates include all the larger and more familiar animals—fishes, amphibians, reptiles, birds, and mammals—so that in the popular mind the words “animal” and “vertebrate” are essentially synonymous. A fish, as all should know, is an aquatic backboned animal which breathes by gills and swims by fins. An amphibian, such as a frog, may, in a general way, be thought of as a fish that early in life, at the end of the tadpole stage, discards its gills, develops lungs, substitutes five-toed limbs for fins, and begins a terrestrial existence. Similarly, a reptile, say a lizard, may be pictured as an amphibian that has relegated, as it were, the amphibian tadpole stage to the egg, and therefore emerges with limbs and lungs. Birds and mammals may be

regarded as separate derivatives of the reptilian stock which have transformed the scales of the reptile into feathers and hair, respectively, and have developed a special means of caring for their young—the birds by incubation of the eggs, and the mammals by retention of the embryos within the body of the female until birth occurs. (Figs. 185, 192, 196.)

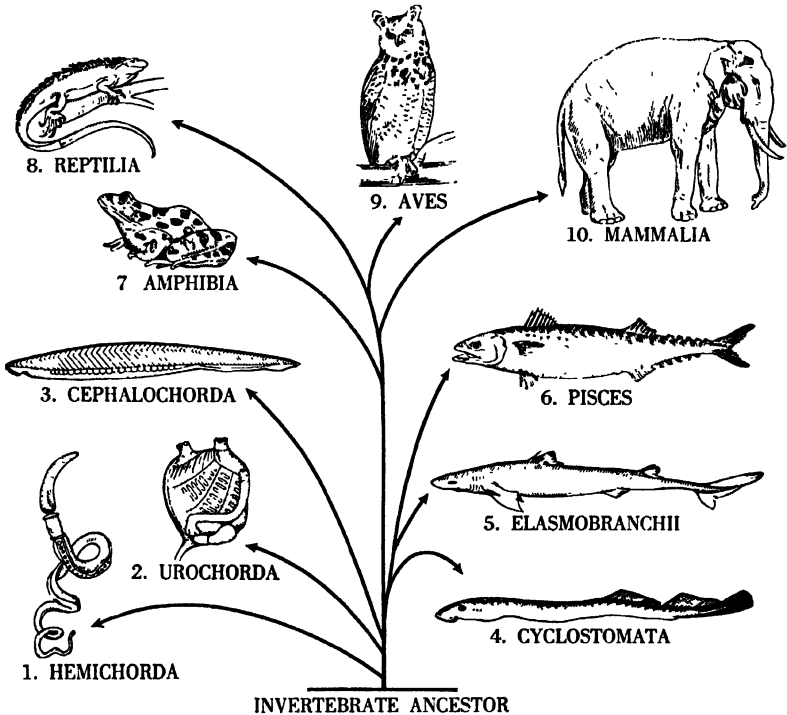


FIG. 444. General relationships of the chief divisions of the phylum Chordata. 1, Dolichoglossus; 2, sea squirt; 3, amphioxus; 4, lamprey; 5, shark; 6, mackerel; 7, frog; 8, iguana; 9, owl; 10, elephant. See classification of fishes (p. 697) for new names of classes 4, 5, and 6. Not drawn to scale. (From Hegner, after various authors. Modified.)

It will be appreciated, of course, that other important characteristics, many of which will be apparent in the later descriptions, delineate these chief vertebrate groups; nevertheless, the vertebrates as a whole are remarkably homogeneous both structurally and functionally, notwithstanding obvious external differences. Some of the outstanding characters typical of vertebrates, in addition to the notochord, liv-

ing endoskeleton, dorsal spinal cord, and gill slits are: bilateral symmetry, some degree of segmentation, coelom, red blood cells, brain encased in a skull, paired appendages (fins or limbs), and a tail. (Figs. 82, 83.)

Vertebrates are *the* modern animals: the “athletes of the animal kingdom.” They have parceled out to some extent the available environment among themselves: fishes dominate the water; birds, the air; and mammals, the land. To be sure, the amphibians waver between water and land, and the reptiles are chiefly terrestrial, but both are minor groups today; the earlier supremacy of the reptiles passed to the mammals in the geological yesterday, and man is a mammal.

FISHES

Living as they do in an aquatic environment, fishes find at least two of the problems of large-bodied, active, terrestrial animals considerably simplified. In the first place, the density of water makes less necessary

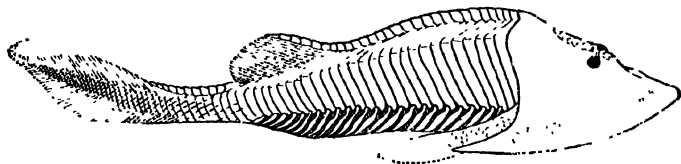


FIG. 445. *Cephalaspis*, one of the Ostracodermis—the oldest known vertebrates. Extinct. (From Newman, after Patten.)

either supports to raise the body or sturdy muscles to move it. Thus the paired fins and tail of a fish are adapted chiefly for propulsion and steering. However, greater expenditure of energy is required to propel a body through water than through air, a disadvantage which is typically compensated for by “streamlining,” so that some fishes are capable of speeds that compare favorably with those of terrestrial animals. In the second place, although an efficient respiratory apparatus is re-



FIG. 446. A cyclostome, the sea lamprey, *Petromyzon marinus*. (Redrawn, after Dean.)

quired in fishes, no special provision is needed to keep the respiratory membranes moist. The water merely passes into the mouth, over the gills, and out through the gill slits. (Fig. 112.)

Fishes possess no mechanism to maintain a constant body temperature—a character they share with the amphibians and reptiles. Most species are said to be OVIPAROUS, since the eggs are laid; but some, such as the well-known guppy, are called VIVIPAROUS, because the eggs develop within the mother's body, and the young are born. In fact, in fishes all stages from oviparous types to a condition of viviparity which rivals that of the mammals are to be found.

We may pass by the primitive fishlike creatures devoid of true jaws and paired fins, known as CYCLOSTOMES (Agnatha), and consider the true fishes, where two main groups are recognized: the CHONDRICHTHYES with an internal skeleton of gristle, or CARTILAGE, and the OSTEICHTHYES in which the cartilaginous skeleton is largely replaced by one of BONE. (Fig. 446.)

Cartilaginous Fishes. The most primitive of the true fishes are the sharks and rays, or Chondrichthyes, a small remnant of a once dominant group of vertebrates. They differ from higher fishes chiefly by

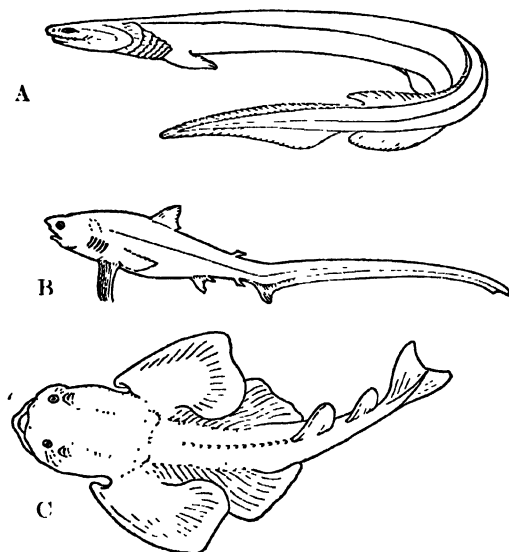


FIG. 447. Sharks. A, frilled shark, *Chlamydoselachus anguineus*; B, thresher shark, *Alopias vulpes*; C, angel shark, *Rhina squatina*. (From Newman.)

virtue of a cartilaginous skeleton. gills communicating directly with the body surface by several gill slits, and a skin roughened by small toothlike projections, or **PLACOID SCALES**. These scales are modified in the jaws of sharks and rays to form **TEETH**, and are also the primitive exoskeletal basis of teeth, scales, and bony plates in higher vertebrates. (Figs. 85, 447.)

The vast majority of sharks are marine and most abundant in the tropics. The most common species off our coasts are the small dogfish sharks, notorious pests to fishermen but favorites for dissection in zoological laboratories. (Figs. 127, 447.)

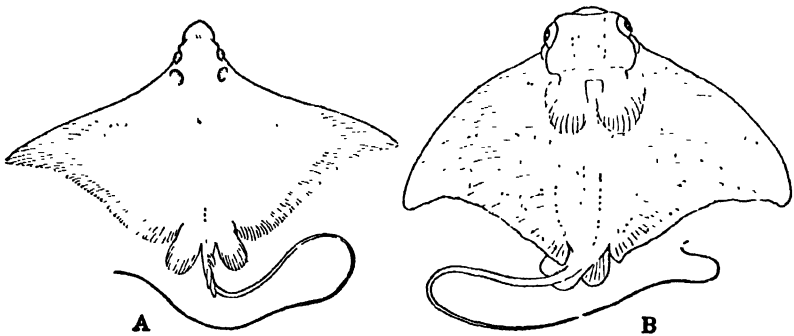


FIG. 448. A, sting ray, *Stenosodon narinari*; B, eagle ray, *Myliobatis aquila* (From Newman, after Jordan and Evermann, and Bridges.)

Whereas sharks have the typical streamlined body of swift swimmers, the rays, or skates, are bottom dwellers, and have a greatly flattened body with eyes on the dorsal surface, and mouth and gill slits on the ventral surface. The most famous of the rays are the torpedoes, so called because they are able to give a severe electric shock. (Fig. 448.)

Bony Fishes. All fresh-water fishes, as well as the great majority of

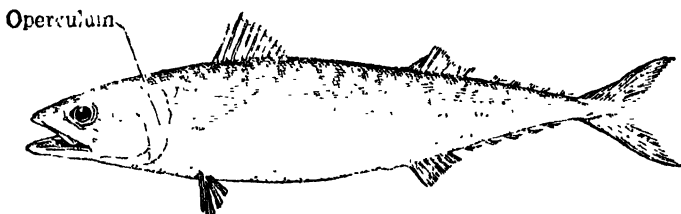


FIG. 449. Mackerel, *Scomber scombrus*.

those dwelling in the sea—the dominant fish population of the earth today—have a skeleton of bone, and usually a body covering of scales. These are bony fishes or Osteichthyes. With few exceptions, such as the more primitive lobe-finned fishes, lungfishes, sturgeons, and gar-pikes which have partially cartilaginous skeletons and bony plates instead of scales, all are members of the great subgroup of TELEOSTS. (p. 697.)

Teleosts typically have the external openings of the gill slits covered by a protecting flap, or OPERCULUM, so that water, after bathing the gills, leaves the body by a single opening at the posterior edge of the operculum on either side of the head. Some types are provided with an AIR BLADDER, which arises as a saclike outpocketing of the alimentary canal and functions chiefly as a hydrostatic organ but in some cases acts as an accessory respiratory organ, or primitive lung. (Figs. 90, 98, 449, 450.)

There are innumerable modifications of the typical fishlike form of swift-swimming fishes that have been assumed by various species in

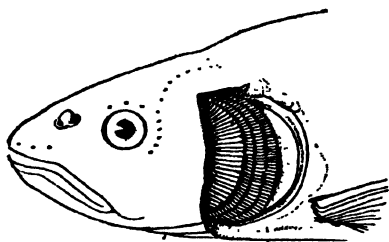


FIG. 450. Gills of a fish, the European Dace, revealed by the removal of the external operculum. (After Forbes and Richardson. Redrawn.)

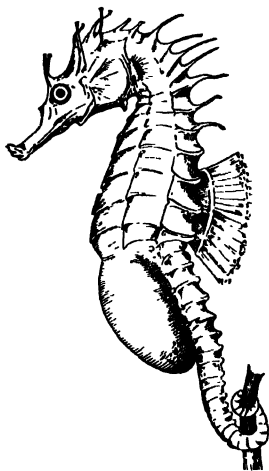


FIG. 451. Sea-horse, *Hippocampus antiquorum*. Male showing brood pouch formed from combined pelvic fins. Eggs are transferred for development to the brood pouch of the male. The sea-horse swims in an erect position and has a prehensile tail as shown. See Fig. 291. (From Doflein. Redrawn.)

adaptation to different habitats and modes of life. One immediately thinks of the snakelike body of the eels, the grotesque form of the sea horses, and the compressed body of the flatfishes, such as the flounder and halibut types. Flatfishes are hatched with typical fish form, and it is only as the animals settle down on one side that the under eye gradually moves so both eyes are on top. Even the bizarre form exhibited by the flying fishes that jump and fly above the water

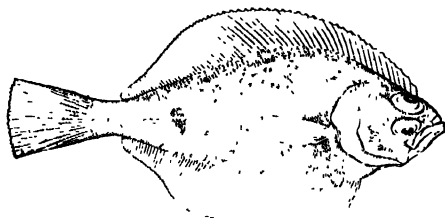


FIG. 452. A flat-fish.

is exceeded by the fish in the ocean's deepest areas where sunlight never penetrates, the pressure is tremendous, and the temperature is only slightly above the freezing point. In such surroundings some fish have luminous organs, some have immense eyes to make the most of little light, some are blind and depend upon tactile organs, some have an immense mouth and an enormous stomach capable of digesting a fish nearly their own size, and so on and on, the adaptations seemingly endless. Least of all is a goby one-third of an inch long—the smallest known vertebrate. (Figs. 451-453.)

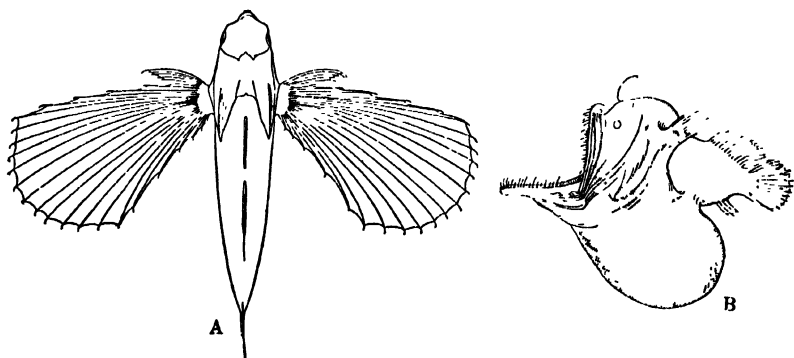


FIG. 453. A, a flying-fish; B, a deep-sea fish. (From Gunther, and Lull.)

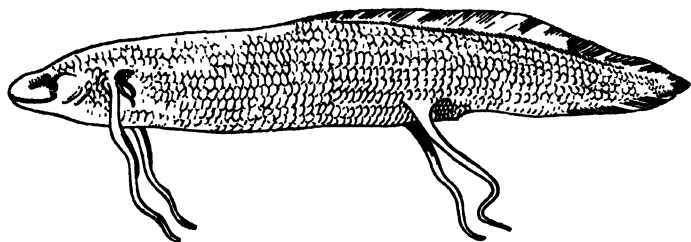


FIG. 454. African lung-fish, *Protopterus annectens*. (From Dean.)

Finally we must turn to the lungfishes, or dipnoans, represented today by only five fresh-water species—a mere remnant of a flourishing population in the geological past. They are of special interest because the air bladder opens into the pharynx and regularly functions as a lung. This is of advantage to the fish when water is lacking during a drought. Lungfishes have been regarded as intermediate between fishes and amphibians, but more recent evidence indicates that both are descended from a very primitive stock, known as lobe-finned fishes, which had already begun the development of adaptations for land life—in particular, air bladders for air breathing and fin-lobes that are prophetic of amphibian limbs. (Figs. 454, 455.)

There is some reason to believe that all fishes originated in fresh water and that the ancestral fresh-water forms gave rise to modern marine fishes and to the land vertebrates. Strange to say, the modern fresh-water teleosts apparently represent a relatively recent remigration from the sea.

Fishes are of such great economic value that many governments

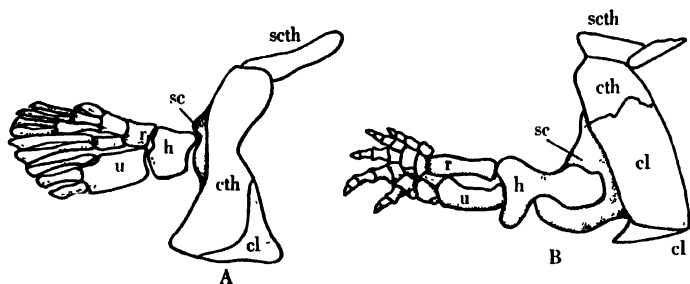


FIG. 455. Comparison of the skeleton of the right pectoral limb and shoulder region of a lobe-finned fish (A) and of a primitive amphibian (B). Homologous bones are identically lettered. (From Newman, after Romer.)

spend large sums for their study, protection, and propagation. The important food and game fishes are, almost without exception, teleosts, relatively modern forms that did not exist during the Age of Fishes, when fishes were the only vertebrates, but appeared later during the Age of Reptiles. (Fig. 266.)

AMPHIBIANS

The members of the class AMPHIBIA, commonly represented by the frogs and salamanders, made a great forward step in vertebrate evolution by adopting—if somewhat falteringly—the land-habit. This opened up to them a vast environment closed to fishes but at the same time demanded efficient lungs and supporting limbs as well as innumerable other structural and physiological adaptations essential to the new conditions. Apparently the limbs were derived from the fin lobes of the paired fins of fishes and were built on the PENTADACTYL plan which persists in all the higher vertebrates. (Figs. 93, 94, 455.)

Amphibians are cold-blooded, slimy-skinned animals that spend the early part of their life with median fins, tail, and gills, and only substitute, or add, limbs and lungs when finally they emerge on dry land. During this metamorphosis from the larval to the adult form they apparently recapitulate broadly the evolutionary history of the species. (Figs. 183, 185.)

Nearly all amphibians return to water to breed, and many spend the cold months in a dormant condition buried in mud at the bottom of ponds and streams. During this HIBERNATION period the metabolic processes are greatly reduced, and the temperature is little above that of the surroundings. However, frogs cannot survive being actually frozen although they may remain alive when embedded for a time in a solid block of ice.

The common amphibians that retain the tail throughout adult life constitute the order CAUDATA, and those deprived of this structure during metamorphosis, the order SALIENTIA.

Salamanders and Newts. The tailed amphibians, usually known as urodeles, such as the salamanders and newts, though hatched as aquatic larvae, or LADPOLES, undergo a relatively inconspicuous metamorphosis which varies considerably among different species. Some retain their gills throughout life, though functional lungs are developed; others resorb the gills but retain the gill slits; and still others lose all traces of both gills and gill slits. Some, in fact, even go to the extreme

of losing their lungs, and thus are obliged to depend solely upon the moist skin as a respiratory membrane. Obviously the lung-breathing method is not consistently adopted.

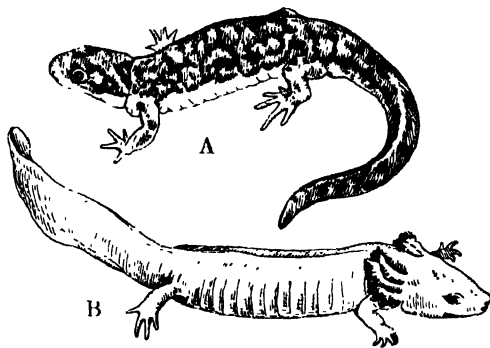


FIG. 456. Tailed amphibians. A, *Amblystoma tigrinum*; B, *Necturus*, *Necturus maculosus*.

Common species of tailed amphibians include *Necturus* (mudpuppy), *Cryptobranchus* (hellbender), *Amblystoma* (blunt-nosed and tiger salamanders), and *Triturus* (the newts). Several species have recently proved a boon to biologists interested in fundamental problems of growth. From tadpole to adult they possess remarkable

powers of regeneration: they repair minor and major mutilations, restoring excised eyes and amputated limbs and even appropriating the limbs of other species when grafted on them. (Figs. 203, 456, 457.)

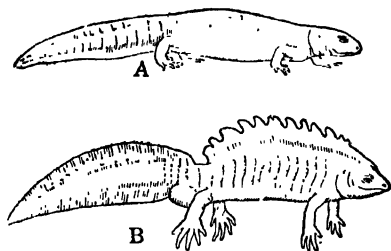


FIG. 457. Newt, *Triturus cristata*. A, female; B, male during the breeding season. (From Gadow.)

Toads and Frogs. The majority of amphibians, some nine hundred species, are without tails in the adult condition and so are called anurans. They are the

toads and frogs with a relatively clear-cut metamorphosis from tadpole to limbed, lung-breathing, tailless adult. The common toads, such as *Bufo americanus*, hop about chiefly after dusk devouring worms, snails, and insects, and so render a considerable service. In fact, someone has estimated that a gardener owes each toad on his premises nearly twenty dollars at the end of the season. (Fig. 458.)

Tree frogs and tree toads are tiny arboreal forms with soft, adhesive pads on the toe tips. Many of them, such as the common tree toad, *Hyla versicolor*, are able to change their color through various shades of gray, brown, and green, and so are rendered inconspicuous in their natural surroundings.

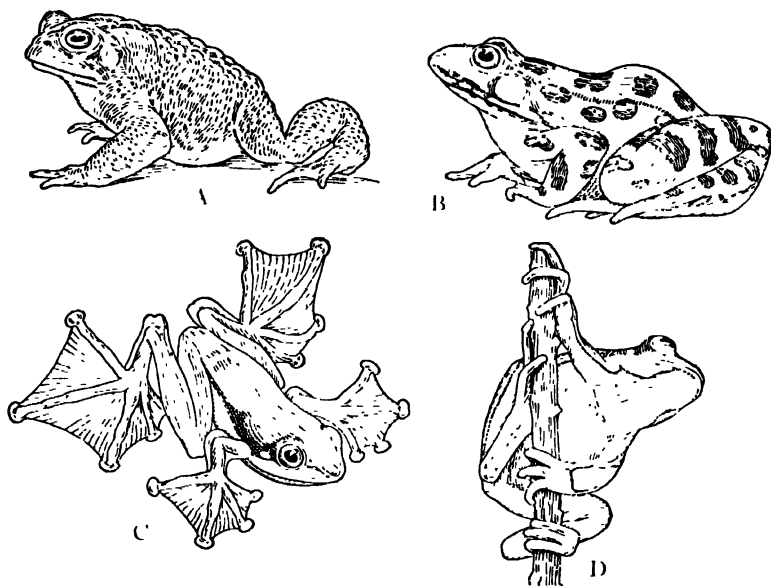


FIG. 458. A, toad, *Bufo americanus*, stalking prey; B, leopard frog, *Rana pipiens*; C, Javan flying frog, *Rhacophorus pardalis*; D, tree toad, *Hyla versicolor*. (From Newman, after Dickerson and Lydekker.)

The typical frogs are represented by several well-known species in the United States, among them the leopard frog (*Rana pipiens*), the bull frog (*Rana catesbeiana*), and the green frog (*Rana clamitans*). Frogs are in many ways ideal subjects for anatomical and physiological investigations, and we have already had occasion to study them in this connection. (Figs. 87, 94, 99.)

REPTILES

Apparently descended from primitive amphibians, the reptiles met new and more favorable land conditions with progressive structural and physiological features: for example, they skipped metamorphosis and started out from the egg with functional lungs and on four feet. The

reptiles very soon, geologically speaking, became the dominant vertebrates on the earth, flourishing both in number of individuals and variety of species adapted to all sorts of land and swamp conditions, and even, secondarily, to aquatic and aerial life. The best-known representatives of the extinct population of the Age of Reptiles are the giant dinosaurs, some of them herbivorous, others carnivorous and

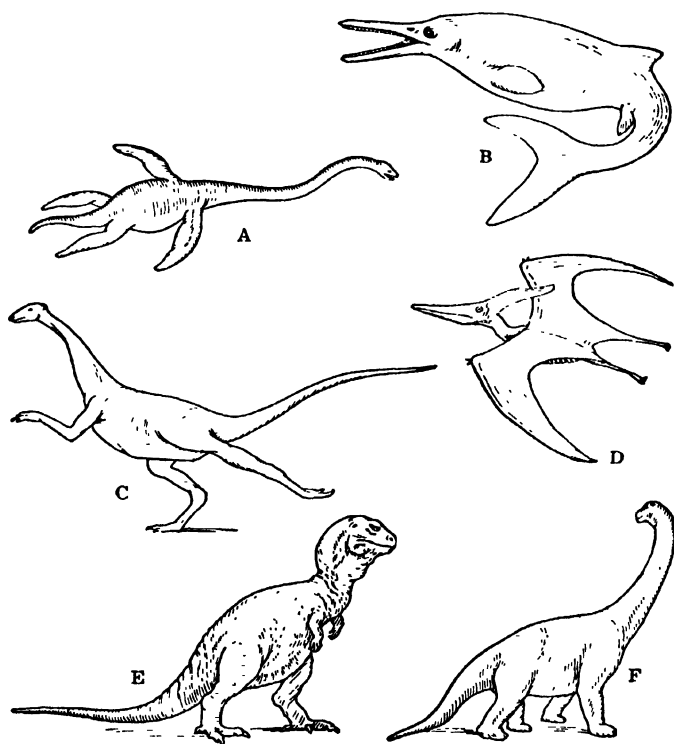


FIG. 459. Reptiles of the past, now found as fossils. A, Plesiosaur, *Elasmosaurus*; B, Ichthyosaur, *Baptanodon*; C, Ostrich Dinosaur, *Struthiomimus*; D, Pterosaur, *Pteranodon*; E, carnivorous Dinosaur, *Tyrannosaurus*. F, herbivorous Dinosaur, *Brachiosaurus*, about 80 feet long. (After Osborn.)

probably the most terrible monsters that ever lived. Extensive deposits of their fossil bones have been set aside in Utah as the Dinosaur National Monument. The famous dinosaur tracks discovered in the Connecticut Valley in 1802 were popularly known as the tracks of Noah's raven. (Figs. 265, 266, 459.)

Although the supremacy of the reptiles eventually passed to the mammals, there are still some 5000 species of these most advanced cold-blooded animals living today. These are arranged in three orders: the CHELONIA, CROCODYLIA, and SQUAMATA, represented by the turtles and tortoises, the crocodiles and alligators, and the lizards and snakes, respectively.

Turtles and Tortoises. Typically encased in a shell composed of bony plates firmly fixed to the backbone and to the ribs, the turtles and tortoises, forming the order Chelonia, depend upon armor rather than speed for protection. In fact a few, like the box turtle, can completely seal themselves up, as it were, between the dorsal CARAPACE

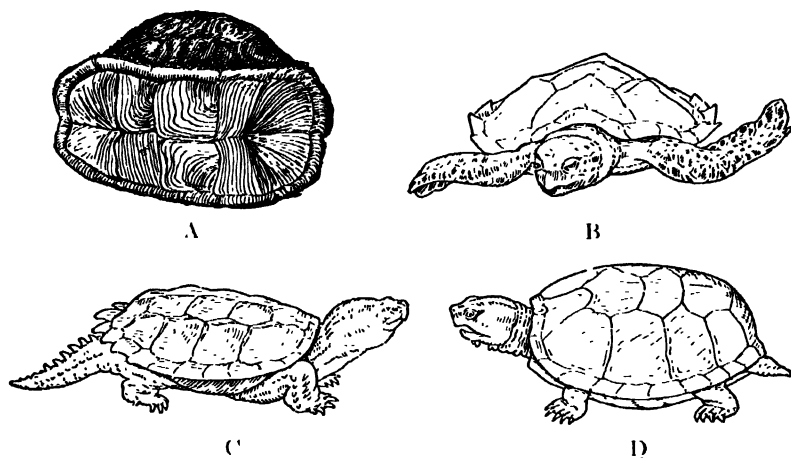


FIG. 460 Turtles. A, box turtle enclosed within carapace and plastron; B, tortoise-shell turtle, *Eretmochelys imbricata*; C, snapping turtle, *Chelydra serpentina*; D, mud turtle, *Cinosternum pennsylvanicum*. (A from Bamford; B, C, D after Lydekker.)

and the ventral PIASTRON. The tortoise shell of commerce is the horny outer layer of the carapace of the hawksbill, or tortoise-shell turtle. Probably the protective shell also accounts, in part, for the fact that the jaws of turtles and tortoises are toothless. Nevertheless, many of these animals can inflict severe wounds; witness the beaked jaws of the snapping turtle. (Fig. 460.)

There is no real distinction between turtles and tortoises, although the former term is usually applied to marine and fresh-water species,

and the latter to strictly land dwellers. Terrapins are certain hard-shelled, fresh-water species that are highly edible.

A wide range in size is exhibited by the various species, the upper limit being represented by some of the giant tortoises of the Galapagos Islands, made famous by Darwin, which may weigh 300 pounds, and by the leathery turtle which may attain nearly half a ton in weight.

Crocodiles and Alligators. The predatory inhabitants of tropical rivers, the crocodiles and alligators, are lizardlike in form, with long, gaping jaws well armed with teeth, and with a thick, leathery skin covered with horny scales. Alligator skin has long been popular for the manufacture of leather goods.

There are about a score of living species of the order Crocodilia, but only two inhabit the Western Hemisphere: the American crocodile of the upper Amazon, and the American alligator of the southeastern part of the United States. The African crocodile, held sacred and preserved as mummies by the ancient Egyptians, is one of the few man-eating species.

Lizards and Snakes. The lizards form a highly diversified division of the order Squamata. Typically they have scaly skin, well-developed limbs, and a long tail. Most species run and climb, some dig, while the flying dragon leaps with the aid of an expanded parachute. Representative are the common iguana, the horned toad, the poisonous Gila monster, and the chameleons famous for their ability to change color rapidly in response to various stimuli. Some species are without limbs and so are quite snakelike in appearance; such are the burrowing worm-lizards and glass snakes. (Fig. 461.)

Snakes, constituting the other great division of the Squamata, are the most recent product, geologically speaking, of evolution among the Reptilia, and without them the class today would be poorly represented. Snakes are essentially limbless lizards in which even the internal supporting structures of the limbs have in most instances disappeared. But apparently snakes should not be regarded as degenerate forms, because their chief characteristics—absence of limbs, greatly elongated body, and loosely articulated jaws—are all highly specialized adaptations for swallowing whole and digesting large prey. (Figs. 263, 462.)

Most species of snakes, in common with the great majority of vertebrates, except the mammals, are oviparous, but a few are viviparous. It is hardly necessary to add that a few have poison glands associated

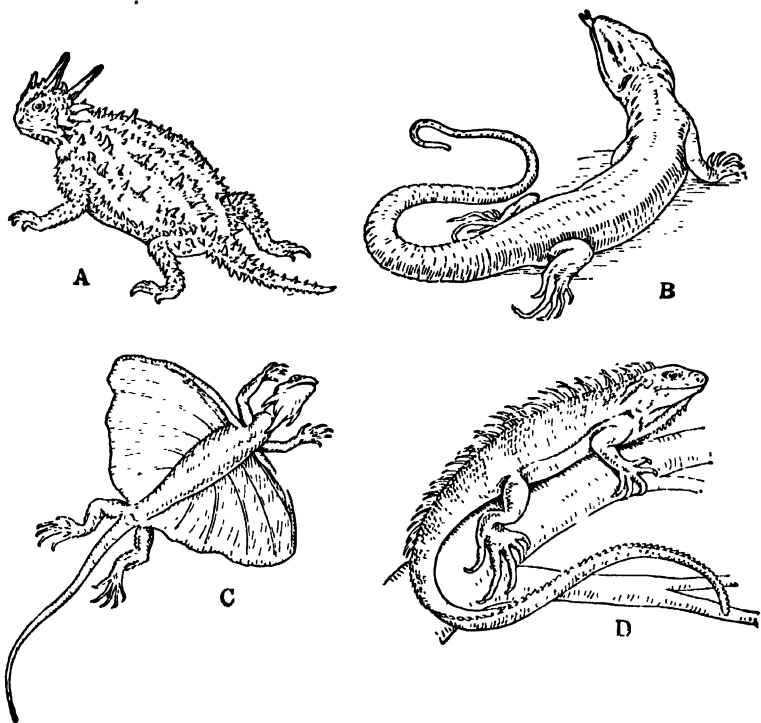


FIG. 461. Lizards. A, horned-toad, *Phrynosoma cornutum*; B, European lizard, *Lacerta viridis*; C, flying dragon, *Draco volans*; D, Iguana, *Iguana tuberculata*. (From Newman, after Gadow and Lydekker.)

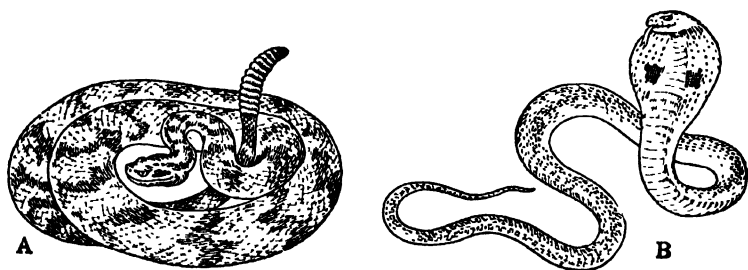


FIG. 462. A, rattlesnake, *Crotalus durissus*; B, cobra, *Naja tripudians*. (From Newman, after Lydekker.)

with special teeth, or fangs. The rattlesnakes, copperheads, moccasins, and cobras are among the most notorious in this respect. However, many species crush their prey; among these are the boa constrictors and pythons. (Fig. 264.)

BIRDS

The birds, constituting the class *AVES*, are the warmblooded (*HOMOTHERMAL*) animals that have made the air their own by the development of forelimbs into wings, and scales into an insulating blanket of feathers, and by many other adaptations. Not the least of their progress is perhaps due to instinctive care of their eggs and young.

Birds have been referred to as "glorified reptiles"; that they are an offshoot from the reptilian stock, probably the dinosaurs, is indicated by the fossil remains of a bird, known as *Archacornis*, with characteristic feathers but lizardlike tail and teeth. (Figs. 266, 269.)

The birds today form a remarkably homogeneous group, probably owing to restrictions imposed by the mechanical problems involved in flight. Sustained exercise in the air necessitates an exceptionally efficient heart to rush supplies to the various parts of the body, and cooperating lungs that communicate with a system of air spaces among the viscera and in the hollow bones. Furthermore, not only does the plumage provide an efficient heat-retaining coat, but also the feathers of wings and tail are well adapted for propulsion and steering. Minimum weight with maximum strength characterizes these living heavier-than-air flying machines.

Feathers are the most conspicuous and characteristic feature of birds and, like the reptilian scales, are specializations of dermal structures. A typical feather consists of a stiff stem divided into a basal hollow *QUILL* and a distal *VANE* composed of a shaft with parallel *BARBS* on either side. The barbs are held together by tiny hooklets which help to make the whole structure at once pliable and resistant. Most feathers are shed periodically, usually in the late summer and sometimes also in the spring, and are replaced by new outgrowths from the follicles of discarded feathers.

Another structure peculiar to birds is the vocal organ, or *SYRINX*, which consists essentially of a flexible valve, at the base of the trachea, that vibrates when air is expelled forcibly from the lungs. Alterations in the tension bring about the changes in the quality of sounds pro-

duced. However, many birds have a syrinx that is by no means a musical apparatus, while some are nearly voiceless.

Although many other kinds of animals migrate, birds do so far more extensively and conspicuously because of their method of locomotion. Some, to be sure, remain in one locality throughout the year but, in the northern hemisphere, most birds fly north in the spring to their breeding grounds and southward in the winter to milder climes. Many species travel at high altitudes during clear nights, the migration wave moving at an average rate of perhaps 25 miles per day. This, of course, does not represent the speed at which the birds can fly, which varies greatly. For instance, the carrier pigeon can maintain for some time a speed of about 35 miles per hour, while certain ducks have been timed at 90 miles per hour for short flights.

How birds, under the urge of changes in temperature, food supply, and the sex impulse, are able to find their way over vast distances with almost clocklike regularity is an unsolved problem. Little more can be said than that they seem to possess an "instinctive sense of direction" that will lead, for instance, the golden plover from its winter home in northern Argentina to the shores of the Arctic Ocean to breed

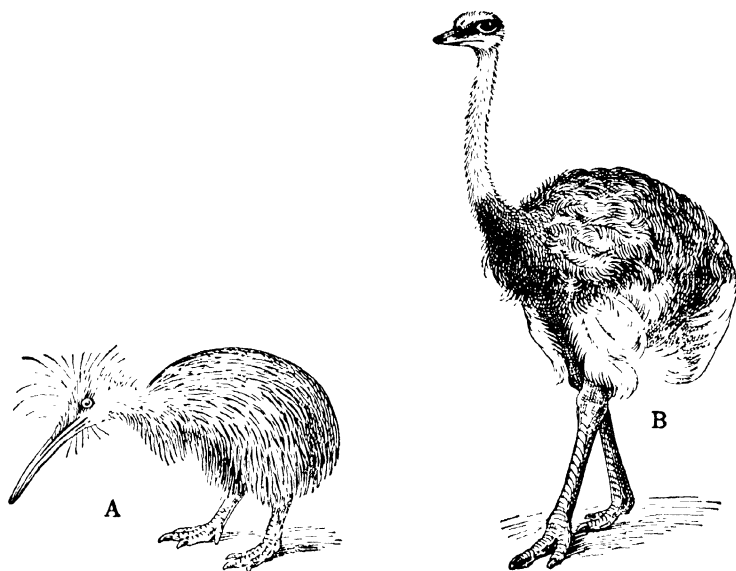


FIG. 463. A, Kiwi, *Apteryx australis*; B, ostrich, *Struthio camelus*. (From Newman, after Evans.)

in June. Moreover, the journeys north and south are made by regular but different routes!

Nest building is characteristic of most birds, though ability in construction varies greatly from one species to another. The American cowbird and the European cuckoo lay their eggs in the nests of other birds who act as foster parents. Eggs of different species vary characteristically in color, markings, and size, the last ranging from less than half an inch in length for certain hummingbirds to more than a foot

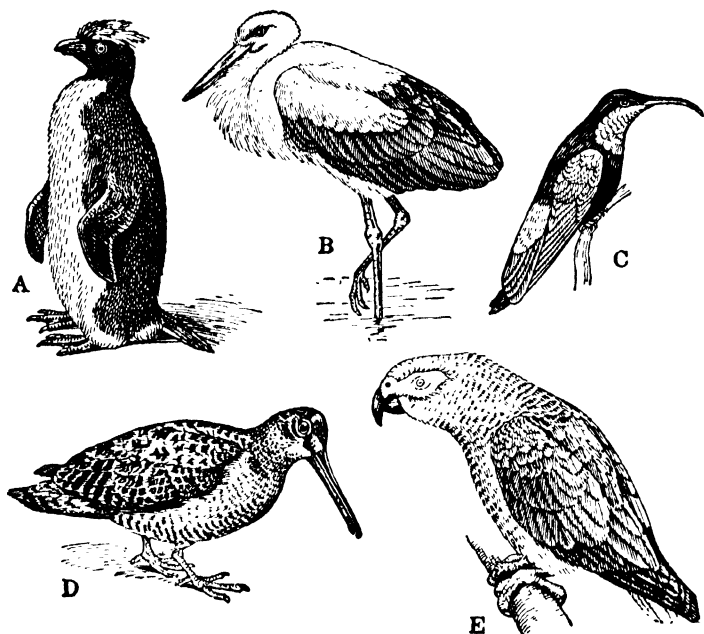


FIG. 464. Carinate birds. A, penguin, *Eudyptes chrysocoma*; B, stork, *Ciconia alba*; C, hummingbird, *Eulampis jugularis*; D, woodcock, *Scolopax rusticula*; E, parrot, *Psittacus erithacus*. (After Lydekker and Evans.)

for the extinct elephant bird of Madagascar. The young of some birds when they emerge from the egg may be very immature, but other types, such as the young chicks of the domestic fowl, are able to run about and shift for themselves at once.

Birds can be arranged naturally in two very unequal divisions, the Ratitae and Carinatae. The first group includes a few species without a keel-like breastbone to support strong wing muscles; among these

are the flightless Apteryx, ostriches, reas, cassowaries, and emus, as well as the relatively recently extinct and gigantic moas and elephant birds. The second division comprises birds with the "keel," represented by about 15,000 species. These are differentiated, for the most part, by minor anatomical characters, particularly in regard to wings, feet, and horny beaks ensheathing toothless jaws, in adaptation to various habitats and ways of life. A consideration of their classification would carry us too far into details; instead, a few outstanding types will be mentioned. (Figs. 463, 464, 466.)

Some of the larger and better-known birds spend most of their time in, on, or near water. They are swimmers, divers, shore birds: all waterfowl in the broad sense of the term. In some the wings as well as webbed feet are used as paddles, and a layer of fat beneath the skin conserves the heat of the body. Their food is usually aquatic plants and animals. Well-known representatives are the petrels, albatrosses,

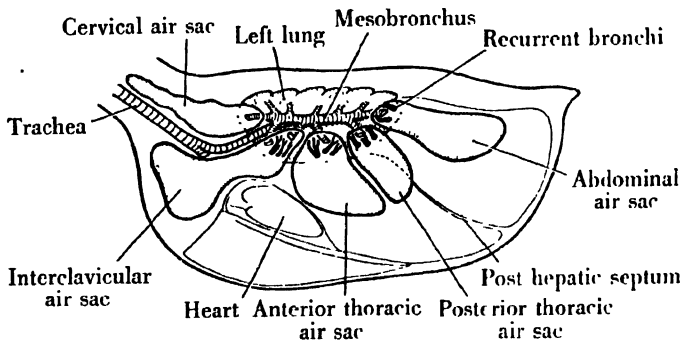


FIG. 465 Diagram of the respiratory organs of a bird, showing accessory air sacs, from the left side. (After Goodrich.)

and frigate birds that are nearly all their life flying at sea, rarely coming to land except to nest; the grebes and loons that swim and dive with great agility; the pelicans with their immense membranous pouch for scooping up small fish; the herons, bitterns, flamingos, and cranes with long legs and bills; the ducks, geese, and swans; and finally, the great assemblage of auks, gulls, terns, sandpipers, and their allies.

The true game birds of the uplands include the wild turkey, quail, pheasant, ruffed grouse, and their kin. The common domestic fowl is probably a descendent of the red jungle fowl, *Gallus gallus*, of India.

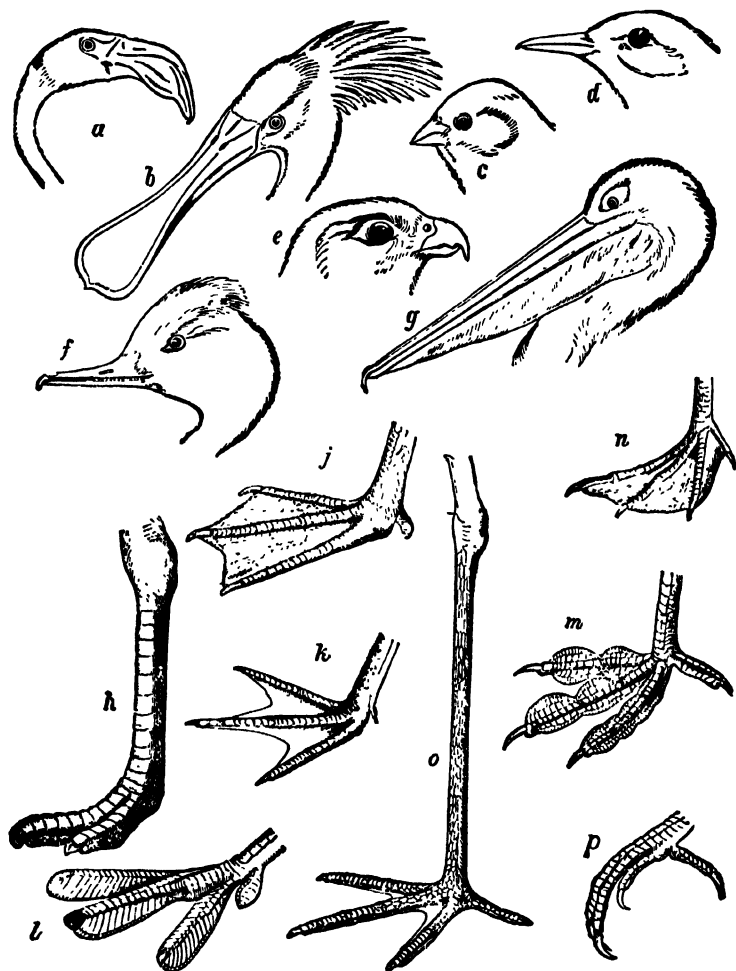


FIG. 466. Representative adaptations of the beaks and feet of birds. *a*, flamingo; *b*, spoonbill; *c*, bunting; *d*, thrush; *e*, falcon; *f*, duck; *g*, pelican; *h*, ostrich (running); *j*, duck (swimming); *k*, avocet (wading); *l*, grebe (diving); *m*, coot (wading); *n*, tropicbird (swimming); *o*, stork (wading); *p*, kingfisher (grasping). (From Hegner, after several authors.)

Then there is the heterogeneous assemblage of pigeons, parrots, kingfishers, woodpeckers, and hummingbirds, the last peculiar to the Americas and including the tiniest birds and most adroit aviators.

Birds of prey form another great group, some of the members hunt-

ing by day and others by night. Well-known types are the hawks, eagles, kites, ospreys, and owls, all of which kill their prey, and the vultures, which are satisfied with carrion.

These and certain minor groups form less than half of the world's avian population. The rest, nearly 10,000 species and subspecies, form the order Passeres, or sparrow-like, perching birds. These are usually the most common denizens of woods, field, garden, and roadside, and include the flycatchers, starlings, blackbirds, orioles, sparrows, vireos, swallows, wood warblers, wrens, bluebirds, and robins and other thrushes.

Enough has been said to show that ORNITHOLOGY is an immense and interesting field of study. It is also of great economic value, for birds contribute in large measure, both directly and indirectly, to the human food supply; directly as domestic and game birds, and indirectly as wardens of forest, field, and garden. They eat almost inconceivable numbers of destructive insects and weed seeds. (Figs. 273, 274, 276; pp. 469-470.)

MAMMALS

The class MAMMALIA includes the highest forms of life on the earth, culminating in man, so here naturally our interest is chiefly focussed. Since attention has already been given to mammalian anatomy and physiology, with special reference to the human body, only the essential mammalian characters and classification need now be reviewed.

In brief, mammals are warm-blooded, lung-breathing, hairy vertebrates. The young of all but the lowest types develop before birth by the utilization of food derived from the mother's blood. All are nourished after birth by milk secreted from MAMMARY GLANDS. On the basis of their methods of reproduction, the mammals are divided into three subclasses: the PROTOTHERIA, or the primitive oviparous monotremes; the METATHERIA, or pouched viviparous marsupials; and the EUTHERIA, or the placentals with a typical placenta. (p. 698.)

Monotremes. The primitive egg-laying monotremes quite evidently point to a reptilian ancestry. Although the females are oviparous, the young when hatched are nourished by milk. There are only three species, each about the size of a rabbit: the duckbill (*Ornithorhynchus*), and the spiny anteaters—Echidna (*Tachyglossus*) and Proechidna (*Zaglossus*) found in Australia, Tasmania, and New Guinea. (Fig. 467.)

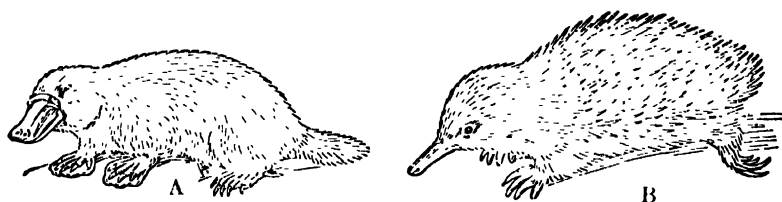


FIG. 467. Monotremes. A, Duckbill, *Ornithorhynchus anatinus*; B, Echidna, *Tachyglossus aculeatus*. (From Newman.)

Marsupials. The pouched mammals, or marsupials, occur today chiefly in Australia and neighboring islands, where they are the characteristic mammalian fauna—a primitive one, represented by many species adapted to various habitats and ways of life, which has flourished there in more or less isolation but is now rapidly declining from competition with the higher mammals that have been imported. The kangaroos, wallabies, and koalas are the best-known examples of the Australian marsupials, and the Virginia opossum is one of the few scattered survivors in America of a group once widely distributed over the earth. (Figs. 298, 468.)

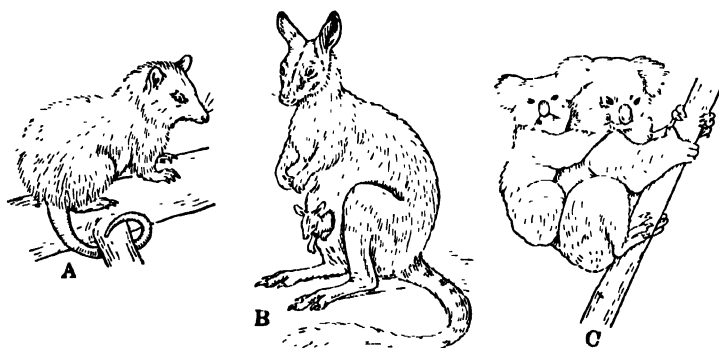


FIG. 468. Marsupials. A, Virginia opossum, *Didelphys virginiana*; B, wallaby, *Petrogale xanthopus*; C, koala, *Phascogale cinereus*. B and C carrying young. (After Vogt and Specht, and Brehm.)

The reproduction of the marsupials is somewhat unique. The eggs hatch, as it were, within the mother's body where development proceeds for a short time, nourishment being provided through an atypical very primitive placenta. Then the young are born in an exceedingly immature condition and make their way to a pouch on the abdomen of

the mother. Here they attach themselves to the teats of the mammary glands and are nourished by milk. Even after the young are well developed the pouch serves as a refuge.

Placentals. The PLACENTALS, or Eutheria, comprises all the rest of the mammals from the lowly Insectivora, such as *Gymnura* and the hedgehog, to the primates, including man. All nourish their young before birth by means of a highly complex placenta which makes possible the protracted development of the embryo under ideal conditions for nutrition and protection within the mother's body, conditions necessary for the correct establishment of structure and function. Thus it is fair to say that the placenta and associated embryonic membranes are to a high degree responsible for the commanding position of this mammalian group in competition with other forms of life. (Fig. 196, pp. 262-265.)

The adaptive radiation of placentals to nearly all types of environments and modes of life— from whales to bats, and moles to men—is an expression of their success which is not reached elsewhere in the animal world even by insects. This makes eutherian classification a difficult problem. However, for our purpose, a survey of the outstanding orders will suffice. (Fig. 293.)

The INSECTIVORA, well represented by the moles, shrews, hedgehogs, and *Gymnura*, are without doubt the most primitive of living placentals. They are small nocturnal animals, with teeth particularly adapted for insect food, and typically live on or under the soil, though a few species are arboreal or aquatic. (Fig. 296.)

The bats, forming the order CHIROPTERA, are the only mammals endowed by nature as aviators. In fact, they are among the most exclusively aerial of all animals, locomotion other than by flight being difficult. Flight is accomplished by thin leathery wings: membranes stretched over greatly elongated fingers and forearms and down over the hind limbs and sometimes the tail. Most species feed on insects, some on fruit, and the notorious vampires solely on the blood of other animals, including man. (Figs. 260, 293, 295.)

Mammals without teeth, or with only a few poorly developed ones, form the order EDENTATA. Representatives are the sloths, which walk upside down hanging from branches of trees as they browse on the leaves, and the anteaters and armadillos, with long sticky tongues for collecting ants and similar insects. Some are provided with an armor of bony plates or scales, to the practical exclusion of hairs; such are

the common nine-banded armadillo of Texas and the scaly anteaters, or pangolins, of Africa, China, and the Philippines. (Figs. 293, 469.)

The gnawing mammals, forming the order RODENTIA, must be regarded as the most successful of the class if the criterion be either number of species or number of individuals, or the trouble they cause humanity. They gnaw their way in, and into, a great variety of habitats by their characteristic chisel-like incisor teeth. Most are ground dwellers, but some are essentially aquatic, and a few glide through the air. Representative rodents are rats, mice, rabbits, guinea pigs, squirrels, chipmunks, gophers, prairie dogs, woodchucks, beavers, and porcupines. (Figs. 236, 293.)

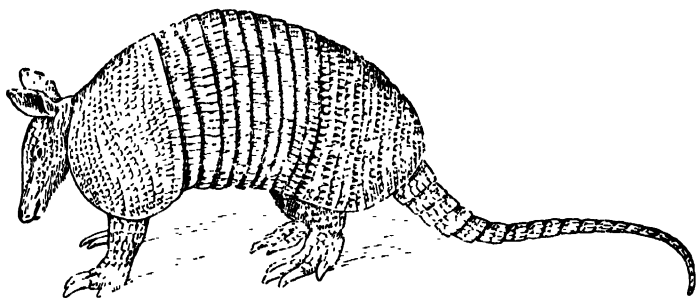


FIG. 469. An Edentate. Texas nine-banded armadillo, *Dasypus novemcinctus texanus*. (From Newman.)

The CARNIVORA is the great order of flesh-eating mammals characterized by prominent claws and canine teeth for seizing and killing prey. Carnivores form several large groups. Examples are the dog family which includes, besides its namesake, the wolves and foxes; the cat family, represented by the lions, tigers, leopards, pumas, lynxes, and domestic cat; and the marten family, containing the otters, weasels, skunks, and badgers. Then there are the species highly modified for aquatic life, such as the sea lions, seals, and walruses. (Figs. 95, 293.)

Mammals with toes enclosed in hoofs constitute the UNGULATA. All walk or run on the ground and feed on vegetation. Hoofed mammals form three groups: the artiodactyls, or even-toed pigs, hippopotami, camels, sheep, deer, giraffes, bison, etc.; the perissodactyls, or odd-toed horses, tapirs, and rhinoceroses; and the proboscideans, or elephants, the largest animals living on land today. (Figs. 260, 270, 271, 293, 470, 489.)

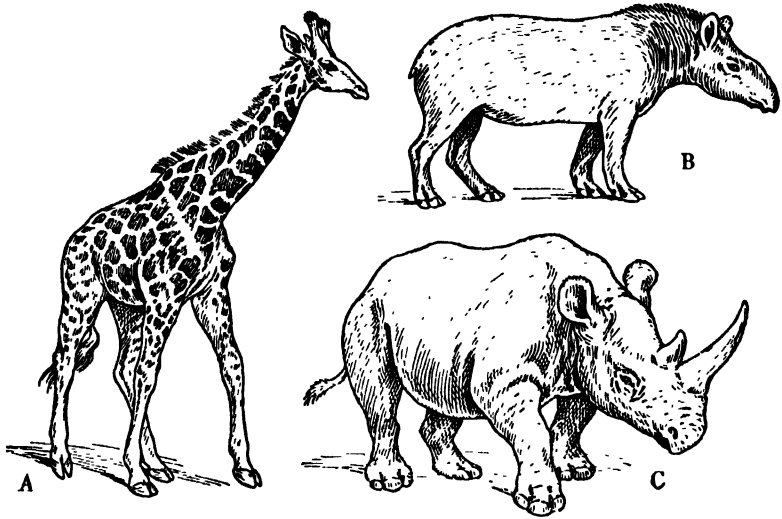


FIG. 470. Ungulates. A, giraffe, *Giraffa camelopardalis*, B, American tapir, *Tapirus terrestris*, C, African rhinoceros, *Rhinoceros bicornis* (From Newman, after Beddard and Lydekker.)

Closely related to the ungulates are the completely aquatic manatees, or sea cows, forming the order SIRENIA. There are only four species of these large herbivorous mammals, one living along the coast of Florida. (Fig. 471.)

Another order of mammals, the CETACEA, includes the whales, porpoises, and dolphins, which have taken to the open sea and become quite fishlike in form, though retaining the basic mammalian char-



FIG. 471. Florida sea-cow, *Trichechus manatus*.

acteristics of their terrestrial ancestors. In this group, size has been gained: the sulfur-bottom whale is the largest animal alive today, and probably larger than any in the geologic past. (Figs. 260, 293, 297, 472.)

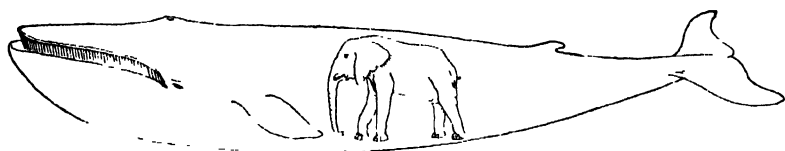


FIG. 472. Sulfur-bottom whale, *Sibbaldus musculus*, and African elephant, *Loxodonta africana*, drawn to scale. (Modified, after Lull.)

The PRIMATES, judged from the standpoint of what they can do, form the culminating order of the mammals and of the animal world. They are the lemurs, tarsiers, New and Old World monkeys, gibbons, orangutans, chimpanzees, gorillas, and man. They predominate chiefly by virtue of mobile grasping hands and bigger and better brains. Quite

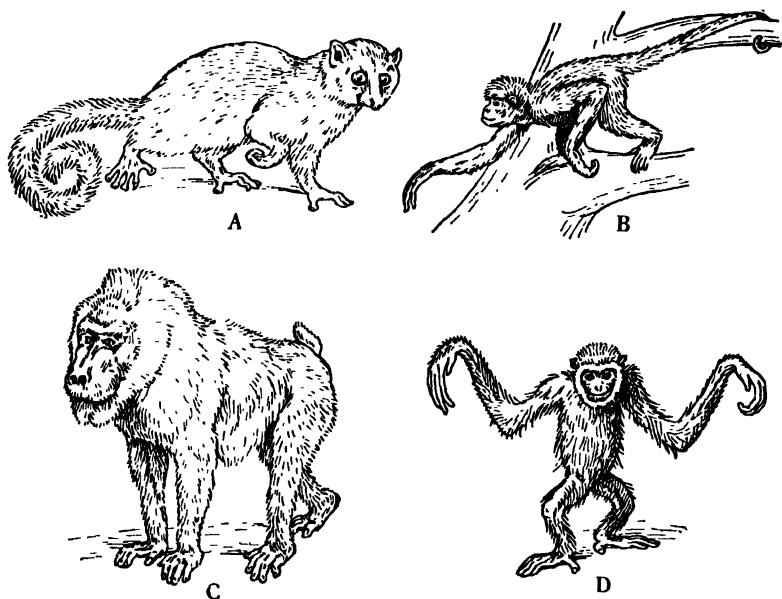


FIG. 473. Primates. A, dwarf lemur, *Microcebus smithii*; B, spider monkey, *Ateles ater*; C, mandrill, *Papio leucophoeus*; D, gibbon, *Hylobates lar*. (From Newman, after Beddard and Lydekker. Redrawn.)

appropriately they have been called "the inquisitive mammals." Man's primate relatives will be considered when the human background is discussed in the chapter following. (Figs. 261, 473; pp. 136, 608.)

This completes a survey of the chief phyla in the varied panorama of animal life from protozoon to mammal. Necessarily brief, it is adequate for our purpose if we are impressed with certain outstanding facts, not the least significant being the versatility and prodigality of life. Nature has tried, as it were, one experiment after another: some phyla have prospered and then waned; some have gone up blind alleys and stayed there; some have met the conditions of life to the full and have flourished: two phyla most impressively, arthropods and vertebrates. Only a few of the lower types have made a real contribution, but this has been tenaciously conserved and appears again and again in higher phyla. Accordingly, there is a trace of structural and physiological continuity woven into the picture of animal life. This unity in diversity is interpreted as evidence of descent with change, or organic evolution. (Chaps. XXIV, XXV.) (Figs. 444, 474.)

CHAPTER XXXIV

The Human Background

Thoughtful men will find in the lowly stock whence Man has sprung, the best evidence of the splendor of his capacities; and will discern in his long progress through the past, a reasonable ground of faith in his attainment of a nobler future.

—Huxley

As the culmination of our survey of the world of life, it is important to consider briefly what is known in regard to human origins—to indicate more specifically human relationship with the evolutionary process and to appreciate the affiliations as evidenced by ancestral strands that persist in human structure.

Primitive man everywhere recognizes his kinship with other animals and even endows them with many human attributes, but sophisticated man has been less generous. In fact, the general recognition of man's place in nature has but recently been attained, although more than two thousand years ago Aristotle placed him at the summit of animal creation, emphasizing his God-like nature, but nevertheless regarding him as only the highest point of the scale of nature. Linnaeus, the founder of our modern method of classification, during the middle of the eighteenth century placed man in the order PRIMATES of the class Mammalia, a position he has since held. (Figs. 491, 499.)

THE PREHUMAN LINEAGE

The order Primates today includes three suborders: the LEMUR-OIDEA, or lemurs; the TARSIOIDEA, or tarsiers; and the ANTHROPOIDEA, or monkeys, apes, and man. Most of the characters which distinguish primates from the other groups of mammals represent adaptations to a tree-dwelling life: adaptations for climbing, for subsisting on a simple and plentiful food supply, and for taking advantage of changing en-

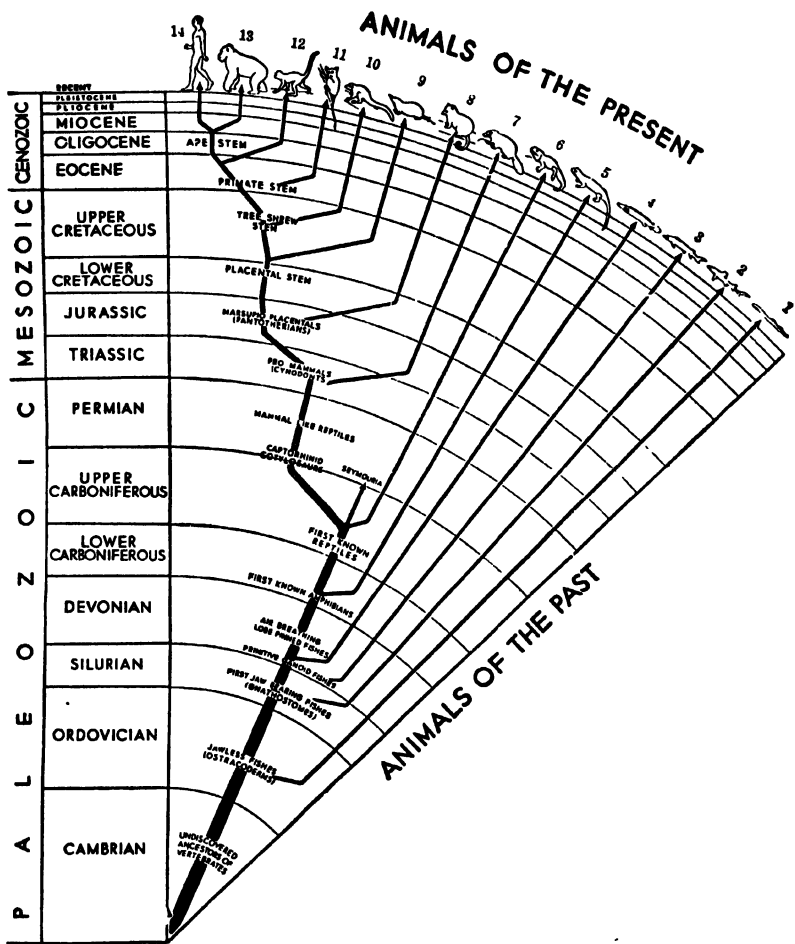


FIG. 474. Phylogenetic tree of vertebrate evolution, especially emphasizing the ancestral history of Man.

The figures on the upper curved line represent an ascending series of vertebrates from the lowest fishes to man. Though these animals of the present are not the ancestors of man, they are the descendants of ancestral animals that lived in earlier periods of the earth's history.

During each successive age progressive species of the "main line of ascent" advanced to the next higher grade of organization, but some of its more conservative side branches, changing more slowly, preserved the principal characters of earlier times. (From Gregory.)

- | | | | |
|---------------|--------------|----------------|----------------|
| 1. Lamprey | 5. Newt | 8. Opossum | 12. Monkey |
| 2. Shark | 6. Spnenodon | 9. Groundshrew | 13. Anthropoid |
| 3. Sturgeon | 7. Platypus | 10. Tree-shrew | 14. Man |
| 4. Polypteru, | | 11. Farsius | |

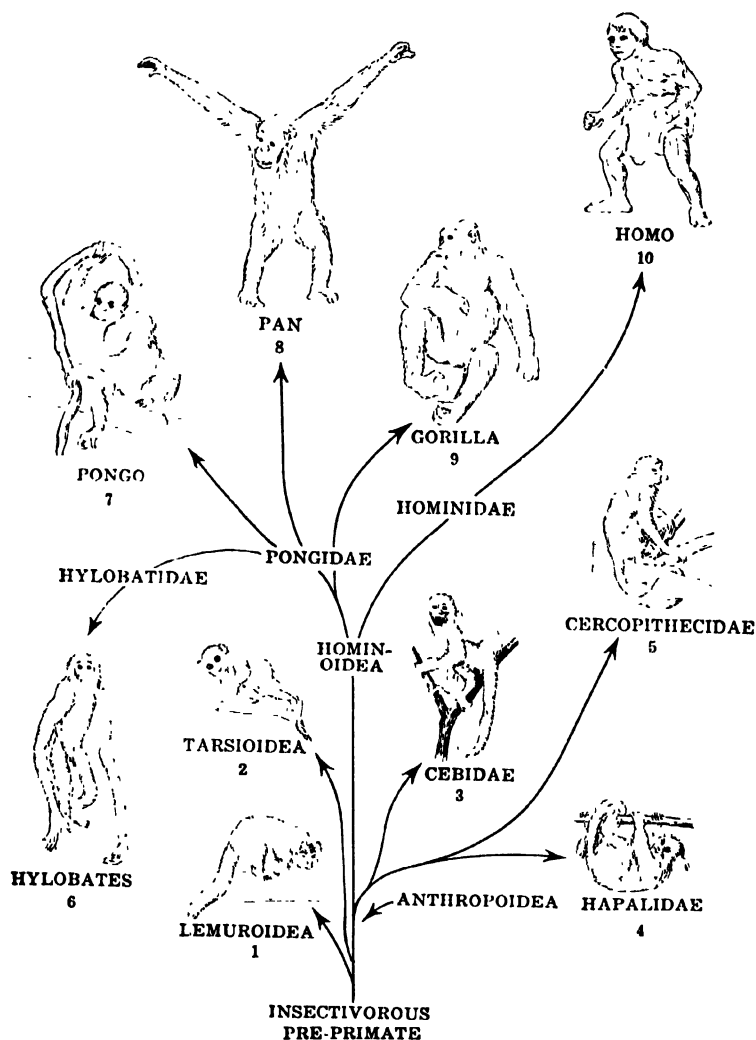


FIG. 475. General relationships of the Primates. 1, lemur; 2, tarsius; 3, New World monkey; 4, marmoset; 5, Old World monkey; 6, gibbon; 7, orangutan; 8, chimpanzee; 9, gorilla; 10, Neanderthal man. See p. 698.

vironmental conditions by the use of a bigger and better brain. (Figs. 473, 474, 475.)

The Anthroipoidea, in which our interest centers, are widely distributed throughout the tropical regions of both hemispheres. Although

those of the Eastern and Western hemispheres doubtless were derived from the same original stock, they have followed somewhat different though, in general, parallel evolutionary paths since their origin more than fifty million years ago, early in the Age of Mammals. (Fig. 265.)

The Old World branch of the Anthropoidea is of especial importance because it is dignified by the inclusion of man. It comprises three families higher in rank than the monkeys. These are the HYLOBATIDAE, or gibbons; the PONGIDAE, or orangutans, chimpanzees, and gorillas; and the HOMINIDAE, or men. The Hylobatidae and Pongidae are known as the manlike, or ANTHROPOID APES. However, all specialists in this field are not agreed that the separation of the anthropoid apes from man is justified, for, as one states it: "between the gorilla and man, barring for the moment the mental and spiritual distinctions, there is hardly more difference than there is between the horse and the ass, and the degree of consanguinity is much the same." Another assigns the separation to the prejudices of "that self-conscious prig who

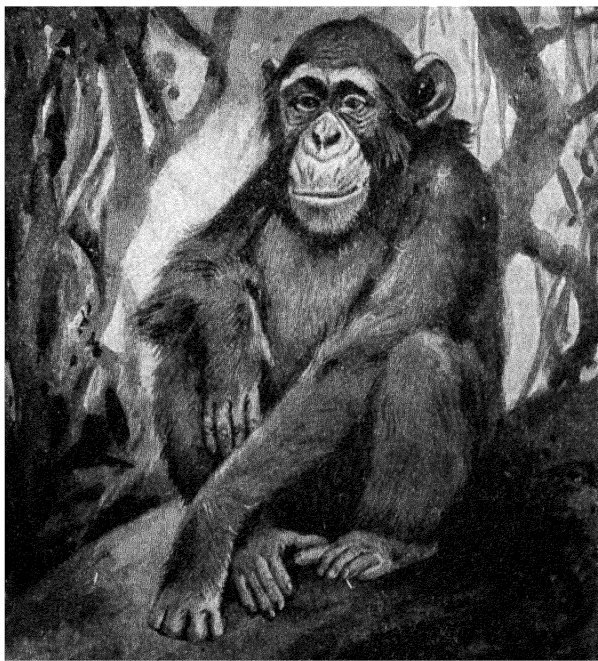


FIG. 476. Chimpanzee, *Pan troglodytes*. Note large ears, long lips, ridge above eyes, long arms, nails on fingers and toes, and hand resting on backs of fingers. Height 4½ feet; weight of male, 160 pounds. (From Hegner. Drawn by Horsfall.)

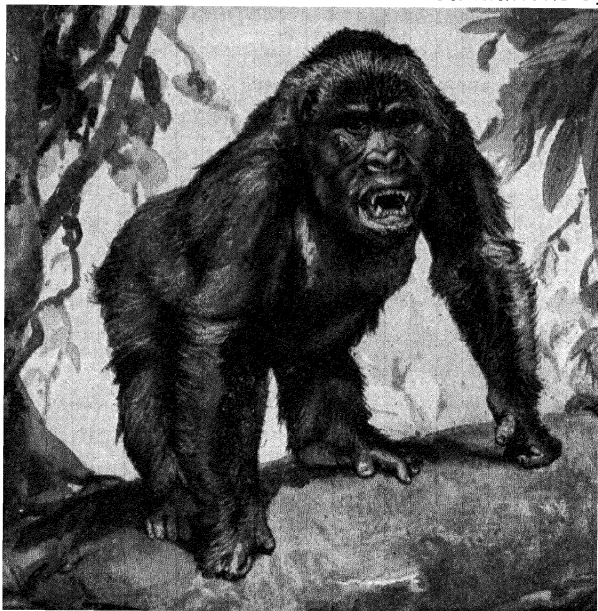


FIG. 477. Gorilla, *Gorilla gorilla*. Note large head, small ears, short lips, large canine teeth, ridges above eyes, and absence of a chin. The gorilla walks on the backs of its fingers. Height about $5\frac{1}{2}$ feet, weight 500 pounds. (From Hegner. Drawn by Horsfall.)

calls himself *Homo sapiens* and is fond of acting like a viceroy of God." Perhaps all may be satisfied by grouping the anthropoid apes and man in a single superfamily, the HOMINOIDEA.

At all events, the inevitable inference is that these various forms have evolved from a common stock, though it should be emphasized that no living species represents the direct human ancestor. The chimpanzee-gorilla group is regarded as the nearest to man, but these apes have evolved along different lines since the divergence of the human lineage in the geologic past. Apparently the common ancestor was a rather large animal with a mode of life more similar to the present-day gibbons than to either the chimpanzees or the gorillas, although anatomically the gibbons today differ more markedly from man than do any of the other anthropoid apes. Gibbons are relatively small active animals with such very long arms that the knuckles reach the ground even when the body is erect. They are strictly arboreal forms whose amazing adaptations for progression through the foliage of trees have been suggested as of prime importance in the development of their

mentality; and so it may have been with the prehuman ancestors. (Figs. 473, 476, 477.)

Antecedent to the common ancestor of the anthropoid apes and man were more and more primitive forms—tarsioids or lemuroids—and so back, receding still further into the past to an insectivorous stem from which the primates originally emerged. It is perhaps somewhat in deference to man that the primates are usually placed as the culminating order of mammals and so of the vertebrate series, because in spite of their larger brain and the uses they make of it the primates retain many primitive characters that elsewhere are found only in the lowly mammalian order, Insectivora. (Fig. 293.)

No useful purpose will be served here by delving further into the geologic past for still earlier antecedent forms, because behind the insectivores the actual record becomes increasingly obscure. However, it seems certain that the insectivores were evolved from still more primitive mammals during the Mesozoic Age, the Age of Reptiles, and that the earliest mammals arose from the reptilian stock.

In the study of man as a primate and his relationships with the anthropoid apes, one is on firmer ground. This relationship is supported by many independent but interlocking lines of evidence, such as the similarities in structure of the brain and viscera, of the musculature and the skeleton in general, and of the hands and feet in particular. The differences are almost entirely in proportions. Man has a larger brain and brain case relative to the facial portion of the skull, smaller development of the canine teeth, complete adaptation of the structure of the vertebral column to the upright position, greater length of the legs as compared with the arms, and almost complete loss of the ability



FIG. 478. Feet of anthropoid apes and man. (From Schultz.)

to bring the great toe in apposition to the other toes. This last characteristic and the small size of the canine teeth are probably "the most marked and easily defined distinction that can be drawn between man and the anthropoid apes." (Fig. 478.)

In general, however, the structures are almost identical. Indeed, even the ridges on the palms and soles, and the chemical properties of the blood indicate affinity. Not the least important evidence is the structure of the premolar and molar teeth: those of man are very unlike those of any other animals except the great apes. Therefore the teeth, especially since they withstand well the ravages of geologic time, afford excellent clues in the search for the fossil anthropoids at the root of the human family tree. (Figs. 261, 474, 475.)

Numerous fossil remains have been found that give evidence in regard to the origin of the anthropoids. Back in the Eocene epoch are various tarsiods and a monkey which bridge the gap to higher primates, and in the Oligocene epoch are several monkeys and anthropoid apes that are near to the main line of ascent. In the Miocene epoch appears *Dryopithecus*, which leads in the Pliocene epoch—perhaps ten million years ago—to *Ramapithecus* with teeth directly foreshadowing those of man. *Australopithecus* is even closer to man, but, since this genus and its kin do not appear until the Pleistocene, it is a contemporary of early man, and not his ancestor. However, our immediate anthropoid forebear must have been very similar to this genus. The number and arrangement of the teeth, the bicuspid pattern of the premolars, as well as various characters of the incisors, the canines, and the milk dentition, are prophetic of the human dentition today, particularly in certain primitive races. It appears that the differences shown by the human teeth are to a considerable extent related to an omnivorous diet, and to changes in the proportions of the jaws, following the great expansion of the cranium to provide for the enlarging brain.

It seems reasonably clear, therefore, that the prehuman ancestors arose through or near the *Ramapithecus* stem, and that human status was attained through a long-continued and profound morphological evolution during the Pliocene and Early Pleistocene epochs. The ancestral type was adapted to live in the vast forests of the Old World, an arboreal habitat being the only one in which the forelimb could become a true hand, and the sense of sight gain the ascendancy over that of smell. But as geologic time progressed, geologic, topographic,

and climatic changes occurred, and the forests became restricted; one may assume that the primates which had not already made a retreat were impelled to renounce, in part, the arboreal habitat for a terrestrial one.

Thus the precursors of man made the next great necessary change to the ground: an environment which was provocative of many adaptations, in particular the erect body with hind limbs supporting the entire weight. This necessitated considerable mechanical readjustment, including the alternating curvature of the vertebral column for the nicer balance of the larger cranium. Moreover, the development of the brain, furthered by the emancipation of the hands from their part in locomotion and by changes in the vocal organs leading to speech, eventually paved the way to the emergence of culture from the biosocial foundations of pre-man—to invention, communication, and social habituation. In the course of the ages man arrived. (Figs. 96, 101.)

FOSSIL MAN

Human evolution, unlike that of other organisms, presents two clear-cut aspects: the physical and the mental. Man's physical evolution was exceedingly slow, but his cultural development, once started, proceeded with increasing momentum. Both can be traced with some assurance from the actual fossil remains of prehistoric man and the relics of his handiwork.

When one realizes how slight are the chances for the remains of prehistoric man to become fossilized and, if preserved, to be unearthed today, and, furthermore, how short is the time that interest has centered in the problem, it seems remarkable that the record is not more fragmentary than it actually is. Some of the important fossil forms are of the greatest significance, though experts are by no means unanimous in regard to the interpretation of details. At present it is premature to attempt to reach a decision in regard to the specific Early Pleistocene ancestors of modern man, but there is reasonable assurance that the problem will eventually be solved. Man probably developed from different centers, each branch taking its own course more or less independently of the others. At all events his emergence is essentially a Pleistocene story. Some representative "fossil men" may be reviewed.

Java Man. In deposits of the Middle Pleistocene of Java, some half a million years old, there have been discovered during the last sixty years

various skeletal fragments which possess many of the attributes of "missing links." The bones found probably represent several species. The first discovered, and most famous, actually consists merely of a skullcap, since the associated bones proved to be unrelated, but more recently portions of three other skulls and an upper and lower jaw have been unearthed. With these fragments as a guide, experts have attempted to restore the chief features of this so-called JAVA MAN, *Pithecanthropus erectus*. However, the much vaunted Java man has become overshadowed in importance by newer discoveries in regard to the similar Peking man, his contemporary. (Fig. 479.)

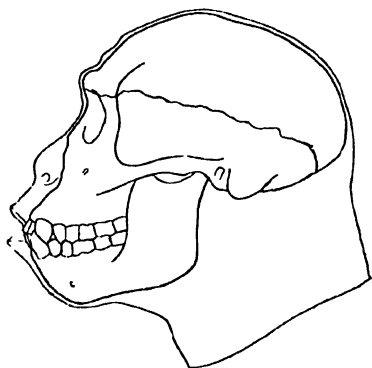


FIG. 479. Skull and face of the Java Man, *Pithecanthropus erectus*. Portion of skull below the irregular line restored. (From Lull, adapted from McGregor.)

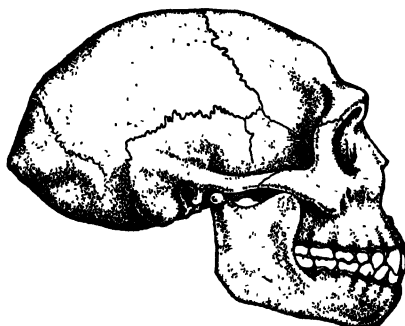


FIG. 480. Peking Man, *Sinanthropus*. The facial region and jaws are mainly restored. (From Romer, after Weinert.)

Peking Man. At various times during the past forty years many fragments of fossil man have been found near Peiping, China, in deposits of Middle Pleistocene age, and careful research on these fossils has established their authenticity. From the fragments discovered—skulls, jaws, teeth, and parts of femurs—it appears that the PEKING MAN, *Sinanthropus pekinensis*, had very thick cranial walls and low cranial capacity. The ridges above the eyes are massive, the nasal bridge broad and short, and the anterior nares wide and low. The teeth are somewhat primitive although essentially human. The femur fragments indicate medium stature and erect posture. The Peking man obviously represents a very primitive type in the general line of advance, which seems to be very closely related to the Java man. More-

over, with this early man there is some evidence of the dawn of culture. Abundance of carbonized material indicates the use of fire, and pieces of crudely chipped stones suggest the use of tools, while split bones make it reasonably certain that cannibalism was indulged in. (Fig. 480.)

Pitldown Man. Significant discoveries were made near Pitldown Common in Sussex, England, from 1911 to 1913. The findings included parts of two crania and a lower jaw, nasal bones, and several teeth. The enormously thick cranial walls of this **PITLDOWN MAN**,

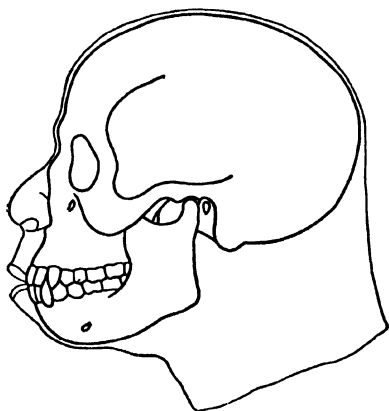


FIG. 481. Skull and face of Pitldown Man, *Eoanthropus dawsoni*. (From Lull, adapted from McGregor.)

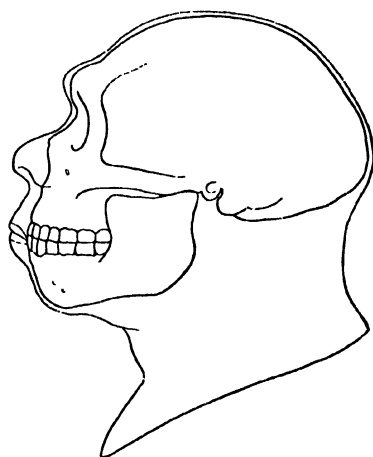


FIG. 482. Skull and face of Heidelberg Man, *Homo heidelbergensis*, based upon McGregor's restoration of the skull, only the lower jaw being known from fossil remains. (From Lull.)

Eoanthropus dawsoni, resemble those of the Peking man, but the forehead and vault of the skull approach nearer to that of modern man. However, the jaw and canine tooth are more apelike than in the man of Peking and probably do not belong to the same skeleton. In fact, they are believed by some to represent a fossil chimpanzee, just as a fossil orangutan is now known to make up part of the original "Java man." Obviously, these important relics are not completely understood as yet, and it is hoped that future finds will fill in the gaps in our knowledge of them. Although they are practically geological con-

temporaries, it is difficult from the scanty data to bring the relatively large-brained Piltown man into relationship with the Java and Peking men. (Fig. 481.)

Heidelberg Man. A second species of early man, of definitely known geologic occurrence, is represented merely by a lower jaw found during 1907 in a sand deposit of Early Pleistocene age near Heidelberg, Germany. The quite massive jaw is of a primitive type, but the teeth are close to the human both in relative size and general appearance. Accordingly, the HEIDELBERG MAN is included in the same genus with modern man, as *Homo heidelbergensis*. However, the relationships of Heidelberg man are obscure, though possibly he is an ancestor of the men of Neanderthal, his successors. (Fig. 482.)

Neanderthal Man. The remains of NEANDERTHAL MAN, *Homo neanderthalensis*, appear in the caverns or rock shelters of Europe

several hundred thousand years after the Heidelberg man. The history of man during the vast interim has not yet been revealed, but one must suppose that he persisted precariously through the intermittent periods of glaciation during the great ice ages. Indeed, the Neanderthal race may have diverged early in the Pleistocene, but it flourished in the last interglacial and the early part of the last glacial epoch. It appears to have sprung from an earlier stock, of which the Java and Peking men were members. (Fig. 475.)

Neanderthal man is known from many skeletons; one of the earliest in point of discovery was found in the Neander Valley, near Düsseldorf, Germany, in 1857, and one of the most recent in the Cave of Robbers near Jerusalem. The men of Neanderthal averaged about

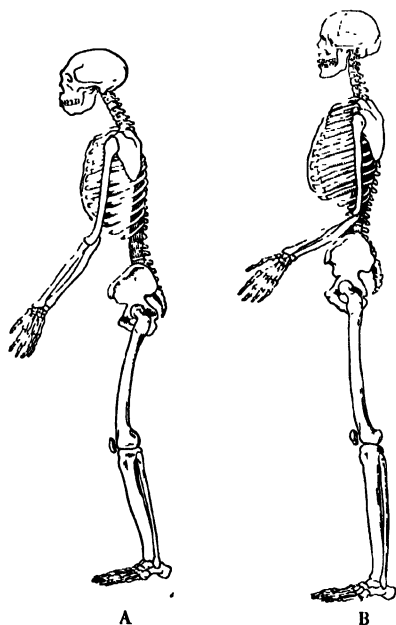


FIG. 483. Skeleton of Neanderthal Man (A), *Homo neanderthalensis*, compared with that of a living native Australian (B), *Homo sapiens*; the latter the most primitive existing race of man. (After Woodward.)

five feet, four inches in height and were stocky and powerful. They probably walked with a shuffling, slouching gait since curved thigh bones and imperfect curvatures of the spine show that the limbs were habitually bent at hip and knee. A large head with heavy jaws was supported by powerful neck muscles. (Fig. 483.)

The skull is notable for its size, but the cranium is low and the forehead retreats from a continuous brow ridge that is distinctive of the race. The large brain is relatively simple compared with that of modern man, especially in the regions devoted to the higher mental activities. However, that these cave men were not without ability is attested by the well-wrought stone hunting implements found associated with their remains. Although, according to modern standards, beastlike features outweighed human, it seems that some higher human traits lurked in the make-up of these men, since in certain instances there is evidence of reverential burial of the dead. (Figs. 484, 486.)

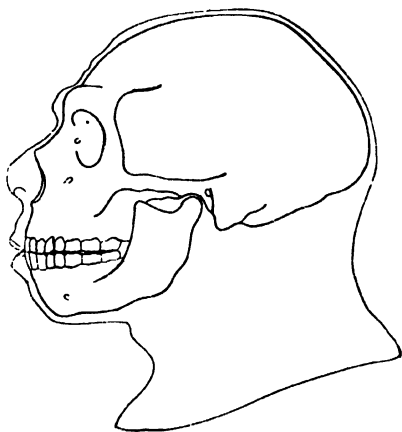


FIG. 484. Skull and face of Neanderthal Man, *Homo neanderthalensis*. (From Lull, adapted from McGregor and Boule.)

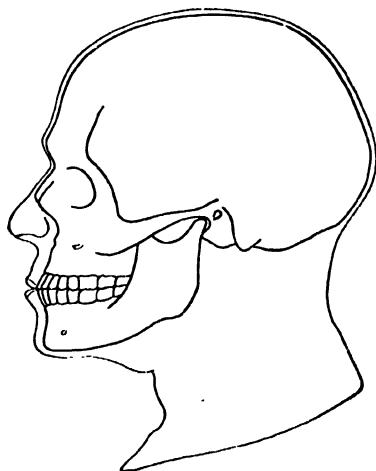


FIG. 485. Skull and face of Cro-Magnon Man, *Homo sapiens*. (From Lull, adapted in part from McGregor.)

Cro-Magnon Man. Sometime in the last glacial epoch the supremacy of Neanderthal man was challenged by a superior race—the first that is recognized as of the same species, *Homo sapiens*, to which modern man is assigned. This invading race of CRO-MAGNON MEN seems to be of different immediate stock from the Neanderthal men of Europe and.

in large part at least, to be responsible for their extinction. Apparently Cro-Magnon man came from an Asiatic source about 40,000 years before the dawn of history, after an antecedent evolution of many more thousands of years from a *Sinanthropus*-like stem. If this is true, modern man may be regarded as Neanderthal man's progressive nephew, though not his direct descendant.

Although numerous remains of the Cro-Magnon race have been discovered, those from the Cro-Magnon cavern in western France represent the type. The men were of large stature, averaging at least six feet in height, while the women were much smaller. The posture was entirely erect with the characteristically alternating curves of the human

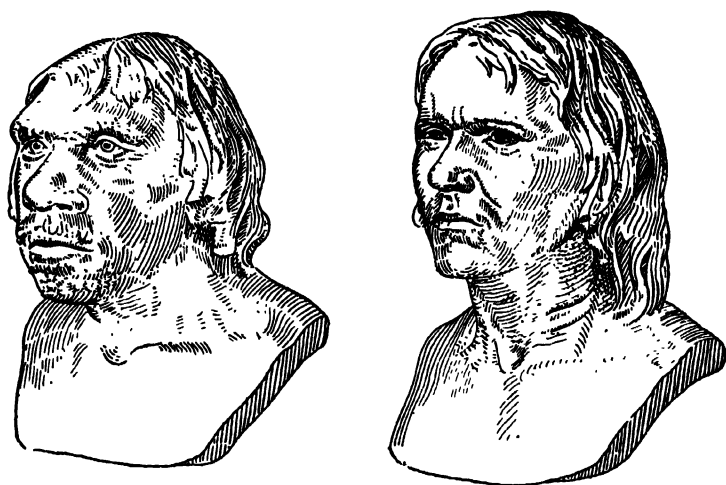


FIG. 486. Neanderthal Man, left; Cro-Magnon Man, right. Original models by Professor J. H. McGregor, in the American Museum of Natural History. Redrawn.

spine, and straight limbs. The cranium was of very large capacity with high, vertical forehead and no brow ridges. The face was broad in comparison with the cranium, and the somewhat prominent chin was narrow and pointed. (Figs. 485, 486.)

The Cro-Magnons were a splendid race physically, and the remarkable Paleolithic art that still survives in certain caverns of France and Spain attests their mental equipment. Thus from both aspects they meet the standard of the species *Homo sapiens*, and differ in no great

degree from their successors, the so-called Mesolithic and Neolithic races which, in turn, closely approach the present-day races of man.

HUMAN VARIABILITY

It is generally agreed that man is represented today by one species comprising several races. The four races commonly recognized are the Australoid, Negroid, Mongoloid, and Caucasoid. Their typical characteristics may be summarized.

AUSTRALOID RACE: brown skin; long skull; prominent eyebrows; large teeth; long, black, wooly hair; long limbs. Habitat: Australia, and scattered regions in India and Ceylon.

NEGROID RACE: brown or black skin and eyes; long skull; round forehead; flattened nose; sloping teeth; short, black, wooly hair. Habitat: Madagascar and Africa from the Sahara Desert southward.

MONGOLOID RACE: golden-brown skin; broad and short skull; flat nose; small, oblique eyes; coarse, straight, black hair. Habitat: east of a line from Lapland to Siam. Chinese, Tartars, Japanese, Malays, Eskimos, and American Indians.

CAUCASOID RACE: usually considered to comprise three varieties: *Mediterranean*—long-headed, short and slender with brown to black hair and eyes; *Alpine*—round-headed, medium height, stocky build, with brown to black hair and eyes; and *Nordic*—long-headed, tall, with flaxen, red, or light brown hair, and blue, gray, or green eyes.

The Caucasoid race shows great variation and includes, in addition to the native peoples of western Europe and their widely scattered descendants, the Moors, Berbers, Egyptians, Persians, Afghans, Kurds, Hindus, Turks, Jews, and Armenians.

Since the early Pleistocene, man has evolved and multiplied; he has eliminated many competing types and has domesticated others, and he has considerably modified not only the biological but also the physical conditions of his environment. In brief, he has become the first organism in the history of life that can with some justice be dubbed the Lord of Creation.

Considered from any standpoint and conservatively stated, this is a unique phenomenon with unique results. From the strictly biological aspect it is significant that *Homo sapiens* probably is the most variable vertebrate and that this variety has been achieved within the limits of a single species, not as in other successful types by expanding into scores of distinct species. And superimposed upon the intrinsic bio-

logical variability is the immense variability due to nurture in the broadest sense—upbringing, profession, etc.—which results in a final variability that would be astounding were it not so familiar. “This enormous range of individual variation often leads to misunderstanding and even mutual incomprehensibility; but it also provides the necessary basis for fruitful division of labor in human society.” All men are born equal only in the sight of the law.

CULTURAL DEVELOPMENT

The obviously unique characteristics that set man apart from the rest of the animal kingdom are the capacity for CONCEPTUAL THOUGHT which is synonymous with true speech, the development of CUMULATIVE TRADITION, and its chief consequence, the continuous development of TOOLS. These are mutually interdependent and collectively are responsible for the dominance of man on the earth. His position above the beasts is based largely upon the fact that he alone possesses a genuine culture. He domesticated himself—man created culture, and culture created man. Of course, the biological basis constitutes the foundations upon which the cultural superstructure rests: man cannot get away from nature. Various culture patterns are impressed upon the individual as habits of thought and action, and this social conditioning demands a complex organism with the ability to make environmental adaptations.

Animals in general exhibit various BIOSOCIAL reactions, such as the group life of bees and ants or the simple family life of the anthropoid apes, which are inherited from generation to generation and are the outcome of evolution. But upon the hereditary biosocial endowment of actions and reactions, man has superimposed processes of a cultural order that are acquired in each generation by the continuity of so-called group conditioning; in other words, habits of body and mind are impressed upon the young by the elders, and cumulative tradition results. Although these cultural processes are an addition to, and are dependent upon, the hereditary biosocial endowment, they are something more than merely an elaboration of it. They are essentially untrammelled by the limitations of the slow process of organic evolution, which is dependent upon germinal variations and natural selection. Apparently there has been no significant changes in the societies of insects for some thirty million years since the Oligocene period; compare this with the evolution of human society during a few thousand

years. The cultural aspect of human nature can and does forge ahead in so far as the physical and mental heritage is adequate to meet the emergency.

PALEOLITHIC CULTURE

Many of the specimens of prehistoric man have been found in Europe, and this holds true also for the evidences of his culture. Our attention may therefore be confined to this region, where human chronology has been worked out most thoroughly.

The first artifacts appear in the Pliocene or very early in the Pleistocene epoch of periodic glaciation, and consist of pebbles that obviously were chipped by man. This culture is evidence of the exceedingly slow dawning of human mental life because it persisted with little improvement for not less than several hundred thousand years. It apparently represents the cultural scale of the Peking and Piltdown men and possibly also of Heidelberg man. However, as time passes, the artifacts increase in variety of form and nicety of manufacture, and the so-called PALEOLITHIC culture emerges. There are cleavers, axes, scrapers, drills, etc., some of them apparently shaped for convenience in grasping, and eventually the work of Neanderthal man is reached. This is the first Paleolithic culture that can be assigned to a definite race of OLD STONE AGE MEN.

The relics of Neanderthal man, unlike those of his precursors, are found typically in rock shelters and caverns. The chief source has been in western France, although a similar culture is widespread in other suitable regions of Europe, and in Palestine and Mongolia. The most famous cavern, at Le Moustier in France, is believed to have served as a human abode for more than 50,000 years, and accordingly the culture of the Neanderthals is known as MOUSTERIAN. (Fig. 487.)

The stone implements of the Neanderthals show technical improvements in the methods of chipping as well as a greater variety of form. In addition to the point and the scraper there are saws, hammers, drills, and skinning implements. Furthermore, tools of bone were used for dressing hides, but there is no evidence of implements for sewing, so it is assumed that clothing, such as it was, consisted of single skins. It may be noted in passing, that the invention of clothing, whenever it occurred, was an important step in human progress, because it largely removed the limitations imposed by climate and so opened up new

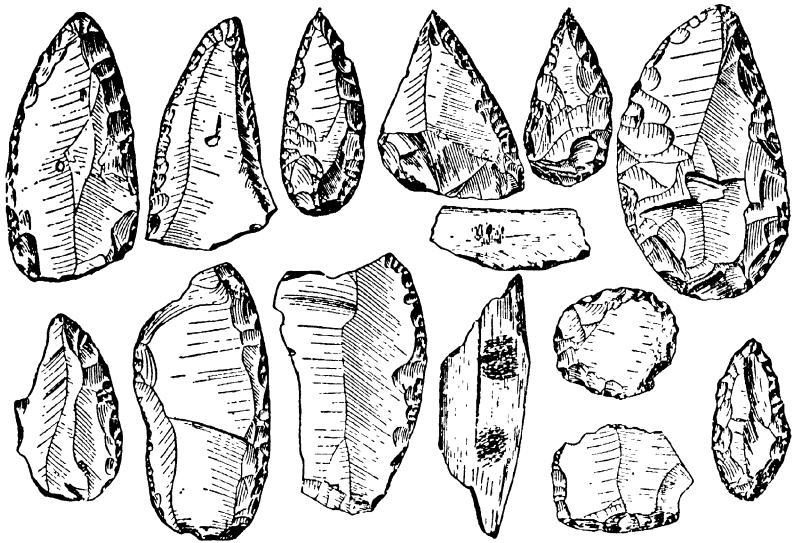


FIG. 487. Mousterian implements. Flint scrapers and points, and two bone compressors from a rock shelter of La Ferrassie (Dordogne), France. Middle Paleolithic Period. (From MacCurdy, after Capitan and Peyrony.)

regions for human habitation, although the use of fire was known as early as Peking man.

It is believed that a wave of migration from Asia brought the Cro-Magnons to western Europe, where they met and to some extent mingled with the Neanderthals, to the eventual extinction of the latter. Clearly it was a case of the survival of the fit, for the Cro-Magnon was essentially like modern man both physically and mentally, and "the characters of their crania reflect their moral and spiritual potentialities." It was a race of hunters and warriors, of sculptors and painters, that lived at the close of the long glacial epoch, some 50,000 years ago.

The marked line of cleavage between the Neanderthal and Cro-Magnon cultures is attested by a newly developed kit of tools. The implements no longer are confined to such as can be fashioned merely by chipping, but include, for example, the harpoon of reindeer horn, the flat bone point with cleft base, the needle of bone or ivory, the dart thrower, and the flint scrapers, knives, and graters. The graters were used both for cutting bone, horn, and ivory and also for engraving and sculpturing. Indeed the Cro-Magnon artist not only

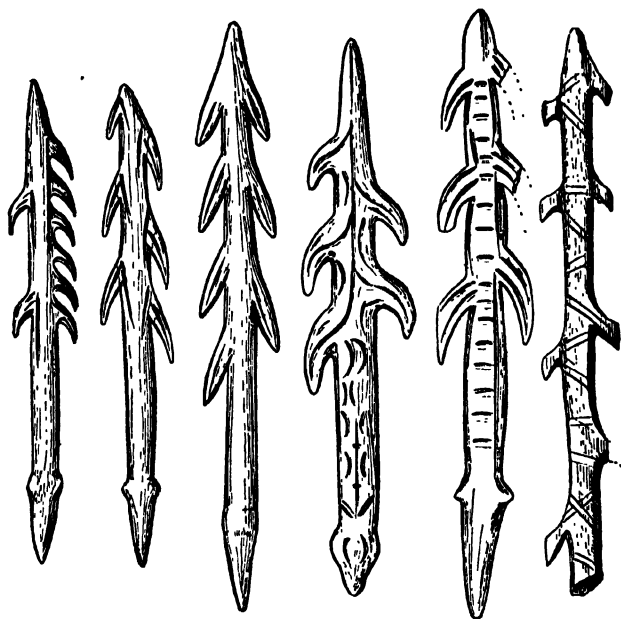


FIG. 488. Harpoons of reindeer horn from France and Switzerland. Late Paleolithic Period. (From MacCurdy, after Breuil.)

modeled in clay, but also was skillful with colors, first simple, later blended, as is still attested by the drawings and frescoes on the walls and ceilings of his caverns. However, the art that depicted the woolly rhinoceros and the mammoth was to fade as the diminishing ice sheets forced these animals north to eventual extinction. This flowering of artistic ability was not exhibited by the immediate successors of Paleolithic man, though comparable art flourished at a very much later period among the Bushmen of South Africa. (Figs. 488, 488 A.)

MESOLITHIC CULTURE

The MESOLITHIC culture succeeded the Paleolithic and represents, as it were, the Dark Ages of the prehistoric era. Characteristic of the period are the huge shell heaps—refuse piles that throw considerable light on the food habits and implements of the people. These are found in Europe, Asia, and America. Usually they were situated near water, as is evidenced by the great abundance of oyster and mussel shells, and of the bones of the duck, goose, gull, and swan. Mammals are represented by bones of the stag, boar, wolf, bear, beaver, etc. It is signifi-

cant that remains of domesticated animals are not present, except possibly those of the dog, the earliest companion of man. Among the implements are arrow points, axes, adzes, and bladelike flints, while remnants of pottery show that at least crudely fashioned bowls and jars were employed.

Other interesting accessions of the period are the curious painted pebbles that are found in stream beds. The pebbles bear symbols of

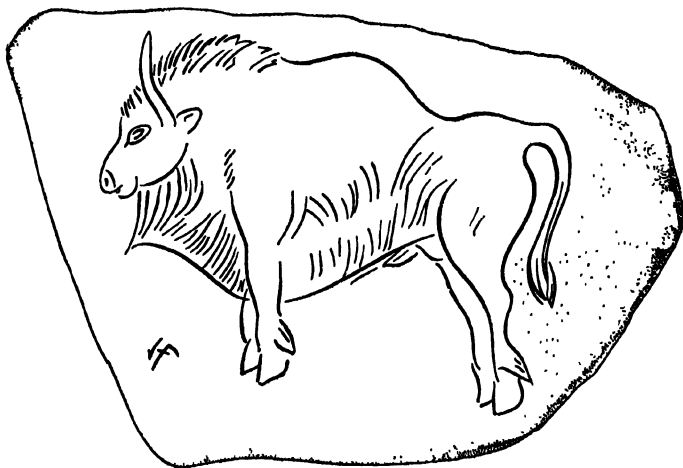


FIG. 488 A. Bison incised on limestone. Rock shelter of Laugerie-Basse (Dordogne), France. Late Paleolithic Period. (From MacCurdy. Redrawn)

various kinds, some of them crudely resembling modern letters. In fact it has been seriously suggested that these symbols represent a mode of writing and that some of them have had an influence on our own alphabet.

NEOLITHIC CULTURE

The culture of the NEOLITHIC, or NEW STONE AGE, is essentially that of modern men who deserted cavern life and took to the open. The animal life is also modern, since no prehistoric animals persisted and none have since become naturally extinct. The human population appears to have been increasing in numbers, and the division of labor between individuals and communities to have become more significant. Thus the Mesolithic hunter and fisherman gave place to the Neolithic husbandman who, to some extent at least, controlled his

food supply and so made possible the development of community life. From a mere food gatherer, man became a food producer.

Almost surely the relatively rapid transformation of the primitive civilization was the outcome of the cultivation of plants, such as wheat, barley, rye, flax, grape, apple, and pear; the domestication of animals, for example the dog, ox, sheep, and goat; and the development of the

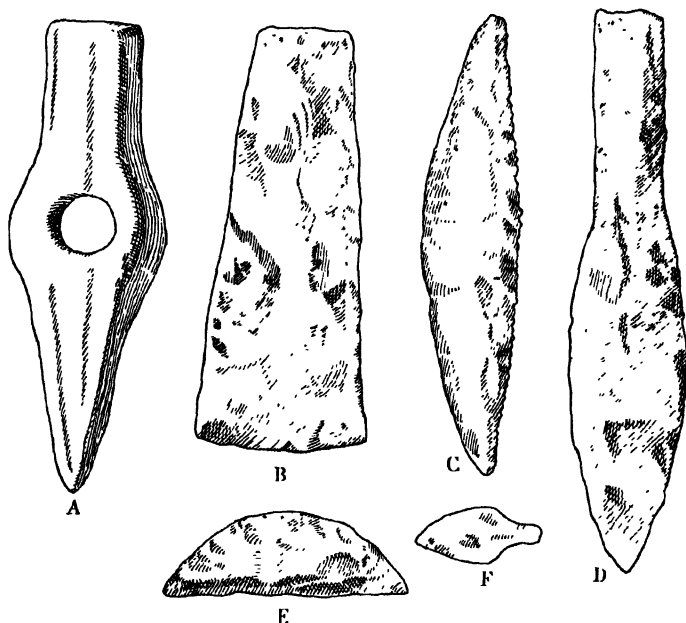


FIG. 489. Implements typical of the Neolithic Period. A, ax-hammer; B, ax; C, saw; D, dagger; E, knife; F, arrow point. (From American Museum of Natural History. Redrawn.)

art of making pottery and textiles. Moreover, pottery and textiles afforded an outlet for artistic ability, which is also evidenced, for instance, in the beautifully chipped flint poniards and knives. The shaping and finishing of stone tools and weapons by a process of polishing appears for the first time in the Neolithic period, which accordingly is frequently referred to as the age of polished stone implements. (Fig. 489.)

Transportation over water by means of dugouts began in Neolithic times, and the custom was developed of erecting habitations on piles in rivers, lakes, and swamps. Such PILE VILLAGES, serving both sanita-

tion and safety, were widely distributed in Europe during the later Neolithic and survived into the following age. The best known representatives are the Swiss lake dwellings.

Transportation by dugout apparently antedates the invention of the wheel, but Neolithic man employed at least crude wheels made from sections of logs, and the significance of this discovery can hardly be overestimated. The wheel is so inextricably woven into the fabric of modern civilization that one is inconceivable without the other; probably nine-tenths of all the energy used by man is spent turning wheels. "Take away fire and the wheel and the world would suddenly revert to sub-Neolithic level."

Although burial of the dead extends further into the past, it reaches ceremonial significance with Neolithic man. Numerous so-called MEGALITHIC monuments still remain, some of them memorials to the dead, and others of unknown symbolic import. Probably the most celebrated is the Stonehenge on Salisbury Plain in England. Finally, in addition to his other accomplishments, Neolithic man developed some surgical skill, as evidenced, in particular, by skulls showing trepanation.

AGE OF METALS

The gradual transition from the Stone Age—Paleolithic, Mesolithic, and Neolithic—to the AGE OF METALS effected perhaps the most important step in the history of human culture. It meant a release from the restrictions inherent in the very nature of stone and the opening up of the almost infinite possibilities of metals in the fabrication of newer and better instruments and utensils. Invention was stimulated.

Each step in the progress of invention toward security of life and property for early man gave further impetus to community living, and this forced a growing respect for simple mutual interests. However, it was only after the stimulus for making inventions had resulted in an easier life with regard to security, food, and shelter, and also had released to individuals more time for physical ease, that growing ethical relations between man and man and tribe and tribe became strongly evident, and community living became smoother. The early aims of each human being seem to have included security for self and family, such as characterize the objectives of most mammals. Then man gradually came to desire the permanent establishment of health, recreation, and contentment as part of his place in the sun.

This turning point in culture was fostered by the development of the art of extracting metals from their ores and of melting and casting them. Copper was the first employed, probably because it was available in its native condition, and this led to a transition period, the AGE OF COPPER. This period gave way to the great BRONZE AGE, with the discovery of the many advantages of this alloy of copper and tin. The Bronze Age extended approximately from 3500 to 1000 B.C. and shows gradual progression in the variety and nicety of fabrication of tools, utensils, ornaments, etc., as well as concomitant progress in many other aspects of human culture. Life in the late Bronze Age is depicted in Homer's *Iliad* and *Odyssey*: Achilles' shield was of bronze. The Bronze Age gradually merged into the IRON AGE, which bridges the transition between prehistoric and historic times.

EVOLUTIONARY PERSPECTIVE

The perspective of life upon the earth makes insignificant the span of man's tenancy while it adds impressiveness to the function he had and is having as an agent in evolutionary processes. *Homo*, our own genus, beginning in the early Pleistocene period, has probably less than a million years of existence, whereas *Homo sapiens*, now dominant, can at the most look back about fifty thousand years. And it was not until the Neolithic age, perhaps fifteen thousand years ago, that man began raising crops and domesticating animals—outstanding achievements toward the control of his environment. (Fig. 474.)

However, for the advent of man as an effective agent of evolutionary, almost revolutionary, change, one must approach very much nearer the present. Only relatively recently has man dominated the earth by his ever-increasing efficiency as a destroyer and as a cultivator. Many factors have aided and abetted this result, in particular man's own great increase in numbers and his various inventions. Within the past three centuries, the human population has multiplied nearly fivefold, to the intensification of agriculture, stock raising, and the spread of industries and commerce, all with profound repercussions upon the original faunas and floras of the world. When the exceedingly short span of human interference is contrasted with the slowness of natural processes, it seems not improbable that, in a few more thousand years of man's inheritance of the earth, most of the old order of living nature will give place to a new order imposed by man. (Fig. 490.)

manifestations of life. All that can with reasonable safety be assumed from our perspective of hundreds of millions of years is that the quiet progress of evolution will continue to flow through life "carrying the world of living things steadily but unobtrusively from one step to a higher."

To come back, as it were, to the earth of today, it is evident that man has traveled far since culture emerged from the mere biosocial pattern. He has gained an increment in each generation and passed it on by consistent social heredity until the cumulative result is monumental. The individual is what he is, and has the significance that he has, not so much by virtue of his individuality, but rather as a member of a great human society.

Granted that competition is a tremendously important factor in the evolution of man and beast this does not necessarily mean the survival of predators and parasites. We know that fitness may be expressed in cooperation for mutual benefit both between species and within intra-specific populations. Witness the high order of endeavor and social integration that has led man to modern science and art and has also created within him the aspirations and ideals that make him unique in the world of life. These things signify modern civilization, which, ideally at least, ministers to the health, wealth, and happiness of mankind.

It is significant that, although cultural evolution has given to humanity greatly increased powers, the hereditary physical basis apparently has remained essentially the same since the origin of *Homo sapiens*. Increased cultural complexity has depended upon the intelligent use of structures and capacities already present and not upon the evolution of new ones. Indeed, the relatively static character of man's nature may possibly constitute a crucial handicap to indefinite human progress. One may be a confirmed optimist and still admit that the increasing momentum of the stupendous cultural advance, chiefly scientific and technical, during the past century is today taxing the adjustment capacity—the adaptability—of the human biological heritage. Consider the release of vast amounts of atomic energy, which has "initiated a veritable revolution of human resources, presenting civilization with a most serious challenge." Surely, man must study himself more intensively.

We may now appropriately reiterate what was stated on an early page: the most pregnant thought from the study of biology in general

and man's past in particular is the unity of nature—the oneness of life—based on the ever-increasing background of knowledge which “robs life of none of its mystery but rather serves to link it securely with the larger mystery of the universe and the Infinite back of it all.” Man becomes more intelligible, and therefore more controllable, when he recognizes his affiliations and the ancestral strands that linger in his fabric. It is encouraging to know that he has behind him not a descent, but an ascent, and that there is some appreciable momentum in the right direction. “By means of his conscious reason and its chief offspring, science, man has the power of substituting less dilatory, less wasteful, and less cruel methods of effective progressive change than those of natural selection, which alone are available to lower organisms. And by means of his conscious purpose and his set of values, he has the power of substituting new and higher standards for change than those of mere survival and adaptation to immediate circumstances, which alone are inherent in pre-human evolution. To put the matter in another way, progress has hitherto been a rare and fitful by-product of evolution. Man has the possibility of making it the main feature of his own future evolution, and of guiding its course in relation to a deliberate aim.”

In brief, man though one with all living beings has the unique and all-important power to study consciously the forces of nature, to direct them, and to adapt himself to them. The knowledge of man's physical development through the ages in no wise minimizes the other aspects of his nature on whose origin biology is silent—aspects which constitute the enormous gap that separates him from the beasts. Man alone has the capacity to know what is good and the freedom of will to strive for it. When the grandeur of the view of life to which biology leads is appreciated to the full, no reassurance is necessary of man's commanding position—his opportunities and his responsibilities.

CHAPTER XXXV

History of Biology

History must convey the sense not only of succession but also of evolution.

—*New York Times*

The story of man's slow emergence from a condition in which he was completely at the mercy of his environment, to his relatively masterful position in our modern civilization, is the inspiring history of the intellectual development of the race. Indeed, as has been seen, knowledge spells power—power to direct and become adapted to the forces of nature—and this knowledge has been acquired after much labor and safely treasured with great pains as a result of scientific study. Truly "the succession of men during the course of many centuries should be considered as one and the same man who exists always and learns continuously"; but we, for the most part, forget the past whose heirs we are, for "the present is vocal and urging, the past silent and patient." Let us for the moment consider the works of some of the outstanding contributors to the history of biology.

Some knowledge of hunting, agriculture, and husbandry was one of the early acquirements of prehistoric man. In their rock shelters, about 40,000 years ago, the Cro-Magnons of France made spirited records of animals which probably were inspired by the chase but which display an imaginative interest beyond mere physical necessities. And at the dawn of history, nearly 6000 years ago, systems of agriculture and medicine apparently had a place in Egyptian and Babylonian civilizations. So, on the practical side, biology has a very ancient beginning. But biology as the science of life, in which emphasis is placed on the study of vital phenomena for their own sake, really begins with the Greeks.

GREEK AND ROMAN SCIENCE

Science reaching Greece from the South and East fell upon fertile soil, and in the hands of the Hellenic natural philosophers was transformed into coherent systems through the realization that nature works by fixed laws—a conception foreign to the Oriental mind but the cornerstone of all future scientific investigation. It is not an exaggeration to say that, to all intents and purposes, the Greeks laid the foundations of the chief subdivisions of natural science and, specifically, created biology.

ARISTOTLE (384-322 B.C.), the most famous pupil of Plato and dissenter from his School, represents the highwater mark of the Greek students of nature and is justly called the Father of Natural History.

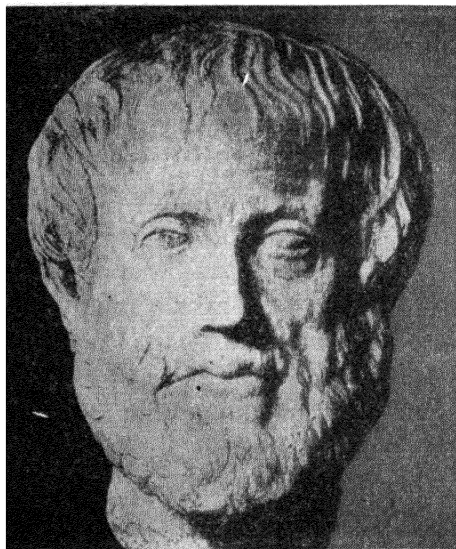


FIG. 491. Aristotle.

Although Aristotle's contributions to biology are numerous, perhaps of most significance is the fact that he took a broad survey of the existing data and welded them into a science. He did this by relying, to a considerable extent, on the direct study of organisms and by insisting that the only true path of advance lies in accurate observation and description. The observational method and its very modern development, the laboratory method of biological study, found their first great exponent in Aristotle. But mere observation without interpretation is not science. It is rather Aristotle's generalizations based on the accumulated facts, and his elaboration of broad philosophical conceptions of organisms, that give to his biological works their lasting significance. (Fig. 491.)

While Aristotle's biological investigations were devoted chiefly to animals, his pupil and co-worker, THEOPHRASTUS (370-286 B.C.), made important studies on plants. Theophrastus not only laid the foundations of botany but also gave suggestions of much of its super-

structure—an achievement which entitles him to rank as the first great student of plant science. (Fig. 492.)

Before we leave the Greeks, HIPPOCRATES (460-370 B.C.), the Father of Medicine, must be mentioned. Writing a generation before Aristotle, at the height of the Age of Pericles, Hippocrates crystallized the knowledge of medicine into a science and gave to physicians a high moral inspiration. It is fair to say that more than 2000 years ago the Greeks delineated the major subdivisions, the philosophical implications, and the social significance of biological science.

The history of medicine and of biology as a so-called pure science are so closely interwoven that consideration of the one involves the other. Indeed, the physicians form the chief bond of continuity in biological history between Greece and Rome. The interest of the Romans lay largely in practical affairs, so it would seem that the advantages to be gained from medicine should have led them to make important contributions. As it happened, however, two Greek physicians were destined to have the most influence: Dioscorides, an army surgeon under Nero, and Galen, physician to the Emperor Marcus Aurelius.

DIOSCORIDES wrote the first important treatise on applied botany. This was really a work on the identification of plants for medicinal purposes but, gaining authority with age and being variously transformed, it became the standard botany for fifteen centuries.

GALEN (131-201) was the most famous physician of the Roman Empire, and his voluminous works represent both a repository for the anatomical and physiological knowledge of his predecessors, improved and worked over into a system, and also a large amount of original investigation. He was at once a practical anatomist and an experimental physiologist, inasmuch as he described from dis-

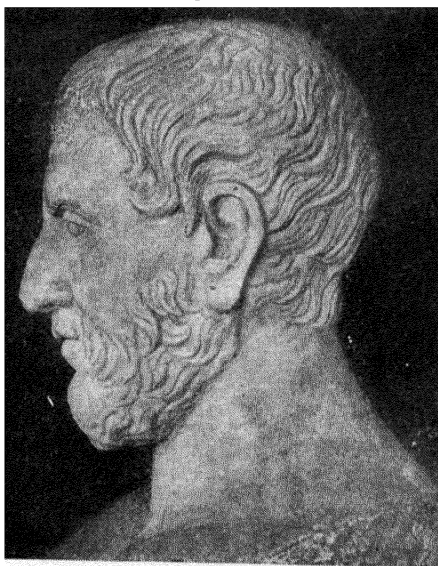


FIG. 492. Theophrastus of Eresus.

sections and insisted on the importance of vivisection and experiment. Galen gave to medicine its standard anatomy and physiology for fifteen centuries.

Any consideration of the biological science of Rome would be incomplete without a reference to the vast compilation of mingled fact and fancy made by PLINY the Elder (23-79). Though aside from the path of biological advance, it was long the recognized *Natural History*, passing through some eighty editions after the invention of printing.

MEDIEVAL AND RENAISSANCE SCIENCE

For all practical purposes one may consider biology at the decline of the Roman Empire to be represented by the works of Aristotle, Theophrastus, Dioscorides, Galen, and Pliny. Even these men exerted little influence during the Middle Ages. Dioscorides, Galen, and Pliny were available to the scholars; but in so far as science reached the people in general, it was chiefly by collections of quotations from corrupt texts of these authors interspersed with anecdotes and fables. Quite characteristic of the times is the oft-quoted *PHYSIOLOGUS*, found in many forms and languages—a collection of grotesque natural history stories in which, for instance, the centaur and phoenix take their place with the frog and the crow in affording crude illustrations of theological texts and in pointing out far-fetched morals.

In fact, science was submerged to such an extent that the scientific Renaissance owes its origin largely to the revival of classical learning, in particular to the translation of Aristotle and Theophrastus, and renewed study of Dioscorides and Galen. Their works were so superior to the current science that, in accord with the spirit of the times, to question their authority became almost sacrilegious. The first studies were merely commentaries on the writings of these authors, but as time went on more and more new observations were interspersed with the old. In short, the climax of the scientific Renaissance involved a turning away from the authority of Aristotle and the past, and an adoption of the Aristotelian method of observation and induction.

Botany was the first science to give visible signs of the awakening, probably because of the dependence of medicine on plant products. "All physicians professed to be botanists and every botanist was thought fit to practice medicine." In the *HERBALS* published in Germany during the sixteenth century can be traced the growth of plant description and classification from mere annotations on the text of

Dioscorides to well-illustrated manuals of the plants of western Europe.

Meanwhile zoology began to emerge as a distinct science; but the less obvious immediate utility of the subject, combined with the greater difficulty of collecting and preserving animals, and therefore the necessity of more dependence on travelers' tales, tended to retard its advance. One group of naturalists, the *ENCYCLOPEDISTS*, so called from their endeavor to gather all the available information about living things, attempted the impossible. However, this gleanings from the ancients and adding such material as could be gathered led to the publication of huge volumes of fact and fiction, which served to popularize zoology and afforded the necessary survey which must precede constructive work. Gesner's great *History of Animals* had the most influence.

Although *GESNER* (1516-1565) of Switzerland was without doubt the most learned naturalist of the period and probably the best zoologist who had appeared since Aristotle, the direct path to progress was blazed by men whose plans were less ambitious. Contemporaries of Gesner, who confined their treatises to special groups of organisms which they themselves investigated, really instituted the biological monograph that has proved to be an effective method of scientific publication.

While the herbalists, encyclopedists, and monographers at work in natural history were making earnest endeavors to develop the powers of independent judgment, long suppressed during the Middle Ages, the chief emancipator of biology from the traditions of the past appeared in the Belgian anatomist, *VESALIUS* (1514-1564). Not content with the anatomy of the time, which consisted almost solely in interpreting the works of Galen by reference to crude dissections made by barbers' assistants, Vesalius attempted to place human anatomy on the firm basis of exact observation. The publica-



FIG. 493. Andreas Vesalius.

tion of his great work *On the Structure of the Human Body* made the year 1543 the dividing line between ancient and modern anatomy, and thenceforth anatomical as well as biological investigation in general broke away from the yoke of authority, and men began to trust and use their own powers of observation. (Fig. 493.)

The work of Vesalius was on anatomy, and physiology was treated somewhat incidentally. The complementary work on the functional side came in 1628 with the publication of the epoch-making monograph *On the Motion of the Heart and Blood in Animals* by HARVEY (1578-1657) of London. No rational conception of the economy of the animal organism was possible under the influence of Galenic physiology, and it remained for Harvey to demonstrate by a series of experiments, logically planned and ingeniously executed, that the blood flows in a circle from the heart back to the heart again, and thus to supply the background for a proper understanding of the physiology of the organism as a whole. With the work of Vesalius and Harvey, biologists had again laid hold of the great scientific tools—observation, experiment, and induction—which since then have not slipped from their grasp. (Figs. 128, 494.)

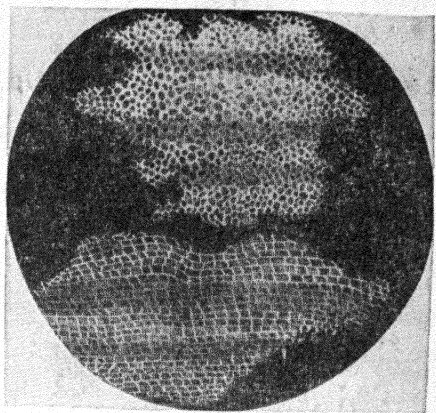
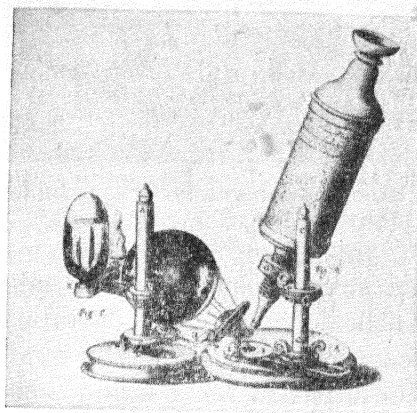
THE MICROSCOPISTS

During this revival period, when collections and accurate descriptions of plants and animals were being made and the study of anatomy and physiology was going rapidly forward, optical inventions occurred which were destined to make possible modern biology. First came the development of the SIMPLE MICROSCOPE, through an adaptation of the principles of spectacles, during the sixteenth century; then came the combination of lenses forming the COMPOUND MICROSCOPE, first effectively employed by Galileo in 1610. By the middle of the century, simple and compound microscopes were being made by opticians in the leading centers of Europe.



FIG. 494. William Harvey.

Significant of the times is the clear appreciation of the importance of studying nature with instruments that increase the powers of the senses in general and of vision in particular, expressed by HOOKE (1635-1703) of London in a remarkable book, the *Micrographia*, published in 1665. Using his improved compound microscope, Hooke clearly observed and figured for the first time the "little boxes



or cells" of organic structure, and his use of the word cell is responsible for its application to the units of modern biology. (Figs. 4, 495.)

Microscopical work was a mere incident among the varied interests of Hooke, while LEEUWENHOEK (1632-1723) of Holland spent a long life studying nearly everything that he could bring within the scope of his simple lenses. With an unexplored field before him, all of his observations were discoveries. Bacteria, Protozoa, hydra, and many other organisms were revealed for the first time by his lenses. But Leeuwenhoek's discovery of the sperm of animals created the most astonishment. His imagination, however, outstripped his observations, for he thought that the next generation must be preformed within the sperm, which he therefore regarded as the complete germ, which has only to be hatched by the female. (Frontispiece; Figs. 199, 496.)

The patience and ingenuity of Leeuwenhoek were equalled in studies on insect anatomy by SWAMMERDAM (1637-1680) of Holland. Inspired largely by the desire to refute the current notion that insects and similar lower animals are without complicated internal organs, Swam-

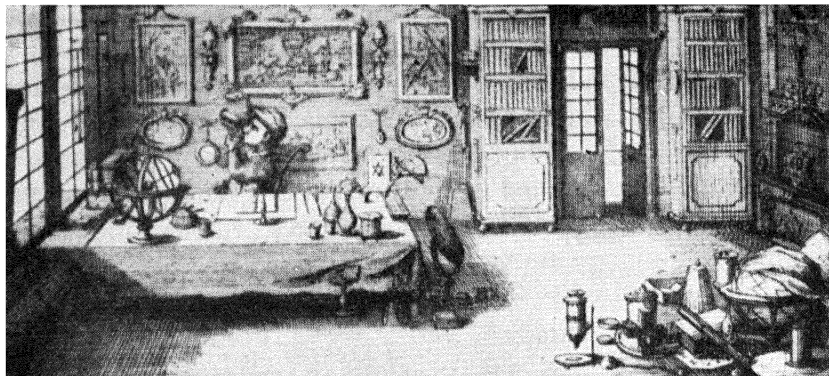


FIG. 496. An early eighteenth century biological laboratory. (From Joblot, 1718.)

merdam spent his life in studies on the structure and life histories of these forms. Revealing as he did, by delicate technique in dissection, the finest details observable with his lenses, Swammerdam set a standard for minute anatomy which was unsurpassed for a century, and dissipated for all time the conception of simplicity of structure in the lower animals. He thus, quite naturally, added one more argument to those of REDI (1626-1698) and others against spontaneous generation—an erroneous theory that survived until the work of Pasteur (1822-1895) in the nineteenth century. (Fig. 497; pp. 478-480.)



FIG. 497. Louis Pasteur. Reproduced from a painting. Courtesy of Dr. Rene Dubos.

Malpighi of Bologna and Grew of London, contemporaries of Hooke, Leeuwenhoek, and Swammerdam, may be considered as the pioneer histologists. GREW (1641-1712) devoted all his attention to plant structure, while MALPIGHI (1628-1694), in addition to botanical studies which paralleled Grew's, made elaborate investigations on animals. The versatility as well as the genius of Malpighi is shown

by his studies on the anatomy of plants, the function of leaves, the development of the plant embryo, the embryology of the chick, the anatomy of the silkworm, and the structure of glands. Skilled in anatomy but with prime interest in physiology, his lasting contribution lies in his dependence upon the microscope for the solution of problems where structure and function merge. This condition is well illustrated by his ocular demonstration of the capillary circulation in the lungs, which is probably his greatest discovery and the first of prime importance ever made with a microscope, since it completed Harvey's work on the circulation of the blood. (Fig. 498.)

DEVELOPMENT OF THE SUBDIVISIONS OF BIOLOGY

The microscopists taken collectively created an epoch in the history of biology, so important is the lens for the advancement of the science. Broadly speaking, the development of biology along many lines during the eighteenth and particularly the nineteenth century went hand in hand with improvements in the compound microscope itself and in microscopical technique. The microscopists in general and Malpighi in particular opened up so many new paths of advance that from this period on it is not possible, even in the most general survey, to discuss the development of biology as a whole. The composite picture must be formed by piecing together various lines of work, such as classification, comparative anatomy of animals, embryology, histology, physiology of plants and animals, genetics, and evolution.

CLASSIFICATION

As already explained, classification has as its object the bringing together of organisms which are alike and the separating of those which are unlike—a problem of no mean proportions when a conservative estimate today shows nearly a million known species of animals



FIG. 498. Marcello Malpighi.

and a quarter of a million plants, leaving out of account the myriads of forms represented only by fossil remains.

Naturally the earliest classifications were utilitarian or more or less physiological: fowls of the air, beasts of the field; edible, poisonous, etc. As knowledge increased, however, emphasis was shifted to the anatomical criterion of specific differences, and thenceforth classification became an important aspect of natural history, a central thread both practical and theoretical. Practical, in that it involved the arranging of living forms so that a working catalog was made which required nice anatomical discrimination, and therefore the amassing of a large body of facts concerning animals and plants. Theoretical, because in this

process zoologists and botanists were impressed, almost unconsciously at first, with the "affinities" of various types of animals and of plants, and so were led to the consideration of problems of their origin. (Fig. 441.)

From Aristotle, who introduced the grouping of organisms on the basis of structural similarities, we must pass over some seventeen centuries, in which the chief work of interest was done by the herbalists and encyclopedists, to the time of RAY (1628-1705) of England and LINNAEUS (1707-1778) of Sweden. Previous to Ray the

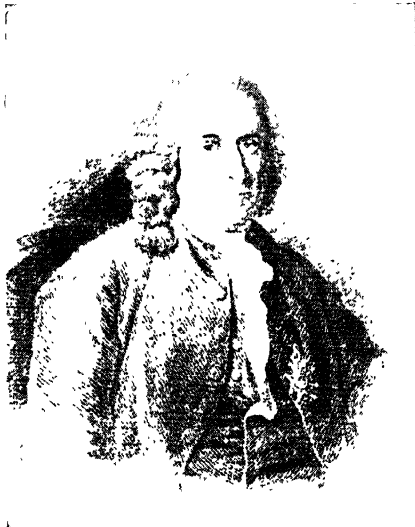


FIG. 499 Carolus Linnaeus.

term species was used somewhat indefinitely, and his significant contribution was to make the word more concrete by applying it solely to groups of similar individuals which seem to exhibit constant characters from generation to generation. This result paved the way for the great taxonomist, Linnaeus. (Fig. 499.)

First and foremost a botanist, Linnaeus published a practical classification of flowering plants which afforded a great impetus to plant study, particularly because he insisted on brief descriptions and the scheme of giving each species a name of two words, generic and spe-

cific, thereby establishing the system of BINOMIAL NOMENCLATURE. Linnaeus' success with botanical taxonomy led him to extend the principles to animals and even to the so-called mineral kingdom: the latter showing at a glance his lack of appreciation of any genetic relationship between organic species. Linnaeus believed that species, genera, and even higher groups represented distinct acts of creation, nevertheless his greatest works, the *Species Plantarum* and *Systema Naturae*, are of outstanding importance in biological history and by common consent establish the base line for priority in botanical and zoological nomenclature.

COMPARATIVE ANATOMY

Owing to the less marked structural differentiation of plants in comparison with animals, plant anatomy lends itself less readily to descriptive analysis, so that an epoch in the study of comparative anatomy is better defined in zoology than in the sister science, botany.

Comparative anatomy as an important aspect of zoological work, in fact as a science in itself, was the result of the lifework of CUVIER (1769-1832) of Paris. It is true that some of his predecessors had reached a broad point of view in anatomical study, but Cuvier's claim to fame rests on the remarkable breadth of his investigations, his survey of the comparative anatomy of the whole series of animal forms. Not content merely with the living, he made himself the first real master of the anatomy of fossil vertebrates, as his contemporary LAMARCK was of fossil invertebrates. (Figs. 265, 501, 515.)

Cuvier's grasp of anatomy was due to his emphasizing, as Aristotle had done before him, the functional unity of the organism: that the interdependence of organs results from the interdependence of function, structure and function being two aspects of the living machine which go hand in hand. Cuvier's famous principle of correlation—

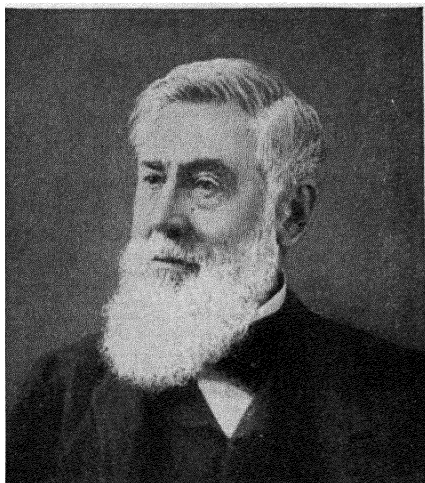


FIG. 500. Asa Gray (1810-1888). The foremost American botanist of the nineteenth century.

"Give me a tooth," said he, "and I will construct the whole animal"—is really an outcome of this point of view. Every change of function involves a change in structure; therefore, given extensive knowledge



FIG. 501. Georges Cuvier.

of function and of the interdependence of function and structure, it is possible to infer from the form of one organ that of most of the other organs of an animal. However, Cuvier undoubtedly allowed himself to exaggerate his guiding principle until it exceeded the bounds of fact.

Among Cuvier's immediate successors, OWEN (1804-1892) of London perhaps demands special mention. He spent a long life dissecting with untiring patience and skill a remarkable series of animal types, as well as reconstructing extinct forms from fossil remains. Aside from the facts accumulated, probably his greatest contribution was making definite the distinction between homologous and analogous structures. This has been of the first importance in working out the pedigrees of plants as well as animals, though Owen himself took an indeterminate position in regard to organic evolution—a position not unlike that of the great teacher and investigator of zoology in America, Agassiz (1807-1873), but quite different from that of HUXLEY (1825-1895), his famous English contemporary comparative anatomist, who supported the theory vigorously. (Figs. 260, 272, 502, 503.)

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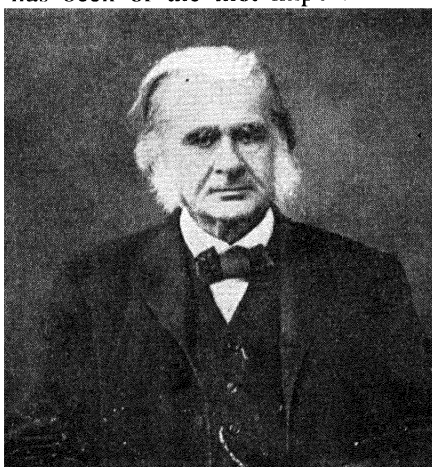


FIG. 502. Thomas Henry Huxley.

PHYSIOLOGY

The functions of organisms were discussed by Aristotle with his usual insight, though with less happy results, since, as might be expected, physiology is more dependent than anatomy upon progress in other branches of science. Galen was similarly hampered in his attempt to make physiology a distinct department of learning, based on a thorough study of anatomy, and the cornerstone of medicine, though fate foisted upon uncritical generations through fifteen centuries his system of human physiology.

Neither Vesalius nor his contemporaries attempted to explain the workings of the body by appeal to physical and chemical laws, and for good reason. Chemistry had not yet thrown off the shackles of alchemy and taken its legitimate place among the elect sciences, it was not until Harvey's lifetime, under the influence of Galileo, that the new physics was born. By the end of the seventeenth century, however, both physics and chemistry, aided by the philosophical systems of Bacon and Descartes, had forced their way into physiology and split it into two schools. The physical school was founded by BORELLI (1608-1679) of Italy, who, employing incisive physical methods, attacked a series of problems with brilliant results; while the chemical school developed from the influence of FRANCISCUS SYLVIVS (1614-1672) of Holland as a teacher rather than as an investigator.

This awakening brought a host of workers into the field, and the harvest of the century was garnered and enriched by HALLER (1708-1777) of Geneva. In a comprehensive treatise which at once indicated the breadth of view and critical judgment of its author, Haller established physiology as a distinct and important branch of biological science. It was no longer a mere adjunct of medicine. Perhaps the most



FIG. 503. Louis Agassiz.

significant advance in Haller's century consisted in setting the physiology of nutrition and of respiration—both of which awaited the work of the chemists—well upon the way toward their modern form.

REAUMUR (1683-1757) of Paris, SPALLANZANI (1729-1799) of Pavia, and BEAUMONT (1785-1853) of Connecticut may be singled out for their exact studies on gastric digestion, which showed "solution" of the food to be the main factor in digestion, although it was not clear how digestive changes differ from ordinary chemical changes. It was left for their successors during the latter half of the nineteenth century to establish the fact that food in passing along the digestive tract runs the gantlet of a series of complex enzyme reactions, each of which has its function in putting the various constituents of the food into such form that they can pass to the various cells of the body where they are actually used. (Fig. 107.)

In regard to respiration, an earlier approach was made toward a true understanding of the process. In France LAVOISIER (1743-1794) demonstrated that the chemical changes taking place in respiration involve essentially a process of combustion, and it chiefly remained for later work to show that this process takes place in the tissues rather than in the lungs. (Fig. 113.)

Most of the firm foundation on which the physiology of animals rests today has been built up by work on vertebrates. Since the middle of the nineteenth century, when the versatile MÜLLER (1801-1858) of Germany emphasized the value of studying the physiology of higher and lower animals alike, there has been an ever-increasing tendency, in so far as possible, to focus evidence from all forms of life on general problems of function. This has culminated in the science of COMPARATIVE PHYSIOLOGY.

The less obvious structural and functional differentiation of plants retarded progress in plant physiology as it did in plant anatomy. Probably of most historical interest, and certainly of most general interest, is the development of our knowledge of the nutrition of green plants. Aristotle's notion that the plant's food is prepared for it in the ground was still prevalent during the seventeenth century when Malpighi, from his studies on plant histology, gave the first hint of supreme importance: the crude "sap" enters by the roots and is carried to the leaves where, by the action of sunlight, evaporation, and some sort of "fermentation," it is elaborated and distributed as food to the plant as a whole. (Fig. 498.)

It is HALES (1667-1761) of England, however, to whom the botanist looks as the Harvey of plant physiology, because in his *Vegetable Staticks* (1727) he laid the foundations of the physiology of plants by making plants speak for themselves through his decisive experiments.

For the first time it became clear that green plants derive a considerable part of their food from the atmosphere, and also that the leaves function actively in the movements of fluids up the stem and in eliminating superfluous water by evaporation. Still the picture was incomplete, and so it remained until the biologist had recourse to further data from the chemist. (Fig. 504.)

In 1779, PRIESTLEY (1733-1804) of England, the discoverer of oxygen, showed that this gas under certain conditions is liberated by plants. This fact was seized upon by a scientist in Holland, INGENHOUZ (1730-1799), who demonstrated that carbon dioxide from the air is reduced to its component elements in the leaf during exposure to sunlight. The plant retains the carbon and returns the oxygen, this process of securing carbon being quite distinct from that of respiration in which carbon dioxide is eliminated. It remained then for DE SAUSSURE (1767-1845) in Geneva to show that, in addition to the fixation of carbon, the elements of water are employed, while from the soil various salts, including combinations of nitrogen, are obtained. However, it was nearly the middle of the last century before the influence and work of LIEBIG (1803-1873) at Giessen led to a clear realization of the fundamental part played by the chlorophyll of the green leaf in making certain chemical elements available to animals. The establishment of the cosmical function of green plants—the link they supply in the circulation of the elements in nature—is an epoch in biological progress. (Figs. 20, 21, 53.)

Perhaps enough has been said to indicate the trend of physiology



FIG. 504. Stephen Hales.

away from the maze of Galenic spirits in which science lost itself, toward the modern viewpoint of science, which assumes as its *working hypothesis* that life phenomena are an expression of a complex interaction of physicochemical laws no different fundamentally from the laws operating in the inorganic world, and that the economy of the organism is in accord with the law of the conservation of energy.

However, it is important to remember that VITALISM—the conception that life phenomena are, in part at least, the resultant of manifestations of matter and energy which transcend and differ intrinsically in kind from those displayed in the inorganic world—has arisen many times in the development of biological thought. This has been either as a reaction against premature conclusions of the rapidly growing science, or as the consequence of an overwhelming appreciation of the staggering complexity of life phenomena. Vitalism attained perhaps its most concrete formulation as a doctrine during the early part of the eighteenth century, in opposition to the obviously inadequate explanations that chemistry and physics could offer for the phenomena of irritability of living matter then prominently engaging the attention of biologists. The vitalists of that period abandoned almost completely all attempts to explain life processes on a physicochemical basis, and assumed that an unknown, mystical, all-controlling hypermechanical force was responsible for all living processes. It is apparent that such an assumption in such a form is a negation of the scientific method, and at once removes the problem from the realm of scientific investigation.

Of course, no biologist at the present time subscribes to vitalism in this form. Some uphold vitalism—if it must still be called vitalism—in its considerably limited modern form, and undoubtedly all will admit that we are at the present time utterly unable to give an adequate explanation of the fundamental life processes in terms of physics and chemistry. “The physical and chemical mechanisms, which we are increasingly learning to know, to understand and to apply in experiment, are to be regarded as mechanisms of control of structure and function on the biological level. Their role has not up to the present been shown to transcend this range. It is therefore fallacious to conclude that the organism is nothing more than a ‘physical-chemical-mechanical conglomerate.’ ” Certainly the twentieth century finds few biologists who really expect a scientific explanation of life ever to be attained or who expect that protoplasm will ever be artificially synthe-

sized. This much, however, is positive: during the past sixty years some biologists have now and then thought they were on the verge of creating life artificially in the test tube, only to leave the problem, like the alchemists of old, with more respect for the complexities of protoplasmic organization and for the imposing gap which separates even the simplest forms of life from the inorganic world. (pp. 31-32; 216-217.)

HISTOLOGY

Studies on the physiology of plants and animals naturally involved the progressive analysis of the physical basis of the phenomena under consideration. However, until the beginning of the eighteenth century, analysis practically remained at the level of the Aristotelian classification of the materials of the body as unorganized substance,



FIG. 506. Theodor Schwann.



FIG. 505. Matthias Jacob Schleiden.

homogeneous parts or tissues, and heterogeneous parts or organs. In fact it was not until the revival of interest in embryology early in the last century that the cell became a particular object of study, and attention began gradually to shift from more or less superficial problems to cell organization. This approach culminated in the investigations of two German biologists, the botanist SCHLEIDEN (1804-1881) and the zoologist SCHWANN (1810-1882), published in 1838 and 1839. Together these studies convinced biologists that all organisms are composed of units,

or cells, which are at once structural entities and the centers of physiological activities. Soon it became clear that the development of animals and plants consists in the multiplication of an initial cell to form the multitude of different kinds of cells which constitute the adult. (Figs. 158, 505, 506.)

Unquestionably the cell concept represents one of the greatest generalizations in biology; it needed



FIG. 507. Max Schultze.

(protoplasm) were recognized as fundamentally the same in all living beings. Indeed, the realization of a common physical basis of life in both plants and animals—a common denominator to which all vital phenomena are reducible—gave content to the term biology and created the science of life in its modern form. (Figs. 14, 507.)

it needed for its consummation only the full realization of the essential identity between the viscid, granular material which zoologists interpreted as the real living matter of animals, and the quite similar material which botanists considered the living substance of plants. This point of view was crystallized about 1865, chiefly by SCHULTZE (1825-1874) of Germany, in the formulation of the protoplasm concept, and thenceforth not only morphological elements (cells) but also the material of which they are composed

EMBRYOLOGY

The cell theory resulted, as has been seen, from combined studies on the adult structure and on the development of plants and animals, and accordingly implies that the science of embryology has a history of its own. As a matter of fact, Aristotle discussed the wonder of the beating heart in the hen's egg after three days' incubation, but there the subject practically rested until FABRICIUS (1537-1619) at Padua, early in the seventeenth century, published a treatise which illustrated the obvious sequence of events within the hen's egg up to the time of hatching. This

beginning was built upon by a pupil of Fabricius, the celebrated Harvey, who added many details of interest, though little progress in embryology was possible without the microscope.

The microscope was first utilized for embryological problems by the versatile MALPIGHI in two treatises published in 1672, and at one step animal development was placed upon a plane so advanced that for over a century it was unappreciated. One conclusion of Malpighi, however, was seized upon by contemporary biologists. Apparently, unbeknown to him, some of the eggs which he studied were slightly incubated, so that he thought traces of the future organism were preformed in the egg. This error contributed to the formulation of the preformation theory, which gradually became the dominant question in embryology.

As a matter of fact, the time was not ripe for theories of development. The preformationists were wrong, but so were Aristotle, Harvey, and later supporters of epigenesis who went to the opposite extreme and denied all egg organization and therefore tried to get something out of nothing. It remained, as we know, for embryologists of the immediate past and present to discover many of the details of the origin and organization of the germ cells, and to reach a level of analysis deep enough to suggest how "the whole future organism is potentially and materially implicit in the fertilized egg cell" and thus that "the preformationist doctrine had a well-concealed kernel of truth within its thick husk of error." (Fig. 508; pp. 274-280.)

Another great advance came in the accurate and comprehensive studies of the Russian, VON BAER (1792-1876), published in the second quarter of the last century. Taking his material from all the chief groups of higher animals, von Baer founded COMPARATIVE EMBRYOL-

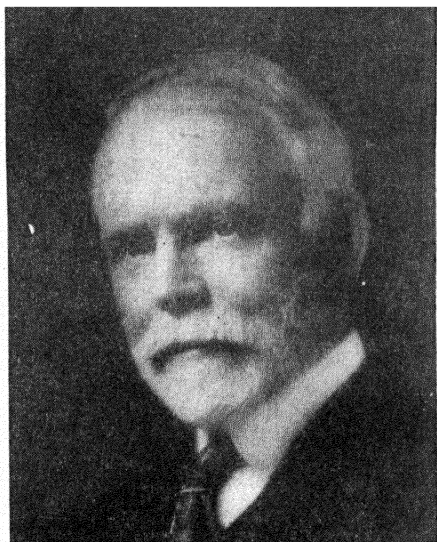


FIG. 508. Edmund Beecher Wilson (1856-1939). The foremost American cytologist of the early twentieth century.

OGY. Among his achievements may be mentioned: the clear discrimination of the chief developmental stages, such as cleavage of the egg, germ layer formation, tissue and organ differentiation; the insistence on the importance of the facts of development for classification; and the discovery of the egg of mammals. His observations on the origin and development of the germ layers, which afforded the key to many



FIG. 509. Karl Ernst von Baer.

general problems of the origin of the body form, and his emphasis on the resemblance of certain embryonic stages of higher and lower animals, were utilized by his successors, under the influence of the evolution theory, as the point of departure for the development of the GERM LAYER THEORY and the RECAPITULATION THEORY. Both were of importance in stimulating research; and although the present generation of biologists has not inherited the earlier implicit faith in the theories, it has profited immensely by the accumulated facts. (Fig. 509; pp. 371-374.)

From every point of view von Baer created an epoch in embryology just when the cell theory began to exert its influence on biological research, and thenceforth it became the problem of the embryologist to interpret development in terms of the cell. It is unnecessary to follow historically the establishment of the fact that the egg and the sperm are really single nucleated cells; that fertilization consists in the fusion of egg and sperm and the orderly arrangement of their chief nuclear contents, or chromosomes; that the new generation *is* the fertilized egg, since every cell of the body as well as every chromosome in every cell is a lineal descendant by division from the zygote, and so from the gametes which united at fertilization to form it. Such, however, are the chief results of cytological study since von Baer. But embryologists have not been content to employ merely the descriptive method, and the dominant note of the most modern research is physiological—the experimental study of the significance of fertilization, the dynamics of

cell division, the basis of differentiation, the influence of environmental stimuli, and so on. CHEMICAL EMBRYOLOGY has emerged. (Figs. 159, 169, 201; pp. 281-282.)

GENETICS

The study of inheritance could be little more than a groping in the dark until embryology, under the influence of the cell theory, afforded a body of facts clearly indicating that typically the fertilized egg is the sole bridge of continuity between successive generations. Indeed, the modern science of genetics has a history largely confined to this century.

Although clearly intimated by a number of workers, the conception of the continuity of the germ plasm was first forced upon the attention of biologists and given precision by WEISMANN (1834-1914) of Germany in a series of essays culminating in 1892 in his volume entitled *The Germ Plasm*. He identified the chromatin material, which constitutes the chromosomes of the cell nucleus, as the specific bearer of hereditary characters, and emphasized a sharp distinction between germ cells and somatic cells. (Figs. --

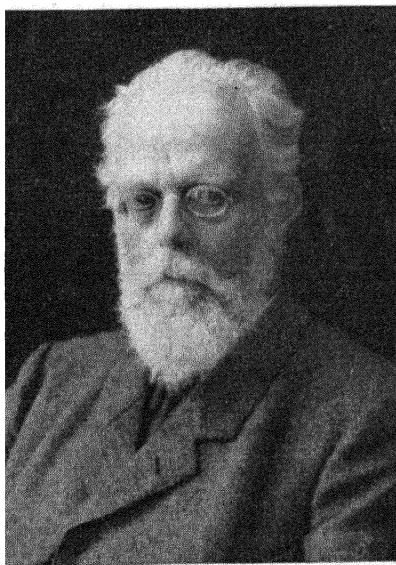


Fig. 510; August Weismann.

While this point of view had been gradually gaining content and precision, the science of genetics had been advancing not only by exact studies on the structure and physiology of the germ cells, but also by statistical studies of the results of heredity, the various characters of animals and plants as exhibited in parents and offspring. The studies of this type which first attracted the attention of biologists were made by GALTON (1822-1911) of England. In the eighties and nineties of the last century, he amassed a great volume of data concerning, for example, the stature of children with reference to that of their parents, and derived his well-known laws of inheritance. (Figs. 229, 279.)

But the work which eventually created the science of genetics was

that of MENDEL (1822-1884) of Brünn, Austria. Mendel combined in a masterly manner the experimental breeding of pedigreed strains of plants and the statistical treatment of the data thus secured in regard to the inheritance of certain characters, such as the form and color of the seeds in peas. His work was published in 1865 in an obscure natu-



ral history periodical, and he abandoned teaching and research to become the Abbot of his monastery. Thus terminated prematurely the scientific career of one of the epoch-makers of biology, and the now famous Mendelian laws of inheritance remained unknown to science until 1900, when other biologists, arriving at similar results, unearthed his thirty-five-year-old paper. (Figs. 230, 511.)

It has already been seen that the fundamental principle of the segregation of the genes during development of the gametes, which Mendel's work indicated, has been

extended to other plants and to animals, and that instead of being, as at first thought, a principle of rather limited application, it appears from the investigations of a host of workers, in particular T. H. Morgan and his school, to be the basis of all inheritance. The present results are extremely convincing, because cytological studies on the architecture of the chromosome complex of the germ cells keep pace with and afford a picture of the physical basis of inheritance—the mechanism by which the segregation and independent assortment of characters by the Mendelian formula take place. Such is the deeply hidden element of truth in the old preformation theories of development. (Figs. 174, 252, 512.)

ORGANIC EVOLUTION

A question which has interested and perplexed thinking men of all times is how things came to be as they are today. The historian of human affairs attempts to trace the sequence and relationship of events from the remote past to the present. Similarly, the geologist endeavors

to formulate the history of the earth; and the biologist, the history of plants and animals on the earth. All recognize that the present is the child of the past and the parent of the future, and that past, present, and future, though causally related, are never the same. It was the Greek natural philosophers who introduced this idea of history into science and attempted to provide a naturalistic explanation of the earth and its inhabitants, and thus started the uniformitarian trend of thought which culminated in the establishment of organic evolution during the past century.

Aristotle says, in substance: Although the line of demarcation is broadly defined, yet nature evolves by ascending steps from one type to another. The first step is that of plants, which, compared with animals, seem inanimate. The second step nature takes is from plants to plant-animals, the zoophytes. The third step is the development of animals, which arise from an increased activity of the vital principle, resulting in sensibility; and with sensibility, desire; and with desire, locomotion. Man is the head of animal creation. To him belongs the God-like nature. He is pre-eminent by thought and volition. But although all are dwarf-like and incomplete in comparison with man, he is only the highest point of one continuous ascent. (Fig. 474.)

Aristotle specifically implies the *scala naturae* concept which attained its highest development during the eighteenth century at the hands of Linnæus. Whether or not Aristotle saw a genetic connection between the terms of the series—which Linnaeus and his contemporaries did not—has, however, been widely debated. If Aristotle were alive today he would probably disclaim having had such an idea but be pleased to have it ascribed to him.

The thread of continuity in uniformitarian thought is not broken



FIG. 512. Thomas Hunt Morgan (1866–1945). The foremost American geneticist for nearly half a century.



FIG. 513. Comte de Buffon.

It is not strange, therefore, that it is often difficult to decide just how much weight should be given to some of his statements. Certainly, however, it is not exaggerating to ascribe to him not only the recognition of the factors of geographical isolation, struggle for existence, artificial and natural selection in the origin of species, but also the propounding of a theory of the origin of variations—that the direct action of the environment brings about modifications in the structure of animals and plants and that these modifications are transmitted to the offspring. (Fig. 513.)

When Buffon's influence had passed its height, ERASMUS DARWIN (1731-1802), grandfather of Charles Darwin, expressed consistent views on the evolution of organisms, in several volumes of prose and poetry, which lead biologists today to recognize him as the anticipator of the Lamarckian

from the Greeks to the present, but from the strictly biological standpoint two Frenchmen, Buffon and Lamarck, and two Englishmen, Erasmus Darwin and his grandson, Charles Darwin, are pre-eminent.

BUFFON (1707-1788) was a peculiarly happy combination of entertainer and scientist, who found expression in each new volume of his great *Natural History*. It was largely between the lines of this work, so to speak, that Buffon's evolutionary ideas were advanced—apparently beyond the reach of the censor and dilettante.



FIG. 514. Erasmus Darwin.

doctrine that somatic variations arise through the reaction of the organism to environmental conditions. "All animals undergo transformations which are in part by their own exertions, in response to pleasures and pain, and many of these acquired forms or propensities are transmitted to their posterity." (Fig. 514.)

LAMARCK (1744-1829) developed with great care the first complete and logical theory of organic evolution and is the one outstanding figure in biological uniformitarian thought between Aristotle and Charles Darwin. "For nature," he writes, "time is nothing. For all the evolution of the earth and of living beings, nature needs but three elements, space, time, and matter." In regard to the factors of evolution, Lamarck put emphasis on the indirect action of the environment as applied to animals, and on the direct action of environment in the case of plants. Animals are, as it were, induced to react and so adapt themselves; whereas plants, lacking a nervous system, are molded directly by their surroundings. The resulting acquired characteristics were believed by Lamarck to be transmitted to the next generation and in this way to bring about the evolution of organisms. (Fig. 515; p. 379.)

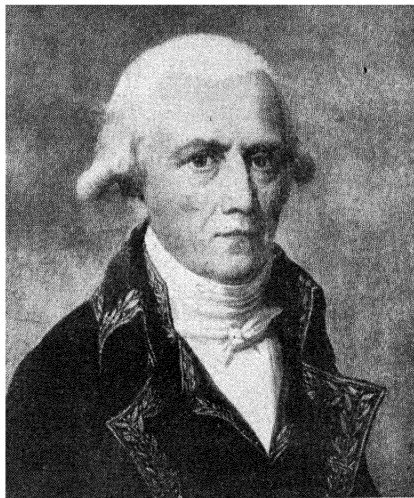


FIG. 515. Chevalier de Lamarck.

Through the relative weakness of Lamarck's successors the French school of evolutionists dwindled to practical extinction; while in Germany, GOETHE (1749-1832), the greatest poet of evolution, and TREVIRANUS (1776-1837) "brilliantly carried the argument without carrying conviction," for the man and the moment must agree. Then in England the uniformitarian ideas elaborated by LYELL (1797-1875) in his *Principles of Geology* established evolution in that field. Thus the way was paved for CHARLES DARWIN (1809-1882) to do the same for the organic world. (Fig. 517.)

True, "the idea of development saturated the intellectual atmosphere—nevertheless the elaborate and toilsome labor of thinking it through for the endless realm of nature was to be done"—and Darwin

did it in his *Origin of Species*, which appeared in 1859. By his brilliant, scholarly, open-minded, and cautious marshaling of the facts pointing toward the universality of variations and the mutability of species, and by the theory of natural selection on the basis of slight adaptive variations resulting in the survival of the fittest in the struggle for existence—which, strange to say, Darwin and WALLACE (1822-1913) reached

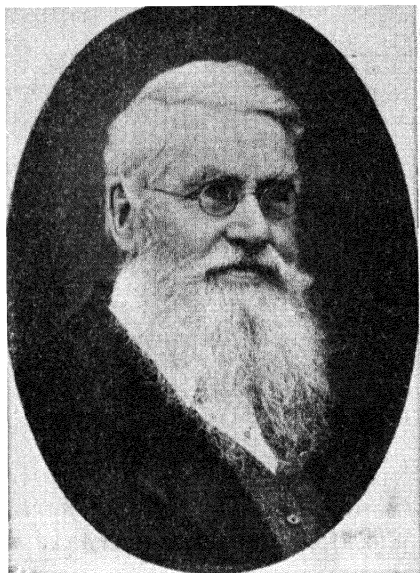


FIG. 516. Alfred Russel Wallace.

simultaneously and independently—Darwin made current intellectual coin out of the old idea and indicated with brilliant intellectual vision the setting of the evolutionary drama. (Figs. 274, 441, 475, 516; pp. 380-384.)

Today biologists do not question the fact of evolution—"evolution knows only one heresy, the denial of continuity"—though in regard to the relative importance of the various factors involved, there is much difference of opinion. It is possible, of course, that there will be reason to depart rather widely from Darwin's interpretation of the effective principles at work in the origin of species.

but this will have little influence on Darwin's position in the history of biology. The great value which he placed upon facts was exceeded only by his demonstration that this "value is due to their power of guiding the mind to a further discovery of principles." The *Origin of Species* brought biology into line with the other inductive sciences, recast practically all of its problems, and instituted new ones. Darwin beautifully and conservatively expressed this new outlook on nature in the historically important concluding paragraph of his epoch-making work:

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a

manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the conditions of life, and from use and disuse; a Ratio of Increase so high as to lead to a Struggle for Life,

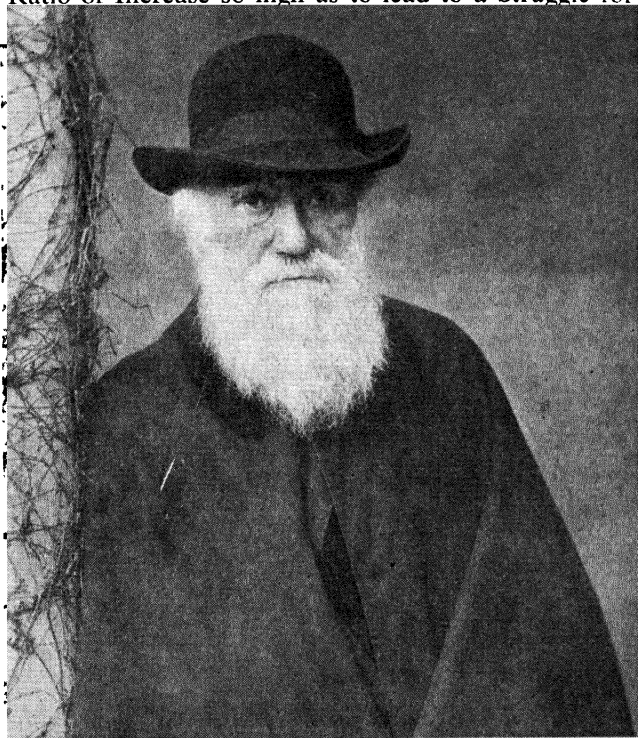


FIG. 517. Charles Darwin.

and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved."

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II. Glossary

ABIOTENESIS. The abandoned idea that living matter may arise at the present time from nonliving matter without the influence of the former. *See* Biogenesis.

ABSORPTION. In biology, the passage of nutritive and other fluids into living cells.

ACETYLCHOLINE. Temporary chemical mediator between endings of nerve fibers and muscles for muscle contraction. It may be quickly destroyed by a specific enzyme, cholinesterase, to bring about muscle relaxation.

ACID. A sour-tasting substance, such as HCl, which yields hydrogen ions on dissociation. Hydrogen is replaceable by a metal to form a salt.

ACOELOMATE. Not possessing a coelom, or body cavity, e.g., hydra.

ACQUIRED CHARACTER. A modification of the body which arises during individual life as a result of environmental influences.

ACTION CURRENT. An electric current, as in a nerve impulse, which passes from one region (excitation region) to an unexcited region.

ADAPTATION. The reciprocal fitness of organism and environment; a structure or reaction fitted for a special environment; the process by which an organism becomes fitted to its surroundings.

ADRENAL GLANDS. Ductless glands situated near the kidneys. Secretion supplies the hormones adrenaline and cortin.

ADSORPTION. The accumulation of a substance, as in catalysis, at the surface of the catalytic agent.

ADVENTITIOUS. Not in the usual position, e.g., aerial roots.

AEROBE. An organism requiring free oxygen. *See* Anaerobe.

AFFERENT FIBER. A sensory nerve fiber carrying impulses to the central nervous system from a receptor.

AFFERENT ROOT. Dorsal, or posterior, root of certain cranial and all spinal nerves through which sensory nerve impulses enter the brain and spinal cord. *See* Efferent Root.

ALBINO. An individual lacking normal pigmentation, e.g., a white rat. Albinism behaves as a typical Mendelian recessive character.

ALGAE. A heterogeneous group of lower plants in which the body is unicellular or consists of a thallus, e.g., Protococcus, Spirogyra, seaweeds.

ALLANTOIS. An embryonic membrane of higher vertebrates, chiefly respiratory in function.

ALLELES. Homologous genes, similarly situated on homologous chromosomes. Allelomorphs.

ALTERNATION OF GENERATIONS. Typically the alternate succession of a sexual and an asexual generation in the life history, e.g., moss, Obelia.

ALTERNATIVE INHERITANCE. *See* Dominant Character.

AMINO ACID. Components of proteins. Organic acids in which one hydrogen atom is replaced by the amino group (NH₂).

- AMNION.** A delicate membrane enclosing the developing embryos of reptiles, birds, and mammals.
- AMOEBOID.** Usually applied to the flowing movements of a cell, as in amoeba and white blood cells.
- AMPHIMIXIS.** The mingling of the germ plasma of two gametes in the zygote.
- AMYLOPSIN.** A starch-digesting enzyme secreted by the pancreas. Changes starch to maltose, the same chemical reaction as carried on by ptyalin in the saliva.
- ANABOLISM.** The constructive phase of metabolism. *See* Katabolism.
- ANAEROBE.** An organism not requiring free oxygen, e.g., certain bacteria and parasitic worms. *See* Aerobe.
- ANALOGY.** Structural resemblance, usually superficial, due to similarity of functions, e.g., wing of butterfly and bird. *See* Homology.
- ANAPHASE.** Period in mitosis involving the separation of the halves of the longitudinal split chromosomes, and the migration of the daughter chromosomes toward the respective centrosomes. *See* Telophase.
- ANATOMY.** The structure of organisms, especially as revealed by dissection. *See* Morphology.
- ANTENNAE.** A pair of appendages of the arthropod head, sensory in function.
- ANTHER.** The part of the stamen which contains the pollen sacs (microsporangia) in flowering plants.
- ANTHRIDIUM.** The organ in plants, such as mosses and ferns, in which the sperm arises.
- ANTIBIOTICS.** The various extracts, such as penicillin, streptomycin, aureomycin, and terramycin, secured from molds and other organisms, and now employed against infections in man.
- ANUS.** Terminal orifice of the alimentary canal. Opening of the large intestine either on the surface of the body (man) or into the cloaca (frog).
- AORTA.** A great trunk artery. *See* Dorsal Aorta.
- AORTIC ARCHES.** Arteries arising from the ventral aorta and supplying the gills in aquatic vertebrates. Undergo many modifications in the ascending series of air-breathing vertebrates.
- APHIDS.** Small sucking insects, e.g., the green plant lice of garden shrubs.
- ARCHEGONIUM.** The organ in plants, such as the mosses and ferns, in which the egg arises.
- ARTERY.** A blood vessel carrying blood away from the heart.
- ASEXUAL REPRODUCTION.** Any method of reproduction without fertilization and involving uniparental inheritance only.
- ASSIMILATION.** Nutritive materials are assimilated by the cells and used to produce new protoplasm or to provide energy reserves.
- ASSOCIATIVE MEMORY.** Representative cerebral activity of the higher animals and man, exclusive of reason which presumably is confined to the latter.
- ASTER.** Radiations surrounding the centrosome during cell division.
- ATOM.** An elementary particle of an element which enters into chemical reactions with atoms of other elements, or it may exist individually or in combination with other atoms of the source element.
- AUTOGAMY.** Origin and union of gametic nuclei in one and the same cell. A type of self-fertilization, e.g., in *Paramecium*. *See* Endomixis.
- AUTONOMIC SYSTEM.** System of outlying ganglia and nerves which communicates with the central nervous system through the spinal and cranial nerves. Regulates nearly all the involuntary functions of the body. Sympathetic nervous system.

- AUTOSOMES.** All of the chromosomes except the sex chromosomes (X and Y).
- AUTOTROPHIC.** Having the power to synthesize food from inorganic substances. Green plants secure the necessary energy from light, and certain bacteria by the oxidation of inorganic substances. *See* Holozoic.
- AUXIN.** Plant hormones associated with cell growth.
- AXON.** A nerve fiber conducting impulses away from the cell body. Dendrons conduct toward the nerve cell body, or cyton. *See* Neuron.
- BACKCROSS.** Mating a dominant with a recessive to determine the genotype of the former.
- BACTERIOPHAGE.** A filterable virus which parasitizes bacteria cells.
- BASE.** A substance, such as sodium hydroxide (NaOH), which yields hydroxyl ions on dissociation and reacts with an acid to produce a salt.
- BIENNIAL.** A plant which completes its life history in two years, usually reproducing in the second.
- BILL DUCT.** Tube which conveys the secretions (bile) of the liver to the small intestine. Usually unites with the pancreatic duct to form a common duct which enters the intestine.
- BINARY FISSION.** The division of a cell, especially a unicellular organism, into two daughter cells, e.g., in *Paramecium*.
- BINOMIAL NOMENCLATURE.** Scientific method of designating organisms by two Latin or Latinized words, the first indicating the genus and the other, the species, e.g., the dog, *Canis familiaris*; man, *Homo sapiens*.
- BIOGENESIS.** The established doctrine that all life arises from pre-existing living matter. *See* Abiogenesis.
- BIOGENETIC LAW.** *See* Recapitulation Theory.
- BIOLOGY.** Study of matter in the living state, and its manifestations.
- BIOSPHERE.** The area in which life exists.
- BIPARENTAL.** Involving two progenitors, male and female.
- BIRAMOUS.** Comprising two branching parts, e.g., abdominal appendages (swimmerets) of the crayfish.
- BLASTOCOEL.** The cavity within the blastula. Segmentation cavity.
- BLASTOPORE.** The opening to the exterior from the enteric pouch of a gastrula.
- BLASTOSTYLE.** Central axis of an individual (gonangium) of a hydroid colony that buds medusae, e.g., in *Obelia*.
- BLASTULA.** The stage following cleavage when the cells of an embryo are arranged in a single layer to form a hollow sphere.
- BLINDING INHERITANCE.** Apparent fusion of parental characters in the offspring, e.g., skin color of mulattoes.
- BLOOD CELLS.** Detached cells present in the fluid plasma of the blood. Two principal kinds in vertebrates, red and white. Blood corpuscles.
- BROWNIAN MOVEMENT.** The continuous oscillatory random movements of microscopic particles dispersed in a continuous medium, as in a colloid. Movements are believed to be due to a bombardment of the particles by molecules of the medium.
- BUCCAL CAVITY.** Mouth cavity.
- BUD.** Growing point of shoot. An undeveloped branch. Branch buds form stem and leaves; mixed buds, both leaves and flowers; flower buds, flowers only.
- BUDDING.** A method of asexual reproduction by the formation and release of a small portion, or bud, of the parent organism.
- BULB.** An underground, storage leaf bud. *See* Corm.

- CALCIFEROUS GLANDS.** Glands opening into the esophagus of the earthworm and secreting calcium carbonate, probably to neutralize acidity of food.
- CALORIE.** The unit of heat energy, and therefore largely of food value. Heat required to raise 1000 grams of water 1° C. Large Caloric.
- CALYX.** The outer whorl of modified leaves composing a typical flower. Usually green. The sepals collectively.
- CAMBIAL.** Actively dividing cells usually situated between xylem and phloem of vascular bundles.
- CAPILLARIES.** Microscopic, thin-walled blood vessels. The thin capillary walls permit exchange of materials between blood and surrounding tissue cells.
- CARBOHYDRATES.** Compounds of carbon with hydrogen and oxygen, the hydrogen and oxygen typically in the same proportion as in water.
- CARDINAL VEINS.** Pair of large veins returning blood from posterior part of body, e.g., in the dogfish.
- CARPEL.** One of the innermost whorl of floral leaves which bear the megasporangia. A megasporophyll. Composed of ovule case (ovary), style, and stigma. A simple pistil or one element of a compound pistil.
- CARPILLATE.** Having carpels. Commonly refers to a flower without stamens. Pistillate. *See* Staminate.
- CASTRATION.** Removal of the gonads, especially of the male.
- CATALYSIS.** The inducing or accelerating of a chemical reaction by a substance (e.g., an enzyme) which itself remains unchanged.
- CATALYST.** A substance, such as an enzyme, which modifies the rate of chemical reaction without itself being changed in the process.
- CELL.** A structural and physiological unit mass of protoplasm, differentiated into cytoplasm and nucleus. The smallest unit of protoplasm capable of continued independent life.
- CELL SAP.** Water, with solutes, usually under pressure in a large vacuole in the cytoplasm of certain types of plant cells. Effects cell turgor.
- CELLULOSE.** A carbohydrate which characteristically forms the walls of plant cells.
- CENTROLECIHAL EGG.** An egg with a large amount of yolk concentrated near the center of the egg mass.
- CENTROSOME.** A body, enclosing a minute granule, or centriole, situated in the center of the aster and active during cell division of animal cells.
- CEPHALIZATION.** The concentration of sensory and other elements of the nervous system at the anterior, or head, end of animals, as in the vertebrates, particularly in man.
- CHELIPEDS.** The first thoracic appendages, or walking legs, of the crayfish and its allies. The pincers.
- CHEMICAL AFFINITY.** The force of attraction between elements which causes them to combine with each other to form a new compound, as in the union of hydrogen and oxygen to form water (H₂O).
- CHEMICAL REACTION.** A chemical change, or interaction, between two or more chemical substances, involving a recombination of the constituent atoms into different kinds of molecules.
- CHEMOTROPISM.** Oriented responses to chemical substances by plants and animals.
- CHLORAGOGEN CELLS.** Outer layer of intestine and central region of typhlosole of earthworm. Probably excretory in function.
- CHLORENCYMA.** Chlorophyll-bearing tissue, chiefly of the leaf.

- CHLOROPHYLL.** The characteristic green coloring matter of plants, by which photosynthesis takes place. Comprises two similar but distinct pigments.
- CHLOROPLASTS.** The special cytoplasmic bodies containing chlorophyll.
- CHOLESTEROL.** A complex monohydric alcohol of the lipid series. Closely related to vitamin D, certain hormones, and experimental cancer-producing substances. *See* Lipids.
- CHOLINESTERASE.** *See* Acetylcholine.
- CHORDATE.** An animal whose primary axial skeleton consists temporarily or permanently of a notochord. All vertebrates are chordates, but the lowest chordates are not vertebrates.
- CHORION.** Outer embryonic membrane of reptiles, birds, and mammals.
- CHROMATIN.** A deeply staining substance containing nucleic acid, characteristic of the nucleus and forming chromosomes, etc. *See* Germ Plasm.
- CHROMIDIA.** Scattered chromatin granules in certain cells, such as bacteria, which lack differentiation into nucleus and cytoplasm.
- CHROMOSOME.** One of the deeply staining bodies into which the chromatin of the nucleus becomes visibly resolved during mitosis. A linkage group of genes, or nucleoprotein molecules, arranged in a linear series. *See* Gene, Germ Plasm.
- CILIA.** Delicate protoplasmic projections from a cell, which lash in unison and propel the cell in the water (e.g., *Paramecium*), or move particles over the cell surface, e.g., cells lining various tubes in multicellular forms.
- CLASS.** In classification, a main subdivision of a phylum. *See* Order.
- CLLAVAGE.** Cell divisions which transform the egg into the blastula stage during development.
- CLOACA.** A cavity at the posterior end of the vertebrate body, into which the intestine, urinary, and reproductive ducts open. Not present in most mammals.
- COCHLEA.** The portion of the ear, in communication with the sacculus, which is the essential organ of hearing in the higher vertebrates.
- COELOM.** The body cavity, enclosed by tissue of mesodermal origin.
- COELOMAIL.** Possessing a coelom, or body cavity, as in animals above the coelenterates.
- COELOMIC EPITHELIUM.** *See* Peritoneum.
- COLNOSARC.** Tissue of the tubular branches of a hydroid, e.g., *Obelia*.
- COLLAR CELLS.** Cells with cytoplasmic flange, or collar, surrounding the base of the flagellum. Represented by certain Protozoa, and in the gastral epithelium of sponges.
- COLLOID.** A state of matter in which a substance is finely divided into particles larger than one molecule and dispersed in another continuous substance.
- COLONIAL ORGANISM.** An association of cells, as in *Volvox*, alike in structure and function, except for reproduction.
- COLONY.** An aggregation, or intimate association of several or many individuals to form a superior unit, e.g., *Volvox*, *Obelia*, beehive.
- COMPOUND.** A substance with only one variety of molecules, and consisting of atoms from two or more elements. all chemically combined in definite proportions, as in water (H_2O).
- COMMENSALISM.** Association of two or more individuals of different species. Essentially beneficial to participants.
- COMPOUND EYE.** One composed of numerous facets, or separate visual elements. Affords mosaic vision, e.g., eye of crayfish and locust.
- CONJUGATION.** Union (usually temporary) of two cells, resulting in fertilization, e.g., in *Paramecium*. *See* Endomixis and Autogamy.

- CONSERVATION OF ENERGY.** The law that the total energy of the universe is constant, none being created or destroyed but merely transformed from one form to another.
- CONTRACTILE VACUOLE.** A reservoir in unicellular organisms (e.g., *Paramecium*) in which water and waste products of metabolism collect and are periodically expelled to the exterior.
- COORDINATION.** The control of various parts and processes of an organism to produce harmonious responses.
- CORM.** A solid bulblike expansion of a plant stem below the surface of the ground, for food storage. *See* Bulb.
- COROLLA.** The whorl of modified leaves immediately within the calyx of a flower. The petals collectively.
- CORTEX.** The cylinder between the outer and central cylinders in root and stem of the higher plants. Part of the vertebrate brain.
- COTYLEDON.** A seed leaf. The first leaf (in monocotyledons) or pair of leaves (in dicotyledons) of the young sporophyte within the seed.
- COWPER'S GLAND.** Small ovoid body associated with the prostate gland and urethra in male mammals.
- CRANIAL NERVES.** Nerves which arise from the brain.
- CRANIUM.** The protective case enclosing the brain.
- CREATININE.** A nitrogenous waste product. Present in small quantity in human urine.
- CRETIN.** A defective individual, due to a deficiency of thyroid secretion.
- CROSSING OVER.** The exchange of homologous genes during synapsis of chromosomes. *See* Alleles.
- CRURA CEREBRI.** Thickenings of ventral surface of midbrain.
- CRYPTOGAMS.** Plants without flowers, e.g., thallophytes, mosses, and ferns. *See* Phanerogams.
- CUTANEOUS.** Pertaining to the skin.
- CUTICLE.** The outermost lifeless layer of organisms. *See* Epidermis.
- CYST.** A resistant envelope formed about an organism (e.g., many Protozoa) during unfavorable conditions or reproduction.
- CYTOLOGY.** The science of cell structure and function.
- CYTOPLASM.** Protoplasm of a cell exclusive of nucleus. Cytosome.
- DARWINISM.** Charles Darwin's theory of natural selection. Erroneously used as synonymous with organic evolution.
- DEATH.** Cessation of life activities and destruction of essential protoplasmic structure. Irreversible.
- DECAY.** Chemical decomposition involving putrefaction or fermentation. *See* Putrefaction.
- DENDRON.** *See* Axon.
- DENITRIFYING BACTERIA.** Types of bacteria which break down compounds of nitrogen and set free the nitrogen to the atmosphere.
- DERMAL.** Pertaining to the skin. The dermis is the inner layer of the vertebrate skin. *See* Epidermis.
- DICOTYLEDONS.** One of the two great groups of the familiar flowering plants, a characteristic of which is the presence of two seed leaves, or cotyledons. Contrasted with the monocotyledons having one seed leaf. *See* Cotyledon.
- DIFFERENTIATION.** A transformation from relative homogeneity to heterogeneity, involving the production of specific substances or parts from a general substance or part. Specialization.

DIFFUSION. Intermingling of two substances due to migration of their molecules. Pressure exerted by molecules diffusing through a semipermeable membrane is osmotic pressure. *See* Osmosis.

DIGESTION. Chemical simplification of food so that it can be absorbed and utilized.

DIHYBRID. Progeny of parents differing in two given characters.

DIOECIOUS. A type of organism in which the male and female gametes are produced in separate individuals, as in vertebrate animals. *See* Hermaphrodite

DIPLOID. Having two complete sets of homologous chromosomes. Typical somatic number in animals and the sporophyte generation of plants. *See* Haploid.

DISACCHARIDE. A double sugar, such as cane sugar, or sucrose. Each molecule can be hydrolyzed to form two monosaccharide molecules. Thus in digestion sucrose forms a molecule of glucose (dextrose) and fructose (levulose).

DISPERSION. A mixture in which one or more substances are distributed, or dispersed, throughout another substance, the continuous medium.

DIVISION OF LABOR. Allocation of special functions to special parts which cooperate toward the unity of the whole.

DOMINANT CHARACTER. One of a pair of alternative characters, represented by homologous genes, which appears in the phenotype to the exclusion of the other (recessive) character when both are present in the genotype.

DORSAL AORTA. Chief artery distributing pure blood to the body. Ventral aorta carries blood from heart to gill arteries in fishes.

DUCTLESS GLAND. An organ whose function is to elaborate and secrete a hormone directly into the blood. An endocrine gland.

ECOLOGY. The study of the relations of the organism to environing conditions, organic and inorganic.

ECTODERM. The primary tissue comprising the surface layer of cells in the gastrula. *See* Germ Layer.

ECTOPLASM. Modified surface layer of cytoplasm of a cell. *See* Endoplasm.

EFFECTOR. A structure designed to initiate a definite response to a stimulus, as in a muscle or gland.

EFFERENT ROOT. Ventral, or anterior, root of certain cranial and all spinal nerves through which motor nerve impulses leave the brain and spinal cord. *See* Afferent Root.

EGESTION. The elimination of indigestible solids from the alimentary canal. *See* Excretion.

ELECTROLYTE. A substance in solution which will carry an electric current and whose molecules break up into ions, such as HCl which forms hydrogen ions and chlorine ions.

ELECTRON. An elementary negatively charged particle in an atom. The simplest atom, hydrogen, consists of one electron and one proton.

ELEMENT. A substance built of one kind of atom, such as carbon, hydrogen, oxygen, nitrogen, sulfur, etc. 92 natural elements are established.

EMBRYO. An immature organism before hatching from the egg. In mammals, the fetus before birth.

EMBRYOLOGY. Study of the early developmental stages, or embryos, of organisms.

EMULSION. A mixture of droplets of one liquid dispersed through another liquid.

ENCYSTMENT. The formation of a resistant covering, or cyst wall, about an organism, e.g., *Euglena*. *See* Cyst.

- ENDOCRINE GLAND.** One which secretes a hormone. *See* Ductless Gland.
- ENDODERM.** The primary tissue comprising the inner layer of cells in the gastrula, and in subsequent stages forming the lining of the essential parts of the digestive tract and its derivatives. *See* Germ Layer.
- ENDOMIXIS.** A nuclear reorganization process in some Protozoa (e.g., *Paramecium*) which does not involve the cooperation of two cells (as in conjugation) or synkaryon formation (as in both conjugation and autogamy).
- ENDOPLASM.** The inner cytoplasm surrounding the nucleus, e.g., in amoeba, *Paramecium*. *See* Ectoplasm.
- ENDOPODITE.** The inner of the two distal parts of the typical biramous crustacean appendage. *See* Protopodite and Exopodite.
- ENDOSKELETON.** An internal living skeleton affording support and protection, as well as levers for the attachment of muscles. Characteristic of vertebrates.
- ENDOSPLRM.** A tissue, containing food materials, within a seed.
- ENERGY.** The capacity for doing work. Energy is available as energy of motion (kinetic energy) or as energy of position or stress (potential energy). These are convertible, and the work done during transformation is a measure of energy. (*See* Conservation of Energy.)
- ENTERON.** Digestive, or enteric, cavity lined with endoderm, also the enteric pouch forming its wall, e.g., in hydra.
- ENVIRONMENT.** The external surroundings of an organism or the relations with other organisms, as in biotic environment.
- ENZYMES.** Special proteins which bring about by catalytic action many of the chemical processes of the body, e.g., digestion. *See* Catalysis.
- EPICOTYL.** In seed plants, the portion of the stem above the attachment of the embryonic leaves, or cotyledons. The growing point.
- EPIDERMIS.** The outer layer, e.g., of skin or leaf.
- EPIGENESIS.** Development from absolute or relative simplicity to complexity. *See* Preformation.
- EPITHELIUM.** A layer of cells covering an external or internal surface, including the essential secreting cells of glands.
- EQUATORIAL PLATE.** The equator of the spindle with its group of chromosomes during the metaphase and early anaphase of mitosis. *See* Metaphase.
- ESOPHAGUS.** Tubular passage from pharynx to stomach.
- EUGENICS.** The system of improving the human race by breeding the best. "The science of being well born." *See* Euthenics.
- EUSTACHIAN TUBE.** Passage connecting the vertebrate middle ear with the pharynx. Remnant of the most anterior gill slit, represented in present-day sharks by the blowhole, or spiracle.
- EUTHENICS.** The system aiming at improving the human race by good environment. *See* Eugenics.
- EVOLUTION, ORGANIC.** Present-day organisms are the result of descent with change from those of the past.
- EXCRETION.** The elimination of waste products of metabolism. A waste product. *See* Secretion.
- EXOPODITE.** The outer of the two distal parts of the typical, biramous, Crustacean appendage. *See* Protopodite and Endopodite.
- EXOSKELETON.** A nonliving external skeleton chiefly for protection. The characteristic skeleton of invertebrates, e.g., crayfish, but also represented in vertebrates, as in scales, hair and feathers. *See* Endoskeleton.
- EXTERNAL RECEPTORS.** Sense organs upon the surface of the body. *See* Internal Receptors.

EXTRACELLULAR DIGESTION. Digestion by the secretion of enzymes into a digestive cavity, e.g., in earthworm and man. *See* Intracellular Digestion.

FAMILY. In classification, a main subdivision of an order. *See* Genus.

FATS. One of the chief groups of foodstuffs. Compounds (esters) of glycerol with a fatty acid, e.g., mutton tallow is chiefly the fat stearin ($C_{57}H_{110}O_2$), a combination of glycerol and stearic acid. More oxidizable than carbohydrates. *See* Lipids.

FERMENTATION. The transformation of carbohydrates by the activity of ferments, or enzymes, derived from living organisms. *See* Putrefaction.

FERTILE. An organism capable of reproduction.

FERTILIZATION. The union of male and female gametes, especially their nuclei, by which the chromatin complex of each is arranged to form the composite nucleus (syngaryon) of the zygote.

FETUS. An embryo of a vertebrate, in egg or uterus.

FISSION. Division of an organism into two or more equal or nearly equal parts: asexual reproduction; binary fission in unicellular forms.

FLAGELLUM. A whiplike extension of the cytoplasm which either effects the locomotion of the cell, e.g., in *Euglena*, or aids in nutrition, etc., e.g., in sponges.

FLORAL ENVELOPE. The outer whorls of flower parts, calyx and corolla, not directly concerned in reproduction.

FLOWER. A group of sporophylls and accessory structures.

FLUCTUATIONS. Relatively slight variations, usually forming a finely graded series, always found in organisms; may be either modifications or recombinations, but usually the former.

FOOD. Materials which yield energy for the activities of an organism or which supply essential elements for growth: usually consist of complex carbon compounds.

FROND. Fern leaf, usually both vegetative and spore-producing.

FRUIT. The ripened ovule case (ovary) and contents, together with any structures which by adhesion become an integral part of it.

FUEL VALUE. In organisms, the energy values of oxidized substances, usually expressed in Calories per kilogram.

FUNGI. Colorless plants; e.g., bacteria, yeast, mushrooms.

GALL BLADDER. Receptacle near the liver for the temporary storage of bile.

GAMETANGIUM. A gamete-producing organ, especially in the lower plants.

GAMETE. A cell which unites with another at fertilization to form a zygote. Egg or sperm.

GAMETIC NUCLEI. Nuclei of gametes that unite to form the syngaryon, or nucleus of the zygote.

GAMETOPHYTE. The sexual, gamete-bearing generation in plants.

GANGLION. A group of nerve cells, chiefly the cell bodies, with supporting cells.

GASTRIC VACUOLE. A droplet of fluid enclosing ingested food, in which digestion occurs, e.g., in amoeba and *Paramecium*.

GASTROLITHS. Calcareous bodies found at certain times in the lateral walls of the stomach of the crayfish. Probably represent the storage of material for the exoskeleton.

GASTRULA. A stage in animal development in which the embryo consists of a two-layered sac, ectoderm and endoderm, enclosing the enteric cavity which opens to the exterior by the blastopore.

GEL. A solid or semi-solid state, as in a colloid. The coagulation of blood changes liquid plasma (sol) into a gel.

GEMMULE. An asexual reproductive body liberated by certain sponges.

GENE. Independently heritable factor in the chromosomes which influences the development of one or more characters of the organism. A nucleoprotein. *See* Chromosomes.

GENETICS. The science of heredity.

GENOTYPE. The fundamental hereditary constitution, or gene complex, of an organism or group of organisms. *See* Phenotype.

GENUS. A taxonomic group consisting of one or more species: a main division of a family. *See* Species.

GEOTROPISM. Oriented response in an energy field due to the force of gravity.

GERMINAL CONTINUITY. The concept of an unbroken stream of germ plasma from the beginning of life, from which each generation is derived.

GERM LAYER. A primary tissue (ectoderm, endoderm, or mesoderm) in the embryo from which the tissues and organs of the adult animal develop by further differentiation.

GERM LAYER THEORY. The doctrine that the germ layers are fundamentally similar throughout the Metazoa, and that homologous structures in various animals are derived during development from the same germ layer.

GERM PLASM. The physical basis of inheritance. The chromatin (genes) which forms the specific bond of continuity between parent and offspring. Contrasted with soma or somatoplasm. *Germ.*

GERONTOLOGY. *See* Senescence.

GILL SLITS. Paired lateral openings leading from the anterior end of the alimentary canal to the exterior for the exit of the respiratory current of water. Permanent or embryonic characters of vertebrates. Branchial clefts.

GLAND. One cell or a group of many epithelial cells which elaborate materials and secrete the product for the use of the organism.

GLOCHIDIUM. A bivalved larva of certain fresh-water mussels (clams), that lives temporarily as a parasite on a fish.

GLOTTIS. The opening from the pharynx into the tube (trachea) leading to the lungs.

GLUCOSE. The chief fuel or nutritive substance used to supply energy for most organisms. A monosaccharide, $C_6H_{12}O_6$.

GLYCOGEN. So-called animal starch. Sugar is stored as glycogen in liver and muscle cells.

GOLGI BODIES. Formed elements in the cytoplasm; apparently active chemically.

GONAD. Ovary or testis.

GONOTHECA. Transparent sheath, or exoskeleton, of the reproductive individuals (gonangia) of a hydroid colony, e.g., *Obelia*.

GRAY CRESCENT. Localized pigment granules below the organizer region in the egg of the frog. *See* Organizer.

GUARD CELLS. A pair of cells which open and close a stoma, as in leaves of plants.

GUSTATORY. Relating to the sense of taste.

HABITAT. Suitable environmental area of an organism.

HALTERES. A pair of rudimentary, club-shaped balancers in dipteran insects. Remnants of second pair of wings.

HAPLOID. The reduced (one-half) number of chromosomes. A complete single set of chromosomes. *See* Diploid.

HEMOCOEL. Modification of portion of a body cavity to serve with vascular system.

HEMOGLOBIN. Complex chemical compound, in the red blood cells, which enters into a loose combination with oxygen, becoming oxyhemoglobin.

HEPATIC PORTAL SYSTEM. Food-laden blood, with lowered oxygen content, from digestive tract passes to the liver by the hepatic portal vein. Oxygenated blood reaches liver by the hepatic artery. Both leave by hepatic vein. Thus there is a double blood supply to liver in all vertebrates.

HEREDITY. The transmission of characters from parent to offspring by the germ cells.

HERMAPHRODITE. An organism bearing both male and female reproductive organs, e.g., earthworm. Monoecious. *See* Dioecious.

HETEROSPORY. The condition of producing two kinds of spores, megaspores and microspores, as in the higher plants.

HETEROTROPHIC. A type of nutrition which requires complex organic compounds, as in animals and colorless plants.

HETEROZYGOUS. Hybrid. Formed by gametes dissimilar in regard to a given character, or characters, and producing gametes dissimilar in regard to the character, or characters, in question. *See* Homozygous.

HISTOLOGY. The science of animal and plant tissues. Microscopic anatomy.

HOIOPHYTIC. Type of autotrophic nutrition as in green plants, involving the intake of the simple inorganic compounds, water and carbon dioxide, and the formation of complex organic compounds by photosynthesis.

HOLOZOIC. Type of nutrition involving the ingestion of solid food. Characteristic of animals. *See* Autotrophic and Saprophytic.

HOMOLECITHAL. Even distribution of a relatively small amount of yolk in an egg.

HOMOLOGOUS CHROMOSOMES. The members of a pair of chromosomes of a diploid group, one paternal and the other maternal in origin, which contain homologous genes. *See* Synaptic Mates.

HOMOLOGOUS GENES. Genes similarly situated on homologous chromosomes and contributing to the same expression or different expressions of a character. Alleles.

HOMOLOGOUS ORGANS. Organs which are believed to have a basic relationship by reason of descent from a common type.

HOMOLOGY. Fundamental structural similarity, regardless of function, due to descent from a common form, e.g., wing of bird and foreleg of dog.

HOMOTHERMAL. Provided with a mechanism which maintains the body at a practically constant temperature, usually higher than that of the environment, i.e., the warm-blooded animals, or birds and mammals.

HOMOZYGOUS. Pure. Formed by gametes the same in regard to a given character, or characters, and producing gametes all the same in regard to the character, or characters, in question. *See* Heterozygous.

HORMONE. An internal secretion, usually from a ductless gland. Secreted directly into the blood which distributes it throughout the body where it selectively influences tissues and organs.

HOST. An organism in or on which a parasite subsists.

HYALOPASM. The clear ground substance of protoplasm.

HYBRID. The progeny of parents which differ in regard to one or more characters. A heterozygote.

HYDRANTH. A feeding polyp of a hydroid colony, e.g., Obelia.

HYDROGEN ION. The relative concentrations of the hydrogen ion (H^+) and the hydroxyl ion (OH^-) determine the condition of a solution with reference to acidity or alkalinity. If the concentration is equal, the solution is neutral, as in pure water, and this condition is indicated by a pH of 7.00. A pH below 7.00 indicates an acid condition; above 7.00 indicates an alkaline condition.

HYDROIDS. A group of animals (coelenterates) exhibiting alternation of generations, e.g., Obelia.

HYDROLYSIS. Decomposition of a chemical compound by reaction with water, e.g., in digestion.

HYDROSTATIC ORGAN. Organ for regulating the specific gravity of an organism in relation to that of water, e.g., the air bladder of certain fishes.

HYDROTHLCA. Vesselike expansion of the exoskeleton, or perisarc, about a hydranth, e.g., of Obelia.

HYPOCOTYL. In a seed plant the portion of the stem below the attachment of the embryonic leaves, or cotyledons.

INGESTION. The taking of food into the alimentary canal, as in a vertebrate, or into a single cell, as in Paramecium.

INSTINCT. An unconditioned complex response inherent in an organism and not dependent on previous experiences of the individual.

IMMUNITY. Resistance of the body to infection by disease-producing organisms. Exemption from disease.

INDEPENDENT ASSORTMENT. Genes located in different pairs of chromosomes are segregated independently. *See* Linkage.

INFUNDIBULUM. A funnellike outgrowth from the ventral wall of the diencephalon, forming the posterior lobe of the pituitary gland. *See* Pituitary Gland.

INSULIN. An endocrine secretion of the islands of Langerhans in the pancreas required for carbohydrate metabolism.

INTELLIGENCE. The ability to make judgments and to form conditioned reflexes, that is, to learn by experience.

INTERNAL RECEPTORS. Sense organs within the body. *See* External Receptors.

INTERNAL SECRETION. *See* Hormone and Ductless Gland.

INTESTINE. Portion of the alimentary canal. In higher forms, portion from pyloric end of stomach to cloaca or anus. Usually divided into small and large intestine.

INTRACELLULAR DIGESTION. Digestion of food within the cell itself, e.g., in Paramecium and to some extent in the endoderm cells of hydra. *See* Extracellular Digestion.

INVAGINATION. Sinking or growing in of a portion of the surface, e.g., during transformation of blastula into gastrula.

INVERTEBRATE. Animal without a notochord or a vertebral column.

ION. An atom or a group of atoms, each with an electric charge, formed by the dissociation of a molecule. Thus, HCl dissociates in solution to form positive hydrogen ions and negative chlorine ions.

IRRITABILITY. The power of responding to stimuli, exhibited by all protoplasm.

ISOMERS. Compounds which have the same composition but differ in the positions of the constituent atoms, as dextrose and levulose.

KARYOLYMPH. The more fluid material of the nucleus in contrast with the linin and chromatin.

KATABOLISM. The destructive phase of metabolism. *See* Anabolism.

KINETIC ENERGY. Energy possessed by virtue of motion. *See* Energy.

- LACTEALS.** Lymphatic vessels of the small intestine.
- LAMARCKISM.** Essentially the doctrine of the inheritance of modifications, or acquired characters, as a factor in evolution.
- LARVA.** An immature stage in the life history of certain animals, usually active and differing widely in appearance from the adult, e.g., caterpillar of butterfly, tadpole of frog.
- LENTICELS.** Openings in the plant stem that provide for the entrance and exit of gases.
- LININ.** Nonstainable portion of the nuclear reticulum, closely related chemically to chromatin.
- LINKAGE.** The inheritance as a unit of characters represented by genes in the same chromosome. Independent assortment does not occur.
- LIPIDS.** Fatty substances including the true fats and such compounds as cholesterol ($C_{27}H_{47}OH$) and the lecithins containing also phosphorus and nitrogen. *See* Fats and Cholesterol.
- LYMPH.** Essentially excess tissue fluid, with numerous white cells, passing through vessels on its way back to the blood vascular system. *See* Tissue Fluid.
- MACRONUCLEUS.** The large somatic nucleus in the ciliates with dimorphic nuclei, e.g., in *Paramecium*. *See* Micronucleus.
- MADREPORITE.** A small perforated plate on the aboral surface of certain echinoderms (e.g., the starfish) that allows the passage of water to the water-vascular system.
- MALTOSE.** A double sugar derived from starch by hydrolysis during digestion.
- MANDIBLES.** Jaws.
- MANTLE.** Outer fold of tissue that lines the shell in mollusks.
- MATURATION.** *See* Reduction.
- MAXILLIPEDS.** The three anterior pairs of appendages of the thorax of the crayfish.
- MECHANISM.** The doctrine that the phenomena of life are wholly interpretable in terms of the laws of matter and energy which hold in the realm of the nonliving. *See* Vitalism.
- MEDUSA.** Sexual, gonad-bearing generation of hydroids, and some other coelenterates.
- MEGASPORE.** The large spore, developed in a megasporangium, which in heterosporous plants forms a female gametophyte.
- MEGASPOROPHYTE.** A modified leaf of a heterosporous sporophyte which produces megaspores. A carpel.
- MEIOSIS.** *See* Reduction.
- MENDEL'S LAWS.** Segregation and independent assortment.
- MERISTEM.** Formative (embryonic) tissue with rapidly dividing cells, as in cambium and growing points of higher plants.
- MESENCHYME.** An embryonic tissue developed from the mesoderm.
- MESODERM.** A primary tissue, or germ layer, of animals which develops between the ectoderm and endoderm. *See* Germ Layer.
- MESOGLEA.** The noncellular layer between ectoderm and endoderm in hydra and other coelenterates.
- MESORCHUM.** Mesentery-like membrane supporting the testes.
- METABOLISM.** The sum of the physicochemical processes in organisms, involving the building up, maintenance, and breaking down of the living matter and its constituents. *See* Anabolism and Katabolism.

METAMERE. A segment or somite, e.g., in earthworm and crayfish.

METAMORPHOSIS. A more or less abrupt transition from one developmental stage to another, e.g., transformation of larva into adult during the life history of a butterfly or frog.

METAPHASE. Stage in mitosis involving the arrangement of the chromosomes in the equatorial plate. *See* Anaphase.

METAPHYTA. Multicellular plants with cellular differentiation.

METAPLASM. Lifeless inclusions in cytoplasm, e.g., yolk granules, etc.

METAZOA. Multicellular animals with cellular differentiation.

MICRONUCLEUS. The small germinal nucleus in the ciliates with dimorphic nuclei, e.g., *Paramecium caudatum* has one, *P. aurelia* and *P. calkinsi* have two, and *P. woodruffi* and *P. polycaryum* have several micronuclei. *See* Macronucleus.

MICROSPORANGIUM. A sporangium which bears microspores, e.g., pollen sac in another of stamen.

MICROSPORE. The small spore, of heterosporous plants, which forms a male gametophyte. Essentially a pollen grain.

MICROSPOROPHYLL. A modified leaf, of a heterosporous sporophyte, which produces microspores. A stamen.

MITOCHONDRIA. Bodies in the cytoplasm which apparently contribute to specific chemical processes.

MITOSIS. The typical process of cell division.

MODIFICATION. *See* Acquired Characters.

MOLECULE. The basic and invariable number and arrangement of atoms associated with any compound. For example, a water molecule (H_2O) always consists of two hydrogen atoms and one oxygen atom.

MOLT. To cast off the outer covering, e.g., the exoskeleton of arthropods. Ecdysis.

MONOCOTYLEDON. *See* Dicotyledon.

MONOHYBRID. The progeny of parents differing in regard to one given character.

MONOSACCHARIDE. *See* Glucose.

MORPHOGENESIS. The development of the form and structure of an organism.

MORPHOLOGY. The science of the form of animals and plants.

MOSAIC INHERITANCE. Inheritance of a character in part from each parent but without blending.

MUCUS. A viscous fluid secreted by epithelial gland cells, as in a mucus membrane, particularly in the lining of the alimentary canal where the secreted mucus serves as a lubricating agent.

MUTATION. A heritable variation due to a change in the constitution of the chromosomes (gene) complex, independent of segregation and crossing over. Chromosomal aberrations and intrinsic gene changes.

MYONEMES. Contractile fibrils of certain Protozoa, e.g., Vorticella.

MYOTOMES. Muscle segments in a body wall of lower vertebrates and embryos of higher forms.

NATURAL SELECTION. The processes occurring in nature which result in the "survival of the fittest" individuals and the elimination of those less adapted to the conditions imposed by their environment and mode of life. Essence of the Darwinian theory of evolution.

NEMATOCYST. A nettle or stinging organ developed within an ectoderm cell, e.g., in hydra.

NEPHRIDIOSOME. Funnellike opening of a nephridium into the coelom.

- NEPHRIDIUM.** A tubular excretory organ, e.g., in earthworm.
- NERVE.** Essentially a cablelike association of parallel nerve fibers bound together. *See* Axon.
- NEURAL TUBE.** A tube derived from the ectoderm and forming the brain and spinal cord in vertebrates.
- NEURENTERIC CANAL.** Temporary connection between cavity of enteron and neural tube in vertebrate embryos.
- NEURON.** A nerve cell, comprising cell body and cytoplasmic processes. *See* Axon. Cyton.
- NITRIFYING BACTERIA.** Nitrite bacteria which, in the process of their nutrition, change ammonia (NH_3) into compounds with the NO_2 radical (nitrites), and nitrate bacteria which change nitrites into compounds with the NO_3 radical (nitrates).
- NITROGEN-FIXING BACTERIA.** Types of bacteria which take free atmospheric nitrogen and combine it with oxygen so that nitrates available for green plants are formed. Found in the soil and in tubercles on rootlets of various leguminous plants, e.g., beans, clover, alfalfa.
- NONDISJUNCTION.** Failure of homologous chromosomes to separate after synapsis. Therefore they are not independently segregated during maturation—both pass to the same gamete.
- NOSIMA.** A genus of Sporozoa which parasitizes the silk worm and produces the "pebrine disease" of the silk worm. Another species produces "nosema disease" in honeybees.
- NOTOCHORD.** An axial cord of cells, characteristic of chordates, around which the vertebral column is formed in vertebrates.
- NUCLEOLUS.** A spherical achromatic body within the nucleus, derived from the chromosomes. Function unknown.
- NUCLEUS.** A specialized protoplasmic body in all typical cells. Most characteristic element is chromatin. The seat of the gene complex. *See* Cytoplasm and Gene.
- NUTRITION.** The nourishment of an organism by suitable food substances, their distribution, assimilation, and use in metabolism to permit growth, repair and reproduction.
- OCELLUS.** Sense organ responsive to light, especially the simple eye of insects. *See* Compound Eye.
- OLFACTORY.** Relating to the sense of smell.
- ONTOGENY.** The developmental history of the individual. *See* Phylogeny.
- OOCYST.** Encysted zygote, e.g., of the malarial parasite, Plasmodium.
- OOCYTE.** The ovarian egg before maturation.
- OÖGENESIS.** The development of the mature egg from a primordial germ cell.
- OPTIC LOBES.** Thickenings of the dorsal surface of the midbrain.
- ORDER.** In classification, a main subdivision of a class. *See* Family.
- ORGAN.** An association of tissues for the performance of a certain function, e.g., the heart.
- ORGANIZER.** A region (or substance in a region) capable of self-differentiation and of inducing organization in neighboring regions, e.g., the dorsal lip of the blastopore in amphibians.
- ORTHOGENESIS.** Variation, and therefore evolution, in a definite direction as a result of intrinsic causes.
- OSMOSIS.** Diffusion of dissolved substances through a semipermeable membrane. Osmotic pressure may be produced as a result of the inhibited power of dif-

fusion of a dissolved substance—inhibited because the membrane is *semi-permeable*, i.e., permitting water but not the substance in solution to pass through. The physical phenomena of diffusion and osmosis are complicated in living cells by the fact that their limiting membranes undergo changes in permeability. *See* Diffusion.

OSTEOLOGY. The study of the vertebrate skeleton.

OSTIUM. In sponges, the opening from the gastral cavity to the exterior.

OVIPAROUS. Egg-laying. *See* Viviparous.

OVULE. The body which after fertilization of the egg becomes a seed. The megasporangium.

OVULE CASE. The swollen base of a carpel or pistil in which ovules arise. Ovary.

OVUM. Egg. Female gamete.

OXIDATION. The combination of any substance or its constituent parts with oxygen. Combustion.

PALaeONTOLOGY. The science of extinct animals and plants represented by fossil remains.

PARAPODIUM. Locomotor and respiratory organ of marine worms, e.g., Nereis.

PARASITE. An organism which secures its livelihood directly at the expense of another living organism (host) on or in whose body it lives.

PARASYMPATHETIC SYSTEM. Portion of the autonomic nervous system. It connects anteriorly with the brain, and posteriorly with the spinal cord by elements of certain spinal nerves.

PARENCHYMA. Plant tissue composed of slightly specialized cells, each usually with thin wall and large vacuole, serving for food storage, etc.

PARTHENOCARPY. Development of a fruit without fertilization, as in the banana.

PARTHENOGENESIS. Development of an egg without fertilization.

PATHOGENIC. Disease-producing, especially in regard to the relation of a parasite to its host.

PLAODUPLICATION. Reproduction by larvae, as in certain insects.

PLASMA CELL. Cell membrane or wall enclosing a plasma membrane, as in Paramoecium.

PENTADACTYL. Having five fingers or toes, typical vertebrate limb.

PEPTIDE. Simple chain of two or more amino acids.

PEPTONES. Partially digested proteins following action by pepsin.

PERIANTH. Calyx or corolla, or both when present.

PERICARDIUM. Epithelium lining the pericardial cavity containing the heart.

PERISTALSIS. Rhythmical contractions of the wall of the alimentary canal which force the food along.

PERITONEUM. Membrane lining coelom of vertebrates. Consists of an outer layer of connective tissue next to the muscles of body wall and an inner layer of coelomic epithelium which forms the innermost layer of body wall. Mesodermal in origin.

pH. *See* Hydrogen ion.

PHANEROGAMS. Flowering or seed plants. *See* Cryptogams.

PHARYNX. Region of alimentary canal between buccal cavity, or mouth, and esophagus. Throat.

PHENOTYPE. The somatic, or expressed, characters of an organism or group of organisms irrespective of those potential in the germ cells. *See* Genotype.

PHLOEM. Portion of a vascular bundle in higher plants, forming the system for translocation of food.

- PHOTOSYNTHESIS.** Process by which simple elements are built into complex compounds through the energy of sunlight absorbed by chlorophyll.
- PHOTOTROPISM.** Oriented response in an energy field due to light energy.
- PHYLOGENY.** The ancestral history of the race. *See* Ontogeny.
- PHYLUM.** In classification, a main subdivision of the animal or plant kingdom. *See* Class.
- PHYSIOLOGY.** The study of the functions of animals and plants. The mechanical and chemical engineering of organisms.
- PINEAL BODY.** An outgrowth from the upper wall of the diencephalon. The vestige of an additional eye possessed by the ancestors of existing vertebrates. Possibly functions as an endocrine gland in mammals. Brow spot of frog, well-developed in Lamprey eel and *Sphenodon*.
- PISTIL.** *See* Carpel.
- PITH.** Middle part of central cylinder of a vascular plant shoot. Functions largely for the storage of water and food.
- PITH RAYS.** Extensions of the pith that radiate between the vascular bundles, toward the bark. Medullary rays.
- PITUITARY GLAND.** A glandular body under the brain, formed of tissue from the nervous system (infundibulum) and from the alimentary canal (hypophysis). Secretes several hormones. The master endocrine gland.
- PLACENTA.** A mammalian organ for the interchange of all nutritive, respiratory, and excretory materials between the embryo (fetus) and mother. It also serves as an organ of attachment. In the higher mammals it is composed of both fetal and maternal tissues. *See* Umbilical Cord.
- PLASMA.** Liquid portion of the blood, lymph, and tissue fluid.
- PLASMA MEMBRANE.** Living cell membrane, as distinguished from the cell wall which may also be present.
- PLASTID.** A specialized cytoplasmic body. *See* Chloroplast.
- PLEXUS.** Intercommunication of fibers from one nerve with those of another to form a network, e.g., sciatic plexus.
- POLAR BODIES.** Tiny cells arising during the maturation of the egg of animals.
- POLLEN.** Essentially the microspores of seed plants. Each pollen grain arises by one division of a microspore.
- POLLINATION.** The transference of pollen to the stigma of the pistil in seed plants. Eventuates in fertilization.
- POLOCYTES.** Polar bodies.
- POLYMER.** The product resulting from the combining of two or more molecules of the same substance, as in the formation of starch or cellulose from the monosaccharide molecule.
- POLYMORPHISM.** Occurrence of several types of individuals during the life history, or composing a colony, e.g., *Obelia*, bee.
- POLYP.** Hydra, or a hydralike individual of hydroids, corals, and other coelenterates.
- POME.** Fleishy fruit with a core, e.g., apple, pear.
- PONS.** Portion of the hind brain; an important intermediate area having fiber tracts connecting spinal cord, cerebellum, and cerebrum.
- POPULATION.** Entire group of individuals from which samples are taken for genetical study. Usually comprises several pure lines.
- POTENTIAL ENERGY.** Energy possessed by virtue of stresses or position. Criterion is work done against any restoring force; e.g. kinetic energy of sunlight through agency of chlorophyll separates H_2O into H_2 and O and thereupon is represented by an equal amount of chemical potential energy. Restoring

force is here chemical affinity. Similarly a raised weight possesses gravitational potential energy in amount equal to kinetic energy expended in raising it. *See* Energy and Conservation of Energy.

PREFORMATION. The abandoned doctrine that development is essentially an unfolding of an individual ready formed in the germ. *See* Epigenesis.

PRONEPHROS. Primitive kidney of vertebrates.

PROPHASE. Preparatory changes during mitosis leading toward the disposition of the chromosomes in the center of the cell (equatorial plate). *See* Metaphase.

PROPRIOCEPTORS. Sensory receptors in muscles and joints which receive stimuli associated with body positions and movements and transmit the resulting impulses to the central nervous system.

PROSTATE GLAND. An accessory male genital gland in mammals.

PROSTOMIUM. A lobe which projects from the first segment of the body of the earthworm and forms an upper lip.

PROTEIN. A class of complex chemical compounds, containing nitrogen, which form the chief characteristic constituent of protoplasm.

PROTHALLUS. The gametophyte of ferns.

PROTISTA. Protophyta and Protozoa; all unicellular organisms.

PROTON. An elementary particle with a positive charge of electricity in the atomic nucleus. The simplest atom, hydrogen, has one electron and one proton.

PROTONEMA. A filamentous growth from a moss spore which gives rise to the leafy gametophyte.

PROTOPHYTA. Unicellular plants. *See* Protista.

PROTOPLASM. The physical basis of life. Matter in the living state.

PROTOPLAST. The cell exclusive of the cell wall, especially in plants.

PROTOPODITE. The basal portion of the typical crustacean appendage from which arise the endopodite and exopodite.

PROTOZOA. Unicellular animals. *See* Protista and Metazoa.

PROTOZOOLOGY. The science of unicellular animals, or Protozoa.

PSEUDOPODIUM. A temporary protoplasmic projection for locomotion, feeding, etc., as in amoeba.

PUNNETT SQUARE. A graphic method for showing the possible genic combinations in the offspring resulting from hybrid matings.

PUPA. A rebuilding stage occurring in insects with a complete metamorphosis.

PUPATION. Assumption of a quiescent stage (pupa), in the life history of insects with a complete metamorphosis, during which the larva is reorganized as an adult, e.g., chrysalis of a butterfly and in cocoon of a moth.

PURE LINE. A group of individuals bearing identical genes, for a specific character derived from a common homozygous ancestor.

PUTREFACTION. The simplification of nitrogenous compounds, such as proteins, chiefly through the action of enzymes of living organisms. *See* Fermentation and Decay.

PYLORIC VALVE. Muscular constriction between stomach and small intestine.

PYRENOID. Portion of chloroplast specialized for starch formation.

RADICAL. Association of atoms which act as a unit in chemical reactions, such as NH_2 , COOH , etc.

RECAPITULATION THEORY. Doctrine that individual embryonic development (ontogeny) repeats in greatly abbreviated and modified form the development of the race (phylogeny). Biogenetic law.

RECESSIVE CHARACTER. *See* Dominant Character.

- RECOMBINATION.** Heritable variation due to the typical reassortment of the chromosomes during maturation and fertilization. Crossing over of genes is referred to as gene recombination.
- REDUCTION DIVISION.** The process in maturation which separates synaptic mates and reduces the chromosome number one-half. Involves meiotic mitosis, or meiosis. The mechanism of segregation.
- REFLEX.** Relatively simple and essentially automatic response resulting from the transmission of a sensory impulse to a nerve center and its immediate reflection as a motor impulse, independent of volition. A conditioned reflex is one established by training.
- REGENERATION.** The replacement of parts which have been lost through mutilations or otherwise.
- RENAL PORTAL SYSTEM.** Blood (venous) passes from posterior part of the body to kidneys by the renal portal vein; oxygenated blood to kidneys by the renal artery. Thus in animals with the renal portal system there is a double blood supply to the kidneys. Present in fishes, amphibians, and reptiles; vestigial in birds; absent in mammals.
- REPRODUCTION.** Essentially protoplasmic growth resulting in cell division.
- RESPIRATION.** Essentially the securing of energy from food by oxidation, involving the exchange of carbon dioxide for oxygen by protoplasm.
- RESPONSE.** Any change in the activity of protoplasm, and therefore of an organism as a whole, as the result of a stimulus. *See* Irritability.
- RESTING CELL.** One which is not undergoing mitosis.
- RETINA.** Percipient tissue of the eye by virtue of a sensory layer which is stimulated by light rays.
- REVERSION.** The appearance of an ancestral recessive character in an offspring, after it has been latent for one or many generations. Atavism.
- RHIZOID.** A rootlike filament in lower plants; e.g., in mosses and the prothallus of ferns.
- RHIZOME.** Prostrate underground stem, e.g., in sporophyte of common ferns, and potato.
- ROOT HAIRS.** Prolongations of epidermal cells just above the growing point of roots which afford surface for intake of water and solutes.
- ROTIFERA.** Microscopic, aquatic, multicellular animals. Wheel animalcules.
- SACculus.** The anterior sac of the labyrinth of the ear, a derivative of which becomes the cochlea in higher vertebrates.
- SALT.** Commonly a substance formed by the union of an acid and base, such as table salt (NaCl).
- SAPROPHYTIC.** Type of nutrition involving the absorption of complex products of organic decomposition, e.g., in many groups of bacteria and other fungi, as well as various species of lower animals (saprozoic). *See* Holozoic and Autotrophic.
- SARCOPLASM.** The liquid cytoplasm of a muscle cell which surrounds the myofibrils.
- SEBACEOUS GLANDS.** Glands which elaborate a fatty substance (sebum) and secrete it into the hair follicles. Oil glands.
- SECONDARY SEXUAL CHARACTERS.** Differences between the sexes, other than those of the gonads and related organs.
- SECRETIN.** Endocrine secretion of intestinal mucosa which causes the pancreas to secrete the pancreatic juice containing essential digestive enzymes.

SECRETION. A substance elaborated by glandular epithelium; or the process involved. *See* Gland and Excretion.

SEED. An embryo sporophyte supplied with food and protective envelopes.

SEGREGATION. The distribution of homologous chromosomes, and therefore of homologous genes (alleles), to separate cells during the formation of the gametes. The chief factor of Mendelian inheritance. *See* Reduction.

SEMICIRCULAR CANALS. Portion of the vertebrate ear devoted to the maintenance of equilibrium.

SEMI-PERMEABLE MEMBRANE. A membrane, as in a cell, which permits passage of water but restricts the passage of certain molecules, such as those of salts.

SEMINAL RECEPTACLES. Sacs within the body cavity of certain animals (e.g., earthworm), which receive sperm from another individual and retain them until fertilization is to occur.

SENESCENCE. The process of aging; growing old. The study of phenomena associated with senescence is called gerontology.

SEPAL. A leaf of the calyx of a flower.

SEPTA. The partitions which divide the coelom of the earthworm into a series of chambers, or segments.

SERIAL HOMOLOGY. Homology of a structure of an organism with another of the same organism, e.g., appendages of the crayfish, forelimbs and hind limbs of a vertebrate.

SESSILE. Attached, sedentary, e.g., sponges.

SETAE. Bristlelike structures which protrude from the body and aid in locomotion, e.g., in earthworm and Nereis.

SEX-LINKED CHARACTERS. Characters represented by genes in the X chromosome.

SEXUAL REPRODUCTION. A type of reproduction that involves biparental inheritance, with the fusion of a female gamete (egg) and a male gamete (sperm).

SHOOT. Stem and leaves as contrasted with the root.

SIEVE TUBES. Conducting elements in the phloem portion of the stem of a vascular plant. The end walls of the cells are perforated so as to give a protoplasmic continuity and the passage of liquids from cell to cell.

SOMA. Body tissue (somatoplasm) in contrast with germinal tissue (germ plasm).

SPECIAL CREATION. Doctrine that each species was specially created. Implies fixity of species. *See* Evolution.

SPECIES. In classification, the main subdivision of a genus. A group of individuals which interbreed and do not differ from one another in excess of the limits of individual diversity.

SPERM. Male gamete. Spermatozoon.

SPERMATID. Male germ cells after the final maturation division but before assuming the typical form of mature sperm.

SPERMATOCYTES. Cells arising from the spermatogonia. Primary spermatocyte arises by growth from the last generation of spermatogonia. Primary spermatocyte divides to form two secondary spermatocytes.

SPERMATOGENESIS. The development of the sperm from a primordial germ cell.

SPERMATOPHYTE. Seed plants, including the familiar flowering plants.

SPHENODON. A primitive lizard-like reptile with a well-developed pineal eye. The only living representative of the order Rhyncocephalia.

SPINDLE. The fiberlike apparatus between the centrosomes during mitosis.

SPIRACLES. Openings on the body surface leading into the tracheal system of insects. Also branchial opening in tadpoles and certain other vertebrates.

- SPLEEN.** A vascular ductless organ of most vertebrates, usually situated near the stomach. Its definitive functions undetermined. Apparently acts as a stabilizer of the supply of red blood cells.
- SPONGIN.** A horny material forming the fibers of the skeleton of certain sponges, e.g., the bath sponge.
- SPONTANEOUS GENERATION.** *See* Abiogenesis.
- SPORANGIUM.** A spore-producing structure in plants.
- SPORE.** A cell, liberated from the parent, which gives rise without fertilization to a new individual, e.g., in mosses. Also the resistant phase assumed by certain unicellular organisms, e.g., bacteria, Sporozoa.
- SPOROPHYLL.** A leaf which bears sporangia.
- SPOROPHYTE.** Spore-bearing (asexual) generation in plants exhibiting alternation of generations.
- SPORULATION.** Occurrence of several simultaneous divisions by which a unicellular organism is resolved into many smaller cells, e.g., in Sporozoa.
- STAMEN.** The pollen-bearing organ in seed plants. A microsporophyll. *See* Anther.
- STAMINATE.** Usually applied to flowers possessing stamens but no carpels. *See* Carpellate.
- STATOCYSTS.** Organs of equilibrium, e.g., in medusa and crayfish.
- STELE.** The central cylinder of root and stem, formed of pith and united vascular bundles, in dicotyledonous seed plants.
- STIGMA.** The tip of a carpel (pistil) adapted to receive the pollen and provide for its germination. The eye spot of Euglena.
- STIMULUS.** Any condition which calls forth a response from living matter. *See* Irritability.
- STOMATA.** Openings through the epidermis of a leaf for the interchange of gases and exit of water vapor. The stomatal apparatus comprises the stoma and its guard cells.
- SYMBIOSIS.** The association of two species in a practically obligatory and mutually advantageous partnership, e.g., lichens.
- SYMPATHETIC NERVOUS SYSTEM.** *See* Autonomic System.
- SYNAPSE.** The area of communication of one nerve cell with another, which makes possible the conduction of a nervous impulse from cell to cell.
- SYNAPSIS.** The pairing of homologous chromosomes during maturation of the germ cells.
- SYNAPTIIC MATES.** Homologous chromosomes of maternal and paternal origin that pair during synapsis.
- SYNCYTIUM.** A mass of protoplasm containing several nuclei, but no intermediate cell walls. Examples are seen in the hyphae of the bread mold or in a striated muscle fiber.
- SYNKARYON.** The composite nucleus formed by the union of the nuclei of two gametes. Male and female gametic nuclei united in the zygote. *See* Zygote.
- SYNTHESIS.** The formation of a more complex substance from simpler ones, as seen, for example, in photosynthesis, involving the union of carbon dioxide (CO_2) and water (H_2O) to form glucose ($\text{C}_6\text{H}_{12}\text{O}_6$).
- TACHINIDAE.** A group of flies in which the larvae develop on or in various insects and destroy them.
- TAXONOMY.** The science of classification of organisms.
- TELOLECITHAL EGG.** An egg carrying considerable yolk, unevenly concentrated in the animal pole.

- TELOPHASE.** Final phase of mitosis during which the two daughter nuclei are reformed and cytoplasmic division is completed. *See* Prophase.
- TERATOMA.** A tumor consisting of a heterogeneous mixture of misplaced tissues, sometimes showing incipient organs.
- TETRAD.** A group of four chromosomes formed from a pair of homologous chromosomes during synapsis. Each chromosome splits longitudinally to form two daughter chromosomes, or a total of four tetrads from the pair.
- THALLUS.** A relatively simple plant body, not differentiated into true root, stem, and leaf, e.g., in seaweeds and other algae.
- THORAX.** Portion of the body in mammals, containing esophagus, lungs, heart, and large vessels. The middle portion of the body in the Arthropoda, e.g., in all insects. In the crayfish the head and thorax are fused to form the cephalothorax.
- THYMUS.** A glandular structure in the pharyngeal region of vertebrates. Regresses during early life in man. Function obscure.
- THYROID GLAND.** An endocrine or ductless gland in the pharyngeal region of vertebrates.
- TISSUE.** An aggregation of similar cells, with their derivatives, for the performance of a certain function. *See* Organ
- TISSUE FLUID.** Essentially plasma which has passed through the capillary walls to supply the milieu of the tissue cells. Intercellular fluid. *See* Lymph.
- TRACHEAL SYSTEM.** Series of tubes that convey air throughout the tissues of certain arthropods, e.g., insects.
- TRACHEIDS.** Elongated cells which form water-conducting vessels in the vascular bundles of higher plants.
- TRACHEOPHYTES.** Vascular plants. Chiefly pteridophytes and spermatophytes.
- TRANSPIRATION.** The exhalation of water vapor, particularly through the stomata of the leaf.
- TRICHOCYSTS.** Minute bodies, arranged in the outer part of the ectoplasm of certain ciliates (e.g., *Paramecium*), each of which upon proper stimulation is transformed into a threadlike process protruding from the cell surface. Apparently defensive structures.
- TRIHYBRID.** The progeny of parents differing in regard to three given characters.
- TRIPLOBLASTIC.** Consisting of three primary germ layers: ectoderm, endoderm, and mesoderm.
- TROPHOZOITE.** Growing and feeding form developed from a sporozoite, e.g., in malarial parasite.
- TROPISM.** Element of behavior of organisms. Inherent, directive response, of movement or growth, to an external stimulus, e.g., chemotropism.
- TURGOR.** Pressure within a cell, largely due to the absorption of water, which distends or holds rigid the cell wall. *See* Cell Sap.
- TYPHLOSOLE.** A median dorsal invagination along the entire length of the intestine of the earthworm which increases the area of the digestive and absorptive surface.
- UMBILICAL CORD.** A tubular structure, commonly called the navel cord, by which the embryo is attached to the placenta in mammals. The blood vessels from the embryo to the placenta pass through it. *See* Placenta.
- UNGUICULATE.** Provided with claws.
- UNIFORMITARIAN DOCTRINE.** An interpretation of the present condition of the earth on the assumption of similarity of factors at work during past ages and today.

UNIPARENTAL. Derived from a single progenitor, e.g., in asexual reproduction. *See* Biparental.

UREA. Nitrogenous waste product of animal metabolism. Formed as such in the liver, removed from the blood by the kidneys and eliminated from the body chiefly in urine, $\text{CO}(\text{NH}_2)_2$. A major part of the nitrogen is excreted in this form in human urine. *See* Creatinine and Uric Acid.

URETER. A tube carrying urine from kidney to the cloaca or to the urinary bladder.

URIC ACID. A nitrogenous waste product. Present in small quantity in the urine of man.

UROGENITAL. Relating to the urinary and reproductive systems.

UROSTYLE. Terminal rodlike bone of the vertebral column of the frog.

UTERUS. Lower portion of the oviduct (or oviducts) modified for the retention of the eggs, temporarily or during development.

UTERUS MASCULINUS. Remnant of the pronephric ducts in some male mammals.

URICULUS. The posterior sac of the labyrinth of the ear into which the semi-circular canals open.

VACUOLE. In animal cells a tiny fluid-filled area in the cytoplasm, such as a gastric vacuole or contractile vacuole. In plant cells, a vacuole filled with cell sap which typically fills a large area of the cell and is enclosed by peripheral cytoplasm, as in *Elodea*.

VAGINA. Passage leading from the uterus to the exterior.

VASCULAR BUNDLE. Essentially a system of supporting elements, and of tubes for conducting water and food. A fibrovascular bundle. Characteristic of vascular plants, or tracheophytes. *See* Stela.

VASOMOTOR NERVES. Nerves which regulate the caliber of small arteries by bringing about relaxation or contraction of the muscular layer of their walls.

VERMIFORM APPENDIX. Blind outpocketing of the large intestine near its origin from the small intestine. Vestigial end of the caecum. Found only in apes and man.

VERTEBRA. One of the series of elements forming the backbone, or vertebral column.

VERTEBRATE. An animal with a backbone, the vertebral column. *See* Chordate

VESTIGIAL ORGAN. Non-functional structure, such as the vermiform appendix in man.

VIRUS. Parasitic ultramicroscopic organisms, at the borderline between animate and inanimate. Cannot live outside the cells of their host. Viruses are now revealed by the electron microscope at magnifications of 25,000 times and more.

VITALISM. The doctrine which attributes at least some of the phenomena of life to an interplay of matter and energy which transcends the so-called laws operable in the inorganic world. *See* Mechanism.

VITAMINS. Indispensable accessory food substances.

VIVIPAROUS. Producing young that have developed to a relatively advanced stage in the uterus, e.g., most mammals. *See* Oviparous.

WORKING HYPOTHESIS. A basic assumption to guide the study of a subject, and to be proved or disproved by facts accumulated.

X CHROMOSOME. The so-called sex chromosome.

XYLEM. The woody part with water-conducting vessels of a vascular bundle.

Y CHROMOSOME. The synaptic mate of the X chromosome not always present.

YEAST. A group of unicellular colorless plants (fungi) which are chiefly responsible for alcoholic fermentation.

YOLK. Food material stored within the cytoplasm of an egg. *See* Metaplasm.

YOLK SAC. When a great quantity of yolk is present in an egg, the endoderm gradually grows over it to form the yolk sac which is usually of enormous size in comparison with the embryo proper, e.g., in hen's egg. Its presence in the essentially yolkless egg of mammals is regarded as reminiscent of their ancestry.

ZOOGEOGRAPHY. The science of the geographical distribution of animals.

ZYGOSPORE. A thick walled algal zygote in a resting stage.

ZYGOTE. The composite cell formed by the union of a male gamete (sperm) and a female gamete (egg). Fertilized egg. *See* Syngkaryon.

III. Synoptic Classification of Plants and Animals

(With representative examples and approximate number of known species)

A. THE PLANT KINGDOM

Phylum THALLOPHYTA: Thallus plants, lacking differentiation into true stems, leaves, and roots. See footnote.*

Series of the ALGAE: Thallus plants with chlorophyll (holophytic). (30,000 species.)

Class I. MYXOPHYCEAE: Blue-green algae. Gloeocapsa, Oscillatoria.

Class II. CHLOROPHYCEAE: Green algae. Protococcus, Sphaerella, Ulothrix, Oedogonium, Ulva, Spirogyra, desmids.

Class III. PHAEOPHYCEAE: Brown algae. Kelps and rockweeds. Laminaria, Fucus, Ectocarpus, Sargassum.

Class IV. RHODOPHYCEAE: Red algae. Polysiphonia.

Series of the FUNGI: Thallus plants lacking chlorophyll (saprophytic or parasitic, except for a few autotrophic bacteria). (60,000 species.)

Class I. SCHIZOMYCETES: Bacteria.

Class II. PHYCOMYCETES: Algalike fungi. Black molds, blights.

Class III. ASCOMYCETES: Sac fungi. Blue molds, powdery mildews, yeasts.

Class IV. BASIDIOMYCETES: Club fungi. Smuts, rusts, mushrooms.

Phylum BRYOPHYTA: Liverworts and mosses. Small avascular land plants. (20,000 species.)

Class I. HEPATICAEE: Liverworts. Marchantia, Porella, Anthoceros.

Class II. MUSCI: Mosses. Sphagnum, Polytrichum.

Phylum TRACHEOPHYTA: Vascular plants.

Class I. LYCOPSIDA: Club mosses. Lycopodium, Selaginella.

Class II. SPHENOPSIDA: Horsetails. Equisetum.

* It is now generally recognized by plant taxonomists that the phylum Thallophyta is an artificial group and includes several phyla of relatively simple plants which are believed to have been developed along independent lines and, therefore, not closely related. These groups are now placed in ten separate phyla, including seven phyla of simple chlorophyll bearing plants or "Algae," and three phyla of colorless plants of "Fungi." However, for the non-specialist the terms *Thallophyta*, *Algae*, and *Fungi* are of continuing value to designate plant groups bearing characteristics as stated in the above classification

Class III. PTEROPSIDA: Ferns and seed plants.**A. Pteridophytes: Ferns. (8000 species.)****B. Spermatophytes: Seed plants.****1. Gymnosperms: Cycads and conifers. (600 species.)****2. Angiosperms: Flowering plants.****a. Dicotyledons: Willows, nettles, pinks, buttercups, roses, beans, sunflowers. (150,000 species.)****b. Monocotyledons: Grasses, palms, lilies, orchids. (50,000 species.)****B. THE ANIMAL KINGDOM****1. Invertebrate Animals****Phylum PROTOZOA: Unicellular and colonial animals. (20,000 species.)****Class I. FLAGELLATA: Flagellates, Euglena, monads, trypanosomes.****Class II. RHIZOPODA: Amoeba, Foraminifera, Heliozoa, Radiolaria.****Class III. SPOROZOA: Plasmodium, Monocystis.****Class IV. CILIATA: Ciliates, Paramecium, Vorticella, Stentor.****Phylum PORIFERA. (3000 species.)****Class I. CALCISPONGIAE: Calcareous sponges, Leucosolenia, Scypha.****Class II. HYALOSPONGIAE: Glass sponges, Euplectella.****Class III. DEMOSPONGIAE: Spongia, Spongilla.****Phylum COELENTERATA. (10,000 species.)****Class I. HYDROZOA: Hydra, Obelia, Gonionemus.****Class II. SCYPHOZOA: Aurelia.****Class III. ANTHOZOA: Sea anemones, corals.****Phylum CTENOPHORA: Sea walnuts. (100 species.)****Phylum PLATYHELMINTHES: Flatworms. (7000 species.)****Class I. TURBELARIA: Planaria.****Class II. TREMATODA: Liver flukes.****Class III. CESTODA: Tapeworms.****Class IV. NEMERTINIA: Nemerteans.****Phylum NEMATHELMINTHES: Roundworms. (3000 species.)****Class I. NEMATODA: Ascaris, Trichinella, hookworm.****Class II. NEMATOMORPHA: Gordius.****Class III. ACANTHOCEPHALA: Echinorhynchus.****Phylum ANNELIDA: Segmented worms. (7000 species.)****Class I. ARCHIANNELIDA: Polygordius.****Class II. POLYCHAETA: Sandworms, tubeworms, Nereis.****Class III. OLIGOCHAETA: Earthworms, fresh-water naids.****Class IV. GEPHYREA: Sipunculus.****Class V. HIRUDINEA: Leeches.****Phylum ROTIFERA: Rotifers. (1800 species.)****Phylum BRYOZOA: Bryozoans. (3000 species.)****Phylum BRACHIOPODA: Brachiopods. (130 species.)****Phylum MOLLUSCA. (80,000 species.)****Class I. AMPHINEURA: Chiton.****Class II. SCAPHOPODA: Dentalium.****Class III. GASTROPODA: Snails, slugs.**

Class IV. **PELECYPODA**: Oysters, clams, scallops, shipworm.

Class V. **CEPHALOPODA**: Squid, octopus, nautilus.

Phylum **ECHINODERMATA**. (5000 species.)

Class I. **ASTEROIDEA**: Starfishes.

Class II. **OPHIUROIDEA**: Brittle stars.

Class III. **ECHINOIDEA**: Sea urchins.

Class IV. **HOLOTHUROIDEA**: Sea cucumbers.

Class V. **CRINOIDEA**: Sea lilies, feather stars.

Phylum **ARTHROPODA**. (700,000 species.)

Class I. **CRUSTACEA**. (20,000 species.)

Subclass 1. *Entomostraca*: Daphnia, cyclops, barnacles.

Subclass 2. *Malacostraca*: Crayfish, lobsters, crabs, pill bugs.

Class II. **ONYCHOPHORA**: Peripatus.

Class III. **MYRIAPODA**: Centipedes, millipedes. (2000 species.)

Class IV. **INSECTA**: Insects. (650,000 species.)

Commonly accepted orders are:

- | | |
|---|---|
| 1. <i>Thysanura</i> : Silverfish. | 14. <i>Hemiptera</i> : Bugs. |
| 2. <i>Collembola</i> : Springtails. | 15. <i>Homoptera</i> : Plant lice. |
| 3. <i>Orthoptera</i> : Grasshoppers, crickets, roaches. | 16. <i>Dermaptera</i> : Earwigs. |
| 4. <i>Isoptera</i> : Termites. | 17. <i>Coleoptera</i> : Beetles. |
| 5. <i>Neuroptera</i> : Ant lions, lacewings. | 18. <i>Strepsiptera</i> : Stylops. |
| 6. <i>Ephemeroptera</i> : May flies. | 19. <i>Mecoptera</i> : Scorpion flies. |
| 7. <i>Odonata</i> : Dragonflies. | 20. <i>Trichoptera</i> : Caddice flies. |
| 8. <i>Plecoptera</i> : Stone flies. | 21. <i>Lepidoptera</i> : Moths and butterflies. |
| 9. <i>Psocoptera</i> : Book lice. | 22. <i>Diptera</i> : Flies, mosquitoes. |
| 10. <i>Mallophaga</i> : Bird lice. | 23. <i>Siphonaptera</i> : Fleas. |
| 11. <i>Embiopoda</i> : Embiids. | 24. <i>Hymenoptera</i> : Bees, wasps, ants, ichneumons. |
| 12. <i>Thysanoptera</i> : Thrips. | |
| 13. <i>Anoplura</i> : Sucking lice. | |

Class V. **ARACHNIDA**: Scorpions, spiders, mites. (28,000 species.)

2. Vertebrate Animals (Chordates)

Phylum **CHORDATA**. (65,000 species.)

Subphylum A. **HEMICHORDA**: Dolichoglossus (Saccoglossus).

Subphylum B. **UROCHORDA**: Tunicates, sea squirts, Styela.

Subphylum C. **CEPHALOCHORDA**: Lancelets. Amphioxus.

Subphylum D. **VERTEBRATA**

Class I. **AGNATHA** (Cyclostomes). Lamprey, hagfish.

Class II. **CHONDRICHTHYES** (Elasmobranchs): Cartilaginous fishes, such as sharks, rays, chimaera.

Class III. **OSTEICHTHYES** (Bony fishes: 35,000 species).

Subclass 1. *Choanichthyes*. Latimeria and lungfishes.

Subclass 2. *Actinopterygii*:

Superorder 1. *Chondrostei*: Polypterus, sturgeons, paddlefish.

Superorder 2. *Holostei*: Bowfin, garpike.

Superorder 3. *Teleostei*: Trout, salmon, catfish, eel, goldfish, guppy, cod, flounder, swordfish, perch, etc.

Class IV. **AMPHIBIA**. (2000 species.)

Order 1. *Apoda*: Caecilians, legless amphibians.

- Order 2. *Caudata*: Urodeles. Necturus, salamander, Cryptobranchus, Amblystoma.
- Order 3. *Salientia*: Anurans. Frogs, toads.
- Class V. **REPTILIA**. (4000 species.)
 - Order 1. *Chelonina*: Turtles, tortoises.
 - Order 2. *Rhynchocephalia*: Sphenodon.
 - Order 3. *Crocodylia*: Crocodiles, alligators.
 - Order 4. *Squamata*: Chameleons, lizards, snakes.
- Class VI. **AVES**: Birds. (25,000 species.)
 - Division A. *Ratitae*: Apteryx, ostrich.
 - Division B. *Carinatae*: All familiar birds.
- Class VII. **MAMMALIA**. (15,000 species.)
 - Subclass 1. *Prototheria*: Monotremes. Duckbill, Echidna.
 - Subclass 2. *Metatheria*: Marsupials. Opossums, kangaroos.
 - Subclass 3. *Eutheria*: Placentals. All familiar mammals.
 - Order 1. *Insectivora*: Moles, shrews, hedgehogs, Gymnura.
 - Order 2. *Chiroptera*: Bats.
 - Order 3. *Edentata*: Sloths, anteaters, armadillos.
 - Order 4. *Rodentia*: Rats, mice, rabbits, squirrels, beavers, porcupines, guinea pig.
 - Order 5. *Carnivora*: Cats, dogs, bears, seals, walruses.
 - Order 6. *Ungulata*.
 - Suborder 1. *Artiodactyla*: Oxen, giraffes, camels, pigs, hippopotami.
 - Suborder 2. *Perissodactyla*: Horses, tapirs, rhinoceroses.
 - Suborder 3. *Proboscidea*: Elephants.
 - Order 7. *Sirenia*: Sea cows.
 - Order 8. *Cetacea*: Whales, porpoises, dolphins.
 - Order 9. *Primates*.
 - Suborder 1. *Lemuroidea*: Lemurs.
 - Suborder 2. *Tarsioidea*: Tarsiers.
 - Suborder 3. *Anthropoidea*: Monkeys, apes, man.
 - Series 1. *Platyrrhini*: New World monkeys.
 - Family 1. *Cebidae*: Capuchins, howler monkeys, spider monkeys, etc.
 - Family 2. *Hapalidae*: Marmosets.
 - Series 2. *Catarrhini*: Old World monkeys, apes, man.
 - Family 3. *Cercopithecidae*: Macaques, baboons, mandrills, etc.
 - Family 4. *Hylobatidae*: Gibbons.
 - Family 5. *Pongidae*: Orangutans, chimpanzees, gorillas.
 - Family 6. *Hominidae*: Man.

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