ELEMENTS OF BIOLOGY

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With Special Reference to Their Rôle in the Lives of Animals

BY

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PREFACE

It is the conviction of the writer that the specific objectives of a general course in Biology for students in colleges of Liberal Arts are three: To impart such principles and concepts as will enable the student to appreciate the unity in Nature and the place of living organisms, including Man, in that unity; to instill an understanding of the major laws that govern living organisms and a recognition of the operation of these laws in determining broad social and economic controls in human society; to impart useful information and information of such character that a habit of observing caution in the face of all forms of scientific and intellectual quackery will be developed. A fourth objective that is self-evident and which General Biology holds in common with many other academic disciplines is the development of student power of clear and logical reasoning based upon accurate observation and established facts.

The present volume represents an attempt to collect in succinct form materials which the writer has been employing over many years in his attempts to reach the objectives of a course for non-professional students. He has not failed to take advantage of consultation with the more thoughtful students, with the advisors of students, and with other colleagues. Moreover, the writer has had reason to examine with some care the problems involved in the organization of survey and correlation courses and has made a most serious attempt to arrange his subject matter in alignment with such programs. As the writer sees his responsibility, his task has been the clarification of principles that are abstruse, not their elimination. The probable needs of the student in the years after college have been kept constantly in mind; the content of the volume includes the understanding and information that the intelligent layman might reasonably be expected to have as a result of his experience in a general course. In adhering to this idea some of the minutiæ of conventional Biology have been cut away. In some cases certain liberties have been taken with controversial subjects and decisions are stated which may be open to some differences of interpretation. This is in alignment with the policy of keeping the student mind clear of non-essentials in order that broad principles may stand out more clearly. Laymen are not interested in disputed questions of detail, nor need they be.

For a number of reasons the writer regards the exclusive use of so-called representative forms as undesirable in a course limited to one year. Important among the objections is one raised by students; in general, students never were and never will be interested in the detail of structure of the conventional type forms, clam, frog, earthworm, crayfish, and so on. Examples and illustrations of the operation of principles are indispensable, however. The criticism has been repeatedly advanced that in a course devoted to the development of the principles of vital phenomena much is taught about a great number of animals but very little about any one animal. The statement, raised as a criticism, expresses a very desirable objective of a general course for Liberal Arts students. The writer expresses the opinion that if intensive attention is to be devoted to any one animal, that animal should be the human. Thus wherever it is possible to illustrate the operation of a biological principle with clarity, or wherever it seems best to add information concerning the human body, he has had no hesitation in making reference to Man. Moreover, the chief interest of the student is in his own body; he already has some knowledge of its workings. Thus advantage is taken of the sound pedagogical principle which relates the known to the immediately related unknown. In alignment with this principle and for the sake of student interest and information, the writer pleads for a more general use of small mammals as laboratory materials in a general course.

It is a common experience that most of the students in courses in General Biology have had no previous training in Chemistry, or at most a preparatory school course in that science. The present status and outlook of the science of Biology demands that one must have at his command at least the rudiments of the science of Chemistry in order to appreciate the principles as they are weighted; vital phenomena are evidences of the dynamics of matter. The responsibility for establishing a background of knowledge of the structure and behavior of matter devolves upon the instructor in Biology; without it he cannot successfully develop his subject. More especially is his responsibility real because in very many cases Biology is the only science scheduled in the curricula of particular students. An attempt is made here to develop just so much of the principles of Chemistry that at the very start the student is indoctrinated with the concept of Mechanism and establishes as a point of departure the First Principle, that life is dynamic. The writer appreciates the difficulties involved and recognizes the fact that a comprehension of even the rudiments of the structure and behavior of matter requires that the student exercise a controlled and vivid imagination and that he be able to project his imagination into the realm of the infinitely small, properties of mind that are usually associated with maturity and with the experience gained by slow development of logical thinking. The difficulties faced do not justify one in avoiding the attempt; it has been gratifying to realize that a certain degree of success is attained with some frequency.

The writer is well aware of the fact that the text contains some repetitions. For instance, the hydra is described no less than three times in different sections of the volume. Experience has taught that for pedagogical reasons this is quite desirable. It will be noted that in each case of apparent repetition the subject matter is developed from a different point of view; under such circumstances restatements serve as refreshers and enable the student to follow the thought more readily and more effectively. The writer has come to regard the subject matter of the fourth chapter, Taxonomy, as very important in the developing of the course; he has always been aided in the presentation of this subject by teaching collections and appropriate charts. In emphasizing the various forms and their position some of the rules of capitalization have been violated in this chapter. Moreover, in order to assist the reader in locating quickly such subject matter as relates to Man, the word has been capitalized throughout the volume.

Any text book of this sort must of necessity consist largely of a compilation, for no new facts and no new principles are to be presented. For illustrative examples frequent recourse has been made to original papers for which no acknowledgment of source has been made. Credit for original work is largely the concern of the professional scientist, not of the Arts student; the instructor is only too happy if he succeeds in imparting the information or establishing a principle. Analogies and expressions have been freely used, whatever may have been their source. The writer recalls the origin of some of them; others have been obtained from casual reading and their source forgotten by him.

It has always been the ambition of the writer to so stimulate the student that he acquires some interest in reading Science. The suggested readings placed at the end of each chapter are some that have been found useful in testing the interest, capacity, and achievement of the more alert and responsive students. The lists have been made up from the readings that have been recommended to such students as have stopped at this instructor's desk to inquire where they might find further information and discussion on topics mentioned in the lectures; the assignments are quite frankly extensions, not collateral materials. Hence they are diverse in character, some old and some quite recent. They merely indicate that a wide choice should be made available. At the end of the last chapter the suggested readings include materials dealing with Science in general, some of which are so advanced as to be of use almost solely to advanced students. Titles appear here that may occasion surprise in a text of this sort. The writer remembers that in very many cases this is the only course in Science which the student undertakes during his college career; he also remembers that many students have asked him for just this sort of reference material.

Acknowledgment is made of obligations to Professor W. C. Allee, of the University of Chicago, who read a copy of the manuscript as it was being developed and offered encouragement and valuable suggestions. Advantage was also taken of criticisms made by Mr. Henshaw Ward, who was kind enough to read an earlier copy. No small credit for such values as this volume may possess is due to the cooperation and active assistance of the writer's wife, Pearle Oliver Buchanan; its preparation was made possible by her assistance in discussions and her part in the tedious task of correcting proof. The practical suggestions and efficient handling of copy by Miss Ona Cunningham, Secretary of the Department of Zoology, were valuable aids. The writer also appreciates the generous help of the publishers, Harper and Brothers, and their care in the manufacture of the book. Finally, an indebtedness that cannot be redeemed here is acknowledged to former and present colleagues, and to former students, whose opinions, either by positive suggestion or by the friendly clash of ideas that is so often fruitful, have aided the writer in formulating his course.

For the preparation of the figures it was indeed fortunate that the services of Miss Maudjean Gail were available and the writer is indebted to her for much assistance and careful work. In general, the figures are those which the writer at one time or another has found valuable in his course. Emphasis is placed on diagrams rather than reproductions. We prepared a considerable number of dissections and had at our disposal many histological preparations. Many of the figures were drawn from such dissections and preparations and from living and preserved forms at hand. In some cases models, charts, or texts now out of print were made use of. It was not possible to trace the origins of a few of the figures. Regardless of source every figure was redrawn or made diagrammatic and re-labelled especially for this text. Figures adapted from original contributions are acknowledged in the legends by the name of the investigator. Cheerful acknowledgment is also made of permission to re-draw with modifications from current texts published by the following: The University of Chicago Press. The University of California Press. Oxford University Press. P. Blakiston's Son and Co. W. B. Saunders and Co. Henry Holt and Co. Longmans, Green and Co. McGraw-Hill Book Co. The Macmillan Co. D. Appleton and Co. Harper and Brothers. Gaston Doin et Cie, Paris. Georg Theime, Leipzig.

J. William Buchanan

Evanston, May, 1933.

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BIOLOGY

Chapter I

THE NATURE OF LIFE AND OF LIVING MATERIAL

The Nature of Science. A SCIENCE consists essentially of a series of related principles or regularities which account in an orderly and rational way for a group of facts that the human mind may observe or be aware of. That is to say, Science is that type of human interest which deals with order. The method and scope of the Sciences may be made clear by paraphrasing an analogy employed by a modern critic. Three men sit around a table on which is a Mexican jumping bean, each interested to explain its peculiar behavior. One starts with the preconceived idea that the jumping of the bean is caused by a supernatural power. From this he develops with flawless logic a clear and convincing conclusion concerning the powers of the supernatural. The second man starts with the premise that the motion of the bean is due to an emotional state and with equally clear and convincing logic he arrives at conclusions regarding the nature of the emotions.

The third man, without any fixed preconceived notions, observes and calculates the physical characteristics of the bean and of its motions. Then he opens the bean and finds therein a small animal, the wormlike larva of an insect. He, also by sound logic, draws the conclusion that the motion of the bean is caused by a physical phenomenon, the motion of the larva within. The third man is the scientist and Science first and foremost is characterized by the absence of fixed preconceived explanations. Science sets itself the task of opening the bean, and to carry the analogy still farther, of opening the insect larva to determine why it moves. The material is probed more and more deeply; as each larva is found the problem of what causes its motion must be undertaken. Thus Science as it succeeds in establishing one principle, finds itself faced with still more difficult and obscure problems.

The NATURAL SCIENCES have the task of explaining the materials and actions that, our senses tell us, make up the world about us and extend out into space. ASTRONOMY deals with the stars; GEOLOGY with the Earth; PHYSICS with the laws of energy; CHEMISTRY with the nature and behavior of the ultimate particles of which matter is composed.

The Science of Biology. The science of BIOLOGY consists of the principles that characterize all living bodies and are responsible for that phenomenon which we term LIFE. Being the science of matter in the living state, Biology is in large measure made up of principles that are derived from Physics and Chemistry. The chief value of a knowledge of the science of Biology to one who has no vocational interest, lies in the enrichment it brings to one's appreciation of the unity of all material things and in the enlargement of ability to comprehend broad and general principles. ANIMAL BIOLOGY is concerned with the manner in which the principles of living matter apply in the lives of animals. These are evident to us when we compare and analyze a multitude of facts. Consequently the study of Animal Biology involves familiarizing oneself with facts. But ability to memorize and to re-state facts does not constitute knowledge; it is only when one has considered the relation of the facts to each other and has a conception of the underlying order that pervades all life that the science of Animal Biology becomes a useful and enriching mental experience. This experience is gained only by acquainting oneself with many animals and many processes that are not met with in everyday life, by following a reasonable plan in arranging these facts, and by thoughtful contemplation of the significance of the various forms and activities of animals and their relation to plant life. Many of the facts are not a part of public information; hence a special terminology and vocabulary are necessary and unavoidable. In the study of Biology one encounters concepts that are among the most profound and abstruse which the human mind attempts; consequently, the study challenges the best effort of which the individual is capable.

We generally recognize that the human body has many characteristics that are common to all living things. To an inquiring mind this raises the question of the extent of Man's relationship to other animals and as to the nature of the phenomena which constitute living. Since Man is only one of a wide variety of objects that are alive, an understanding of the broad principles of life processes wherever they may occur is necessary to a comprehension of Man as a living being and of his position in relation to the world about him. Human biology is therefore only one aspect of Animal Biology. The task we have set for ourselves here is an examination of the principles of vital phenomena in general and of the manner in which these operate in the animal body, including the human body.

Life. Before proceeding farther, we must establish and agree on a meaning of the term life. The word has been devised by Man to distinguish the peculiarities of a particular sort of object in the world about him. The word Life calls to mind certain attributes of a class of bodies in the same fashion that the word Rock brings to mind the characters that are common to a class of materials with which we are all familiar. In order for an object to be recognized as living it must possess in greater or less degree five features, none of which is solely a property of living bodies.

Irritability: We recognize this character as a part of our own lives because of the five senses that make us aware of our surroundings, smell, taste, touch, sight, and hearing. In other forms of life we may recognize the same general property although they may not be equipped with special sense organs. All living objects are sensitive to their environment and any change in the surroundings affects the organism in such a way as to modify its manner of living. This response to environmental incidents may be a violent reaction, as in the case of the response of an animal to injury; it may be the production of chemical agents which respond to and combat the bacteria of disease, or a slow change of position or direction of growth as in the response to light of a growing plant. Irritability, therefore, as a characteristic common to all living objects includes the entire range of adjustment of a plant or animal to the events which it constantly encounters. Non-living objects are also responsive and change with changes in the surroundings. For example, a metal rod becomes shorter when the temperature is lowered. A distinction between the effect of the environment on living and on non-living objects is that living objects tend to react, that is, attempt by some change in their activities to overcome or to adjust to the changed conditions. When the temperature is lowered the organism responds by some activity which tends to lessen the effect of the change; the metal rod is helpless.

Contractility: This property is apparent to us if we note the change in dimensions of the muscles of the arm when the elbow is flexed or extended. It is noted that the flexing of the joint is brought about by the shortening of certain large muscles which can be felt in the upper arm. It is also noted that as the muscle is shortened it at the same time becomes much thicker. Non-living objects also contract; a metal rod contracts with a decrease in temperature. The distinction is that in the living body contraction involves a decrease in one dimension with a corresponding increase in another, in reality a change in shape, while the metal rod decreases in all dimensions; it actually occupies less space. The property of contractility is concerned in many of the activities of living bodies, in the capture of food, in escape from enemies, in the propelling of fluids within the body. It is a less general property than irritability, for some organisms exhibit it to a very limited degree.

Growth and Repair: A body that is alive increases in size some time during its period of living. The growth of a living body is due to an actual increase in the quantity of living materials, formed by life processes from quite different substances derived from its surroundings. Crystals and other non-living objects also grow, but the increase is largely as added layers, external and local. Repair of injury, a special type of growth, is solely a property of living objects. No non-living body can repair damage brought about by some incident in its surroundings.

Reproduction: Every normal living object at some time during its life is capable of partaking in the reproduction of another body also alive and very much like itself. In general, conditions within the organism bring about reproduction. The property is peculiar as to method in living objects and is a critical test of life.

Organization and Correlation: Living objects always consist of a very definite arrangement of a peculiarly organized substance called PROTOPLASM. The protoplasm is further organized into small units termed CELLS, recognizable as such regardless of the size of the plant or animal and of its other characters. Structural organization in the body of a plant or animal is indissociably linked with its properties of contractility, growth, reproduction, and so on, as many types of machines in a factory are correlated for the production of a common result. A living object is an individual of definite size, its parts so correlated that the whole operates as a balanced unit. Non-living objects, for example, a rock, may vary in size from a very minute to a very large body; but a bird, for instance, does not become indefinitely large, nor does it exist as a bird in a very minute size. The internally directed control that unifies the organism as to size, structure, and activity, is a character that is not duplicated in the non-living.

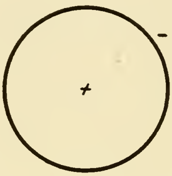
Mechanism and Vitalism. All these are evidences of activity and indicate that some sort of force is operating in living material. The question at once arises: What is the nature of this force that activates living objects? There are two possible ways of conceiving of the powers that give living bodies their peculiar properties. Either these forces that show themselves as irritability, growth, reproduction, and so on, represent transformations of energy according to laws we are familiar with in the non-living world, or else a supernatural force outside our ability to measure is the activating factor in life. The first of these concepts is termed MECHANISM; the second, VITALISM.

If we adopt the view that life is a manifestation of some supernatural force, vitalism, then any attempt to understand such a force is futile, for it could not be recognized by our senses. It could not be weighed, measured, nor controlled, for such an activating principle is not subject to the laws of energy, nor to any other known laws of Physics or Chemistry. The biologist adopts the view as a working hypothesis or supposition, that the vital activities, irritability, contractility, reproduction, and so on, are visible evidence of the operation in protoplasm of the laws of Physics and Chemistry that apply everywhere else in the Universe, that the manner in which these laws operate in the living body is knowable, although in many cases indeed not yet known. This point of view is justified by the fact that, with mechanism as a working theory or basis, very much has been discovered concerning the nature of life. Each decade marks progress in enlarging our understanding of how protoplasm operates in carrying on the activities that are peculiar to it. Here we shall regard the characters of living objects as manifestations of the laws of Physics and Chemistry operating in a peculiar substance, protoplasm.

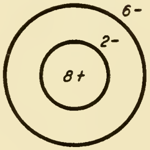
Nature of Matter. *Elements*: Life, then, from this point of view, consists of a complex of phenomena, each of which is an expression or manifestation of energy, in a body composed of finite materials. To appreciate its nature it is necessary first to comprehend the fundamental concepts of the nature of matter and of the laws of energy, for life is one of the consequences of matter and energy. To do so requires that the imagination be projected to consider the structure and behavior of particles that are almost infinitesimally small, and that one visualize the behavior of the units of which they are composed, an order that is as complex as the relations between the sun and the planets.

According to the modern theory of the nature of all matter, all substances are made up of exceedingly small particles, termed ATOMS. The atomic theory is in reality a very old one; in its earliest form it was based upon pure speculation, but modern Science by experimental methods has substantiated the essentials of this early theory and has greatly enlarged it. When a material is composed of atoms of the same kind it is known as an ELEMENT. There are known to be ninety-two elements. Some are solids at ordinary temperatures, as gold, iron, carbon, lead; others are gases, oxygen, nitrogen, hydrogen, and others; one, mercury, is a liquid. For convenience the elements are designated by symbols: C is carbon, O is oxygen, Na is sodium, Cl is chlorine, K is potassium, S is sulphur, and so on. The atoms of the various ninety-two elements differ greatly in size. The hydrogen atom is the smallest; one gram of the hydrogen gas contains 660,000 times a million billion hydrogen atoms. The heaviest element is uranium, an atom of which weighs as much as 238 hydrogen atoms. The atoms of all the elements are so very minute that they are utterly beyond the range of vision of the highest power of the microscope; their existence, structure, and behavior, are known from indirect evidence.

The structure of the atom has been one of the chief problems of modern science; it is now generally regarded as being composed of two types of electrical charges, ELECTRONS, which are negative, and PROTONS, which are positive. It is thought that the centre of the atom is composed of a nucleus of protons (positives) around which an equal number of electrons (negatives) form a succession of shells. According to some theories, the electrons describe regular orbits at fixed distances from the nucleus. The different properties of the atoms of the various elements are determined by the number and arrangement of the electrons in the outermost shell or orbit, and by the ease with which these outer electrons may be detached, or by their tendency to take up more electrons. The arrangement is conventionally represented by diagrams. Thus in the simplest case, the hydrogen atom, the arrangement of the single proton and the single electron may be:



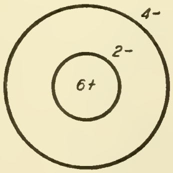
It is thought that in the oxygen atom the electrons form two shells, the inner containing two, and the outer six electrons:



It is known that the six electrons on the outer shell of the oxygen atom do not entirely satisfy the electrical conditions in the system; it will associate itself with two more electrons. Thus when oxygen and hydrogen are mixed they combine promptly, the oxygen atom attaching two hydrogen atoms by reason of the two electrons thus obtained. The combination of atoms formed in this fashion is called a MOLECULE. One speaks of the number of bonds by which an atom attaches to other atoms as the VALENCE of that particular substance. Thus hydrogen has the valence 1, oxygen 2, chlorine 1, carbon 4, and so on. The valence of an element, then, simply states the number of electrons that an atom will give or take.

Molecules: The molecule that is formed when oxygen and hydrogen unite is water. One speaks of molecules thus formed of different types of atoms as CHEMICAL COMPOUNDS. For convenience, the molecule is represented by symbols of the atoms of which it is composed, showing how many and what kind of atoms are present. Thus two atoms of oxygen form a molecule of oxygen, written O_2; the water molecule is H_2O; sulphuric acid is written H_2SO_4, being composed of two hydrogen, one sulphur, and four oxygen atoms. Any given chemical compound always contains the same constituents always in the same proportions; a molecule of water always consists of two hydrogen and one oxygen atoms. If the number of atoms is changed the characters of the compound are likewise changed. If an atom of oxygen is added to the water molecule, H_2O, a new compound, H_2O_2, hydrogen peroxide, is formed, the characteristics of which are different from those of water.

Organic Compounds: If a bit of plant or animal substance, for example, a leaf or a piece of meat, is heated in a tube not easily reached by the air, there remains a residue of black materials, largely composed of charcoal, or a crude form of carbon. This simple test demonstrates that the element carbon is a conspicuous part of protoplasm. This being true, it becomes necessary to understand at least some of the characteristics of the carbon atom.



It is known that the carbon atom has four electrons on its outer shell or orbit and will accept four more, that is, it has the valence 4.

It is therefore very reactive with other atoms, and forms a very great number of compounds. So great is the known number of compounds of carbon that their study constitutes a separate branch of chemistry, known as Organic Chemistry. The name is due to a belief of chemists of more than a century ago that all carbon compounds were formed solely in living organisms. Compounds that do not contain carbon atoms are known as inorganic compounds.

For clarity it is convenient to represent the relation of carbon atoms with other atoms in a compound by conventional diagrams, commonly called structural formulæ. All four of the unsatisfied bonds of the carbon atoms may take up hydrogen atoms, as we have seen how the oxygen atom holds two hydrogens in the water molecule. The resulting carbon compound is written structurally as:

$$\begin{array}{ccccc} & & \mathrm{H} & & \\ & & | & & \\ \mathrm{H} & — & \mathrm{C} & — & \mathrm{H} \\ & & | & & \\ & & \mathrm{H} & & \end{array}$$

This is the gas, methane, the chief component of natural gas. Or one or more of these bonds may be taken by another carbon atom with its hydrogen atoms and other types of atoms that may be associated. Thus

$$\begin{array}{ccccccc} & & \mathrm{H} & & \mathrm{H} & & \\ & & | & & | & & \\ \mathrm{H} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{OH} \\ & & | & & | & & \\ & & \mathrm{H} & & \mathrm{H} & & \end{array}$$

is regarded as the arrangement of the atoms in common grain, or ethyl, alcohol. Common cane sugar contains twelve carbon atoms arranged in a similar fashion, the side bonds being satisfied by twenty-two hydrogen and eleven oxygen atoms. The common way of representing the numbers of various atoms in cane sugar is $C_{12}H_{22}O_{11}$; the structural formula is cumbersome.

The ability of carbon atoms to combine with other carbon atoms and with other types of atoms in the manner illustrated accounts for the almost infinitely great number of carbon-containing compounds. Furthermore, in many of these the carbon atoms are arranged in long chains, forming what are actually known to be long molecules. This is the nature of the protein molecules, which will be discussed farther on.

Solutions. When a substance is scattered in a liquid so that the molecules are separated, it is stated that the substance has dissolved. In a true solution the molecules are equally distributed and do not settle out. Most of the compounds which are important in living materials dissolve rather freely in water, but the living substance, protoplasm, does not itself dissolve. Some substances, for instance fats, which are organic compounds, do not dissolve in water and hence are not found uniformly distributed in the living material.

Ions. When inorganic molecules, for example, caustic soda, NaOH, dissolve in water, some or nearly all of the molecules separate into two portions or RADICALS. By the loosing of electrons each acquires an electric charge. The atom or radical written on the left in the formula acquires a positive charge because it loses an electron while the radical on the right, OH in this case, by gaining an electron becomes negatively charged. In a solution of NaOH, then, are to be found positively charged Na atoms and negatively charged OH radicals. Atoms or radicals so charged are termed IONS, and compounds which behave in this way are known as ELECTROLYTES. In general, organic compounds, that is, the complex carbon compounds, exhibit much less of this property of ionization than do inorganic compounds.

Reactions. The formation or breakdown of a molecule is called a REACTION. Reactions are written in the form of equations.

For example, zinc chloride, $ZnCl_2$, and the gas hydrogen are formed by the reaction between hydrochloric acid, HCl, and metallic zinc, Zn. The reaction is written:

$$2\ HCl + Zn \rightleftharpoons ZnCL_2 + H_2$$

Zinc (valence 2) combines with two chlorine atoms and hydrogen with but one; therefore two molecules of HCl are necessary in the formation of each molecule of $ZnCl_2$. Theoretically, all chemical reactions are reversible; hence in the equation the equals sign is modified to show this reversibility. Many organic molecules are transformed into different substances by the addition of a molecule of water. Thus in the human digestive system cane sugar (sucrose) is converted into dextrose and fructose.

$$\overbrace{C_{12}H_{22}O_{11}}^{\text{Sucrose}} + H_2O \rightleftharpoons \overbrace{C_6H_{12}O_6}^{\text{Dextrose}} + \overbrace{C_6H_{12}O_6}^{\text{Fructose}}$$

A reaction in which water is involved in this fashion is known as HYDROLYSIS.

Acids and Bases. Inorganic molecules that contain one or more atoms of hydrogen which ionize in water, and some organic molecules that behave in the same fashion are termed ACIDS. Acids are highly reactive, their reactivity being due to the presence of ionized hydrogen and proportional to the extent to which they ionize, in other words, to the number of hydrogen ions. Both inorganic and organic molecules that contain OH radicals which ionize in water are termed BASES or ALKALIS. The OH radical is also highly reactive and whether a substance containing OH radicals behaves as a weak or a strong alkali depends on its degree of ionization. Ionized hydrogen atoms, it will be remembered, are positively charged while ionized OH radicals are negatively charged. Thus when both are present in a solution in equal numbers they neutralize each other; the solution is then described as neutral and reacts neither as an alkali nor as an acid. Water is such a solution, for some few water molecules, (HOH), dissociate into H and OH ions, but in pure water their numbers are exactly equal.

Salts. When the hydrogen atoms of an acid are replaced by some other type of atom, the compound is known as a SALT. Thus if the H atom in hydrogen chloride (hydrochloric acid, HCl) is replaced by a sodium atom, the compound formed is common table salt, NaCl. If the two hydrogen atoms in sulphuric acid, H_2SO_4, are replaced by a single magnesium atom, Mg, the resulting compound is magnesium sulphate, $MgSO_4$, commonly known as Epsom Salts. Salts of inorganic acids ionize freely when in solution and thus exhibit electrical properties as do acids and bases.

Compounds in Living Matter. The elements found in protoplasm are comparatively few, twelve or more of the common ones, oxygen, hydrogen, nitrogen, sodium, iron, potassium, calcium, phosphorus, sulphur, chlorine, iodine, and usually traces of others. It is worth noting that none of the rare elements are found; so the behavior of protoplasm cannot be ascribed to any peculiar element. Living protoplasm contains inorganic salts, bases, and acids. These are dissociated, that is, ionized, to some extent in protoplasm, for protoplasm contains a large proportion of water. If the number of molecules of one of these compounds is changed, changes also occur in the others because the electrical conditions are disturbed. Particularly is this true of the balance between acid and alkali; it appears that this balance is essential in the life of the material, for any great disturbance of the acid-alkali balance constitutes a serious injury to the living mechanism. Of the inorganic molecules in protoplasm, undoubtedly water is the most prominent and in many respects the most important. Its usefulness will be referred to farther on. Water almost invariably forms at least 70 per cent of the weight of living bodies.

The chief organic compounds in protoplasm may be grouped into three categories. Of these PROTEINS are the most prominent. These are complex chain molecules with many carbon atoms linked together and, of course, many side bonds that may in turn be attached to complex arrangements of carbon and associated atoms. Their structure and the fact that the carbon atom has four bonds to be satisfied make for the almost infinite variety of compounds that form the protein group. Some are known to be made up of many thousands of atoms; the weight of a single protein molecule may equal that of more than sixty thousand hydrogen atoms.

Protein molecules are in reality made up of various combinations of molecules of distinctly simpler nature, known as AMINO-ACIDS. Nineteen different amino-acids are known to exist. They all contain one or more radicals, known as CARBOXYLS, with the structure COOH, and one or more nitrogen-containing radicals, NH_2. The COOH gives them an acid property, since the H will ionize when in water, and the NH_2 gives them their alkaline property because in water it tends to behave like ammonia, NH_4OH. Proteins are formed by the combination of various amino-acids, the COOH radical of one being combined with the NH_2 radical of another, and so on. The amino-acid molecules usually contain more than one COOH radical and more than one NH_2, so they are capable of being combined in many ways to form many varieties of protein. For purposes of clarifying the rôle played by amino-acids in the formation of proteins and the intermediate compounds that represent steps in the reaction, we may compare the relation of the various substances with the use of type in forming words, sentences, and paragraphs. Let the letters represent the amino-acids. Words then represent various combinations of letters, as intermediate compounds represent various combinations of amino-acids. Sentences are formed of combinations of words; and the combination of intermediate compounds are steps in the formation of proteins. Finally, sentences form paragraphs that have definite meanings; and intermediate compounds form proteins of definite character. As the number of words, sentences, and paragraphs that may be formed by the letters of the alphabet are almost infinitely great, so the number of compounds that may be formed by the nineteen different amino-acids is likewise almost infinite. It should now be clear that it is possible for two quite dissimilar organisms to contain some proteins that are identical and that it is possible for two quite similar organisms to contain some proteins that are different. Similarly, in the same animal different parts of the body contain quite dissimilar proteins.

The general physical properties of the proteins are similar to those of gelatin and of egg white, which are in fact proteins. Proteins constitute approximately 15 per cent of protoplasm and in quantity exceed all other types of substances except water. Thus many of the physical properties of protoplasm, its fluidity and viscosity, its tendency to coagulate when exposed to high temperature, its changes with time, its responses to chemical agents, may be ascribed to the behavior of the proteins of which it is composed.

The FATS form the second group of organic constituents. All fats are much more complex than inorganic molecules and contain carbon, oxygen, and hydrogen, but not in the same arrangement as in the proteins. Three types occur in the living organism; fats containing no nitrogen nor phosphorus; fats containing nitrogen but no phosphorus, and fats containing both nitrogen and phosphorus. They are sparingly soluble in water and in protoplasm are in general found associated with or composing various boundaries and surfaces.

The CARBOHYDRATES are the third organic group found in the living system. These always contain carbon and also hydrogen and oxygen in the same proportions as in water. For example, muscle sugar, also known as glycogen, is considered as having the following formula: $(C_6H_{10}O_5)_n$. The n represents an unknown number of the $C_6H_{10}O_5$ groups that make up the molecule. Other carbohydrates with which all are familiar are the starches, sugars, and cellulose, the last being the substance of which paper is composed.

The chemical structure and chemical properties of all these substances may be, and in many cases have been studied by the chemist. But none of these are alive when isolated from protoplasm, although they behave in the test tube much as they are known to behave in the living material.

Life as a Chemical Process. Of the many types of compounds that occur in protoplasm, some react readily, some are loosely bound, unstabile molecules, some are inert, and some are stabile. A number of simple chemical reactions have been given here to illustrate the principles. In the living organism some of the reactions are similarly simple; others are exceedingly complex, for example, changes and re-combinations in the proteins. In 1828 Wöhler artificially manufactured urea ($CO\langle{}^{NH_2}_{NH_2}$); it was the first of the so-called organic compounds to be synthesized artificially. This led to the study and synthesis of other organic compounds and gave impetus to the idea that life is a chemical process. It was reasoned that since protoplasm was made up of organic and inorganic compounds and continues always to build up these substances, life itself must be a series of chemical reactions. This led further to the idea that protoplasm is alive because it may be composed of a peculiar type of organic molecule; the expression "the living molecule" is still occasionally used. But the living properties of protoplasm are not identical with the properties of any single type of molecule found in the system; they are the products not only of the chemical properties but also of the physical properties of many sorts of molecules. For instance, water in protoplasm has the same properties that water in the stream has; proteins have the same properties as in a test tube. In protoplasm these properties contribute to the characters of life but are not themselves life. In other words, the process of living is the summation of a complex series of both physical and chemical events in which all compounds present take part. Eventual success in artificially producing living protoplasm rests entirely on the hope of being able to unravel this series. No realization of this hope appears possible in the immediate future. Chemical analyses of many of the compounds found in protoplasm have been made but they do not reveal why protoplasm is alive. Nor are these analyses always wholly trustworthy as regards the chemical structure of the substance in question when it is in the living protoplasm, for sometimes the extraction of the substance for chemical study alters it chemically. Our ideas concerning the chemical processes of life are in part drawn from known facts and reliable analyses, and in part from inference from similarly reacting non-living systems, for example, the behavior of gelatin as a chemical agent.

Energy. If we consider for a moment the nature of the characters that distinguish living bodies from non-living objects, we arrive at the conclusion that all of them are indications of change, of activity in the protoplasm of which the bodies are composed. One of the first principles of mechanism is that wherever change takes place, work is done. Power to do work is a property of protoplasm and power to do work is the usual definition of ENERGY. Energy is ordinarily measured by the amount of work it may perform. Energy, then, is involved in all the changes that are constantly going on in the living organism. Energy occurs in a variety of forms. It is convenient to think of it in terms of electrical energy, chemical energy, radiant energy, heat, or mechanical energy, although other forms are possible. Energy in action is spoken of as KINETIC ENERGY; the energy a body possesses by reason of its condition or position is known as POTENTIAL ENERGY. Kinetic energy may become potential energy and potential energy may become kinetic. When a weight is lifted, kinetic energy is expended in the effort, but the weight now possesses an exactly equivalent amount of potential energy by reason of its position. If energy is required in forming a molecule of a compound, then that same amount of energy resides in that molecule in potential form and becomes kinetic, or, active when the molecule is broken down. If energy is required to build up a sugar molecule, then when that molecule is broken down in protoplasm, energy is released. Energy is converted from one form to another without decrease; when a quantity disappears at any place, either in the organism or in the nonliving world, an exactly equal quantity appears at another place in some form or forms. Energy is not created anew; it merely changes form. An animal does not create energy in order to move; it merely transforms energy from some potential supply.

All chemical reactions involve changes in the distribution of energy. A common example is the effect produced when oxygen and carbon unite in the presence of a sufficient supply of oxygen. A single atom of carbon unites with two atoms of oxygen, forming the gas CO_2, with the release of energy. This energy makes itself evident in the form of heat. The amount of energy released by this reaction is the same, whether the reaction takes place slowly or rapidly, or whether it takes place as the burning of fuel in a stove or of sugar in the body of an animal.

Energy and Life. Some chemical reactions require energy; in other words, they cannot occur in the absence of heat or energy in some form. Both sorts of reactions, those which release, and those which take up energy, occur in the living organism. Energy-releasing reactions liberate energy that makes the reactions which require energy possible. Furthermore, living objects are constantly dissipating energy as they live, as heat, or as mechanical work. Some compounds in the organism must therefore contain potential chemical energy. The ultimate source of this energy must be from outside the organism; otherwise a living object would be a perpetual motion machine. We know this is not true. So protoplasm, the physical basis of life, is composed of compounds arranged as a system in which energy is being constantly transformed from potential to kinetic and from one form to another, requiring for its maintenance a constant inflow of potential energy and constantly exhibiting evidence that work is being done.

Physical Structure of Protoplasm. In appearance protoplasm is unimpressive (Fig. 1). Under the microscope there is nothing particularly striking in its translucent, jelly-like appearance. But its peculiar powers always prompt a searching analysis of its make-up. The question is always uppermost: What structure or arrangement in this watery, gelatinous mass is the seat of its life processes? It was not until the latter part of the nineteenth century that the physical nature of protoplasm was determined; its most intimate details still elude analysis. Prior to this time observations and speculations had led to various conclusions concerning its structure. By some it was thought to be a mass of living fibres in a watery liquid; others observed granules and concluded that the living portion was granular, the granules being suspended in a watery liquid. Other observations showed that the structure is that of a foam, the minute cells of the foam filled with fluid. But in the last years of the century observations on both living and carefully killed and prepared protoplasm showed that all these pictures could be found in the same protoplasm at different times. It is now generally agreed that the whole of protoplasm is essential to its life and that it consists of visible fibres, foams, and granules, in a watery medium, the exact structure of which is not known but which is undoubtedly a complex colloid.

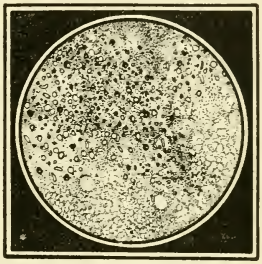


Fig. 1.—Living human protoplasm as it appears when examined under a high power of the microscope. The specimen was taken from the lining of the mouth and put under light pressure; the field of observation was intensely illuminated.

Colloids. Colloids were first defined by a chemist in 1861. Since the living substance of all living objects, Man as well as the most obscure plant, is colloidal, some understanding of the nature and characteristics of colloids is essential to an appreciation of the principles of Biology. A colloid in the broadest sense consists of one or more substances finely divided into particles greater than one molecule and suspended in another substance. Under this definition a cloud is a colloid, consisting of water finely divided and suspended in air. The nature of the suspending medium may often be the chief factor in determining much of the physical nature of a colloidal system. Two common substances illustrate this clearly. Cream is essentially a suspension of finely divided droplets of oil suspended in water; butter is an oily mass containing finely divided water droplets (Fig. 2). It is a familiar fact that cream is highly fluid, while butter much more closely resembles a solid. The difference in physical properties between cream and butter is obviously due to a simple difference in the physical arrangement of the two substances, oil and water. Where water is the suspending medium the fluidity of the system resembles that of water. Where oil is the suspending medium the characteristics resemble those of the oil.

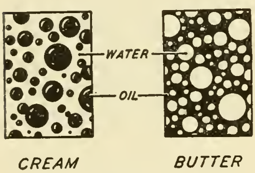


FIG. 2.—Diagram illustrating the difference in distribution of water and oil in cream and butter.

But cream and butter are systems in which essentially only two substances are concerned; that is to say, the system is diphasic. Protoplasm is much more complicated. Suppose a system consisting of a liquid finely divided into masses greater than one molecule and suspended in another liquid in which it does not dissolve. Further, suppose to this is added small quantities of salts, a trace of acid, a trace of alkali, and some fats. Further, suppose that a variety of colloidal particles and large molecules of various sorts are added, some to the suspending medium and some to the finely divided substances. The result is a complicated, polyphasic, colloidal system. Protoplasm is regarded as a polyphasic system of still greater complexity. The chief suspending medium, or continuous phase, or external phase, as it is called, is water. The suspended substances, or internal phase, or discontinuous phase, are chiefly substances that are wetted by water, that is, they take up or absorb water in a manner similar to the adsorption of water by gelatin. It is quite probable that there is a great variety of suspended substances, some of which may be considered as clumps or aggregates of molecules, in other words, colloidal particles, but many of which, particularly the proteins, are large molecules that because of their large size exhibit the characters of molecular aggregates. One may with some accuracy think of these bodies or large molecules as being surrounded by an envelope of water molecules, the thickness of the envelope varying with the constant changes that are characteristic of living protoplasm. This picture gives us a concept, however inaccurate, of the ground substance of protoplasm which under the microscope appears to be structureless. Visible bodies are fibres, granules, vacuoles, rods, and films.

In order to comprehend the immensity of the problem of understanding the physico-chemical nature of the processes in protoplasm that result in the phenomena known as irritability, growth, and so on, it is necessary to examine the nature of the behavior of colloidal systems in general, fundamental properties that are common to non-living as well as living systems.

Surface Phenomena. Each particle of a colloidal suspension exposes a surface to the suspending medium and the sum of the surfaces in a colloid is a very great area. It is considered that the peculiar properties of colloids that distinguish them from molecular dispersions or true solutions are largely due to the properties of the boundaries, or, surfaces, between the suspended and the suspending media. Since protoplasm is a colloid, it becomes necessary to consider the chief facts concerning surface phenomena, particularly as they are related to colloid behavior.

Surfaces in Protoplasm. But how much surface is to be found in the protoplasmic colloidal system? It must be understood that when the term surface is used it must be applied to all the boundaries between suspended substances and the external phase, not merely the boundary between the environment and the protoplasm. Typical colloids are regarded as being composed of particles not greater in diameter than 0.1 of a thousandth of a millimeter, or 0.1 micron, and not less than 0.001 of a micron, or 1 millimicron. Now if a solid having a diameter of 1 centimeter is divided into particles with diameters of 0.1 micron, that is, the largest of colloidal particles, the combined surfaces of the particles is 126 square meters, equal to the area of one side of a fence a little more than a yard high and nearly 130 yards long. If the substance is divided into particles with diameters of 1.0 millimicron, the smallest of colloidal particles, the entire surface exposed by the particles is 12,000 square meters, or equivalent to the surface on one side of a fence a bit more than a yard high and over seven miles long. Since the colloidal substances in protoplasm are between the extreme diameters given here, the total surface in a mass of protoplasm with a diameter of 1 centimeter is somewhere between 126 square meters and 12,000 square meters, in any case a tremendous area. It is therefore not difficult to understand that the actual surface in protoplasm that is constantly responding to the laws of surfaces is relatively very great in proportion to the volume of protoplasm.

Surface Tension. We are all familiar with the fact that the surface of a container of water is a film that behaves as if it were stretched. The surface of the water is in reality the boundary between water, H_2O, and air, which is a mixture of nitrogen, oxygen, carbon dioxide, and traces of other gases. If a fine droplet of oil is suspended in water, the surface of the droplet is the boundary between the oil and the water; it is more properly called an interface. Such boundaries are in a state of tension and therefore represent an equilibrium between some sort of forces.

According to commonly accepted theories, each material particle in the cosmos exerts an attractive force on all other material bodies. This is regarded as true among molecules of a substance as well as between celestial bodies of enormous size. Thus, in a container of water the water molecules attract each other, the property being termed COHESION. In the deeper portions of the water, away from the sides and surface, each molecule is attracted by adjacent molecules in all directions with equal force (Fig. 3). But at the surface, the interface between the water and the air, the water molecules there located are attracted downward by the underlying water molecules and upward by the molecules of the gases in the air. The attraction of the gas molecules for the water molecules is not so great as that of the water molecules toward each other. The pull on the surface water molecules is therefore unequal. Equilibrium is attained when the number of the water molecules at the surface is the least possible, that is, when the surface is as small as possible. So surfaces always tend to contract; hence a drop of a liquid always tends to assume a spherical form. The tension that results is termed surface tension and differs widely between different substances. The surface tension of water is given as 72 dynes per centimeter; that of ether is 16 dynes per centimeter.

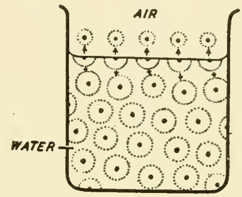


FIG. 3.—Scheme illustrating the theory of surface tension. Water molecules at the boundary between the water in the beaker and the air above are subjected to unequal pull. They are more strongly attracted by the water molecules below than by the molecules of the gases of which the air above is composed. Because the liquid is incompressible, its surface is therefore in a state of tension.

The surface of a liquid substance, whether in contact with air or with a suspending medium, being in a state of tension, is a seat of potential energy. Consequently, if the area of the surface is reduced, energy is thereby released; since free energy always tends to become bound it is transformed into some other type.

It has been established that substances which reduce surface tension accumulate at surfaces. This means that when some suitable substance, such as alcohol or ether, is added to water, the molecules of the added substance accumulate in greater proportion at the surface than elsewhere in the solution. Hence the amount of potential energy at the surface of a water-alcohol solution is materially less than in a surface of pure water. So when various adulterants are added to water the surface energy relations are distinctly altered.

If this is true in non-living systems, like water-alcohol solutions, it is also true in protoplasm, which is at least 70 per cent water. It is known that protoplasm contains and constantly manufactures substances that reduce surface tension, for example, fats. Furthermore, protoplasm is also constantly using up and reducing the amounts of such substances. Consequently, in the colloidal protoplasm the energy relations and characters of the interfaces between the colloidal particles and the suspending medium are constantly undergoing change; surfaces increase and decrease and the proportions of different sorts of molecules vary as compounds are broken down or as new compounds are formed.

Electrical Charges at Surfaces. If an inorganic substance such as hydrochloric acid, hydrogen chloride, is dissolved in water, an appreciable number of the HCl molecules are decomposed into positive hydrogen ions and negative chlorine ions. These electrical charges are real, not merely theoretical. Hence in this solution there are to be found water molecules, HCl molecules, positive H ions, and negative Cl ions. The surface film will be composed of some of each of these constituents. Now it happens that the H ions and the Cl ions do not move about with the same speed, nor do they reduce surface tension to the same degree. The H ions move much the more rapidly and will be somewhat in excess at the surfaces of the solution. This preponderance of H ions confers thereon a positive electrical charge that may be detected and measured with suitable instruments. Similarly, in all cases where a substance dissociates into ions, electrical charges, either positive or negative, are found at surfaces in the solution. If colloidal particles are present in the solution, they too bear surface charges, since they expose surfaces to the surrounding liquid that suspends them.

In protoplasm, salts, acids, and bases are present and dissociated into ions. Thus these substances confer charges on the surfaces at which they accumulate. And so it has been found that these colloidal particles each bear an electrical charge, each minute in itself, that may be changed as chemical reactions take place in protoplasm or ionizing substances are introduced from the outside environment.

Protoplasm as a Reaction System. The properties of water are indissociably linked with the properties of protoplasm. Water is an almost universal solvent; its electrical characteristics are such that chemical reactions take place in water more readily than in any other environment; its specific heat is high and it therefore serves as a heat buffer, that is, retains and dissipates heat energy slowly. Furthermore, the plasticity and fluidity of protoplasm are largely expressions of the presence and state of water in the system. It has been pointed out that the compounds in protoplasm are extremely numerous and very complex. With water universally present throughout the protoplasm, the stage is set for an intricate, interrelated series of actions and reactions between the water and other constituents, and between the complex compounds, new compounds being constantly formed and others being broken down, an amazingly complicated system with many dependent and probably many independent variables. All these reactions are bound to affect the surface energy relations and electrical conditions in this colloidal state, as these in turn affect and determine the reactions. But it must not be thought that this complex of action and interaction is in any way chaotic. On the contrary, all the evidence indicates that the whole is an orderly and unified system. It is merely our lack of anything like a complete knowledge of the workings of matter in the living state that leads us into confusion. In other words, the confusion is subjective, not objective. We have at hand only the merest outlines and probably they are not very accurate. Electrons and protons determine the behavior of the elements; the elements in protoplasm are arranged into extraordinarily complex molecules that react toward each other because of the elements they contain, and the whole is arranged in a colloidal condition, with all the properties that characterize the colloidal state.

From the foregoing it is plain that no very complete description of protoplasm as a reaction system is at present possible. It is the purpose of modern Biology to study the reactions by inference from models and reactions in non-living systems, and by experiment on living protoplasm, and thereby to evaluate the rôles played by these various physical and chemical phenomena in the energy transformations which are described as the characteristics of life.

Since protoplasm is alive because of its peculiar organization, a very great difficulty is placed before the technical processes involved in analyzing the physico-chemical nature of life. If one trifles with this intricate system with any violence, the organization is destroyed and the observer is left with a non-living mass from which the very characters he hoped to study have disappeared.

Life and Machines. Living organisms are often compared to man-made machines. The analogy is convenient but not very accurate. In the sense that both are composed of parts that by transformations of energy do work, the comparison is justified. But a living organism possesses powers that Man has thus far been unable to introduce into a machine. No man-made machine can repair itself nor secure its own sources of energy. Furthermore, no machine directs its activities from within itself, nor can it reproduce itself unless directed and controlled by plans that do not originate from its own work, from its own expenditure of energy.

General Consideration. In the chapters to follow, many phenomena of animal life will be described and discussed. Only occasionally will it be possible to relate or to describe them in terms of the principles of Chemistry and Physics that the present-day biologist knows to be their fundamental nature. With a background of knowledge that all living processes are expressions of this intricate physico-chemical system there comes a profound realization of the amazing complexity of all living forms and of the fact that every character or action whether it occurs in a plant or in Man, however small or apparently insignificant, in some way is the result of energy transformations in a substance that is infinitely more complex than any other substance or system that the human mind has thus far studied. To attain this realization is to master the *First Principle* in appreciation of the science Biology.

But the reader will ask why he has been guided through this maze of technicalities; of what practical or personal interest or value are the laws of Chemistry and of Physics as exemplified in protoplasm; what have the abstruse principles of surface action and of colloid behavior to do with everyday life? To point out one aspect should suffice. Human disease is fundamentally some sort of disorder in human protoplasm. Every human is sooner or later intimately concerned with disease. It is the task of the human body to overcome this disorder and it is the profession of the physician to assist. Intelligent understanding of the nature of protoplasm, when converted into intelligent care of the body, tends to reduce the probability of disorder, and the more profound the physician's understanding of the workings of the protoplasmic system, the more intelligent and effective are his attempts at assistance.

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Chapter II

THE CELL. ITS NATURE, FUNCTION OF ITS PARTS, AND ITS SOURCE OF ENERGY

Structure of the Cell. Living objects are not merely masses of a generalized substance, protoplasm. The protoplasm is organized into various types and into structural and functional units called CELLS (Fig. 4). The term is somewhat of a misnomer, since the units are not empty, nor fluid-filled cavities, but are compact masses of protoplasm, each mass usually surrounded by a limiting MEMBRANE. Within this limiting boundary is to be found protoplasm of various types. Thus, each cell contains at or near its centre a highly specialized mass of protoplasm called the NUCLEUS. The nucleus, except when it is undergoing division, is bounded by a thin membrane of a still different type of protoplasm, the NUCLEAR MEMBRANE. The greater volume of the cell is occupied by a type of protoplasm called CYTOPLASM. In the cytoplasm are to be found specialized masses, more dense than their surroundings, called PLASTIDS, of which there appear to be many sorts. Adjacent to the nuclear membrane, in animal cells at least, is to be found an important, though small, body, the CENTROSOME. In the vicinity of the centrosome the cytoplasm is somewhat different in appearance from the remainder; this region is known as the CENTROSPHERE. Rod-like structures are frequently found scattered throughout the cell outside the nucleus. These are named MITOCHONDRIA. They appear to be of regular occurrence, but their significance is still a matter of dispute. The outer boundary of the cytoplasm is itself a distinct type of protoplasm, although it is continuous with the underlying substance. This boundary, known as the PLASMA MEMBRANE, may be, and in many cases is, surrounded by a non-living pellicle or CELL WALL, formed by substances constructed by the chemical processes within the cell.

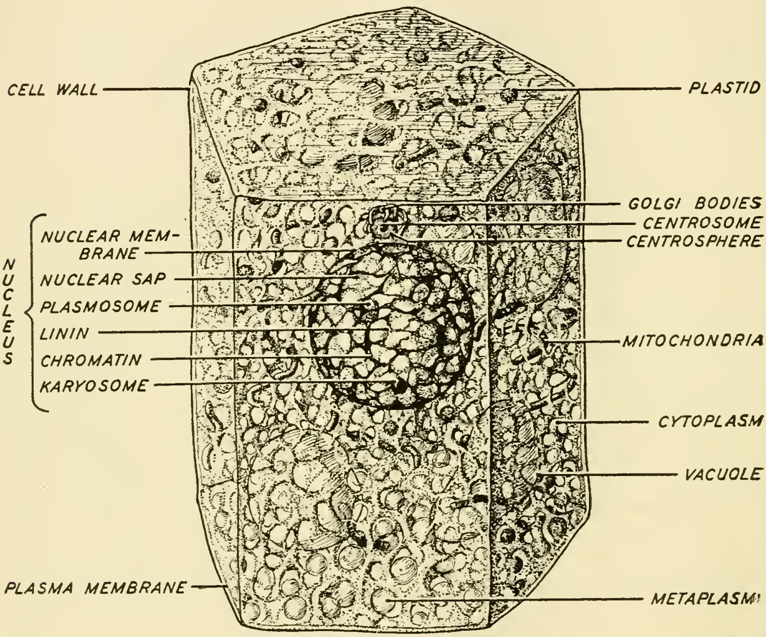

FIG. 4.—Diagram representing the structure of a cell. It must be understood that only the structures visible under the microscope are illustrated; these are comparatively coarse bodies. The colloidal nature of the seemingly structureless clear ground substance can be demonstrated only by special tests.

Thus it is seen that the term protoplasm is a word of broad meaning, since there are many types of protoplasm within a single cell. But its significance is still wider, for the protoplasm of each variety of plant and animal has its own peculiarities and the protoplasm of no two individual organisms is identical. Cells, however, are definitely organized bodies common to all organisms and the general pattern of cell organization is very much alike in all cells. Studied in one cell, this pattern serves as an interpretation of the arrangement of cell substances in any other cell. The study of cells and intracellular structures is called CYTOLOGY.

Shape of Cells. It is not possible to state that cells assume any particular shape. If the cell contents were a pure liquid and the cell were not confined, its shape would be spherical, due to the fact that the surface tension of drops of pure liquids impels the drops to a spherical shape—the law of minimal surfaces. But in

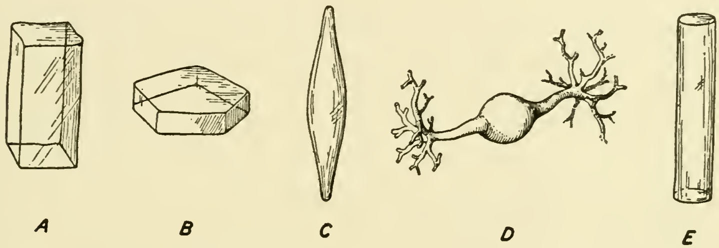

FIG. 5.—Diagrams illustrating several types of cell shapes. *A*, columnar, as are the cells forming the lining of the human intestine; *B*, pavement, the shape and arrangement of cells lining the bladder; *C*, spindle, as the muscle cells in the wall of the stomach; *D*, nerve, the general shape of nerve cells in the spinal cord; *E*, cylindrical, characteristic of the long muscle cells which make up the large voluntary muscles. In addition to those illustrated, plant and animal cells assume many other shapes.

many cells the protoplasm is a stiff jelly which resists a tendency to form a sphere. In other cells the contents are confined and the cell has the shape imposed by the confining walls. The shape of some cells is determined by the fact that they are compressed together. But in general, the shape of the cell is as peculiar to it as are its other features and functions, an expression of its organization (Fig. 5).

Function of Cell Structures. The fact that these different intracellular types of protoplasm differ in appearance, react differently to chemical agents and to artificial staining, and are regular in location and behavior in all cells, proves that protoplasm in its living has formed into types chemically different in nature with special duties to perform; in other words, specialization of both structure and function has taken place. The study of the function of the cell and its parts is termed CELL PHYSIOLOGY. The exact functions of many observable parts of the cell are not completely known, but as evidence accumulates through careful observation and experiment, the general functions of some of the cell structures become clear.

The Cell Boundary. The limiting boundary of the cell, the plasma membrane, being the area of contact between the cell and its surroundings, serves as a regulator of admission and escape of materials. This function it exercises by reason of its properties as a membrane; it must not be thought of as possessing any power resembling an ability to select substances needed within the cell by any sort of intelligence. Its importance in the life of the cell directs our attention to the properties of membranes.

Membrane Permeability. Membranes may be of many sorts and are classified with regard to their relative PERMEABILITY. Thus a membrane may be impermeable to small particles but permeable to molecules. Other membranes may be impermeable to large molecules but permeable to small molecules. Still other membranes may be impermeable to molecules but permeable to ions. Living membranes are usually considered as SEMI-PERMEABLE; in general, they are impermeable to large molecules but may be permeable to small molecules, for example, H_2O, and rather freely permeable to some ions but not to all. The plasma membrane of the cell is regarded as a membrane of this type.

Semi-permeable membranes such as the plasma membrane may be thought of as sieves, the pores of which determine the size of the substances that will pass through, as small oranges may be sorted from large ones by being passed over a sorting board with small holes. But the size of the molecule is not the sole condition determining whether or not a substance will pass a cell boundary. In non-living semi-permeable membranes it is possible to demonstrate the fact that other qualities of the penetrating substance are important. Thus water will not pass through a rubber membrane, while alcohol, consisting of much larger molecules, will pass. This is regarded as due to the fact that alcohol will dissolve in a membrane of rubber while water will not. The boundary of the cell, being composed of watery protoplasm and also containing fatty substances, has solubility properties that in part determine its permeability. So the passage of a substance through a semi-permeable membrane into and out of a cell is determined by at least two conditions, namely, the size of its molecules and its solubility in the membrane. Any material entering or leaving the cell must be in such physical and chemical state that it may pass the cell boundary. Colloidal particles and large molecules like the protein molecules may be expected to be restrained by the cell boundary.

As cells differ in other respects so do they differ as regards the property of boundary permeability. The cells that make up the muscle of the human arm, for example, have properties of permeability that are somewhat different from those of the cells that compose the human brain. Thus the plasma membrane of the individual cell is a most important organ in regulating the life of the protoplasm.

Many important membranes in the animal body are composed of layers of cells and the permeability of such membranes is the sum of the permeabilities of the cells of which they are composed. The lining of the human intestine is a layer of cells that has the property of allowing certain substances to pass; similarly, the lining of the human lung allows certain gases to pass. The former cannot be substituted for the latter because of these differences in permeability.

Diffusion. If a crystal of some water-soluble substance, such as copper sulphate, be placed in water and allowed to dissolve undisturbed, the molecules will diffuse out through the water and in time the concentration, that is to say, the number of molecules of copper sulphate per unit of volume of the solution, will be exactly equal in all parts of the container. This is a phenomenon that always occurs when substances dissolve, whether it be a solid dissolving in a liquid or one liquid dissolving in another liquid. The molecules always pass from a region of higher to a region of lower concentration. So, if the plasma membrane of a cell is permeable to a certain substance, for instance oxygen, whether or not any oxygen actually passes into the cell will depend on how great a concentration of oxygen is already present. If the concentration of oxygen is less inside the cell than outside, oxygen will diffuse through the plasma membrane and enter the cell. It is likewise true in the case of substances formed within the protoplasm, for example carbon dioxide; if the concentration of carbon dioxide is greater within the plasma membrane than without and the membrane is permeable to carbon dioxide, the substance will pass out of the cell so long as this relative concentration on the two sides of the membrane exists.

Osmotic Pressure. But the plasma membrane is not freely permeable to many sorts of substances. The effect of its obstruction to the exit or entrance of such substances is very important in vital processes. To examine the nature of this effect under the most simple conditions, we may construct a model (Fig. 6). If an animal membrane, for example a sausage casing, is tied over the mouth of a glass cylinder and the cylinder partially filled with a strong solution of cane sugar, then inverted in water, the sugar molecules, being too large, will not be able to pass through the membrane from the region of higher to the region of lower sugar concentration. Water molecules will pass through the membrane into the sugar solution, however, thus obeying the principle set down above and moving from the region of higher to the region of lower water concentration. As the migration of the water molecules progresses, the sugar solution is diluted and the quantity of liquid within the cylinder increases and rises above its original level. Presently this rising column of liquid develops a distinct HYDROSTATIC PRESSURE that finally restrains the inward passage of water completely. The pressure developed varies with the concentration of the sugar; the greater the concentration of the sugar in solution

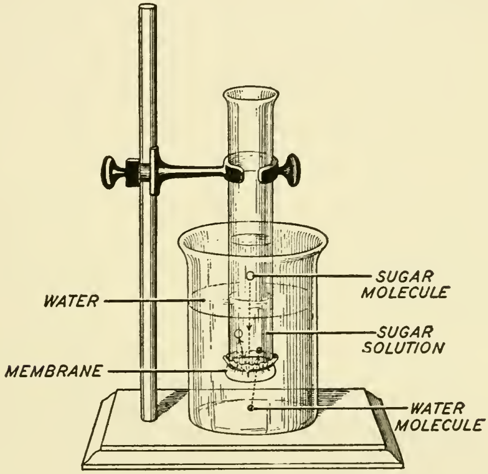

FIG. 6.—Diagram to illustrate the nature of osmotic pressure. The content of the suspended tube is a solution of sugar in water. The mouth of the tube is closed by a semi-permeable membrane and the beaker contains pure water. While the sugar molecules constantly bombard the membrane, they do not pass through; the water molecules readily pass into the tube containing the sugar solution. The result of the passage of water into the tube is a rise in the level of the tube contents above that of the surrounding water and a consequent development of a hydrostatic pressure that exactly equals the osmotic pressure of the sugar molecules.

the greater the pressure that is necessary to arrest further passage of water through the membrane. Now the passage of a substance through a semi-permeable membrane by diffusion is termed OSMOSIS and this hydrostatic pressure that is developed by the invasion of water into the sugar solution is exactly equal to the osmotic pressure of the sugar solution. Osmotic pressure is derived from the fact that all the dissolved molecules of the sugar are in motion and collide with the membrane; obviously the greater the number of sugar molecules the greater the number of impacts and the greater the pressure developed.

If we add to the water outside the cylinder sugar or any salt that will not pass through the sausage casing, then the migration of water into the cylinder will be reduced and will cease altogether when the concentration of molecules that do not pass is exactly equal outside and inside the cylinder. If we continue to add sugar to the water outside the cylinder, then the migration of water molecules is reversed and the contents of the cylinder shrink. Three terms are employed to describe the osmotic pressure relations between the contents of the cylinder and the surroundings. When the osmotic pressure of the sugar solution is greater than that of the water outside, it is termed a HYPERTONIC solution. When the concentration of molecules that do not pass the membrane is exactly equal within and without the cylinder, the solution is called ISOTONIC. When the contents of the cylinder are more dilute than the surrounding solution, it is spoken of as HYPOTONIC.

Function of the Cytoplasm. The relations between the cytoplasm of the cell, the cell boundary, and the surroundings are in many respects similar to the relation between the contents of the glass cylinder and the water. Colloids exhibit osmotic pressure, for colloidal particles do not readily pass through a semi-permeable membrane. Moreover, the cell contains large, osmotically active, molecules. The colloidal cytoplasm of the cell is placed against the semi-permeable plasma membrane; if the concentration of salts or other substances that do not pass through this membrane is less outside the cell than the concentration necessary to balance the osmotic pressure of the cytoplasm, then water continually flows into the cell. If this occurred in all living cells, then the cells would distend until the osmotic pressure within exactly balanced that without. On the other hand, cells would shrink if the osmotic pressure of the cytoplasm were materially less than that of the surroundings (Fig. 7).

From all this it is obvious that the contents of the cell must be isotonic with its surroundings, or else the plasma membrane must be less than freely permeable to water. The osmotic pressure of living protoplasm varies between different forms, but is usually approximately that of the surroundings of the cell. For example, the osmotic pressure of human body cells is approximately equal to that of a ten-per-cent sugar solution and that of the human blood stream is closely similar. If a blood cell is removed and placed in distilled water which contains no salts, it distends and bursts; if placed in strong salt (hypertonic) solution it shrinks and dies.

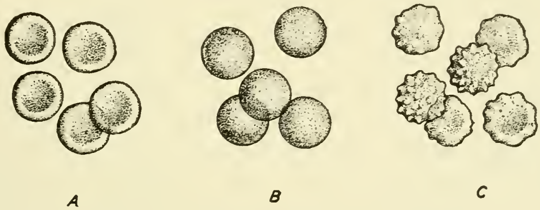

FIG. 7.—Effects of different osmotic pressures on the shape of red blood corpuscles. *A*, in an isotonic solution the normal shape is retained; *B*, in a hypotonic solution the corpuscle is distended because of water uptake; *C*, in a hypertonic solution the corpuscle shrinks because of water loss. Compare with Fig. 6.

Maintenance of the normal osmotic pressure within the cell is of very considerable importance in the maintenance of structure and function. It determines the turgidity of the cell and thus influences its shape; it in part determines the amount of free water in the cell and thereby in part determines the fluidity of the protoplasm. We have seen how the reactions in protoplasm are closely linked with its physical properties. Any violent disturbance of the normal osmotic pressure relations between the cell and its surroundings tends to disturb the living processes.

In addition to its properties of osmotic pressure, the cytoplasm of the cell has other equally important functions. It contains stored-up materials; it is a reaction medium, a theatre in which chemical and physical changes are constantly occurring; in egg cells its organization determines the beginnings of organization of the new individual.

Function of Nucleus. The cell nucleus is indissociably linked with the continuation of life of the cell, for if a fragment of a cell does not contain a nucleus it is certain to die within a short time. On the other hand, cell fragments containing a nucleus, or a portion of the nucleus, may reorganize, recover, and live normally. Just why the nucleus is such a vital part of the cell life is not definitely known. The statement is frequently made that the nucleus is the controlling centre of the cell; while this is true it gives us no picture of how nor why the nucleus exercises this function.

The nucleus is not a homogeneous mass of a single type of protoplasm but contains various types. Most prominent among the nuclear contents is a substance which stains heavily with certain types of stains and is therefore called CHROMATIN (Fig. 4). When a cell is about to divide, the first indications are in the behavior of the chromatin, and the ensuing phenomena of division seem to be devised to assure an equal division of the chromatin to the daughter nuclei. By a complicated process that will be described in detail later, the chromatin is concentrated into a characteristic number of bodies called CHROMOSOMES and these divide equally, giving rise to the same number of chromosomes in each daughter nucleus. All of the evidence points to the conclusion that the inheritable qualities of the cell are in some way associated with this substance, chromatin.

Function of the Centrosome. The centrosome is not present in some cells. Its real function is not known. It appears to act as a leading element in cell division, for the centrosome is first to divide, one portion eventually going to each of the daughter cells.

Plastids. The various types of plastids in the cytoplasm appear to be centres of reactions. Thus in the cells of green plants a type of plastid which contains a green coloring matter, CHLOROPHYLL, is the locus of the reaction whereby the cell manufactures carbohydrate. Other plastids are known to be the site of formation of fats and others are known to be the origin of ferments, or enzymes (p. 78).

Plants and Animals. Biology is a study of life processes wherever they may take place. We are familiar with the fact that two different types of life may be recognized, PLANT and ANIMAL. The study of plants is called BOTANY, the study of animals is called

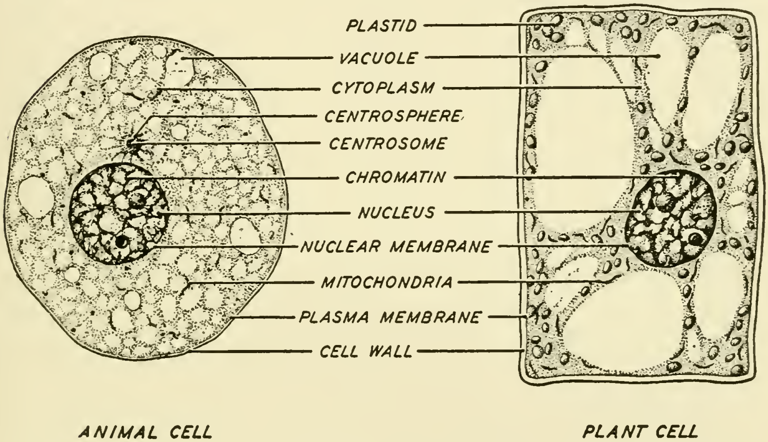

FIG. 8.—Diagrams to show certain structural similarities and differences between animal and plant cells. It will be noted that the centrosphere and centrosomes are absent from the plant cell and that plastids are more numerous and more conspicuous in the plant than in the animal cell. The wall of the plant cell is in general thicker than that of the animal cell.

ZOOLOGY. An organism may be studied in several ways; one may concentrate on its ANATOMY, or structure, or on its functioning, or PHYSIOLOGY. From what has gone before, we are now aware of the fact that to comprehend the major principles of living the study of structure and of function cannot be separated. So both Anatomy and Physiology are incorporated into the study of Animal Biology. But at once we are confronted with the questions: What constitutes an animal? What distinguishes animals from plants? Are the differences solely structural? (For in everyday life we make no mistakes in distinguishing animals and plants.)

The answer to these questions must first be sought in the answer to the question: What distinguishes animal cells from plant cells? Before going farther, it may be stated that there are living forms that partake of the characteristics of both plants and animals; in the last analysis, there is no sharp line of distinction between the two groups. But as regards typical plants and typical animals, the differences are clear. Some differences are to be found in cellular structures (Fig. 8). In general, typical plant cells possess a cell wall composed of a substance peculiar to plants, called CELLULOSE. It is the chief component of manufactured papers and is a carbohydrate, related to starches and sugars. Plant cells also frequently contain a large cavity filled with a non-living fluid called cell sap; the cavity is known as the SAP VACUOLE.

But the chief difference between typical plant and typical animal cells is in their method of subsistence. In order to understand this difference it is necessary first to discuss the main features of subsistence in living objects in general.

Metabolism. Previously the intricate nature of the physico-chemical system, protoplasm, was described. It was also shown that constant change is the constant feature of the system and that these events are wrought in a watery colloidal medium. The collective term that applies to this constant series of physico-chemical events is METABOLISM. Some of the processes serve to build up new compounds and new protoplasm; this phase of metabolism is termed ANABOLISM. Some of the metabolic processes are destructive. These reactions are described as CATABOLISM. Both are concerned in the vital phenomena which we have called the tests of life. Both anabolic and catabolic reactions are in reality transformations of energy, and the vital phenomena are effected only by an expenditure of energy. It is obvious, therefore, that protoplasm must have a source of energy which must be available in a potential state so that it can be converted into kinetic energy by the metabolic processes. The container of potential energy for protoplasm is commonly called a FOOD. Foods also have a second value, namely, the providing of materials used in building protoplasm.

Photosynthesis. The chief difference between green plants and animals is in their methods of obtaining foods, both as a supply of potential energy and as a source of ingredients necessary for the maintenance of the cell. In the green plant cell the green substance, CHLOROPHYLL, is located in plastids known as CHLOROPLASTIDS (Fig. 8). It is an activator which causes a reaction to take place between two common and otherwise undistinguished substances, water and carbon dioxide. This reaction can be effected by chlorophyll only in the presence of sunlight, the energy necessary for the combination of the substances being derived from solar energy. The result of the reaction is a carbohydrate; the molecule contains potential energy derived from the sun. The steps in the reaction are not yet thoroughly understood but may be summarized briefly as follows:

$$CO_2 + 3\ H_2O \text{ (In presence of sunlight)} = CHOH + 2\ H_2O_2$$
$$6\ CHOH = C_6H_{12}O_6 \text{ (a sugar)}$$
$$2\ H_2O_2 = 2\ H_2O + O_2$$

The end results of the reaction, which in reality is a series of reactions, are by-products, water and oxygen, and a carbohydrate containing potential energy.

Carbohydrates are formed only in this way, by the trapping of the energy of the sun in green plant cells. The entire supply of carbohydrate for all animals and all plants therefore depends on the action of chlorophyll, and the ultimate source of energy for all living objects is the sun. This process of the synthesis of carbohydrate by chlorophyll and solar energy is called PHOTOSYNTHESIS.

The proteins, which form a most important group of protoplasmic constituents, are nitrogen-containing compounds. Although the air is about 79 per cent nitrogen, neither plants nor animals are able to utilize the atmospheric nitrogen in building proteins.

Plants are, however, able to use nitrogen in the form of nitrites $\overbrace{(KNO_2)}^{\text{potassium nitrite}}$ and nitrates $\overbrace{(KNO_3)}^{\text{potassium nitrate}}$. Proteins also contain hydrogen, carbon, and oxygen, which are also the constituents of carbohydrates. Plants are able to construct proteins by utilizing the nitrogen from the soil nitrates and the substances in carbohydrates, the energy for the reactions being afforded by the carbohydrate molecules. Animal cells are utterly unable to perform this synthesis and are consequently dependent on plants for the proteins from which animal proteins are formed.

The chemical processes and changes involved in the building up of complex protein molecules by the metabolism of plants are intricate; they may be given here only in their most simple terms. We have seen how in the process of photosynthesis a carbon atom is added to a water molecule to form a simple carbohydrate unit, CHOH. Now if an atom of oxygen is added the result contains a carboxyl radical, COOH, which was shown elsewhere (p. 14) to be present in all amino-acids and hence in all proteins. Thus in the simplest case a fatty acid may be formed by the addition of an oxygen atom and combining of three molecules of CHOH; the result is CH_3COOH, acetic acid, the acid of common vinegar. Now suppose that one of the H atoms is replaced by a nitrogen-containing radical, NH_2. The result is CH_2NH_2COOH, known as amino-acetic acid, or glycine, or glycocoll; it is the simplest of all amino-acids. In a similar fashion other and more complex amino-acids are formed and are united to compose protein molecules. Thus the processes of protein construction include the formation of carbohydrates by photosynthesis, an oxidation, the addition of NH_2, and the union of the resulting amino-acids into protein molecules.

Plant Nutrition and Animal Nutrition. The nutrition of green plants is therefore an essentially constructive process, including the synthesis of energy-containing carbohydrates and the building up of proteins; it is known as HOLOPHYTIC NUTRITION. In contrast, animals in their metabolic processes are constantly liberating the stored-up energy from the compounds formed by plants and deriving their peculiar proteins from the proteins that plants have synthesized. The nutrition of animals, HOLOZOOIC NUTRITION, is therefore essentially destructive. Here, then, is a most important difference between typical animals and typical plants, and these facts constitute the most fundamental relation in the science of Biology.

Some types of plant cells, for example, molds, are able to extract what energy remains after animals and other plants have utilized food, and can absorb substances directly from living or dead bodies. This type of nutrition is known as SAPROPHYTIC. Animals which carry on their subsistence in this fashion are known as SAPROZOOIC.

The Nitrogen Cycle. It is now clear to the reader that nitrogen is necessary for the formation of proteins of all sorts, both plant and animal, and that the source of nitrogen is the nitrogen-containing salts in the soil. The relation between plant and animal nutrition and their respective places in Nature are best shown by following the history of nitrogen from the air, through plant and animal proteins, and back again to its original gaseous condition. A diagram (Fig. 9) shows the essentials of the cycle of nitrogen in living organisms.

Although green plants are capable of synthesizing carbohydrates from inorganic materials and upon carbohydrate bases construct proteins, they, like animals, are unable to employ atmospheric nitrogen and depend upon soil nitrates. For the replacement of the soil supply of inorganic nitrogen compounds green plants are dependent on the peculiar properties of the metabolism of minute plants, NITROGEN-FIXING BACTERIA. These microscopic organisms live in the soil associated with the roots of certain green plants, for example, the clover. In their life processes they normally utilize the nitrogen of the air, a characteristic that occurs in no other living organism. The nitrogen is combined with potassium and oxygen to form potassium nitrite, KNO_2, by some types of nitrogen-fixing bacteria. The cells of green plants can oxidize this nitrite to the nitrate, KNO_3, and then employ this salt in the series of reactions that eventually forms proteins. For the most part, however, other soil bacteria convert the nitrite to the nitrate and thus accomplish another step in the process before the salt is absorbed by the green

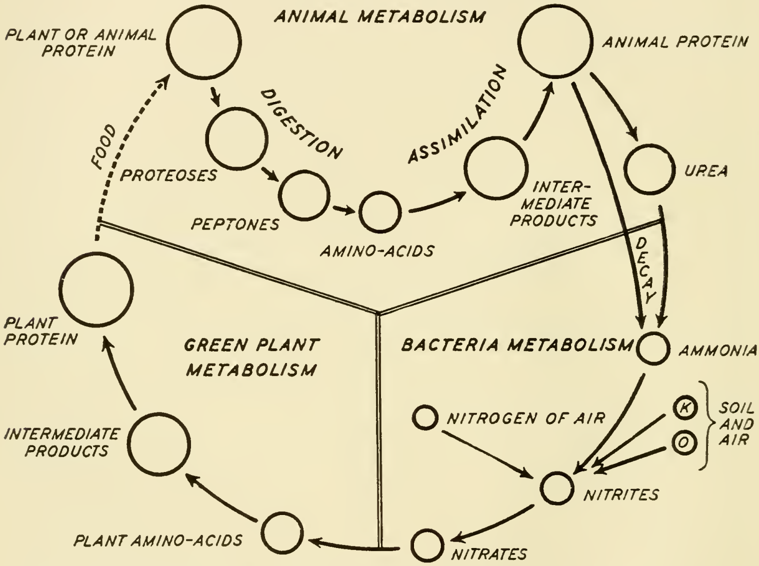

FIG. 9.—The nitrogen cycle. A scheme to illustrate the sequence in the utilization of nitrogen to form proteins and its return to the soil. The scheme also illustrates the nature of the changes which occur during the digestion and assimilation of protein by animals.

plant. Still other soil bacteria, termed DENITRIFYING BACTERIA, may undo this synthesis and rob the soil of its fixed nitrogen by breaking down these molecules and liberating free nitrogen gas. In the scheme showing the cycle of nitrogen the dependence of Man and all other animals on green plants and on the metabolic activity of the obscure nitrogen-fixing bacteria appears very clearly. From the relations that it represents one may also conclude that soil fertility is intimately associated with the nitrogen salts the soil may contain and that nitrogen fixation, that is, its capture and combination in usable form, is one of the most important of all chemical processes.

From these relations flows a tremendous influence on human society. The harvesting and removal of plants from fields year after year eventually robs the soil of its nitrogen salts. Consequently, plants that house nitrogen-fixing bacteria in their roots, fertilizing crops, must be planted in order to restore soil nitrogen. Thus agriculture is involved in a constant battle to maintain the usefulness of soils. Out of this struggle has grown methods of artificial nitrogen fixation, transportation chains for importing nitrogen salts from foreign sources, struggles by war and diplomacy for new and as yet fertile areas, and the manufacturing and transportation of the engines and machinery that are required.

The Carbon Cycle. In a similar fashion a cycle of carbon may be traced (Fig. 10). All organic compounds, as was shown earlier (p. 9), contain one or more carbon atoms. In the synthesis of carbohydrates by chlorophyll in the metabolism of green plants the carbon atoms are introduced into organic compounds, carbohydrates, proteins, and fats, as well as various other substances. By the oxidation of these substances carbon is combined with two atoms of oxygen and eventually appears again as the gas, carbon dioxide. The oxidative processes are the energy-releasing reactions whereby the potential energy accumulated from sunlight is converted into kinetic energy, that is, becomes available to do the work carried on by protoplasm. Not all carbon-containing compounds are oxidized with equal ease. Carbohydrates are the most easily oxidized in the protoplasm. So carbon may be returned to gaseous carbon dioxide by the breakdown of carbohydrates, or it may enter into much more complex molecules that are oxidized less readily and less completely. The carbon cycle and the nitrogen cycle are in contact at the point where carbon dioxide is utilized in the manufacture of carbohydrate.

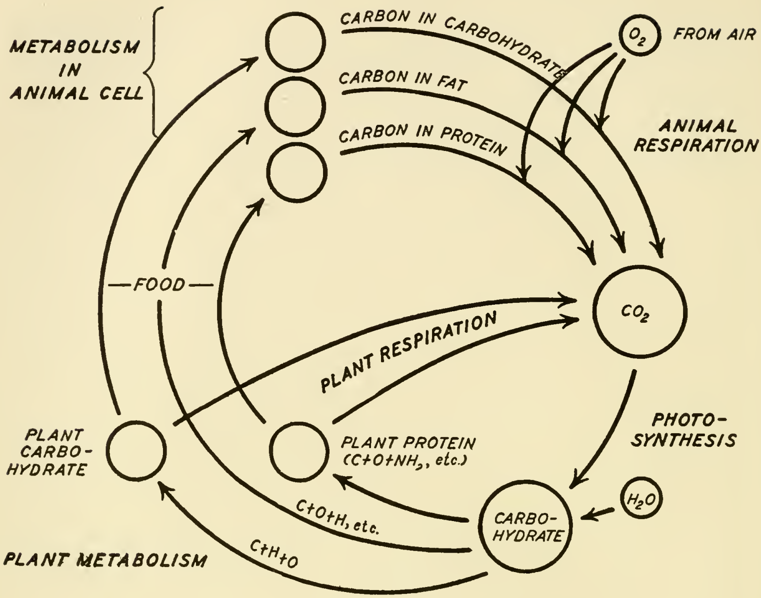

FIG. 10.—The carbon cycle. A scheme to illustrate the sequence in the utilization of carbon in the metabolism of plants and animals.

One Cell and Many Cell Organisms. We have noted that living objects may be grouped into two great kingdoms, Plant and Animal. An examination of the structure of animals reveals that there are two widely different types of organization. Some animals consist of a single cell or cells arranged as colonies. On the basis of this common simplicity of cellular structure these are for convenience in study grouped together as a sub-kingdom, and collectively termed the PROTOZOA. Animals consisting of many cells of different sorts and functions are grouped as another sub-kingdom named METAZOA. Single-cell and similarly simple plants are placed in a plant sub-kingdom, the PROTOPHYTA. Plants consisting of many cells organized into special working groups are included in a second sub-kingdom, the METAPHYTA.

Tissues. In both the Protozoa and the Protophyta, all the various activities involved in living are performed in and by a single cell. In other words, a single-cell animal must move about and capture its own food, perform the processes that digest and convert it into chemical form that the protoplasm may have energy and materials for maintenance, must escape from enemies or injurious conditions around it, and must reproduce itself. But among the Metazoa and Metaphyta the various activities are taken over and carried on by different types of cells. For example, in the body of a metazoon some types of cells exaggerate the function of contractility. In general, these are termed MUSCLE CELLS. Others have developed the function of irritability very highly; these are the NERVE CELLS. This specialization of function or division of labor is accompanied by differences in structure and in metabolism; it is called DIFFERENTIATION. A group of cells of the same sort, together with the intercellular substances incorporated with them is known as a TISSUE. Thus the muscle cells make up muscle tissue; bone cells together with their deposits form bone tissue; nerve cells compose nervous tissue. A tabular list of the tissues of the human body aids in familiarizing one with the nature of tissues. (Fig. 11).

Organs. Various types of tissues are combined into working units called ORGANS. For example, the human stomach is made up of a variety of tissues, muscular, glandular, epithelial, and so on, and functions as a unit in performing a special phase of the conversion of foods into forms which the body may utilize. The term organ refers to a functional unit and does not necessarily mean that all organs are made up of multicellular tissues. Only metazoon organs are composed of tissues. In every cell are structures that are functional units and are properly termed cell organs. Similarly, in the Protozoa there are many types of cell organs consisting of specialized protoplasm. One must realize that such organs are made up of protoplasmic structures that are not cellular in character. The diminutive term ORGANELLE is often applied to cell organs.

Epithelial Tissues (Surfaces)	Squamous	Pavement type. One layer of cells. Example, lining of lungs. Stratified type. Several layers of overlapping cells. Example, lining of mouth.
	Columnar	Simple type. Single layer of cuboidal cells. Example, lining of intestine. Ciliated type. Columnar cells with free surface equipped with cilia. Example, lining of trachea.
	Endothelium	Single layer of irregularly shaped thin cells. On surfaces that do not communicate with the atmosphere. Example, lining of blood vessels.
Connective Tissues (Connection and support)	Reticular	Flat, star-shaped cells forming a network or supporting framework. In lymph nodes.
	Fibrous	The most common form. Occasional cells with an intercellular mass of fibres, some white and some elastic. Example, ligaments. There are several varieties of fibrous tissue.
	Adipose	Connective tissue modified to include fat. General in distribution.
	Cartilage	The intercellular fibres are so firmly condensed as to appear to be homogeneous. Example, cartilages in wall of trachea.
	Bone	The intercellular substance is impregnated with lime salts and is very rigid.
Muscular Tissues	Plain	Bundles and thin sheets of elongated cells that are contractile but not under control of the will. Example, muscles in wall of stomach.
	Cardiac	Found only in the wall of the heart. Irregularly shaped cells forming a reticulum or network.
	Striated	Long, cylindrical, multinuclear cells bound in bundles by connective tissue. Usually voluntary and usually attached to bone.
Nervous Tissue	......	Consists essentially of (*a*) nerve cells, known as neurons; (*b*) long fibrous outgrowths of neurons, known according to function as axones and dendrites; (*c*) a special type of binding and sustaining tissue known as neuroglia.

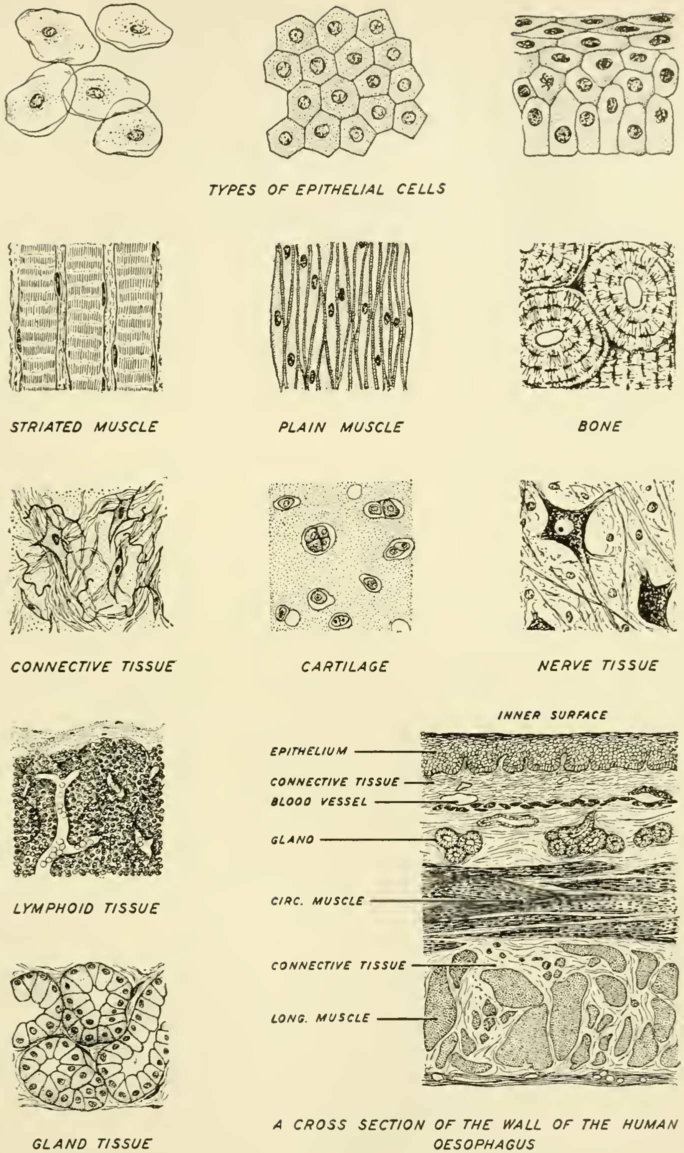

FIG. 11.—The appearance under the microscope of some of the principal tissues; made somewhat diagrammatic. The wall of the human oesophagus illustrates how various tissues are combined in the structure of an organ.

A group of organs which have a common major purpose is considered an ORGAN SYSTEM, as all the organs concerned in the digestion of foods in Man form the digestive system. In a metazoon body the several organ systems are interdependent. For our purposes here we may consider an *individual* to consist of the essential interdependent organ systems that enable a body to perform the functions of life.

Cooperation. The relation of cells, tissues, organs, and organ systems to each other and to the individual as a whole may be compared with the relation of private soldiers and the various military services to the function and mission of a field army. An army functions because of the sum of the efforts of the individual soldiers, but the duty of any one soldier is only an exceedingly minor part of the whole function of the army and may have no apparent relation to the mission of the larger force. In order to carry on as a functional unity, various types of soldiers are organized into groups of specialists; for example, the signal service, the service of supply, and so on. So also in the multicellular organism, the functioning of the individual is the sum of the functions of the individual cells, but the function of each cell is not identical with that of the whole organism. The various tissues are to be compared with the specialist branches of an army organization, it being the sum total of the diverse functions of the several tissues and organs that brings about the characteristics of the individual. The analogy may be carried still further. The effectiveness of an army depends on the physical condition, abilities, training, and general morale of all the units of the service. The characteristics of an animal are conditioned upon the efficiency and activities of the cells that make up its several special tissues.

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Chapter III

THE BIOLOGY OF UNICELLULAR FORMS AND THEIR RELATION TO THE BIOLOGY OF MULTICELLULAR ANIMALS

Fields of Study. Since the cell is the unit of structure and of function, the study of the fundamentals of animal life logically begins with the cell. But it does not cease there, for all living objects are influenced to a greater or lesser degree by other living objects. Consequently, the principles of Animal Biology comprehend something more than the lives of single cells, for they include the interrelations between cells. And because animals exhibit so many different forms and so many aspects, they may properly be studied from many different points of view. In any broad consideration of animal life in general it is convenient to approach the study of an animal, or of animals in general, with ten interrelated groups of principles in mind, all of which are more or less plainly illustrated by all animals.

(1) Principles of procurement and utilization of energy and materials: the science of NUTRITION.

(2) Principles of the release of energy by protoplasmic reactions and its transformation in the functioning of muscles, nerves, glands, and other tissues and in the work done by the organism as a whole; important divisions of the science of PHYSIOLOGY.

(3) Principles of waste disposal; the physiology of EXCRETION.

(4) Principles of unification of the organism by internal regulating mechanisms that control protoplasmic reactions and responses; the sciences of ENDOCRINOLOGY, of NEUROLOGY, and of

BEHAVIOR, that is, of hormones, of nerves, and of responses to the environment.

(5) Principles of structural and of functional unity; the science of ANATOMY and the relations between the anatomy and physiology of the organism.

(6) Principles of progressive complexity of structure and of function in relation to the history of animal life on the earth and in relation to the orderly classification of present-day animals; the sciences of EVOLUTION, and TAXONOMY or classification.

(7) Principles relating to perpetuation of kind; the sciences of REPRODUCTION, of development of the adult, that is, EMBRYOLOGY, and of INHERITANCE.

(8) Principles of adjustment to contact with the environment; the sciences of ECOLOGY, that is, distribution of animals, and of ADAPTATION.

(9) Principles of association with other organisms; PARASITISM, ANIMAL COMMUNITIES and ANIMAL SOCIOLOGY.

(10) Principles of changes with time; the sciences of GROWTH and of SENESCENCE or aging.

In reality none of these can be discussed independently of the others and each includes materials that comprise one or more extensive biological science. Hence it is clearly impossible to treat each or any exhaustively here. Nor is it desirable, for the major objective we have set is a comprehension of the fundamental relations between these groups of principles, in the lives of animals. Hence we are limited to illustrative examples from all these groups in order to demonstrate just what an animal is and what it does. A necessary preliminary to the understanding of the operation of these principles in the case of any animal is a knowledge of the structure of the animal and obviously the logical organism with which to begin their study is the organism that is most simple.

The PROTOZOA are whole organisms that consist of single cells. Here one finds the least complicated application of the principles of animal life. The illustration of certain fundamentals is still clearer in the life processes of some of the single cell plants, the PROTOPHYTA. Moreover, the lives of some of these minute plant and animal forms are passed in the tissues of the human body; hence they are of great interest because they profoundly affect human welfare.

While the Protozoa are often spoken of as the simplest of animals, it must not be understood that the body of a protozoon is a simple type of system; on the contrary, the actual physico-chemical processes that are involved in protozoon life are not as well understood as are those of the human body, or at least no better understood. The simplicity of the Protozoa rests solely on the fact that their bodies are single cells. Vital processes are demonstrated in their most primitive aspects, and observations are simplified.

Types of Protozoa. Four classes of Protozoa are recognized, the basis of distinction being, for our purposes here, largely their differences in methods and organs of locomotion (Figs. 28, 29, 30, 31). Members of one class, called the SARCODINA, move by means of temporary extrusions of the cell, the cell substance flowing out into these extrusions and withdrawing elsewhere. These temporary organs of locomotion are known as PSEUDOPODIA. There are a great many different Protozoa that move about in this fashion. For convenience the biologist divides the class on the basis of other resemblances into subordinate groups that are in turn still further divided into groups termed GENERA. A GENUS is further divided into smaller groups, within which the animals are almost identical, known as SPECIES. The genus Amœba is the most common representative of the class Sarcodina and the species "proteus" is usually regarded as representing a typical member of the class. Animals are ordinarily designated in terms of their genus and species, the name of the genus being capitalized, for example, *Amœba proteus; Rana pipiens* (common frog); *Homo sapiens* (Man).

The second class of Protozoa includes those forms that have a constant shape and move by means of fine fibre-like structures extending from the cell wall called CILIA. The class has been named INFUSORIA (Fig. 30).

The third class also has a constant shape, but the animals move by means of one or more whip-like FLAGELLÆ, attached either to the forward or rear end of the animal, that by a whirling motion pull or drive the organism through the water. These are the MASTIGOPHORA (Fig. 29).

The fourth class, the SPOROZOA (Fig. 31), are not active but may at times move by pseudopodia, or in other periods of their lives by means of flagellæ. They are never found free in Nature but always living within the bodies of other animals. They increase in number by multiple division, a single cell thus giving origin to many daughter organisms, or SPORES, simultaneously.

Amœba. The common types of amœbæ are free living animals found in partially decaying infusions of vegetable material. They may be obtained in numbers by collecting water plants, together with some mud from a stagnant pool, and allowing the mass to decay in water. Although tending toward a spherical or flattened disk shape, the outline of the amœba is not fixed but depends on the state of motor activity of the animal (Fig. 12). Under the microscope an active amœba appears to be flowing across the field of vision; numerous pseudopodia may be seen. The protoplasmic contents appear to be flowing into these extrusions, extending them and bringing about a shift in the position of the animal. The surface of the amœba is covered by a thin, non-living pellicle or layer, under which is a region of protoplasm slightly denser and more refractive to light than the deeper portion, known as the ECTOSARC (Fig. 12), made up of ECTOPLASM. The more fluid inner cytoplasm is known as the ENDOSARC, made up of ENDOPLASM. In the endoplasm may be seen considerable numbers of cavities, the food or gastric vacuoles, each containing a bit of food. A large liquid-filled vacuole makes its appearance periodically, distends with liquid, then expels its contents into the water, disappearing only to reappear again slowly. This is the CONTRACTILE VACUOLE (Fig. 12). It is not a feature common to all animal cells, nor to all species of Amœba,

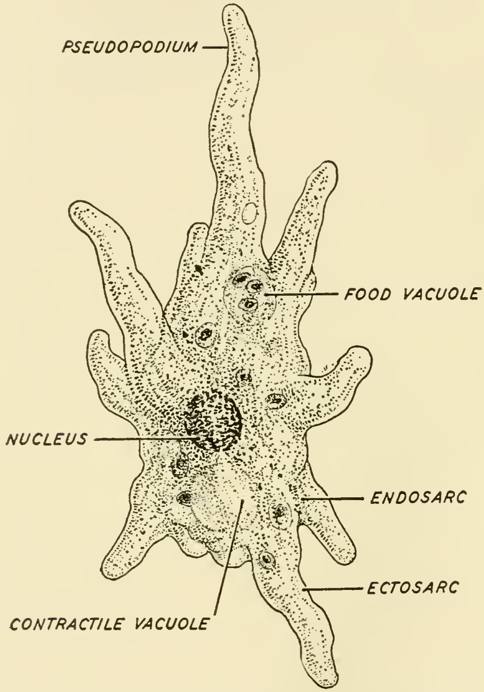


FIG. 12.—An amœba as commonly observed in the laboratory. As it was being sketched the animal was withdrawing the pseudopodia shown at the bottom of the figure and advancing those at the top.

but is found in many varieties of Protozoa. Its chief function appears to be the maintenance of the proper water content of the cell, for it is lacking in marine Protozoa, which are surrounded by water with a relatively high osmotic pressure. The nucleus of the amœba may be seen in the living animal as a somewhat dense central body, approximately spherical in shape.

Nutrition. With this seemingly meagre equipment the amœba carries on all the functions of life. We may now examine the means by which these functions are performed. Since the energy-consuming functions depend on the potential energy in food, the method of securing and utilizing foods, the nutrition of the animal, is first to be considered. The amœba feeds on bits of plant material that it may encounter, and on other Protozoa. Like many animals that live in water, the amœba cannot swim, but creeps about over such surfaces as may be present, a stem, bits of detritus, or the bottom. On contact with a food bit it sends out pseudopodia on either side of the object that soon engulf it, forming a food vacuole. Thus the wall of the food vacuole is formed from a portion of the body wall of the animal. Then from the cytoplasm there diffuses into the vacuole certain substances that act upon the food in several ways, dissolving the soluble portions and changing it chemically and physically into a condition that will permit the useful ingredients to pass through the wall of the vacuole and into such chemical forms that the metabolic processes of the animal may make use of them. This process of altering food so that it will pass through living semi-permeable membranes and so that it is chemically available to protoplasm is called DIGESTION. The process in Man, while much more complicated than in amœba, includes these general and necessary processes. In the amœba the solid food particles are taken into the cell and there digested. This is INTRACELLULAR digestion. The processes of utilizing the food after it has been digested are collectively termed ASSIMILATION.

The amœba apparently has little power of discrimination between particles that contain food and other substances, for it will engulf bits of insoluble material, such as finely divided carbon. The indigestible substances which it picks up, either as a part of a food body or inert substances, for example carbon particles, traverse the endoplasm of the amœba in the food vacuoles and are eventually left behind as the vacuole comes to the surface and opens. The fact that the endoplasm is constantly streaming (cyclosis) is of material assistance in the distribution of the digesting substances throughout the cell.

Respiration. After the food has been digested and assimilated, its utilization either in building up protoplasm or in providing energy for cell activities is dependent on a very common chemical reaction between the assimilated food and a common gas, oxygen. The most common reaction occurring in the non-living world is oxidation. A wide variety of common substances when exposed to the oxygen of the air unite with it. The union of oxygen with any substance takes place with the evolution of energy in some form; in a fire, for example, this energy is apparent in the form of heat. It is of interest that not only does living protoplasm basically consist of the more common elements and that the most prominent of its substances is water, but also that the fundamental energy releasing chemical reaction in the system is the reaction most common in the non-living world.

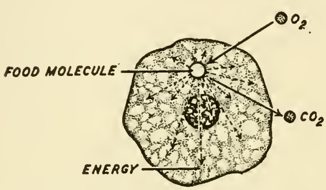


Fig. 13.—A scheme to represent the principles of the process of respiration in a cell. By osmosis oxygen molecules enter the cell, there to react with food molecules. Carbon dioxide is one of the products of the chemical action; by osmosis it passes out of the cell. Energy, inactive in the food molecule, is released by the oxidative reaction and is transformed into various forms in the protoplasm.

In protoplasm the union of oxygen with the various substances that are oxidizable releases energy which has several fates (Fig. 13). Some of it is degraded into heat. Some of it is utilized in work. Some of it is employed in the building up of protoplasmic compounds that require energy in their synthesis. The most common chemical end-product of oxidation in protoplasm is a completely oxidized carbon atom, carbon dioxide. This substance is a chemically inert gas which in the protoplasm is dissolved in water. In water its presence results in the ionization of hydrogen from water molecules, and consequently such a solution is acid. It does not accumulate in any considerable quantity in the cell but passes out by diffusion (osmosis) through the cell boundary. Its presence in the protoplasm, however, has a great deal to do with the acidity of the system; since H ions are positively charged, its presence influences the whole series of protoplasmic reactions that are controlled by electrical conditions.

The source of oxygen for the amœba, and in fact for all but a few organisms that live in water, is the oxygen dissolved in the water. At ordinary room temperature water contains nearly 6 cubic centimeters of oxygen per liter, or approximately 0.6 per cent. This is materially lower than the concentration of oxygen in air, which amounts to approximately 20 per cent, but it suffices as the supply for aquatic forms. The cell boundary of the amœba is permeable to oxygen and to carbon dioxide. The oxygen that enters the cell is being constantly bound into compounds, so there is a constant flow of free oxygen inward from the higher concentration in the surrounding water to the lower concentration inside the cell. Likewise, the oxidative reactions within the cell are constantly producing carbon dioxide, so there is a constant outward flow of this dissolved gas. The various steps of entrance of oxygen into the cell, its union with oxidizable substances there, and the outward flow of carbon dioxide are collectively called RESPIRATION (Fig. 13). The processes involved are not greatly different in all cells of all organisms, strictly comparable so far as their fundamental nature is concerned, with the processes as described for amœba. We commonly term the mechanical act of breathing respiration. There are many kinds of breathing mechanisms, but their common and fundamental function is to afford a supply of oxygen for the cells of the organism and as a means of escape for carbon dioxide. Calling breathing respiration has the virtue of common usage, but it must be remembered that the fundamentals of respiration are events occurring in the several cells, not the mechanical act of inspiring air, or causing water that contains oxygen to flow over gills. The fact that water forms an important part of protoplasm has been mentioned several times. In respiration water also plays an important rôle, for all cells, even the brain cells of Man, are aquatic and receive their oxygen and discharge their waste products, including carbon dioxide, by means of an aqueous medium.

For the amœba, as for all other animals, including Man, the food materials taken in contain three general types of available substances: These are the carbohydrates, the fats, and the proteins. In animal cells the carbohydrate is the most easily and most completely oxidized and when so oxidized such substances yield exactly the same quantity of energy as when the same substance is burned in a calorimeter. Exactly the same number of CO_2 molecules are given off as there are O_2 molecules taken up.

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O.$$

In other words, in the utilization of a carbohydrate, for example, grape sugar, the ratio $\frac{CO_2}{O_2}$ is always 1. This value is called the RESPIRATORY QUOTIENT. Proteins are less completely oxidized than are carbohydrates, hence their respiratory quotient is less than 1. Still lower ratios hold for fats, which, in general, are less completely oxidized than are the proteins. The determination of the respiratory quotient in an animal, or in a process, enables one to understand approximately what sort of material is providing the energy. For example, if an athlete while running is known to have a ratio of carbon dioxide given off to oxygen taken in of 1, or nearly so, it may be concluded that the metabolic process involved in running is the oxidation of a carbohydrate. No such determination has been made on amœba but data on the respiratory quotient of many animal activities are available.

Excretion. When a carbohydrate is oxidized in the amœba, or in any cell, the products are: energy, utilized by the cell; water, also used in the cell or else diffusing out; and carbon dioxide, a gas dissolved in the cell liquids. When fats and proteins are oxidized or otherwise broken down in cell metabolism, many of the substances formed are dissolved non-gaseous substances which in the pure state are either liquids or solids. These waste products in all cells pass out by diffusion through the cell wall and in addition in amœbæ some are passed out with the water in the contractile vacuole. A sharp distinction must be drawn between this true excretory process in which substances derived from and by the cell metabolism are gotten rid of, and the expulsion from the gastric vacuoles of undigested and indigestible materials, or DEFECATION. In the first case the substances were formerly a part of the protoplasm; in the second case, the material never was within the cell and is in reality a foreign body. This distinction between true excretion and defecation applies not only to amœbæ but to all animals. In fact, the two processes are so separate and distinct that quite different mechanisms function to expel the two types of materials.

Amœboid Movement. There have been many and varied attempts to solve the problem of how the amœba moves and how it engulfs its food. The problem is important for this type of cell locomotion is not confined to the amœba alone, but is found in independent cells in most animal bodies. Even in Man one type of cell found in the blood stream (white cells) normally moves in a similar manner. Prominent among the explanations that have been advanced is the surface-tension theory of amœboid movement. This theory is based on the fact that if the surface of a drop of liquid is weakened at some local area, the tension on the remainder of the drop remaining high, the contents of the drop are thus forced to push out the weakened area. So, a drop of chloroform in water can be made to move about in a manner resembling the motion of the amœba by the local application of a substance which lowers surface tension (Fig. 14). The theory holds that, either from an external or an internal source, substances effect local lowering of surface tension on the amœba and thus the formation of pseudopodia is brought about. More recent work indicates, however, that the process is much more complicated. Apparently internal changes in the protoplasmic structure are constantly going on, so that from a central core of liquefied protoplasm materials are flowing in the direction of the forming pseudopodium. Near the tip these materials are constantly being added to a distinctly less liquid rind

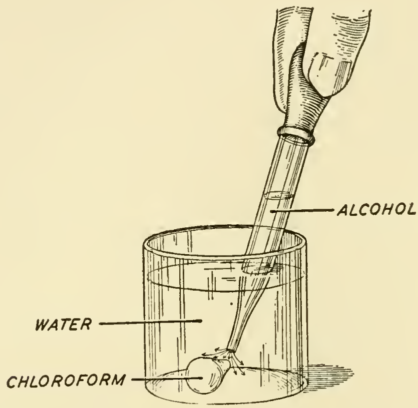


Fig. 14.—Diagram to show how a chloroform drop in water may be made to exhibit extrusions resembling pseudopodia by the local application of alcohol. The alcohol from the mouth of the pipette causes a local lowering of the surface tension of the chloroform. The surface tension of the remainder of the drop is unaltered and, being greater than that of the region affected by the alcohol, causes the chloroform drop to bulge at the weakened area.

and there jelled, while at the opposite extremity of the animal the gel is being liquefied and flowing into the central core. The pellicle appears to behave somewhat like the continuous tread of a tractor, the living organism moving forward on the pellicle as a fulcrum (Fig. 15). Just what the physico-chemical events are that bring about this phenomenon is unknown.

Irritability in Amœba. Any object or condition in the environment of the amœba that will affect it first encounters its surface. So the first response of an amœba, or of any other cell, is the response of its surface. In amœbæ the type of response is necessarily limited. When attacked, an amœba may do only one of three things: It may move, it may become quiet, or it may be unresponsive. Responses are of necessity slow. It does respond, however, to a variety of conditions. It furthermore is able to select from those available the environment most suitable for its existence. This can be shown by a simple experiment. A culture of amœbæ is placed

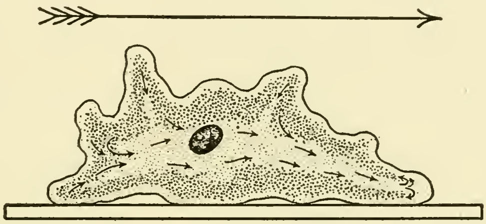


Fig. 15.—Diagram of an amœba in motion, to show how the cytoplasm changes position and condition with the advance of the leading pseudopodia. The materials in the fluid central region flow forward and are added to the stiffened outer rind. (Simplified after Mast.)

in a long dish so arranged that the temperature, acidity, or other condition, varies along the dish, forming an intensity or concentration gradient from one end of the dish to the other. In time it will

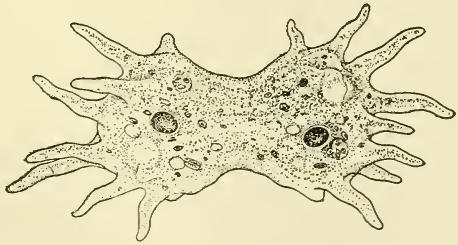


Fig. 16.—An amœba in the process of binary fission. The nucleus has already divided and a constriction is about to separate the animal into two daughter animals.

be found that the greatest number of amœbæ have accumulated in that region of the water that is most suitable for the normal life of the animal.

Reproduction in Amœba. As in all other living organisms, the growth of an amœba continues at a gradually diminishing rate until a certain maximum size is reached, which probably varies with a number of conditions in the environment. Further increase in the amount of living protoplasm is accompanied by a division of the amœba into two daughter amœbæ. This is accomplished by the elongation of the nucleus, which tends to become dumb-bell shaped, accompanied by a similar change in shape of the entire cell (Fig. 16). The nucleus divides, accompanied by a division of the cell. In such a reproductive process the parent disappears. Hence the amœba in the absence of accident or unfavorable change in its environment, is immortal, the processes of division restoring the two daughter organisms to the characteristics of young systems. This simple type of equal division, which is common among Protozoa, is called BINARY FISSION.

Paramœcium. Other classes of Protozoa illustrate distinctly higher types of organization of the various parts of the organism, new and more efficient specializations of the protoplasm. The members of the class Infusoria include protozoons which move by means of cilia, short, fine fibrils extending outward from the surface, their bases embedded in the ectosarc. These cilia must not be compared nor confused with hair, for hair is found only among the highest animals (mammals) and each hair consists of several layers of cells. The cilia of Infusoria are specialized protoplasmic structures which exhibit constant contractility. The contractions are synchronized and their beat is in regular order, thus imparting a bullet-like motion to the organism. In some the cilia occur over the entire surface of the animal; these are termed HOLOTRICHIA. In the HYPOTRICHIA, the cilia are absent on the upper surface. In the HETEROTRICHIA the cilia occur over the entire surface but are very much longer about the mouth. In the PERITRYCHIA the cilia are absent except in the region of the mouth.

The fresh water holotrychous ciliate, *Paramœcium caudatum*

(Fig. 17), may be examined in detail to illustrate the specializations that appear as one goes from the simple amœba to more advanced types. It is found in great numbers in decaying vegetable matter and is easily cultivated in the laboratory. If a handful of dry grass

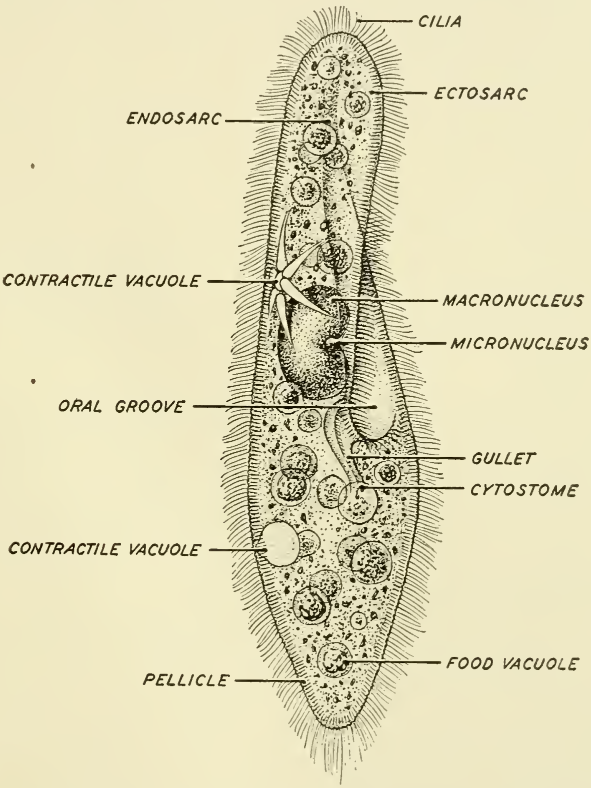


Fig. 17.—Paramœcium. The upper end in the figure is the leading or anterior end of the animal. The anterior contractile vacuole is in the process of filling; the posterior vacuole is about to discharge its contents. (From a preparation and various authors.)

is covered with water in a jar and then seeded with a bit of mud from a stagnant pool and allowed to ferment, in a few days great numbers of paramœcia will appear. In general, the shape of the animal is that of an elongated hen's egg, and unless it is creeping through obstructions, or changes direction suddenly, its shape is constant. In addition to the cilia, which form part of the mechanism of food taking as well as locomotion, the animal is covered with a non-living membrane or pellicle, under which is the ectosarc. The cilia constitute an example of specialization of protoplasm, for these structures exaggerate the function of contractility and carry on for the remainder of the cell, which in general is much less contractile than amœba. In the ectosarc is also to be found another specialized system of structures, the TRYCHOCYSTS. Ordinarily these are not visible under the lower powers of the microscope, but the paramœcium may be induced to discharge them if it is brought into contact with a bit of acetic acid or other irritant. The appearance of the discharged trychocysts is that of a fine fibre entanglement forming a sort of defending net, thus serving to keep an enemy at a distance.

The cytoplasm of the animal is constantly circulating, a phenomenon known as CYCLOSIS (see p. 58), and usually contains numbers of food vacuoles. The nuclear parts consist of two structures, a large MACRONUCLEUS, closely adjacent to which is a much smaller MICRONUCLEUS. There are also two contractile vacuoles, one in the forward and one in the rear region.

Nutrition in Paramœcium. The paramœcium almost invariably moves with its sharpest end as the leading element and the cilia are so coordinated as to direct this movement. Its stream-lined shape facilitates motion through the water. A distinct groove, called the ORAL GROOVE, occurs on one aspect of the animal, so placed that it opens forward. This groove is lined with cilia somewhat longer than usual, and in it is suspended a thin membrane, the UNDULATING MEMBRANE. The cilia and the membrane by their motions sweep water containing bacteria and other bits of food material down the oral groove and into a short passage, the GULLET, at the base of which is a region of ectosarc which is specialized to engulf the food particles in a manner similar to the taking in of food in vacuoles by the amœba. This region at the base of the gullet that is thus a special food-receiving organ, is called the CYTOSTOME. Here the gastric vacuoles form and their progression by the cyclosis of the cytoplasm and the processes of digestion and assimilation are very similar to those in the amœba. The undigested materials and foreign particles are finally ejected at a definite spot on the body wall, known as the ANAL SPOT. The paramœcium represents a more advanced mechanism than the amœba in the localization of a definite region for engulfing food and another definite region for the expulsion of indigestible stuffs, and in other ways.

Irritability in Paramœcium. Paramœcium responds much more actively to outside influences, which will henceforth be called stimuli, than does amœba. Obviously the surface of the animal is the region which receives the stimulus, and recent work has indicated that the impulse set up by such stimuli is transmitted by specialized paths through the protoplasm, forming a sort of rudimentary nerve net. Thus by the connections between these paths the action of the entire animal is coordinated. This coordination system is not easily visible in paramœcium and is described in more detail in a heterotrychous ciliate, DIPLODINIUM (Fig. 18). In diplodinium, just forward of the oral groove in the endoplasm, is a small body, the NEUROMOTORIUM, which is connected by strands to the base of each cilium. If the strand from a single cilium is cut, that one ceases to beat. This coordination mechanism sharply illustrates two facts: First, the Protozoa are not simple rudimentary systems intermediate between non-living and living, but are in fact complex individuals, although they consist of but one cell; second, that while in many respects the Infusoria contain functions and structures that are similar to those of Amœba and hence indicate a relationship, the members of the class have developed new and strikingly different specialized protoplasmic devices.

Paramœcium responds negatively to gravity; one always finds them in greatest numbers at or about the surface of a culture. By trial and error (Fig. 19) it also finds the most suitable temperature, salt content, acidity, and other features of the environment. Furthermore, when attacked, its trychocysts are instantly thrown out. So, in general, both the property and mechanism of irritability, as

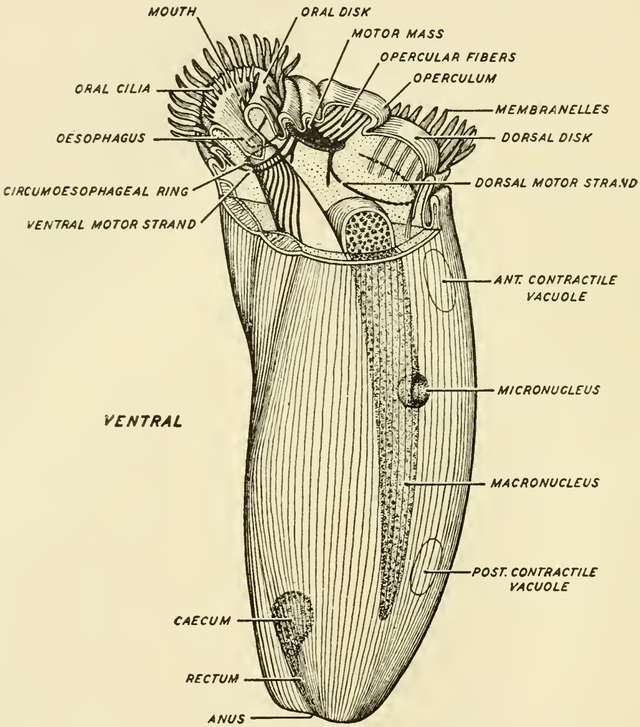


Fig. 18.—The neuro-motor apparatus of a diplodinium. An upper portion of the animal has been cut away to show the relations and paths of the conducting fibres. (After Sharpe.)

well as those of response, or contractility, are much more distinct and better developed in paramœcium than in amœba. This fact may be taken to mean that the chemical processes in the protoplasm which build up and maintain such structures are more complicated in paramœcium than in amœba. The term DIFFERENTIATION is employed to describe this specialization of structure and metabolic activity.

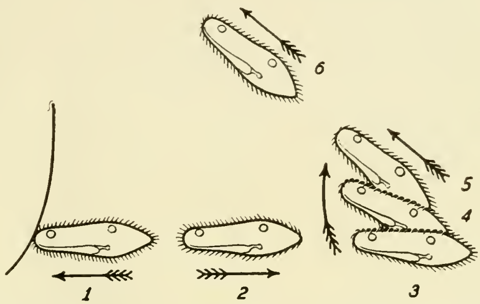


Fig. 19.—The "trial and error" method of solving difficulties as illustrated by the attempts of a paramœcium to pass by an obstacle. (After Jennings: *Behavior of the Lower Organisms*. Columbia University Press.)

Reproduction in Paramœcium. Paramœcium reproduces by binary fission (Fig. 20). Preceding division, the oral groove disappears. Both the macronucleus and the micronucleus elongate

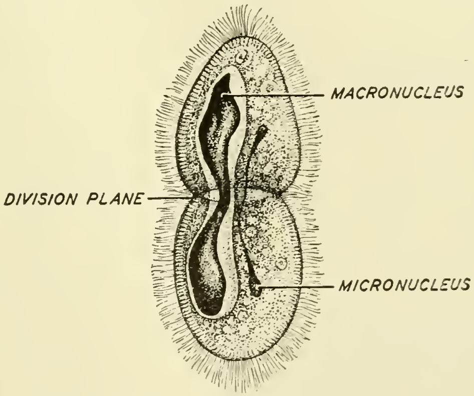
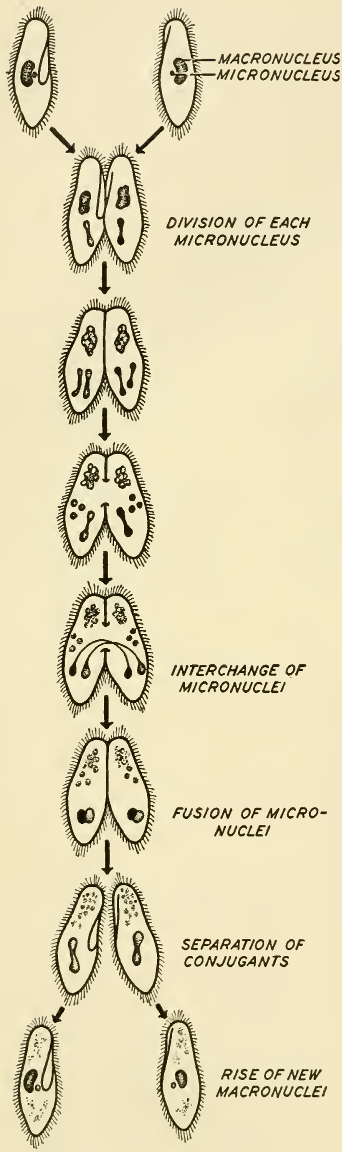


Fig. 20.—Binary fission of a paramœcium.

and at the same time a constriction appears about the animal. Division is completed when the elongated nuclei have separated into two and the constriction has progressed to separate the parent ani-



mal into daughters, each with a portion of both macro- and micronucleus. The oral groove now reappears in each of the daughter paramœcia, which are now in form identical with the original parent. The protoplasm of the animal, which before the division may be regarded as old, has by reason of the changes that occur during division become the protoplasm of young animals. The restoration of the properties of young protoplasm to protoplasm which has become aged is called REJUVENESCENCE.

Conjugation. The paramœcium is apparently capable of continuing to divide in this fashion indefinitely so long as the conditions in which it lives are suitable. However, more often the rate of division slows down after a time and is restored after an interchange of nuclear material between two individuals takes place, a process that is essentially sexual and undoubtedly is comparable to the fertilization process in higher animals. This process is called AMPHIMIXIS. It is effected as

FIG. 21.—Scheme representing the conjugation of two paramœcia. Note the disappearance of the macronuclei, the repeated divisions of the micronuclei, and the interchange of micronuclei.

follows: Two paramœcia which are not distinguishable as to sex, fuse together along their oral surfaces (Fig. 21). The oral grooves disappear in each, as do also the macronuclei. The micronuclei then divide three times, giving eight in each of the conjugating animals. Of these eight, seven disappear. Then in each the remaining micronucleus divides again into two, one of which is stationary and the other migratory, moving across into the endoplasm of the other CONJUGANT. The animals thus exchange micronuclear material. Then in each the two micronuclei unite and the conjugating animals separate. The fact that the micronucleus of each of these ex-conjugants is derived one-half from each member is important, for this provides a vehicle whereby all future descendants of either shall have inherited equally from both members of the conjugating pair.

Following the fusion of the two micronuclei and the separation of the pair, the micronuclei in each undergo rapid divisions followed by a series of cell divisions and the division rate remains at a higher level for some time. The question now presents itself: Is this fertilizing process of amphimixis a device that corrects the effects of time, that is to say, the effects of old age, and brings about rejuvenescence, a restoration to the condition of a young animal? The answer is apparently in the affirmative, but this is not the only method that will restore the original division rate. In some races the animals singly undergo a periodic reorganization of the micronuclear material that is comparable to the behavior of a single member of a conjugating pair, called ENDOMIXIS, which is followed by an increase in division rate. Nor is the process of amphimixis identical in all varieties of ciliate Infusoria. In some the micronucleus is not visible.

Metabolism. The metabolism of the paramœcium is holozoic and the processes of oxygen intake and carbon dioxide outgo are, as in the amœba, directly through the body wall by diffusion. Non-gaseous wastes are also excreted as in amœbæ. In fact, this direct transfer of materials through the cell wall is common to all cells of all animals. In complex multicellular organisms additional machinery is provided whereby these substances may be conveyed to and from the cells, but the essential facts concerning the processes as regards each cell are identical in amœba, paramœcium, or Man.

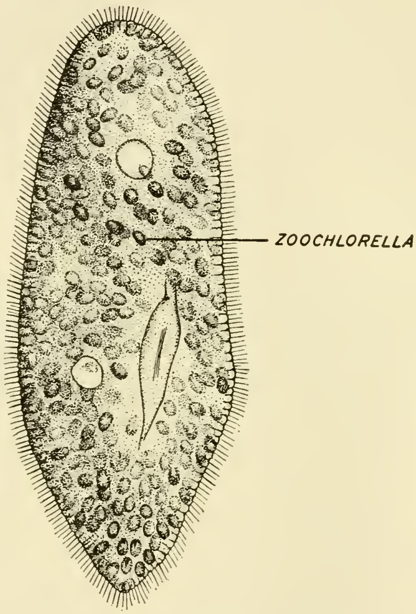


FIG. 22.—*Paramœcium bursaria* containing symbiotic plant cells, Zoochlorella. (Re-drawn after Conn.)

Symbiosis. Certain species of Paramœcium, for example, *Paramœcium bursaria,* are frequently infected with a green plant cell growth (Fig. 22). This small unicellular green plant, Zoochlorella, is found in sufficient numbers to give the animal a green color. This relation between the host paramœcium and the invader plant cell is a curious partnership, for not only does neither of the associates harm the other, but they are mutually helpful. Such a relationship is called SYMBIOSIS. Symbiotic relations are not confined to this one case, however, for the phenomenon is not a rare one among other forms. In *Paramœcium bursaria* it has been found that when the animals are infected with zoochlorella they may live without an external food supply for over a year. If the zoochlorella are destroyed and no external food supply is present, the paramœcia very soon die. The relations of the two organisms are that the paramœcium, in its respiratory metabolism, affords the plant cell a constant supply of carbon dioxide, which, in the presence of sunlight and water, it converts into a carbohydrate. The plant cell thus supplies an internal source of carbohydrate for the energy-requiring processes of the paramœcium, for apparently the plant manufactures enough carbohydrate for both its own and the requirements of the animal cell. Thus, in the absence of bacteria or other outside food, the paramœcium subsists on the food made by the zoochlorella. In turn, the plant cells have at hand a constant supply of carbon dioxide for the photosynthetic processes.

Symbiotic relationships similar in nature are not unusual; sometimes two plants are associated, as in the lichens, sometimes two animals are associated, as in the intestinal Protozoa in certain insects; sometimes, the association is that of a plant and an animal, as in this example. A less intimate association, which is merely mechanical in nature, is that of COMMENSALISM. In such associations one animal merely serves as the motive power to carry another type of animal to its food supply, or one animal follows the other around and thus finds its food. An example of commensalism is the shark sucker, a type of fish that attaches itself to the dogfish shark and is carried about. When the shark makes a kill, the shark sucker is present and thus is assured of food.

Parasitism. Sometimes an invading animal or plant lives on the substance of, and harms the supporting animal or plant. This is termed PARASITISM. The invading organism is called a PARASITE and the supporting organism is called the HOST. This sort of relation between organisms is of tremendous importance to Man, for many human diseases are actually the parasitization of the human body by some other organism that either destroys body substance or by reason of its poisonous metabolic products produces violent disturbances which may eventuate in the death of the host. Organisms which produce disease as a result of their invasion are called PATHOGENIC, in distinction to NON-PATHOGENIC types. The metabolism of such organisms is saprophytic or saprozooic; their source of energy is from materials that are already formed and partially utilized by the host.

Some species of Paramœcium are parasitic in higher animals. Other Infusoria also occur as parasites, some of which are pathogenic. But the most important pathogenic Protozoa are found among the class Sporozoa. The particular sporozoon which is the most common pathogen of the group is the one causing human malaria. There are several species of malarial Sporozoa, each producing a somewhat different type of disease.

Malarial Parasite. The life history of the malarial parasite, all of which belong to the genus *Plasmodium*, is rather complicated, for it requires two hosts in order to complete its life, Man and the mosquito. Apparently all modern races of Man serve as suitable hosts, but not all types of mosquitoes serve as the other host, only the members of the genus *Anopheles*, a widely distributed genus, however. In the blood stream of a human having the disease are tremendous numbers of small sporozoa, known in this stage of their life cycle as TROPHOZOITES (Fig. 23). These live in the red blood cells. If a mosquito of the proper variety bites the person, it withdraws some of these forms with the blood. In the mosquito all of the sporozoa are destroyed except one type, the GAMETOCYTES. The gametocytes are of two sorts, one destined to form numbers of smaller MICROGAMETOCYTES, designated as sperms, and the other to become single MEGAGAMETOCYTES, or eggs. A single sperm unites with an egg and this fertilized egg enters the wall of the stomach of the mosquito. Here it divides rapidly into a number of individuals, known as SPOROZOITES. Then they burst free into the body cavity of the mosquito and the parasites finally enter its salivary glands. When this mosquito bites another human some of these

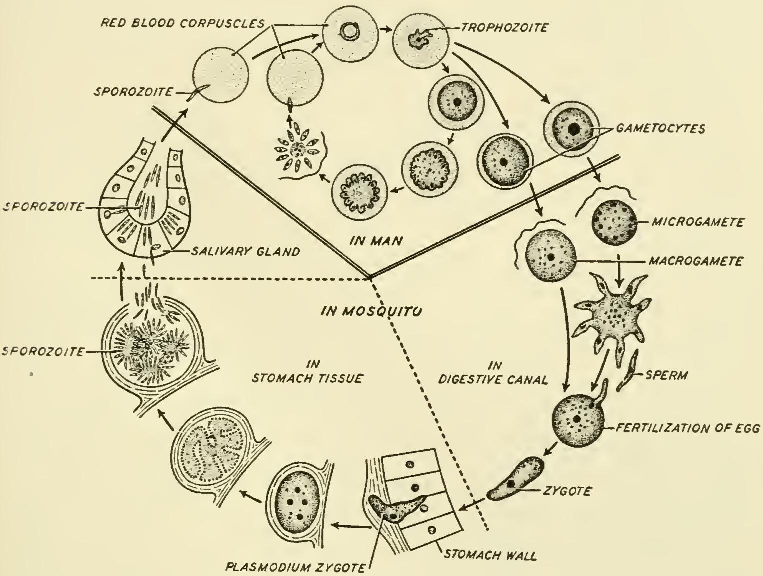


FIG. 23.—Scheme representing the life history of the sporozoon, *Plasmodium vivax,* which is the cause of one type of human malaria. Note that the divisions occurring in the human red blood corpuscles are asexual fissions, while the divisions in the wall of the stomach of the mosquito follow the fertilization of the egg and are therefore sexual. (Re-drawn from Kühn: *Grundriss der allgemeinen Zoologie.* Georg Theime, Leipzig.)

sporozoites are injected into the wound with the poison that the mosquito injects to keep the blood from clotting. In the human body they penetrate into the red blood cells and there form trophozoites. Thus there are two types of reproduction in the life cycle of the parasite. In the body of the mosquito reproduction is preceded by the union of an egg and a sperm cell; this is known as SEXUAL

REPRODUCTION, which always involves components from two organisms as a preliminary to reproduction. In the blood of Man the parasite reproduces by rapid divisions of the cell, a process that is independent of any other individual cell. This is ASEXUAL REPRODUCTION. In the life history of the malarial parasite these two processes are in necessary sequence; the sexual always follows the asexual, and the mosquito host must always follow the human host. The disease is therefore not transmissible from one human to another, and its control involves the eradication of the mosquito.

Although all classes of Protozoa contain some kinds that are parasitic, not all the animal parasites that infest other animals are Protozoa. Some of the parasites of Man, for instance, are multicellular animals that are quite large, for example, the tapeworm (p. 106). Some have very complicated life histories, requiring several hosts, or spending part of their life cycles as free living and part as parasitic animals. The parasitization of Man by unicellular plants will be discussed farther on.

Enzymes. Simple plants most clearly illustrate certain biological principles that it is now desired to develop. It has been stated that the Plant kingdom, like the Animal kingdom, may be divided into sub-kingdoms, the single cell or simple plants, Protophyta, and the Metaphyta, or many-cell plants. In the sub-kingdom Protophyta a single phylum is recognized, the phylum Thallophyta. The Metaphyta are three phyla: the Bryophyta including the mosses and their allies, the Pteridophyta, the ferns and their allies, and the Spermatophyta or seed-bearing plants. Of the phylum Thallophyta, there are three series: the Algæ, which include the green pond scums; the Fungi, which include the Yeasts and Molds; and the Schizophyta, which are the plants which reproduce by binary fission and include the Bacteria (see top of page 77).

The Algæ contain chlorophyll, or some substance closely related, and are holophytic. The Fungi and Schizophyta are saprophytic.

Phylum Thallophyta (Simple. Often single cells. Lack true tissues.)
- Schizophyta (Reproduce by fission)
  - Blue-green algæ
  - BACTERIA
- Algæ—Contain chlorophyll. Seaweeds, Pond Scums.
- Fungi (No chlorophyll)
  - YEASTS
  - Molds
  - Smuts
  - Mushrooms
  - Puffballs

Phylum Bryophyta. Mosses and their allies.
Phylum Pteridophyta. Ferns.
Phylum Spermatophyta. Seed-bearing plants.

The yeast plant, one of the Fungi, in its saprophytic nutrition strikingly illustrates a chemical process of metabolism that in some form or other is carried on in the cells of all plants and animals and is one of the most important of the metabolic phenomena. This process is enzyme action.

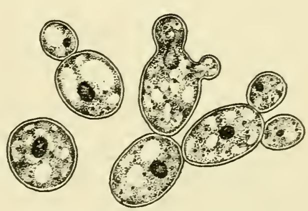


FIG. 24.—Yeast plants.

The yeast plant consists of single cells, or chains or loose groups of cells. Different species of yeast cells may be cylindrical, ellipsoidal, or spherical in shape (Fig. 24). Yeasts reproduce by a modified form of fission called budding, in which the parent cell does not divide into two equal cells, but gives off a small daughter cell or cells, which may remain attached to the parent for a time. At moderately high room temperature the yeast plant multiplies with considerable rapidity. The common yeasts live quite well in sugar solutions and obtain their energy by breaking down the sugar into carbon dioxide and alcohol. The general name for this process is FERMENTATION, but organisms perform many such processes, so the term fermentation does not specifically mean the breakdown of sugar by yeasts. The reaction by which the yeast breaks down grape sugar is usually written:

$$\underset{\text{sugar}}{C_6H_{12}O_6} = \underset{\text{alcohol}}{2C_2H_5OH} + \underset{\text{carbon dioxide}}{2CO_2} .$$

The particular substance which effects this splitting of the sugar molecule is known as an ENZYME, this particular enzyme being named ZYMASE. Yeasts may ferment starches and other carbohydrates, but the reaction in these cases takes place in several steps, a different enzyme effecting each step, finally converting the carbohydrate into the form of grape sugar and then zymase acts to produce alcohol and carbon dioxide. Hence there may be a chain of enzyme reactions involved in a living process.

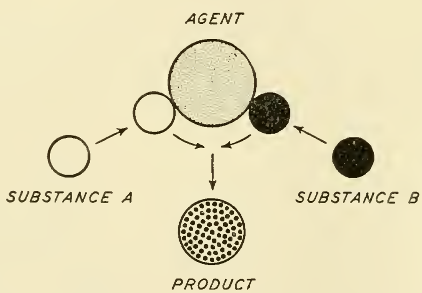


FIG. 25.—Scheme representing the activation of a chemical reaction by a colloidal catalytic agent. It is assumed that substance *A* and substance *B*, because of their electrical characteristics, do not ordinarily react with each other. Both are taken up (adsorbed) by the agent, and their contact with the agent so alters their electrical properties that they react and produce a third substance which is different from either.

Catalysis. In the non-living world a class of substances are known which also effect reactions without being used up in the process. These are termed CATALYSTS (Fig. 25). The phenomenon of catalysis may be illustrated by the common device known as a platinum sponge. When held over escaping illuminating gas it appears to accumulate the molecules of the oxygen in the air and the gas molecules in such fashion that they unite and a flame results.

Catalysis is also employed in many important commercial processes; for example, in the artificial fixation of nitrogen in the manufacture of fertilizers a catalyst is employed to bring about the union of the nitrogen of the air with hydrogen, or in some processes, with carbon. The exact nature of catalytic action is not fully decided by the investigations that have been made. It is certain that many catalysts are finely divided substances, colloidal in nature, and it also seems certain that the reactions which they initiate or accelerate occur at the minute surfaces of the colloidal system.

In the cells of all living organisms various types and varieties of enzymes are known to exist which act in speeding up metabolic reactions, or in performing molecular splittings and syntheses. They appear to act like catalysts and must be regarded as such. That a great many of the chemical reactions in protoplasm are catalyzed by enzymes is known; perhaps most of them are so controlled. Evidence that one of the most important chemical reactions in the human body, respiration, is accelerated by some sort of catalytic system is immediately at hand. If a quantity of grape sugar is placed in the open air at 98.6°F. it is practically unaffected by the oxygen of the air, even when in solution in water. But if this substance is taken into the human body at the same temperature, it is completely oxidized within a few hours, the heat output of its oxidation assisting in maintaining the body temperature. This constitutes strong inferential evidence that the oxidative processes in the human body are controlled, speeded up, by enzymes. More direct evidence confirms this.

Since much of metabolism is influenced by enzymes, since also the food of all animals is made available for metabolism by chemical processes that are controlled by enzymes, it is most important that the idea of catalysis be understood and made a part of our concept of what is occurring in protoplasm when it carries on respiration, growth, and other metabolic phenomena, and what is occurring when food is digested in the food vacuoles of amœba and paramœcium, or in the alimentary system of Man. To obtain a fair concept of how protoplasm works without incorporating an understanding of the nature of enzymes as catalysts is impossible.

Some important characteristics of enzymes now concern us. In the first place, the rate of a chemical reaction that is controlled by enzymes depends on the concentration and effectiveness of the enzyme, rather than the amount of the substances which are being chemically changed. Thus the rate of oxidations in the cells of the human body is not appreciably affected by the presence of excess food and excess oxygen, the ability of the oxidative enzymes to transfer oxygen being the determining factor. Secondly, an enzyme-controlled reaction may be slowed down or completely stopped by some agent or condition which adversely affects the enzyme. For example, respiration in the cell may be almost completely arrested by prussic acid even in the presence of oxygen, the acid almost completely destroying the ability of the enzymes to transfer oxygen.

Third, each enzyme has its own characteristics as regards the optimum acidity, temperature, and so on, for its action. For example, the enzyme in the saliva of Man operates best when the medium is slightly alkaline; the enzyme in the digestive fluid in the stomach operates best when acid is present in dilute solution.

Fourth, the products of an enzyme reaction may affect the activity of the enzyme. A good example of this is found in the metabolism of the yeast plant. If a sugar solution is planted with yeast and a small amount of alcohol is added, the sugar is converted to alcohol and carbon dioxide much more rapidly than in the absence of alcohol. So the product of the reaction accelerates the reaction. This type of enzyme action is known as AUTOCATALYSIS, and many biological reactions are thought to be of this nature. On the other hand, when the alcohol concentration becomes too high, the activity of the enzyme is lowered thereby, and the reaction automatically stops itself by means of its own products.

Anaerobes. Now it follows that if an organism is equipped with an enzyme system that will break up compounds which contain potential energy and thus release energy for the organism, that particular organism may be expected to survive and in fact to thrive in the absence of free oxygen, since the union of its food with free oxygen is not necessary for supplying energy. Both plants and animals that flourish in the absence of air-containing oxygen are common. These are called ANAEROBES. Some types are killed by atmospheric oxygen; they are obliged to live shielded from the air. These are the OBLIGATORY ANAEROBES. Others periodically live in the absence of oxygen; these are FACULTATIVE ANAEROBES.

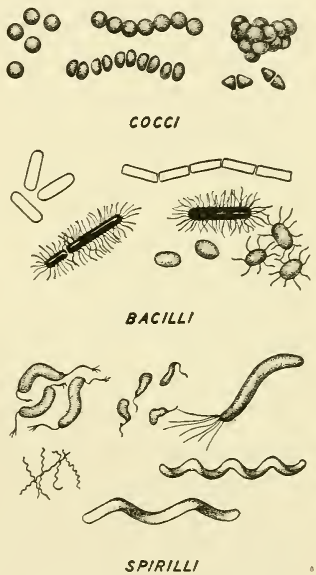


FIG. 26.—Various forms of bacteria. (From several authors.)

Bacteria. We return now to the parasitization of animals by microscopic forms. The most important of these are plant parasites which belong to the Schizophyta, the fission plants. These are the bacteria (p. 77). Not all bacteria are parasitic on Man, nor do all those which do parasitize Man cause disease. Bacteria are small single-cell plants, so small that none of them can be distinguished by the unaided eye and so small that some of them are beyond the powers of the microscope. A single definite nucleus is not distinguishable; what is taken to be nuclear material in some forms is scattered throughout the cell. They reproduce rapidly under suitable conditions. There are very many varieties known and perhaps many others unknown; they parasitize all sorts of animals and plants, feed on dead tissues of all sorts, and are commonly present in all natural environments unless special effort is made to remove them.

According to their shape, visible bacteria may be grouped into the following (Fig. 26):

Coccus: These are spherical in shape. They may exist singly, scattered about without any pattern or arrangement, the Micrococci; doubled in pairs, the Diplococci; in chains, the Streptococci; or in groups of eight arranged as two tiers of four each, the Staphylococci.

Spirilli: These are motile spiral forms; in some types the spiral is flat, in others open, as a corkscrew.

Bacilli: Blunt motile rods, or longer non-motile rods.

Bacteria are also classified according to their efforts on the host. Those which cause disease are termed PATHOGENIC, and those which are without injurious effect are termed NON-PATHOGENIC.

Pathogenic Bacteria. Bacteremia. The action of bacteria in producing disease may be of two general types. In some diseases the bacteria become scattered throughout the body, thus working a general destructive effect. This is BACTEREMIA or SEPTICEMIA. It is invariably accompanied by the second type of effect, namely, TOXEMIA. In toxemia the distressing effect on the host is the result of the poisonous metabolic products of the bacteria circulating in the body of the host and having both general and specific toxic effects on the tissues of the host.

Toxemia. Bacteria, like all other living organisms, carry on metabolism and in their metabolic processes produce waste substances. It happens that the waste products of some types of bacteria are poisonous, in some cases incredibly so. A toxemia is therefore the effect of a local growth of bacteria producing poisonous substances that are distributed throughout the body of the host. In some types of disease these TOXINS affect some tissues more than others. For example, in the case of tetanus, or lock jaw, the growth of bacteria is confined to the immediate neighborhood of the wound, but the toxins there produced are carried about and appear to affect the nervous system more than other tissues, particularly the nerves which cause muscle contraction. Those muscles which close the jaw are noticeably affected; hence the name, lock jaw. Similarly, in diphtheria the growth of bacteria is local, usually in the throat, but the toxins are distributed and affect other regions in a violent fashion.

But it must be remembered that in general bacteremias, the bacteria, although not localized, are producing toxins; hence bacteremias or septicemias are in reality special forms of toxemias. It may be remarked here that this action of the parasitic organisms in producing a toxin that destroys its host is a striking example of uneconomic arrangement in Nature, for the parasite is bringing certain eventual destruction on itself by the destruction of its own food supply.

Response of Animals to Bacterial Invasions. The host is not entirely helpless against the attacks of bacterial parasites, for the body cells of the host may, and in many cases do, produce substances that neutralize or destroy the toxins produced by the invading bacteria, or destroy the bacteria, or may by the production of a wall about the infection isolate it and thus prevent its spread. Also, a certain type of white blood cell acts as a defense agent and engulfs bacteria and other foreign particles in a manner similar to the engulfing of food by amœba. This is an important factor in the defense of the animal; the process is called PHAGOCYTOSIS and this type of blood cell is called a PHAGOCYTE.

Two general types of substances are produced by the host which tend to neutralize the invasion of the bacteria; these are ANTITOXINS, which neutralize the toxins, and BACTERIOLYSINS, which destroy the bacteria. Collectively they are spoken of as ANTIBODIES.

Immunity. A general protection against infection by a pathogenic micro-organism is called IMMUNITY. Immunity may be of several sorts.

Natural Immunity: Man is immune to certain diseases of other mammals and birds. In other words, certain bacteria which produce disease in lower forms do not find the human protoplasm a suitable food for their subsistence. Similarly, some lower animals are immune to certain diseases that affect Man. In some cases NATURAL IMMUNITY has a somewhat different basis. For example, it is apparently not the lack of suitable food material in the body of the horse that renders that animal immune to diphtheria, but the fact that the body cells of the horse provide a superabundance of antibody that destroys the infecting bacteria and their toxins. Therefore the symptoms of the disease do not develop.

Acquired Immunity: This is obtained by having had the disease. It may persist for a period of years. Immunity acquired in this way is usually explained as follows: When the toxins of the microorganisms appear in the blood stream, the body cells, or certain of them, are stimulated by these toxins and respond by producing antibodies in their metabolic processes. This is a type of stimulation known as CHEMICAL STIMULATION. If the antibodies are produced in sufficient quantities the progress of the disease is checked. The metabolic process which produces the antibodies once initiated does not immediately cease when the invading organisms have been driven to extinction, but continues to produce the antibodies for a longer or shorter period; in some individuals and in some diseases, throughout life. Thus new infections meet with a supply of antibody that either totally prevents their development, or results in the production of only a mild form of the disease. Unfortunately for Man, not all diseases have this effect on human body cells and as a result no immunity of any appreciable duration is conferred by having such disease. For example, immunity acquired by having had a common cold is of short duration; attacks seem to succeed each other by re-infection from local cultures in the nose and throat. On the other hand, smallpox confers an immunity that may persist for life. Immunity against one type of pathogenic bacteria affords no protection against other types.

Artificial Immunity: Since the body cells respond to the presence of certain disease-producing bacteria by forming antibodies, the question arises: Is it possible to induce these cells to produce antibodies by means other than the invasion of active and virulent disease-producing bacteria? Attempts to so activate body responses by artificial means have met with considerable success. The reaction may be induced in two ways: One, by the injection of a live culture of the disease germs that are so weakened that they produce only very mild symptoms, but their toxins are sufficient to elicit a response of antibodies from the body cells. Two, by the injection of a killed culture of the disease germs; their disintegrated bodies liberate toxin in quantities sufficient to cause an outpouring of antibodies. The first is the method employed in immunizing against smallpox. Long before the bacterial cause of disease was understood this method of ARTIFICIAL IMMUNIZATION had been employed by Jenner in the eighteenth century. The reasons for the success of Jennerian vaccination are now clear.

Vaccines. The organism that causes smallpox is so small that it has never been seen; in fact, so small that it will pass through the pores of a porcelain filter. Such minute organisms are found to be the cause of a number of diseases, for example, hog cholera, and are called FILTERABLE VIRUSES.[1] In understanding vaccination in the case of smallpox it must be remembered that bacteria, including the filterable viruses, execute all the phenomena of living just as do all other cells and organisms. They are subject to the same limitations in their environment; their food supply must be adequate in quantity and of certain quality, or they do not flourish; they become weakened, ATTENUATED. So in the case of the virus that causes smallpox, the human body appears to be its natural environment, but it will live, although weakened, in the body of the cow. A culture of this attenuated strain from the cow is not potent to produce the disease in man; only a small pustule develops at the point of inocu-

[1] There is considerable important evidence that the filterable viruses are quite distinct from bacteria. However, this distinction primarily concerns the bacteriologist.

lation. But the presence of the small amount of toxin from this local attenuated culture is sufficient to set in action the defense mechanism and the body cells pour out antibodies. Thus an immunity is conferred that usually persists for a long time. In the case of typhoid fever and certain other diseases, it has been found that the dead bodies of the bacteria, when broken up, release a substance that when injected into the human will cause the body to produce typhoid antibodies. So cultures of typhoid bacteria are killed and used as inoculations to bring about immunity. Attenuated cultures, such as smallpox described above, and killed cultures, such as typhoid, when used to produce artificial immunity are called VACCINES.

Serums. The natural immunity mechanism of lower animals to certain diseases which affect man is taken advantage of in the treatment and prevention of human disease. For example, in the blood stream of the horse inoculated with diphtheria is to be found a relatively high concentration of diphtheria antitoxin, sufficient to prevent the development of the disease in that animal. Thus the horse so inoculated with diphtheria is a convenient source of antitoxin and the blood of that animal is withdrawn in small quantities, the blood cells removed and the resulting serum rectified and standardized and used by injection to increase the antitoxin in the blood of a human affected with diphtheria. The powers of the human body to produce antitoxin are thus supported by added antitoxin from the horse and the amount at hand for defense against the invasion of diphtheria bacteria materially increased. This method of treatment is known as SERUM THERAPY. The search for serums rich in antibodies is continuous and from time to time new successes are attained.

Sterilization. Disease-producing bacteria may be killed in a number of ways. Most chemicals when present in sufficient strength will destroy them. However, it is not practical to introduce strong chemicals into the human body, for in concentrations that kill bacteria most of them also kill the human cells. If a chemical could be found that would destroy pathogenic bacteria and not adversely affect the human cells, then the treatment of disease would be considerably simplified. In recent years certain successes have been attained. Some drugs now obtainable are very effective in destroying bacteria in concentrations that apparently are without injurious effect on the human body. Treatment with chemicals in attempting to destroy invading micro-organisms is known as CHEMOTHERAPY.

Many pathogenic bacteria are killed by heat without great difficulty. Thus if milk is heated to 50° C., the typhoid bacteria and allied forms are killed. This process of partially sterilizing milk by low temperature heating was developed by the great French bacteriologist, Pasteur; hence the name, PASTEURIZE. However, some types of bacteria when in a dry or otherwise unfavorable environment form spores that are highly heat resistant and withstand drying for a long time. Some spores are able to withstand heat above the boiling point of water for an hour or more. But if the temperature is reduced to a point compatible with their normal life, the spores develop into active bacteria. So, in intermittent sterilization, the food or other material is heated to the death point of active bacteria, then allowed to cool, then re-heated after allowing sufficient time for the spores to develop into active forms, the process being repeated several times. Thus all the inactive and resistant spores are induced to become active bacteria and are then killed.

Some bacteria in their energy-transforming metabolism are unable to use the oxygen of the air, but derive their energy by an energy-releasing reaction system that is too complicated to discuss here. These are obligatory anaerobes. The tetanus bacillus is of this type. Not only are such organisms unable to utilize the oxygen of the air, but, curiously enough, atmospheric oxygen acts on them as a poison. So in deep wounds, when the air is shut off, tetanus bacilli find conditions suitable for growth. It is for this reason that deep wounds or punctures that are closed off from the air without having been thoroughly cleaned are quite likely to develop tetanus, or other anaerobic infection. The free circulation of clean and filtered air through such wounds is an important agent in preventing the growth of tetanus bacilli.

Colonial Protozoa and the Prototypes of Metazoa. It has been said earlier that two sub-kingdoms of both plants and animals are recognized, on the basis of the number of cells that form the individual, the Protophyta and Metaphyta among plants, and the Protozoa and Metazoa among animals. It may be set down as a rule, however, that these distinctions are not absolutely accurate. Invariably between closely related groups one finds intermediate types, partaking of the characteristics of both. So between single-cell animals and the commonly recognized multicellular forms, there occur a number of types of organisms that are commonly grouped with the Protozoa, but are made up of cell aggregations or colonies, more or less well organized. Also, the distinction between plants and animals is not sharp, and certain forms are intermediate between plants and animals. A common protozoon that illustrates both the intermediate between plant and animal and between unicellular and multicellular is the common fresh water *Volvox*. Volvox (Fig. 27) is usually classified as a member of the class Mastigophora. An individual consists of a colony of cells, often a thousand or more, forming a hollow sphere. Each cell is equipped with a tuft of two whip-like flagellæ, so that the surface of the spherical colony is studded with flagellæ. The members of the colony by their metabolism secrete a gelatinous substance which forms the matrix in which the cells are embedded, each cell being connected with adjacent cells by means of bridges of protoplasm.

While a volvox colony exhibits many animal characters, being highly motile, lacking cellulose, and in general resembling other Mastigophora, the metabolism is holophytic, chlorophyll being present. Thus in an important character the organism resembles plants.

Organization. In several ways volvox anticipates the organization attained by the multicellular animals. In the first place, the whole colony is correlated in such fashion that the flagellæ beat synchronously, thus imparting an orderly motion to the colony. Secondly, there is a certain division of effort on the part of the various

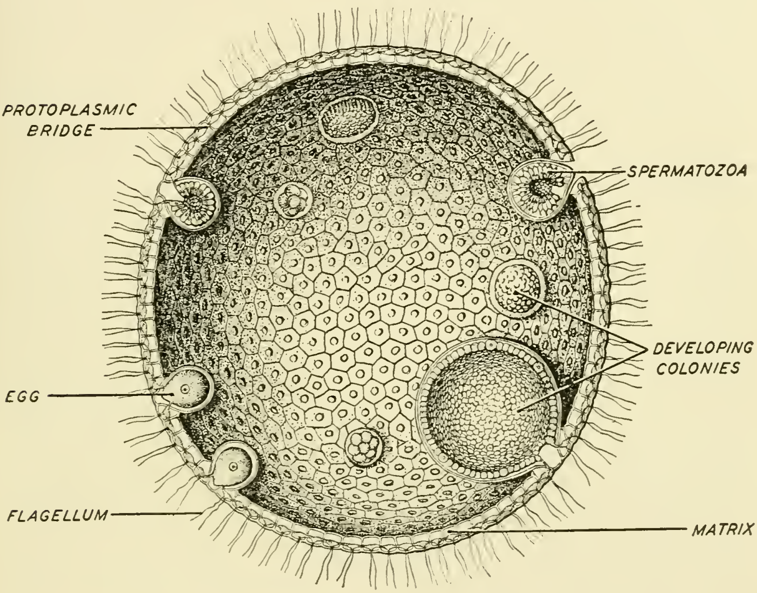


Fig. 27.—Mature volvox colony. (After Janet, modified.)

members of the colony, a forerunner of the very great differences in function between the various types of cells found in multicellular animals. This division of labor in volvox is limited to the setting aside of certain members of the colony as reproductive cells. Thus the members of the colony do not reproduce singly, but rather the colony reproduces itself.

Reproduction. Two types of reproductive processes occur. In the more simple, asexual type, a single cell, a PARTHENOGONIDIUM, is intruded into the central cavity of the colony, which by cell divisions develops into a daughter colony. It is not unusual to observe several daughter colonies of this type within the central cavity of a flourishing volvox.

The sexual process of reproduction is more complex, involving the setting aside in the colony of two different sorts of reproductive cells. One of these becomes larger and is passive, its cytoplasm becoming dense with stored-up materials. This is the female element, the OVUM. The other type is an actively swimming cell, derived by division from a single cell intruded into the cavity. These active cells are the male elements, the SPERMS or SPERMATOZOA. Collectively, reproductive cells are called GAMETES. In the cavity a single sperm cell, on contact, fuses with an ovum, a process known as FERTILIZATION. The now fertilized egg, called a ZYGOTE, no longer a single simple element, embarks on a series of cell divisions resulting in the formation of a new colony. Usually the egg is fertilized by a sperm from another colony, but this is not invariably true.

Metazoon Characters of Volvox. A third manner in which Volvox anticipates multicellular organization is in its geometrical form. If one studies the history of any multicellular animal from the egg to the adult, without exception it is found that early in the process of development the new individual consists of a single-layered, hollow sphere, or some modification of such a structure. This fact is frequently regarded as indicating the common origin of all multicellular animals.

Volvox, then, consists of something more than a chance association of like cells; it is an individual, the cells being subordinate to the colony. Its locomotion results from the coordinated motor activity of the cells; reproduction is effected by the assignment of this function to certain types of cells; the gelatinous matrix that holds the colony together is the result of the collective metabolism of the cells. Among Protozoa and Protophyta there are many other examples of colonial aggregations, exhibiting collective efforts and various degrees of specialization among members of the colony.

Specialization is confined to individual cells in all cases; nowhere among such colonial forms is a tissue of like cells found. The development of tissues and complex organs composed of tissues is found only in the multicellular forms.

Comparisons with the Simplest of the Metazoa. While colonial protozoons as exemplified by volvox anticipate to a slight extent some of the relations that exist between the cells and tissues of a metazoon body, there is a rather wide gap between such comparatively simple colonies and the body of the most simple metazoon. It is said that a volvox colony may consist of as many as 1,200 cells; the most simple adult metazoon body usually contains many more than that number. Moreover, the division of labor within a protozoon colony is more or less temporary, at least as regards the reproductive process, while the various tissue cells within the metazoon body have functions that are stable and more or less permanent. Perhaps the most simple metazoon that may come to the attention of the reader is a small animal found in fresh water that, when observed casually, very much resembles a plant. The fresh water HYDRA, as it is called, is a vase-shaped organism, never longer than an inch and often much shorter, usually observed attached by its narrow or basal end to a stem or the walls of an aquarium, its opened upper end surrounded by tentacles that appear to be, and actually are extended to grasp any small animal that may come within reach. When seen under the microscope, it is found to be composed of two layers of cells, that is, two chief tissues, the cells of which are distinctly different in appearance and shape (Figs. 33, 79). The inner layer is assigned the function of digesting all the food for the entire animal; this is done by engulfing particles of food within the cells, as do the Protozoa, and also by the enzymes that are freed from these cells into the central or gastric cavity. The cells of the outer layer have taken over several functions. Some cells are quite contractile and may therefore be said to be muscular in their function. Others (Fig. 139) are known to exaggerate the property of irritability and represent a very simple type of nerve tissue. Still others are armed with special defensive organs, not found in any other group of animals except the relatives of hydra. Between the inner and outer layers is a binding layer of jelly-like material that is formed by the metabolism of both the inner and outer cell layers. It may contain a few detached cells derived from the inner layer, but is never itself a continuous sheet of cells. Some of these cells between the inner and outer layers are destined to become sex cells. Those which become the male or sperm cells divide into a large number, forming a pouch by distending the outer layer; this structure is known as the SPERMARY. A somewhat similar distention, the OVARY, is caused by the increase in size of other cells as they develop into mature female or egg cells. Both sperms and eggs are shed into the water, where fertilization takes place. The animal also reproduces by budding, the bud as it becomes larger and more mature separating from the parent.

A review of the way in which the different types of cells in hydra contribute to the life processes of the whole animal, when contrasted with the comparatively simple division of labor among the cells of a volvox colony, emphasizes the very much greater complexity of the organization of the metazoon body, even in the most simple form. Larger and still more complex Metazoa contain literally millions of cells among which the functions of life of the animal as a whole are divided. But division of labor does not mean independence; each tissue operates in harmony with all other tissues, the whole being coordinated to form an individual, a unity.

Before leaving the subject of unicellular animals, it is well to point out in advance of the presentation of facts concerning the structure and relations of cells in Metazoa, that metazoon cells have many characters in common with Protozoa, not only as regards their physiological processes of energy transformation and disposal of the wastes of metabolism, but also with regard to structure. For example, cells in the lining of the human respiratory system are equipped with cilia; white blood cells move about by an amœboid type of locomotion, and the male germ cells move by means of flagellæ.

But before entering into a study of the organ systems and their coordination in the metazoon body it is first necessary to survey the Animal kingdom as a whole in order to acquire a mental picture of the various types of animal organization and their relation to each other.

Suggested Readings

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Chapter IV

THE ORDER AMONG ANIMAL TYPES

The Purpose of Classifying Animals. In the preceding chapters the reader has at his disposal the essentials of the principles of the structure and of the functioning of protoplasm, its organization into cells, and at least some of the facts of animal organization as exemplified by animals that consist of single cells. He can go no farther intelligently in the application of the principles already developed and in understanding still other fundamentals without knowing something of the wide diversity of form among animals. In assembling a body of knowledge, whether it be a history of a human endeavor, a method of manufacture, or an understanding of the application of biological principles and the relation of animals to each other, three steps are involved: One is the discovering of the facts; the second is the placing of these facts in the proper order with reference to each other, the fitting together of the pattern; the third is the analysis of the significance of the pattern revealed when the facts have been fitted together and placed in their proper order. To appreciate the principles of Biology one must first know something of the similarities and dissimilarities among animals and an orderly scale of complexity must be established. Otherwise one cannot take the second step, that of obtaining a full comprehension of the significance of the facts of animal structure and of animal function. A knowledge of the chief characteristics, at least, of the several larger groupings that represent human attempts to indicate the orderly arrangement of animal life as a whole is essential to an appreciation not only of detailed biological principles, but also to a recognition of the unity of animal life. The next task at hand is, then, to acquire a working knowledge of the scale of animal complexity, so that in future pages one may by constant references to the position of animals and organ systems in this scale analyze their significance.

The branch of Biology which concerns itself with the laws and principles of classifying animals, that is, of arranging them into groups which express the relations of the widely diverse forms to each other, is termed TAXONOMY. It involves careful analyses of the structure and development of organisms in order that they may be compared. On the bases of such comparisons animals are arranged into groups based on the relative extent of their similarities and dissimilarities. Observable likenesses and unlikenesses serve as the diagnostic characters in the arrangement of the groups. The system of classification that is used today is the result of long years of study and effort and has come to serve as a universal basis wherever animals are studied. Objections are often raised that biologists employ an unnecessary number of complex and unusual terms as the names of various forms and structures and of various processes which go on in the organism. A detailed defense of the system is out of place here, but it may be pointed out that a system of nomenclature is necessary. This is apparent to anyone after even a brief experience in the field, for animals, structures, and processes outside the experience of everyday life are encountered. Out of the system has grown a language of the science. It is as necessary to a knowledge of Biology to learn its language as it is necessary to learn the vocabulary of a foreign tongue in order to appreciate its literature.

Basis of Classification. Starting with the fact already known to the reader that living objects may be arranged according to their very broadest similarities into two great groups or kingdoms, Plant and Animal, the Animal kingdom has been further divided into two sub-kingdoms, the single cell forms, or PROTOZOA, and the many cell forms, or METAZOA. The sub-kingdoms are further divided on the basis of somewhat closer resemblances, into other groups termed PHYLA. Thus, for example, all worm-like animals that consist of a series of rings, have this and several other grosser features in common and are regarded as related; all animals which conform to these characteristics are placed in the phylum Annelida. The number of phyla that compose the Animal kingdom is frequently given as thirteen, although some authorities divide some of these and recognize more.

Within the phylum there may be many types which resemble each other only in having the diagnostic characters of the phylum. So the phylum may be composed of a number of CLASSES. Similarly, the members of a class are not identical, but are divisible into ORDERS. Orders are further separated into FAMILIES and families into GENERA. Within the GENUS a further grouping is made on the basis of very close resemblances and somewhat minor differences. These ultimate groups are termed SPECIES and within the species only a very close examination reveals individual differences. It is also often convenient to make further sub-divisions of each group, as SUB-KINGDOM, SUB-CLASS, SUB-GENUS, and so on. In passing from the broader to the more narrow groups, from the kingdom to the species, dissimilarities become less and less, while similarities become more and more numerous and extensive, until within the species the various individuals differ in exceedingly minor characters. Expressed as a contracting series of relationships, one may with some accuracy think of members within the Animal kingdom as being related only through some common ancestor in a very remote past; in a similar way the members of a phylum may be thought of as being somewhat more closely related to each other than to members of other phyla; within the species the relationship is real and demonstrable, for various members of the species may in reality stand in the close relationship of parent and offspring or brother and sister.

A natural and likewise sound method of analysis of any subject is to proceed from the simple to the complex. The groupings of the various animal types which follow are arranged on this rational basis. A knowledge of this order is a necessary part of the working equipment of all students of Biology, for not only does it indicate the pattern of animal life as it exists today, but also in a general way at least, it represents the order in which animal forms have appeared in the world's history. The significance of these facts will be discussed in more detail in a later chapter.

Animal Kingdom

Sub-Kingdom Protozoa

All animals that consist of a single cell, either separate or as colonies of cells each of which is a complete animal, are placed in this sub-kingdom. But one phylum is recognized, the phylum Protozoa. It is divided into four classes.

Phylum Protozoa

Class I. SARCODINA (Fig. 28). This class includes forms which move by means of temporary extrusions of the body substance, known as PSEUDOPODIA. All are minute and may be seen only with the aid of the microscope. Many varieties are quite common in stagnant water containing decaying plant and animal materials. The most commonly observed forms are members of the genus Amœba. Some, especially those of the genus Entamœba, are parasites in the tissues of Man and other higher animals and are in some cases the cause of disease, for example, amœbic dysentery. Members of two orders, the Foramenifera and Radiolaria, and some others are encased in hard shells composed of lime.

Class II. MASTIGOPHORA (Fig. 29). Members of this class are distinguished by the fact that they move through the water propelled by means of one or more long fibres known as FLAGELLÆ. All are microscopic. They are common in stagnant water. A common ex-

PROTOZOA

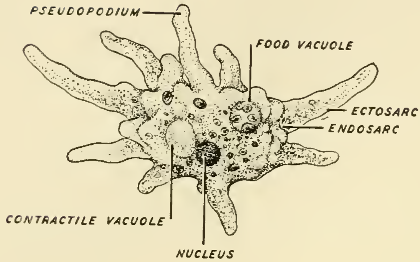


FIG. 28. SARCODINA-AMOEBA

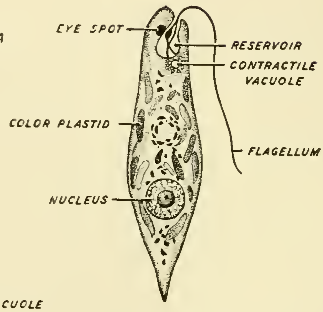


FIG. 29. MASTIGOPHORA-EUGLENA

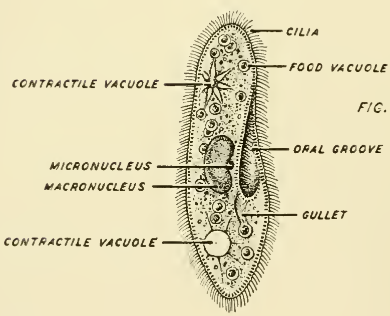


FIG. 30. INFUSORIA-PARAMOECIUM

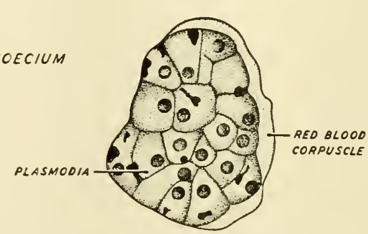


FIG. 31. SPOROZOA-PLASMODIUM (MALARIA)

FIGS. 28, 29, 30, and 31.—Examples of the four classes of Protozoa. (Fig. 29 from various sources; Fig. 31 re-drawn after Calkins: *Biology,* published by Henry Holt and Co.)

ample is Euglena, a cigar-shaped form common in fresh water pools. Some Mastigophora are parasitic. Noctiluca is a spherically shaped form that is phosphorescent; it occurs in unimaginably great numbers in sea water and is chiefly responsible for the phosphorescence of breaking waves and in the wake of ships.

Class III. INFUSORIA (Fig. 30). Some members of this class are large enough to be detected with the unaided eye. All move by means of numbers of fine fibres arising in the ectoplasm, termed cilia. They, like Sarcodina and Mastigophora, are also quite common in stagnant water, where they feed on bacteria and other bits of organic materials. Perhaps the most common form is *Paramœcium caudatum*. Some members of the class are parasitic.

Class IV. SPOROZOA (Fig. 31). The distinguishing character of this class is that all members at some time during their life history reproduce by the formation of considerable numbers of SPORES. All members of the class are parasitic. Various species of the genus Plasmodium are the cause of the several types of malaria (p. 74).

Sub-Kingdom Metazoa

All animal types composed of many cells that are differentiated into different tissues are placed in this sub-kingdom. Various authorities recognize twelve or more phyla of the Metazoa. In order of complexity of cellular arrangement these are:

Phylum Porifera

The Sponges. Vase-shaped, radially symmetrical animals consisting of two layers of cells, the ectoderm or outer, and the endoderm or inner layers, enclosing a central cavity. The walls are perforated by pores, hence the name Porifera (Fig. 32). The endoderm consists wholly or in part of cells termed CHOANOCYTES, that have a characteristic collar in which is a beating fibre or flagellum. Beating of these flagellæ causes water to be drawn inward through the pores and to pass outward through a single large aperture termed the OSCULUM. With some exceptions the ectoderm contains supporting rods or spicules composed in some genera of silicon, in others of a calcium salt, and in others of a peculiar tough substance called SPONGIN. Some sponges are composite individuals consisting of a considerable number of subordinate individuals with the central cavities continuous. The common bath sponge is a composite individual. In its market form it is merely the spongin

PORIFERA

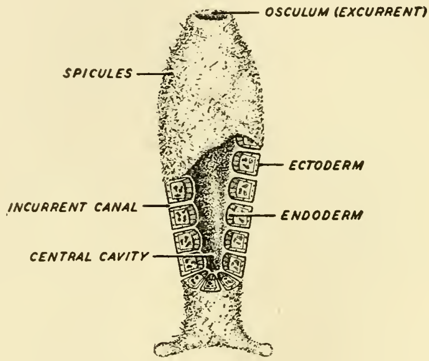


FIG. 32. A SIMPLE SPONGE (WALL CUTAWAY)

network of such an individual from which the tissues of the animal have been removed.

Phylum Cœlenterata

Members of this phylum are also composed essentially of two layers of cells enclosing a cavity, and are vase-shaped. The endoderm lines the sac-shaped cavity which serves as a digestive organ. The cavity has but a single opening, the mouth; the walls are not perforated as in the Porifera. They, like the sponges, are radially symmetrical and occur as single and as composite individuals. All members of the phylum are equipped with a peculiar type of stinging cell termed a CNIDOBLAST. The cnidoblast contains a coiled barbed organ which is employed in defense but more especially in the capture of its food. The ectoderm contains cells which exaggerate the property of irritability and function as a rudimentary nervous system. In this and in other respects the phylum marks a distinct advance over the phylum Porifera. Three classes are recognized:

Class I. HYDROZOA (Fig. 33A and B). Attached or free swimming forms. The digestive cavity is undivided. Examples are the fresh

COELENTERATA

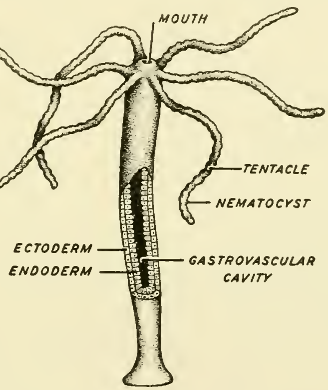


FIG. 33_A. HYDROZOA-HYDRA (WALL CUT AWAY)

water Hydra, the composite attached Hydroids, mostly marine, found usually attached to rocks or debris, and very small free swimming forms shaped like umbrellas, known as Medusæ, which are in reality the free swimming stages of the Hydroids.

Class II. SCYPHOZOA (Fig. 34). The Jelly Fishes. Free swimming forms shaped like umbrellas. Some have stalks and attach to plants or other objects. These animals contain a very high proportion of water and if stranded in the sun soon evaporate to a residue that

COELENTERATA

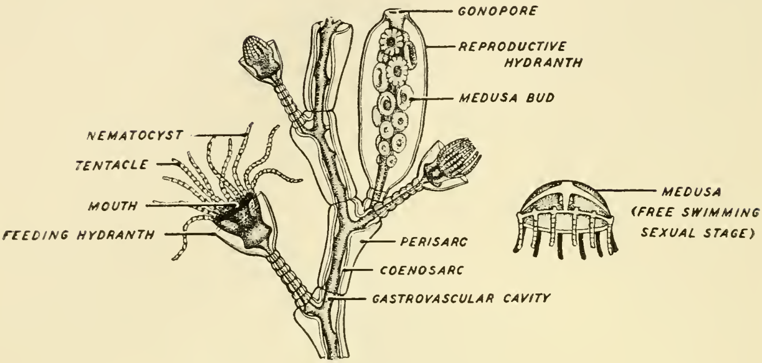


FIG 33_B. HYDROZOA-HYDROID OBELIA

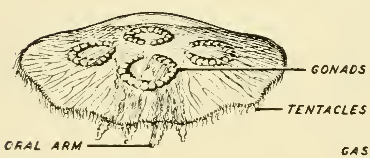


FIG. 34. SCYPHOZOA-AURELIA

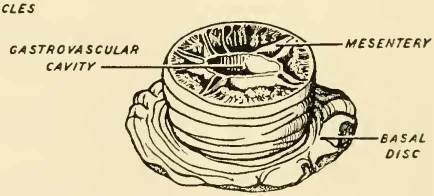


FIG. 35. ACTINOZOA-PORTION OF A SEA ANEMONE

Fig. 33b.—Hydroid Obelia, a colonial animal of the class Hydrozoa. Compare a feeding hydranth with the structure of Hydra, Fig. 33b. (After Parker and Haswell: *Textbook of Zoology,* published by The Macmillan Co.)

Fig. 34.—Class Scyphozoa illustrated by a common jellyfish, Aurelia.

Fig. 35.—Illustration of the body structure of Actinozoa. The animal, *Metridium,* has been cut transversely to show the mesenteries which partition the gastrovascular cavity. The upper disk containing the mouth and tentacles is not shown.

represents only about 1 per cent of the original weight of the animal.

Class III. ACTINOZOA (Fig. 35). Attached forms. The digestive cavity is always divided into compartments by membranous partitions. Some are single individuals, as the Sea Anemone; others are composite, as the Corals. The last named are in large measure responsible for the formation of coral islands and the enormous Great Barrier Reef of the Pacific Ocean. Countless millions of minute Actinozoa have died, each leaving a deposit of calcareous material. The accumulation of this material from enormous numbers of animals over years of time has resulted in the formation of islands and reefs.

Phylum Ctenophora

Includes forms which are commonly called Comb Jellies (Fig. 36) or Sea Walnuts. They do not possess cnidoblasts as do the Cœlenterata. The body wall is composed of three layers, a third layer, the mesoderm, appearing between the ectoderm and endoderm. The symmetry is biradial, that is, the parts are radially arranged, but the animal may be divided by a plane of bilateral symmetry into right and left halves. This group is of considerable interest to the taxonomist because of its possible relation to the Cœlenterata and of the possibility of its being the ancestor of the next higher phylum.

Phylum Platyhelminthes

This phylum includes the Flatworms, the simplest of the truly bilaterally symmetrical animals. The nerve cells are arranged in longitudinal tracts which are near the ventral surface of the animal. Derivatives of three layers—ectoderm, mesoderm, and endoderm—make up the various tissues. The digestive cavity has but a single opening, the mouth. In some of the parasitic types the entire digestive system is lacking. There are three classes:

Class I. TURBELLARIA (Fig. 37). The ectoderm (surface layer of cells) is covered with cilia. This class includes the free living

CTENOPHORA

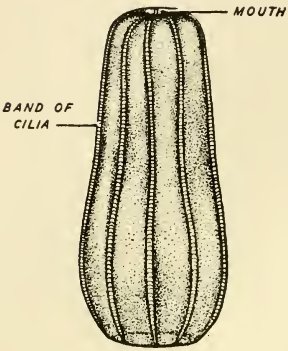


FIG. 36. COMB JELLY

PLATYHELMINTHES

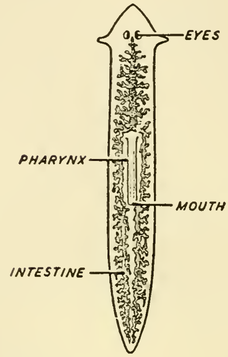


FIG. 37. PLANARIA

PLATYHELMINTHES

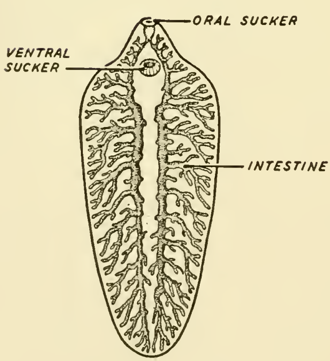


FIG. 38. LIVER FLUKE

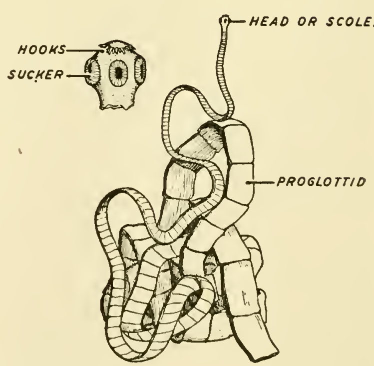


FIG. 39. HUMAN TAPEWORM

Fig. 36.—An example of the phylum Ctenophora, showing external characters only.

Figs. 37, 38, and 39.—Representatives of the three classes of the phylum Platyhelminthes. Planaria are common free living forms, mostly aquatic. The flukes are parasitic in the liver, blood vessels, lungs, bladder, and elsewhere in vertebrate animals. Tapeworms are parasites inhabiting the intestines of vertebrates.

PLATYHELMINTHES

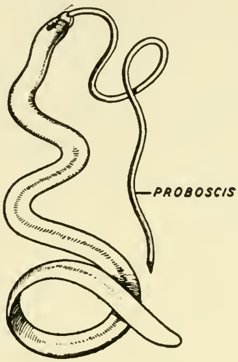


FIG. 40. NEMERTINEA - CEREBRATULUS

NEMATHELMINTHES

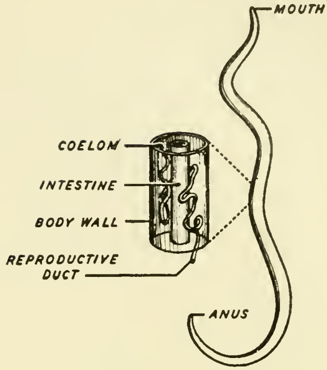


FIG. 41 ASCARIS

TROCHELMINTHES

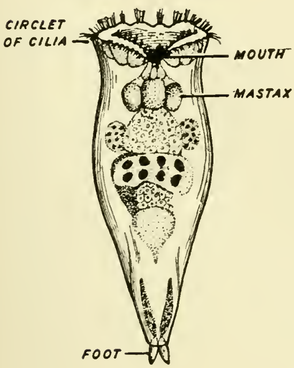


FIG. 42. ROTIFER

MOLLUSCOIDEA

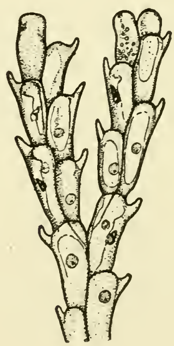


FIG. 43. BRYOZOA - A PORTION OF BUGULA

Fig. 40.—Nemertinea are frequently included in the phylum Platyhelminthes. All are free living marine animals, some varieties attaining a length of many feet.

Fig. 41.—Ascaris, a common representative of the phylum Nemathelminthes. This form and its relatives inhabit the intestines of vertebrates. Other members of the phylum are parasitic in many plants and animals; many representatives are free living. In the figure a portion of the body has been diagrammed to show the structure.

Fig. 42.—A rotifer, representative of the phylum Trochelminthes, much enlarged. These animals may be found attached by the foot and feeding, or swimming about in the water. (Re-drawn after Van Cleave: *Invertebrate Zoology,* published by the McGraw-Hill Book Co.)

Fig. 43.—Bryozoa, a representative of one type of the phylum Molluscoidea. Plume-like forms of this type occur in fresh water.

Planaria and related genera which are very common in both fresh and salt water.

Class II. TREMATODA (Fig. 38). Parasitic forms resembling in general form the Turbellaria, but the ectoderm is entirely free from cilia. Common examples are the Liver Fluke and the Blood Fluke.

Class III. CESTODA (Fig. 39). Also parasitic. Have no digestive canal. The body forms a chain of segments as it increases in length. The tapeworms are the most common examples.

A fourth class of Platyhelminthes is sometimes included, namely, the class NEMERTINEA (Fig. 40). These are flat ribbon-shaped forms, mostly marine and all free living. Some varieties attain a length of several feet. In some important respects they resemble the other free-living flatworms.

Phylum Nemathelminthes

The animal is cylindrical and smooth (Fig. 41). The body is bilaterally symmetrical, derived from three primary layers, and consists of a tube within a tube, the outer tube being the body wall and the inner tube the digestive system. The digestive tube has both an anterior and a posterior opening; this is the simplest type of animal that has an alimentary tract with both mouth and anus. Between the inner, digestive tube and the body wall is a body cavity, probably the same sort of body cavity that occurs in the higher animals. The intermediate layer, mesoderm, forms the lining of the body wall. None of the tissues ever has ciliated cells. The phylum contains both free-living and parasitic varieties. The parasitic forms are very important from the standpoint of public health and economics, for the Hookworm, the Pin Worms, the Muscle Worms or Trichina, and other serious parasitic pests are members of this phylum.

Phylum Trochelminthes

The animals in this group are commonly called rotifers (Fig. 42) and because they are exceedingly small are often mistaken for

Protozoa by inexperienced observers. The whorls or circlets of cilia at the anterior end are in constant motion sweeping food into the mouth. The body wall is of three cell layers and is transparent. The digestive system is a tube with both mouth and anal openings. A specialized region of the tube, termed the stomach, contains a pair of hard plates, that are in constant motion grinding the food. This mechanism is readily observed through the body wall and its presence unmistakably distinguishes a form as a rotifer.

Phylum Molluscoidea

Whether or not the Bryozoa, or moss-like animals, and the Brachiopoda, or mollusc-like animals, that form the two classes of Molluscoidea should be thus joined is a matter of some dispute. Some plumed Bryozoa (Fig. 43) that outwardly resemble Cœlenterata are found in fresh water. The Brachiopoda (Fig. 44) live within a bivalve shell similar in nature to the shells of Mollusca. Their fossil remains show that these animals have existed for many millions of years and were once much more numerous than now.

Phylum Echinodermata

This phylum includes the Starfish and its allies, the most complex animals in which RADIAL SYMMETRY characterizes the adult animal. The structures are arranged in a radial pattern about a central disk, the number of radii being usually five. The body is usually covered with plates containing calcium carbonate, and is characteristically spiny. The body is derived from three layers and the mesoderm is separated into two sheets enclosing a body cavity or CŒLOM which is homologous with the body cavity of the higher animals. The alimentary canal has both mouth and anus. Locomotion is by means of a mechanism peculiar to this phylum called the AMBULACRAL WATER SYSTEM. It consists of a series of canals containing water, connected with tubes which end as feet with suckers operated as organs of attachment by means of bulbs on the walls of the canals. Five classes are usually given:

MOLLUSCOIDEA

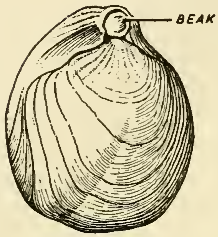


FIG. 44. BRACHIOPODA (SHELL)

ECHINODERMATA

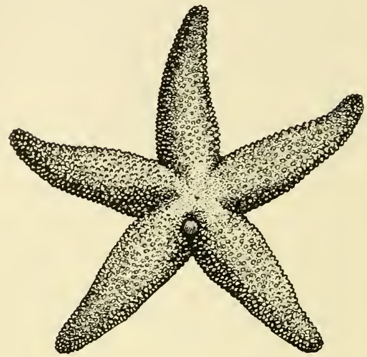


FIG. 45. STARFISH

ECHINODERMATA

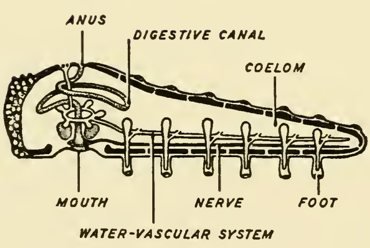


FIG. 46. DIAGRAM OF CENTRAL DISK AND A RAY OF STARFISH

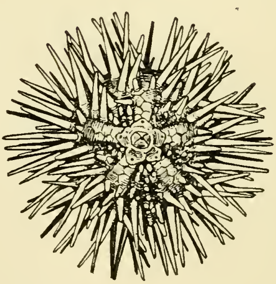


FIG. 47. SEA URCHIN

Fig. 44.—Brachiopoda, a representative of the second type of the phylum Molluscoidea. The calcareous shells of these animals much resemble shells of bivalve Mollusca (Fig. 51).

Fig. 45.—Echinodermata. Upper or dorsal view of a common starfish.

Fig. 46.—Diagram of the internal structure of the central disk and a single ray of a starfish. Actually the stomach is very much larger than represented and occupies most of the coelom. Note the tubular character of the digestive canal and the radially arranged water vascular system.

Fig. 47.—External appearance of the dorsal region of a sea urchin, a representative of the phylum Echinodermata. Its internal structure is similar to that shown in Fig. 46.

Class I. ASTEROIDEA (Fig. 45). The Starfishes.
Class II. OPHIUROIDEA. The Brittle Stars.
Class III. ECHINOIDEA (Fig. 47). The Sea Urchins.
Class IV. HOLOTHUROIDEA. The Sea Cucumbers.
Class V. CRINOIDEA. The Feather Stars.

Phylum Annelida

Members of this phylum (Figs. 48, 49, 50) represent a comparatively high state of organization when contrasted with the forms already given here. The nervous system is well organized and condensed into definite tracts and aggregations of cells termed GANGLIA. The body is derived from three layers and the cœlom is well developed. The body contains a series of tubes which conduct fluid to and from the tissues. This fluid is blood and contains a red coloring material identical with that in the human blood. The general structure is that of a tube within a tube, the digestive system being the inner tube, ventral to which is the main nerve tract. From anterior to posterior, the body consists of a series of rings, each much like adjacent rings, termed METAMERES or segments. This type of segmental arrangement is also characteristic of higher forms, including the early stages of development in Man. Three classes of Annelida are recognized. The most commonly known examples of the phylum are the Earthworms and the Leeches.

Phylum Mollusca

The phylum Mollusca is composed of a very great number of different forms, many of which, to outward appearances at least, do not appear to be related. However, all have in common the following features: Soft unsegmented bodies, usually protected by a shell and derived from three layers; a cœlom is always present. The symmetry is usually bilateral. The body wall is always protected by a MANTLE which forms a characteristic mantle fold; when a shell is present it is formed by the mantle and the type of shell depends on the type of mantle. A single muscular FOOT is always present. There are five classes:

ANNELIDA

FIG. 48 EARTHWORM

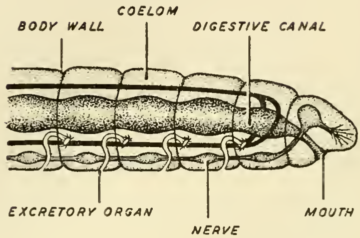


FIG. 49. SCHEME OF ANNELID STRUCTURE

FIG. 50. LEECH

MOLLUSCA

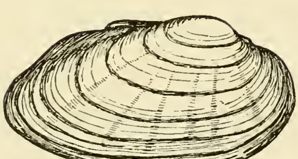


FIG. 51. PELECYPODA - RIGHT SHELL OF CLAM

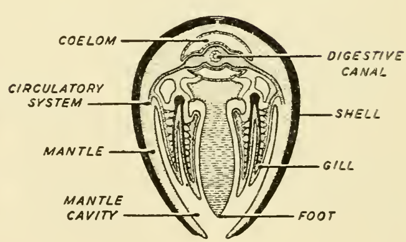


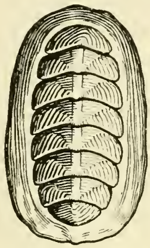
FIG. 52 SCHEME OF CLAM STRUCTURE (CROSS SECTION)

Figs. 48, 49, and 50.—Annelida. Fig. 49 is a diagram of general annelid body structure, particularly of the anterior region.

Figs. 51 and 52.—Mollusca. The right shell of a clam and a diagram illustrating the arrangement of the internal structures of members of the class Pelecypoda when examined in cross section. (Figs. 49 and 52 after Kühn: *Grundriss der allgemeinen Zoologie.* Georg Theime, Leipzig.)

Class I. PELECYPODA (Fig. 51). Shell formed of two opposed halves. Oysters, Clams, Mussels, *etc.*, are common examples.

MOLLUSCA



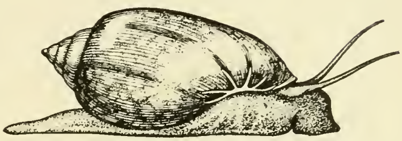


FIG. 54. GASTROPODA-SNAIL

FIG 53. AMPHINEURA-CHITON

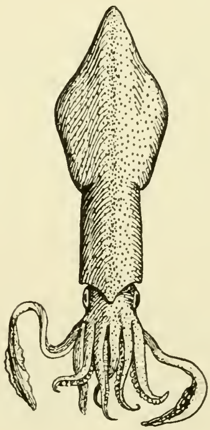


FIG. 55. SCAPHOPODA-TOOTH SHELL FIG. 56. CEPHALOPODA-SQUID

FIGS. 53, 54, 55, and 56.—Representatives of four of the five classes of the phylum Mollusca. See also Fig. 51 and Fig. 52. Although quite different in outward appearance, all have the essential features of the phylum, viz., mantle and mantle cavity, ventral muscular foot, unsegmented bodies, and usually a shell. (Fig. 55 greatly enlarged.)

Class II. AMPHINEURA (Fig. 53). Deep marine forms. The shell when present consists of eight transverse calcareous plates. This is not a familiar form; Chiton is perhaps the most common example.

Class III. GASTROPODA (Fig. 54). Asymmetrical forms with rather large and well-developed heads. The shell when present is spiral. Snails and Slugs are common examples.

Class IV. SCAPHOPODA (Fig. 55). The mantle forms a tube which secretes a tubular shell open at both ends and larger at one end than at the other. The Tooth Shell, Dentalium, is a type form.

Class V. CEPHALOPODA (Fig. 56). Outwardly to the uninformed observer the Squids, Octopods, and similar forms which make up this class appear to be totally unlike such forms as the Oyster and the Clam. However, the mantle fold and other essential structures of the phylum are present.

Phylum Arthropoda

This phylum contains the greatest number of species. The distinguishing characteristics are: The body is made up of segments, each segment being covered with a tough external skeleton composed of CHITIN. Most of the segments bear a pair of appendages which are jointed. The head bears one or more pairs of long, jointed antennæ. The digestive canal forms an inner tube, the body wall forms an outer tube, and the cœlom is the body cavity between these two tubes. The symmetry is bilateral. The nervous system is well organized and condensed into segmental ganglia with connecting tracts. All segmental ganglia except the most anterior pair are ventral to the alimentary canal. The hearts are modified dorsal or segmental blood vessels. Two types of respiratory mechanisms are found; GILLS attached to the bases of the walking appendages, as in the Crayfishes, or modified as BOOK LUNGS as in certain Spiders; and TRACHEÆ, which are fine tubes that plumb the air throughout the tissues, as in the Insects. There are five classes:

Class I. CRUSTACEA (Fig. 57). Examples, Crayfish, Lobsters, and Crabs.

Class II. ONYCHOPHORA (Fig. 58). A form which in some important respects resembles the annelids and is of interest because it may represent the transitional type between the two phyla. No

ARTHROPODA

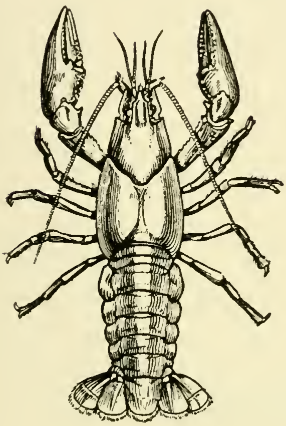


FIG. 57. CRUSTACEA - CRAYFISH

FIG. 58. ONYCHOPHORA - PERIPATUS

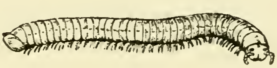


FIG. 59 MYRIAPODA - MILLIPEDE

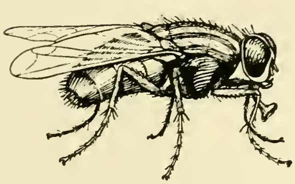


FIG. 60. INSECTA - HOUSE FLY

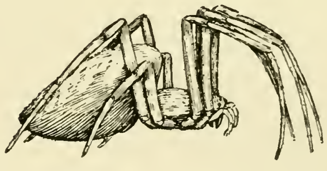


FIG. 61 ARACHNIDA - SPIDER

FIGS. 57, 58, 59, 60, and 61.—Representatives of the five classes of Arthropoda. The arthropod characters are less conspicuous in the figure of *Peripatus* (Fig. 58) than in the others; the jointed structure of the appendages can be distinguished. (Fig. 58 after Sedgwick.)

examples are found in North America. Peripatus is a South American representative of the class.

Class III. MYRIAPODA (Fig. 59). Centipedes and Millipedes.

Class IV. INSECTA (Fig. 60). Body divided into HEAD, THORAX, and ABDOMEN. Always three pairs of walking legs attached to the thorax. Breathe by means of tracheæ. Nineteen orders of Insect are recognized, many of which have the power of flight. Because of their highly specialized tissues, their extraordinary display of instincts, their tendency to assume social life, their ready adaptability, and other characters, some authorities regard the Insects as equal to the Mammals in complexity (Fig. 73).

Class V. ARACHNIDA (Fig. 61). The Spiders. Four pairs of walking legs attached to the thorax. Never have wings.

Phylum Chordata

Members of this phylum are characterized by the following common features: At some time during their life history there is present a longitudinal rod or axis dorsal to or above the alimentary canal, termed the NOTOCHORD (Fig. 64); the main portion of the nervous system consists of a tube of nervous tissue dorsal to the notochord and hence dorsal to the digestive tube; the anterior portion of the animal is perforated by paired slits which connect the forward region of the digestive tube with the outside. These slits are always present in the embryo but in many forms are widely changed in the adult. Chordates are commonly divided into four sub-phyla:

Sub-phylum I. ENTEROPNEUSTA (Fig. 62). Worm-like animals not very clearly related to other chordates.

Sub-phylum II. TUNICATA (Fig. 63). The Sea Squirts. The adults of this group appear to be degenerate types, for the larvæ are free swimming forms outwardly resembling small frog tadpoles, while the adults are attached forms in which the chordate characters have become somewhat obscured.

Sub-phylum III. CEPHALOCHORDATA (Fig. 64). The Lancets. These are small forms shaped like fishes; in some sections of the world they are widely used for food. The form is of peculiar interest to

CHORDATA

FIG. 63. TUNICATA - SEA SQUIRT

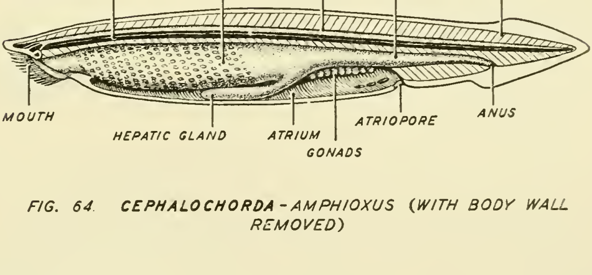


FIG. 64. CEPHALOCHORDA - AMPHIOXUS (WITH BODY WALL REMOVED)

FIG 62. ENTEROPNEUSTA - BALANOGLOSSUS

Fig. 62.—A representative of the sub-phylum Enteropneusta, of the phylum Chordata; Balanoglossus. The larval form of Balanoglossus much resembles the larva of Echinodermata. A notochord is present in the adult.

Fig. 63.—Representative of the sub-phylum Tunicata, a sea squirt. The larval form is free swimming and shaped much like a small frog tadpole. After attaching itself it becomes transformed into the adult form as represented in the figure. The upper opening is the mouth; the lateral opening is known as the atriopore; the contents of the intestine and the water taken in through the mouth are expelled through the atriopore.

Fig. 64.—Amphioxus, representative of the sub-phylum Cephalochordata. Diagram. Note the dorsal position of the main nerve cord and of the notochord. The segmental character of the muscles, the presence of pharyngeal slits and of a hepatic or liver gland should also be noted.

the zoologist because it contains in rudimentary form many of the characters of the higher animals. The type form usually given is Amphioxus.

Sub-phylum IV. VERTEBRATA (Fig. 65). Members of this phylum have a notochord during their early existence, but in later life it is

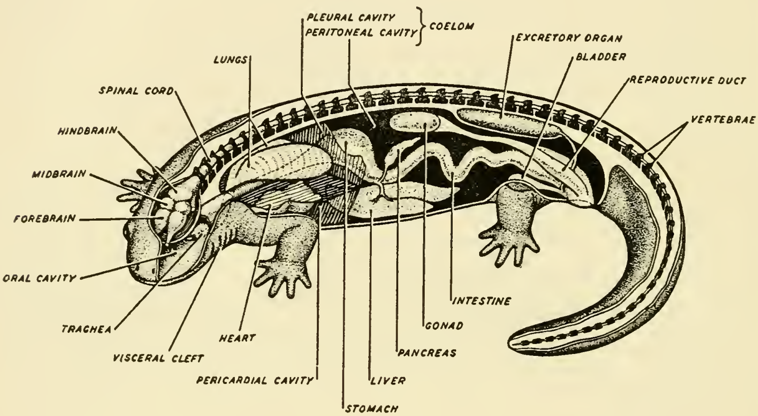


FIG. 65. A SCHEME OF VERTEBRATE ORGANIZATION

FIG. 65.—Scheme of organization of Vertebrata. When lungs are present, as in Amphibia, Reptilia, Aves, and Mammalia, they communicate with the floor of the anterior region of the digestive canal by way of the trachea. Water breathers expel water through the visceral or branchial clefts, indicated in the figure. In mammals the lung cavities are separated from the pericardial cavity and the peritoneal region of the coelom. These partitions are indicated by horizontal and perpendicular planes.

more or less completely replaced by a series of spool-like bones or cartilages forming what is known as the vertebral column. True skin composed of two layers, bony teeth, bone, hair, and feathers, are found only in the Vertebrata, although, of course, not all Vertebrata have all these characters. All Vertebrata exhibit segmentation, have red blood, are bilaterally symmetrical, have two pairs of

PISCES

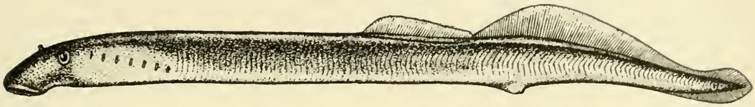


FIG. 66. CYCLOSTOMATA (LAMPREY EEL)

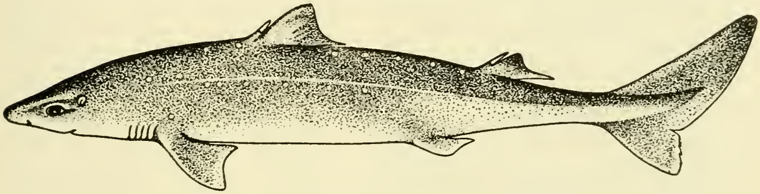


FIG. 67. ELASMOBRANCHII (DOGFISH SHARK)

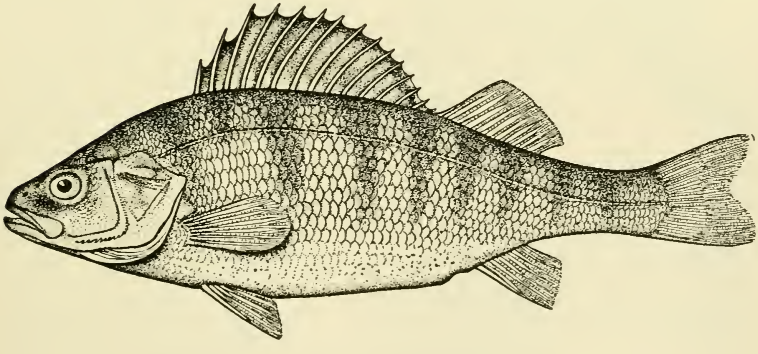


FIG. 68. TELEOSTII (RINGED PERCH)

Figs. 66, 67, and 68.—Representatives of three types of Pisces. Compare and note the changes from the simple toward the complex in the gill clefts which in the perch are covered and protected by the shield-like operculum, the fins, the mouth region, and the integument.

limbs either functional or rudimentary (except in the class Cyclostomata), and reproduce solely sexually. The cœlom is separated into two or three compartments. There are seven classes:

FIG. 69. FROG

Fig. 69.—A common frog, *Rana pipiens*. As in all modern Amphibia, the integument is free from scales. Compare this feature with the well-developed scales of fishes (Fig. 68) and with Reptilia (Fig. 70). Note also the absence of claws; compare with the reptile (Fig. 70).

Class I. CYCLOSTOMATA (Fig. 66). Lamprey Eels and Hagfishes. Do not have paired limbs. The mouth is at the extreme anterior end and has no jaws. The embryos of these forms in many respects resemble the adult Cephalochordata, Amphioxus. Found in both fresh and salt water. Lampreys are used for food in some countries.

Class II. ELASMOBRANCHII (Fig. 67). Sharks and Rays. The internal skeleton is entirely of cartilage and the integument is covered with SCALES consisting of a bony basal plate bearing an enameled spine. The gill openings are not covered.

Class III. PISCES (Fig. 68). The true Fishes. The skeleton always contains more or less bone. The gills are covered by a bony shield. Scales are not always present; when present they consist of smooth plates without the enamel that characterizes the scales of the Elasmobranchii. Practically all the forms that are commonly known as fishes belong in this class, although

Sharks, Lampreys, and Whales (which are Mammals) are often mistakenly called fishes.

Class IV. AMPHIBIA (Fig. 69). Frogs, Toads, and Salamanders. The young are aquatic, the eggs being laid in water, except in some unusual forms that live in dry environments. None of the present-day Amphibia ever have scales.

Class V. REPTILIA (Fig. 70). Snakes, Lizards, Turtles, Crocodiles. The eggs are laid on land, although the adult may be adapted to live in the water. The skin is usually scaly. Members of this and of the class Amphibia are frequently confused, although the distinction is quite clear.

Class VI. AVES (Fig. 71). The Birds. Only this class and the class Mammalia are warm blooded. Members of the class Aves are characterized by wide changes from the usual vertebrate structure as a consequence of their adaptation for flight. The body is covered with feathers, which are highly modified scales. The forelimbs are modified for flight (Fig. 212).

REPTILIA

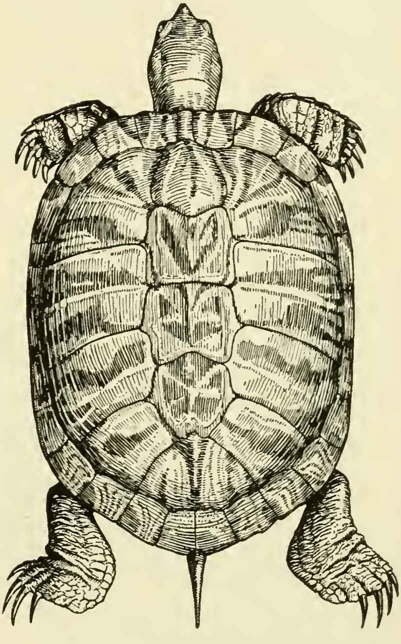


FIG. 70. TURTLE

FIG. 70.—A common turtle, representative of the class Reptilia. Compare with Fig. 69 and with Fig. 71, particularly as regards beak and claws.

Class VII. MAMMALIA. Have a hairy covering at some time in their life cycle. The young are nourished by the secretion of certain modified skin glands termed mammæ. There are three sub-classes:

Sub-class I. PROTOTHERIA (Fig. 72). Egg-laying mammals. No nipples for feeding the young. Two Australian forms, the Duckbill and the Echidna.

Sub-class II. METATHERIA (Fig. 73). The Marsupials. The young are born in a very immature state and complete their development in a pouch or MARSUPIUM on the ventral body wall of the female.

AVES

FIG. 71 BIRD

FIG. 71.—A common bird, representative of the class Aves. Compare the beak and claws with those of a reptile (Fig. 70). For the internal structure of a bird, see Fig. 212.

The Marsupials include such forms as the Kangaroo and the Opossum. The Opossum is the only North American representative of this group.

Sub-class III. EUTHERIA. All other Mammals except those described in the above two sub-classes. There are nine modern orders of Eutheria:

Order I. *Insectivora.* Moles, Hedgehogs, *etc.*

Order II. *Edentata.* Sloths, Anteaters, Armadillos.

FIG. 72 DUCKBILL FIG. 73. KANGAROO YOUNG

Fig. 72.—An egg-laying mammal, the Australian Duckbill.

Fig. 73.—Marsupial. An immature embryo of the Kangaroo attached to the maternal nipple in the marsupium. (After Parker and Haswell: *Textbook of Zoology,* published by The Macmillan Company.)

Order III. *Chiroptera.* Bats.

Order IV. *Rodentia.* Rats, Rabbits, Mice, Squirrels, Beavers, *etc.*

Order V. *Primata* (Fig. 74). Mammals with nails.
Eight families:
Family I. Lemuridæ. The Lemurs.
Family II. Chiromuidæ. The Aye-ayes.
Family III. Tarsiidæ. Tarsiers.
Family IV. Hapalidæ. Marmosets.

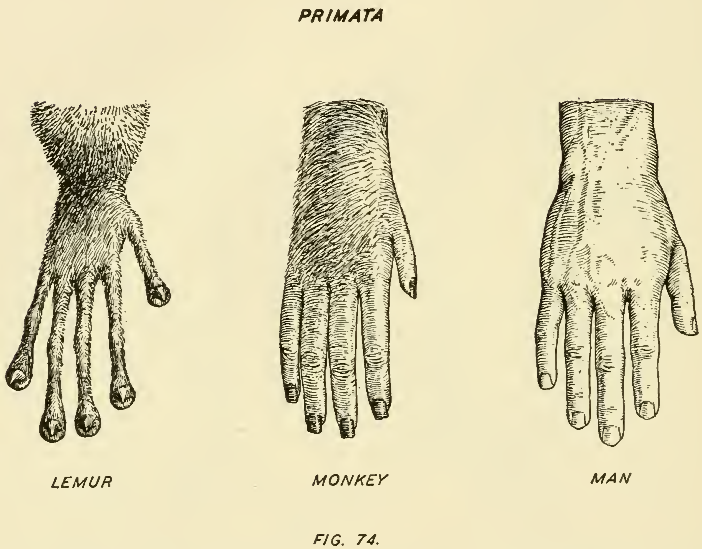


Fig. 74.—The hands of a Lemur, a Monkey, and Man. Note the similarity of form and the characteristics of the nails.

Family V. Cebidæ. South American Monkeys.
Family VI. Cercopithecidæ. Old World Monkeys.
Family VII. Simiidæ. Anthropoid Apes.
Family VIII. Hominidæ. Man.
Two species of Hominidæ are commonly recognized. One, *Homo neanderthaler,* is extinct. Modern Man is classified as *Homo sapiens.*
Order VI. *Carnivora.* Cats, Dogs, Seals, Bears, *etc.*

Order VII. *Cetacea.* The Whales.

Order VIII. *Sirenia.* The Sea Cow, Manatee.

Order IX. *Ungulata.* Hoofed animals, Horse, Cow, Elephant, Giraffe, *etc.*

Procedure in Classification. Identifying an animal as a member of one of the larger groups is in most cases a relatively simple matter; distinctions are very pronounced. The assignment of the organism to its proper ultimate group, the species, is often a matter of some difficulty, for in some cases the differences between species are slight or obscure. For purposes of illustration, let us assume that we have at hand a living object. It is noted that it moves rapidly and responds actively to light and to touch; obviously we may clasisfy it as a member of the Animal kingdom. Only a brief examination is necessary to discover that it is composed of many cells; therefore we know it to be one of the sub-kingdom Metazoa. We note that it is segmented, the body being composed of rings that are externally visible. Only three phyla of the Metazoa show this external segmentation so distinctly, namely, Arthropoda, Annelida, and Chordata. The facts that the segments are covered with a tough armor and that its walking appendages are jointed enable us to place it in the phylum Arthropoda. The animal has three pairs of walking legs and also is equipped with wings; obviously it agrees with the description of the characters that are common to the class Insecta. The wings are a single pair, transparent and membranous. Insects that have wings of this sort and number are grouped in the order Diptera, the Flies. Examination shows that the ANTENNÆ are three jointed, with a bristle on the third segment, and that the head bears a PROBOSCIS. These facts, together with certain characteristic arrangements of the veins in the wings, conform with descriptions of the flies that are grouped in the family Muscidæ. The abdomen of the fly we are examining is not bristly, as in some members of the family Muscidæ; hence it may be placed in the sub-family Muscinæ. Its mouth parts are not adapted for piercing and in other minor characters it agrees with descriptions of the genus Musca. Its size, method of breeding, minor characters of its wings and other structures enable us to regard it as identical in form with a fly which is quite common and the species name *domestica* is assigned to it. Recapitulating, the unknown has now, in our minds at least, been placed in its proper relation with all other living forms:

Kingdom—Animal
  Sub-kingdom—Metazoa
    Phylum—Arthropoda
      Class—Insecta
        Order—Diptera
          Family—Muscidæ
            Sub-family—Muscinæ
              Genus—Musca
                Species—domestica
                  Common name—house fly

Phylogenetic Relationships. The order of probable actual relations between the different phyla is conventionally represented by a diagram (Fig. 75) variously termed "the tree of life," "the phylogenetic tree" or other terms indicating probable descent of the more complex animals from the simpler forms. Too much confidence must not be placed in the accuracy of this diagram, for the relations represented are in many cases still matters of dispute. Hence other diagrams have also been arranged that satisfy an order in relations. Moreover, it is extremely probable that no phylum that we recognize among present-day animals is descended from any other modern forms. The diagram assists in visualizing in a broad way a scale of complexity and the general relations between present-day types. The position of an animal with reference to other phyla is commonly termed its PHYLOGENETIC RELATIONSHIP. The term

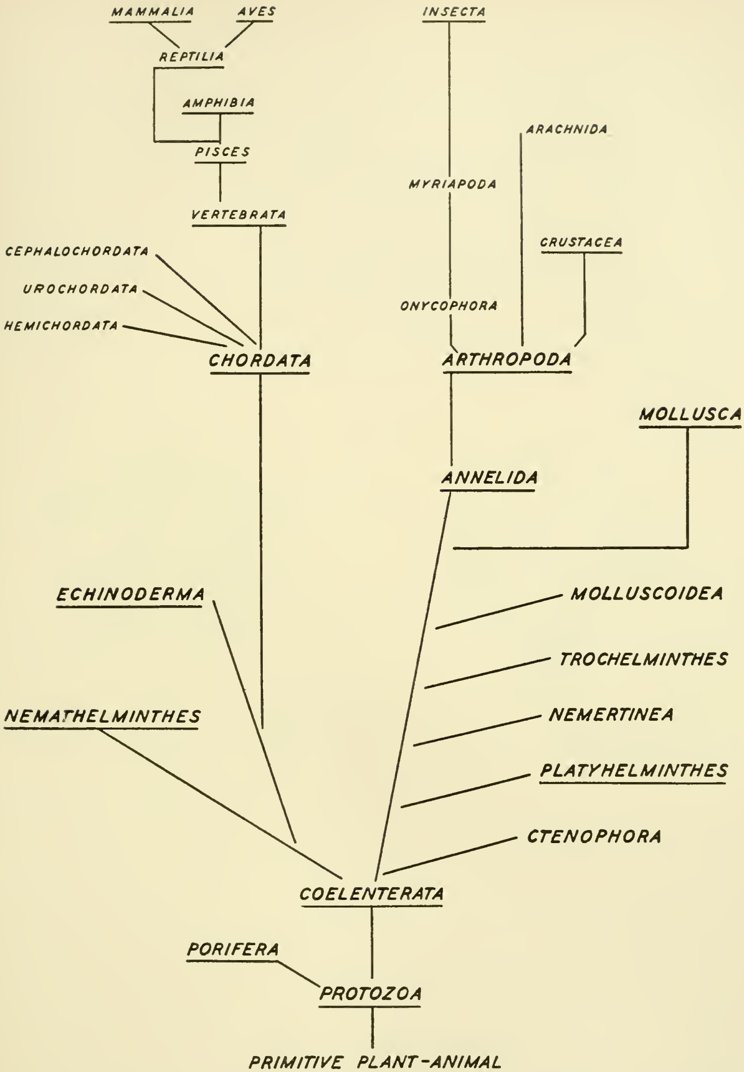


Fig. 75.—Scheme representing a possible relation of the various animal groups. The phyla are given in large, and the classes in small, type. When read from the bottom of the figure the diagram is useful in that it represents accurately a series of ascending levels of animal complexity. Some authorities consider the Chordata to have originated by way of the Annelida; others regard the Arthropoda as the source of the Chordata. Still other interpretations are possible. (After Allee, slightly modified.)

really connotes that the various phyla have appeared in the order given, but the historical origins are in most cases by no means clear.

As an example of procedure in establishing the position of an animal the simplest possible method has been given, namely, comparing the external features of the adult house fly with those of other animals and classifying it according to similarities and dissimilarities. But the specialist has still other criteria that show relations between animals. Regardless of the apparent differences in the structure of adult animals, it is considered that animals which pass through the

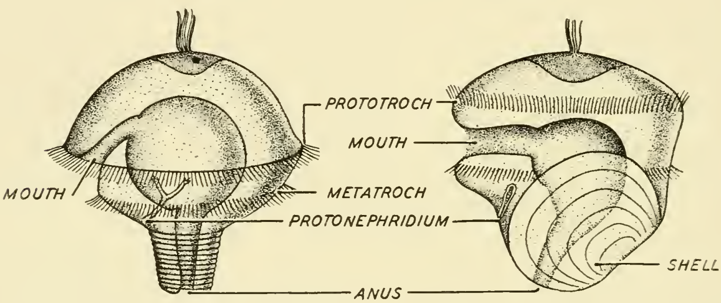


FIG. 76.—Two types of trocophore larvæ. Compare the trocophore of an annelid on the left with that of a mollusc on the right. (After Kühn: *Grundriss der allgemeinen Zoologie.* Georg Theime, Leipzig.)

same or like stages during their development from the egg are related. Thus many Annelida, Mollusca, some Molluscoidea, and a worm-like form of uncertain position (Gephyrea) all pass through a larval stage, called a TROCHOPHORE (Fig. 76), that is very similar; these phyla consequently may be regarded as more or less remotely related. Likewise, all Vertebrata pass through very similar stages and develop in much the same fashion. Then, too, fossil remains of animals frequently indicate that some of the modern animals are related through common ancestors. Consequently, technical classification is based upon three criteria, comparison of the adult forms, developmental history, and relation to fossil types.

Suggested Readings

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Chapter V

THE STRUCTURE AND FUNCTIONS OF MULTICELLULAR ANIMALS

I. Architectural Plans and Organ Systems

The Scale of Complexity. If one examines the structure of the various types of multicellular animals and arranges them serially in their order of increasing complexity, the bodies of the most complex animals, for instance the human body, appear to be fabrics woven of anatomical features that originate in the more simple forms. In the structurally simple animals appear principles of anatomy, and of function as well, that are continued as basic features throughout the series. Passing from simple to increasingly complex types, new structures appear in succession that are added to, and incorporated with those present in simpler forms, which in turn are modified to compose a correlated whole. It is convenient to employ this scale of increasing complexity in comparing the structures and functions of animals, and to refer to an animal as higher or lower in the sense that because of the complexity or simplicity of its anatomy it falls high or low in this scale. Thus it is proper to refer to a fish as high in the scale in comparison with an earthworm, which is a distinctly less complex animal; for the same reason, in comparing the anatomies of a fish and Man, the fish may be defined as a lower animal. Here and there in the series appear structural characters that are highly important features of some types, but are not continued into the more complex animals. One gets the impression that the series is one of trial and error, that along with the origin of structural and functional features that are efficient and worth retaining for the composition of the more advanced animals are also developed some characters that are inefficient or impractical, or at least not suitable for fitting the complex animals to cope with their environment. In a sense, the study of structure and function with this scale as a criterion may be thought of as a study of the history of the characteristics of animals.

All the many and varied forms of animal life are expressions of the possibilities of protoplasm; all are similar in some respects, for all must provide for the same fundamentals; all differ in other respects, for nutrition, reproduction, irritability, *etc.,* may be performed in a wide variety of ways. It now becomes our task to study the members of this scale in some detail, and to consider in a comparative way the architecture of animals and the nature of the various organ systems by which they carry on the necessary functions common to all life. It would lighten our task greatly if we could study some typical animal intensively, but there are no typical animals. In any scale of increasing complexity, no single member is representative of the whole scale. So, among animals, no single type is representative of animal structure; on the other hand, every animal represents the essentials of animal function.

Our plan contemplates a view of the entire animal kingdom; hence the approach is by means of comparisons. The characters of animals that first come to our attention are their external form, the number and relations of the layers that compose the animal body, the types of symmetry, the cavities of the body, and the nature and arrangement of the protective and supporting structures that tend to maintain a certain permanence of shape and arrangement. A study of the organ systems and their functioning by revealing differences and similarities completes the picture of the unity and continuity among animals.

Origin of Cell Layers. In order to understand the major principles of animal organization in Metazoa it is necessary first of all to be familiar with the beginnings of form as they appear when the animal is developing from the egg. A fertilized egg undergoing the changes that result in an adult is called an EMBRYO and the developmental history of an adult is termed its ONTOGENY. The study that treats of development is termed EMBRYOLOGY. The ontogeny of all multicellular animals includes some features that are universal; hence the adults of all animals exhibit some common anatomical principles. The fertilized egg, by repeated divisions, gives rise to a

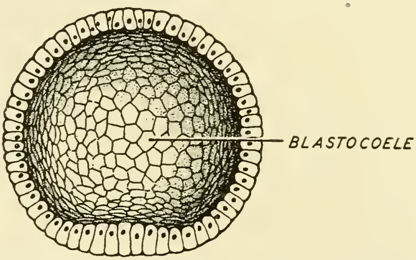


FIG. 77.—Diagrammatic section through the blastula stage in the development of an echinoderm (starfish).

considerable number of cells, which in the simplest cases assume the form of a hollow sphere (Fig. 77), resembling the shape of a volvox colony. This stage of the embryo is known as the BLASTULA. An organism that in its adult stage is composed of the derivatives of a single layer of cells would be described as a MONOBLASTIC ANIMAL. No adult monoblastic Metazoa occur, but all animals pass through such a stage during their ontogeny. Some animals consist of the derivatives of two layers of cells, that is, are DIPLOBLASTIC. The formation of two layers from the single layered blastula of the embryo is accomplished by the inversion of one hemisphere into the other to form a cup-shaped structure consisting of an inner layer or ENDODERM and an outer layer, or ECTODERM, the cell layers being continuous around the rim of the cup. The open mouth of the cup is termed the BLASTOPORE and the process of its formation is known as GASTRULATION. One speaks of this two-layer stage as a GASTRULA (Fig. 78). In all Metazoa some modification of this process of gastrulation occurs and all embryos pass through a gastrula stage during development.

Among the Metazoa only the Porifera and the Cœlenterata are diploblastic in their adult stages. All other animals consist of the derivatives of three layers, that is, are TRIPLOBLASTIC. The third layer,

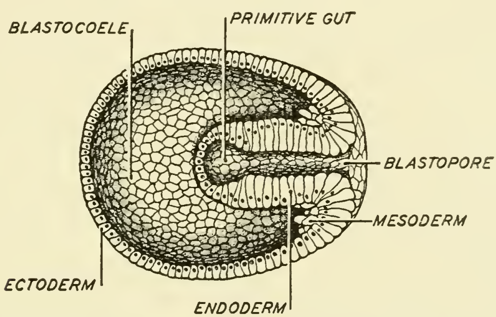


FIG. 78.—Diagrammatic long section through the gastrula stage in the development of an echinoderm (starfish).

the MESODERM, originates immediately following gastrulation, between the ectoderm and the endoderm, largely in the region of the lips of the blastopore (Fig. 78). Concurrent with the appearance of the mesoderm the embryo begins to exhibit the basic plan of symmetry of the future adult.

Diploblastic Animals. The members of the phylum Porifera and the phylum Cœlenterata are described as the most simple Metazoa because they consist of the derivatives of but two layers of cells, that is, they are diploblastic. The bodies of sponges[1] and of cœlen-

[1] The origins of the ectoderm and endoderm in the development of the Porifera are not identical with the processes of development of these layers in other Metazoa; hence these layers in the sponges are not homologous with ectoderm and endoderm of other animals. However, the adult sponge is a diploblastic animal and here we are regarding it as one of the most simple and primitive of the Metazoa.

terates are, in the most simple types, vase-shaped, the walls consisting of the outer or ECTODERM layer, and the inner, or ENDODERM layer. The ectoderm is charged with the functions of support and protection, of receiving and transmitting stimuli, and of performing such contractions as are necessary for the capture of food or for locomotion. Differences in the functions of cells are always associated with differences in structure; hence the ectodermal cells are not all identical but are of several types. As the ectodermal cells have become differentiated for special purposes they lack the power of digesting food. Digestion for the entire animal is carried on by the cells of the inner layer, or endoderm. In these simple types of multicellular animals occur a number of resemblances to the Protozoa. As was stated previously (p. 91) perhaps the most prominent of these in the Cœlenterata is that the endodermal cells ingest solid particles as do the Protozoa; they retain, so to speak, the property of carrying on INTRACELLULAR DIGESTION. The cavity of the vase-shaped body (Fig. 79) also receives enzymes from the endodermal cells; it forms a primitive digestive cavity, for within it the digestive enzymes carry on EXTRACELLULAR DIGESTION. The products of digestion in the cavity pass by osmosis into and through the endodermal cells and are assimilated by both endoderm and ectoderm.

Triploblastic Animals. In the diploblastic animals the ectoderm contains both contractile cells and cells that are more sensitive to stimuli than others. Thus it performs both muscular and nervous functions. In the triploblastic, or three-layered, animals, the ectoderm is the layer of origin of all purely nervous elements, including the brain of the higher animals, but the property of contractility as a function of the ectoderm is largely lost, being assumed by cells that are derivatives of an intermediate layer, the MESODERM (Fig. 78). The mesoderm is also the layer of origin of the connective tissues, of blood and the circulatory system, of the excretory system, and of the reproductive cells and associated organs. The endoderm is universally the layer of origin of all parts of the digestive system

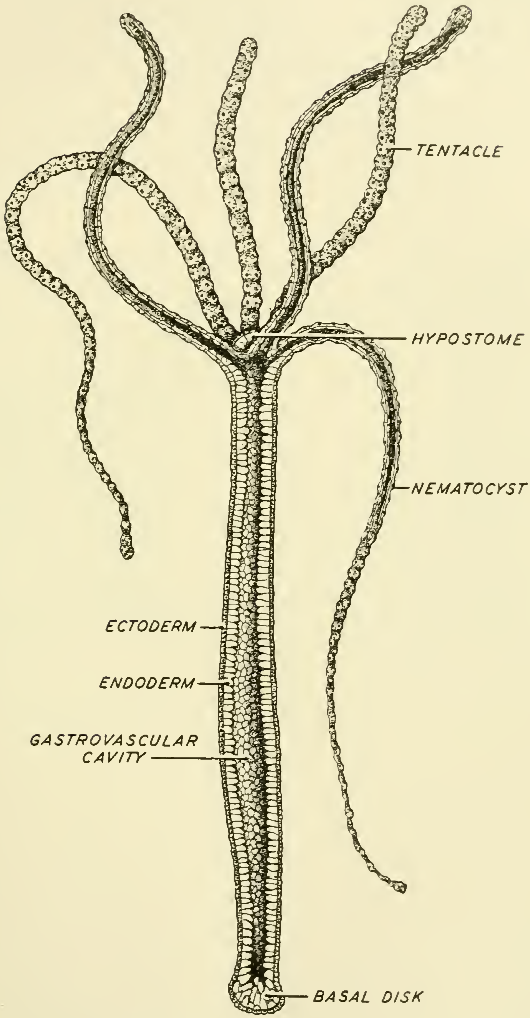


FIG. 79.—A common fresh water hydra, diagrammed to show structure.

that are directly concerned with the chemical modification of the foods, a function that is solely endodermal from the most simple type of multicellular animal to the human body. The muscular elements of the digestive systems of all animals, like all muscles, are derived from mesoderm.

Symmetry. The forms assumed by Metazoa are grouped into only two main types of symmetry, RADIAL and BILATERAL. A form is

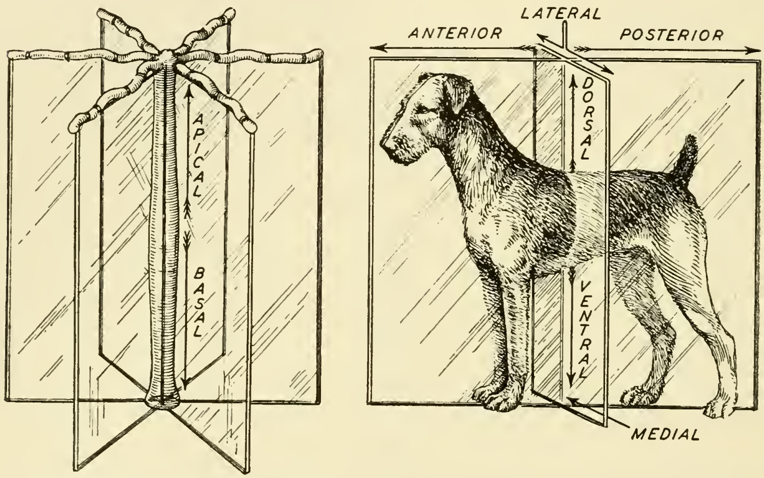


FIG. 80.—Diagrams to show the planes of symmetry and orientation in radial and bilateral forms.

spherically symmetrical if its parts are identically placed with reference to a point. Among the Protozoa a colony of volvox is spherically symmetrical, as are also typical metazoon blastulæ (Fig. 77), but no spherically symmetrical adult Metazoa occur. In the diploblastic animals, Porifera and Cœlenterata, the symmetry is radial, that is, the parts are symmetrically arranged in imaginary planes which pass through a common axis (Fig. 80). Such organisms appear to be ineffectively oriented for locomotion and this type of symmetry is not extensively characteristic of animals. Plants, however, are almost all radially symmetrical. The most complex animals that exhibit this character are the starfishes and their allies, the members of the phylum Echinodermata. Most are familiar with the general shape of the common starfish (Fig. 45). While it is truly radially symmetrical, this animal finds it necessary in its locomotion to have a permanent orientation, so that when the animal moves a certain ray always leads.

The more active and advanced animals are built upon some modification of bilateral symmetry, oriented in such fashion that the longest dimension coincides with the line of usual movement. It has been found necessary to describe the location of various parts and regions of a bilaterally symmetrical animal by a set of terms. Thus, the leading end, or controlling region is called the ANTERIOR end, the opposite end being the POSTERIOR (Fig. 80). That region of the body which is usually presented upward is called the DORSAL region, or dorsal surface, as the case may be. The nether surface is spoken of as the VENTRAL surface. If one imagines a plane passed through a bilaterally symmetrical animal dividing it into right and left halves by passing through the anterior and posterior ends and at the same time coinciding with the mid-lines of the dorsal and ventral surfaces, then each half is a mirror image of the other (Fig. 80). Parts that fall outside this plane of symmetry are spoken of as lateral with reference to the plane. All descriptions of the location of parts employ the adjectives anterior and posterior, lateral and medial, dorsal and ventral. The adverbs or adjectives CEPHALAD and CEPHALIC are also used to refer to anterior structures; CAUDAD and CAUDAL are also used to refer to posterior positions.

The Body Cavity. In most forms more complex than the diploblastic animals the mesoderm, the intermediate layer that develops between the ectoderm and endoderm, in an early embryonic stage splits into two sheets. The sheets are separated by a cavity and the outer sheet becomes closely applied to the inner surface of the ectoderm, while the inner sheet becomes associated as the outer covering of the endoderm. The cavity between these two sheets of mesoderm is the CŒLOM (Fig. 81); it forms the body cavity of the adult. The cavity is not formed in the Ctenophora, and in the members of the phylum Platyhelminthes it is largely, if not entirely, obliterated in the adult, a second cavity, termed the PSEUDOCŒLE, appearing in its place. A distinction is thus established between the ACŒLOMATE and CŒLOMATE animals. The cœlom presently becomes the most prominent cavity of the animal body. In the most advanced

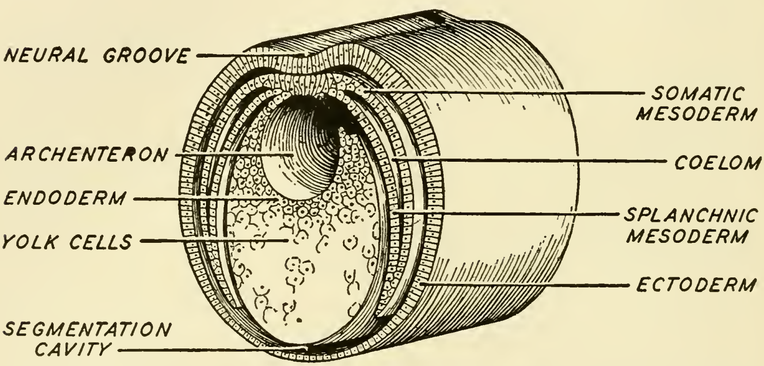


FIG. 81.—Perspective diagram of a portion of a chordate embryo to show the relative positions of cell layers and coelom.

animals it is the cavity that is occupied by the digestive system and associated structures, by the heart, and by other organs that require space within the body proper.

In the fishes a portion of the anterior region of the cœlom is separated off by thin membranes; it forms a smaller cavity containing the heart and is known as the PERICARDIAL CAVITY (Fig. 82). In the human body, as well as in all other mammals, in addition to the pericardial cavity, which is thus derived from the cœlom, a transverse partition separates the cœlom into an anterior PLEURAL and a posterior PERITONEAL CAVITY. This partition contains muscles and is known as the DIAPHRAGM. The pleural cavity is further divided by

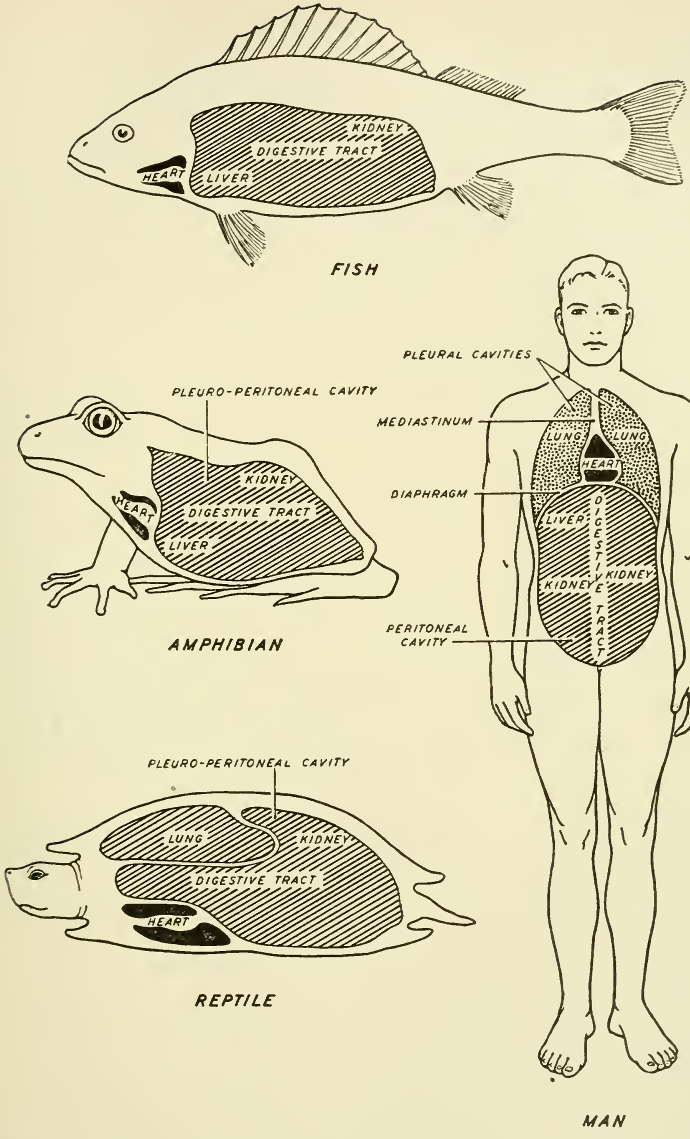


Fig. 82.—Diagrams showing the coelom and its divisions in various vertebrates. For the arrangement in birds, see Fig. 212.

a longitudinal partition, the MEDIASTINUM, into right and left pleural cavities containing the right and left lungs.

The Body Plan. Bilaterally symmetrical forms always tend to develop so that the greatest dimension is in the median plane of symmetry. The primary layers are thereby elongated. In triploblastic forms the architecture is that of a tube-within-a-tube, the body wall forming the outer tube, the digestive canal the inner tube, and the cœlom the cavity between the two tubes. The inner tube in the most simple triploblastic animals, for example, the Platyhelminthes, is in reality not a tube but a more or less sac-like structure having but a single opening, the mouth. In this they resemble the diploblastic animals. In all others the inner tube or digestive canal has both a mouth and an anal opening. A simple arrangement is found in some of the members of the phylum Nemathelminthes, the round forms (Fig. 41). Here the body wall and the digestive canal are the same length, the cavity between being continuous and filled with fluid and certain reproductive organs. The body cavity of the Nemathelminthes differs in origin from that of cœlomate animals, in that the mesoderm is wholly applied to the under surface of the ectoderm and does not form the covering of the digestive canal.

Segmental Animals. In the members of the phylum Annelida the cœlom is divided into a series of compartments by cross partitions known as SEPTÆ. These compartments or METAMERES are occupied by the cœlomic fluid and in some regions by the expansions of the digestive canal and by the organs of reproduction. This encroachment of organs into the cœlomic space is still more marked in the members of the phylum Arthropoda. In the phylum Chordata, particularly in the vertebrates, the cœlom is not divided by regularly spaced cross partitions, the septæ being in evidence only in the body wall. The great development of the digestive glands, such as the liver, the great length of the digestive canal, and the relatively larger space required by reproductive and excretory organs, fill the cœlom and its divisions (Fig. 65).

The distinctive feature of the Annelida is the division of the body into segments or metameres. Metamerism is most highly developed in this phylum; it continues to be a characteristic of the structure of more advanced animals up to and including Man. The earthworm, while not a typical annelid, is one with which most are somewhat familiar and serves to illustrate metamerism for our purposes here. An examination of the anatomy of an earthworm shows it to consist of a series of rings (Fig. 83). In the posterior region these rings are practically alike, each containing the same organs similarly arranged and each separated from adjacent metameres by the septæ which extend across the cœlom. The body therefore consists of a series of secondary individuals, or partial individuals, each closely resembling adjacent members. In an ideal segmental animal all metameres would be identical and each would be provided with appendages for loco-

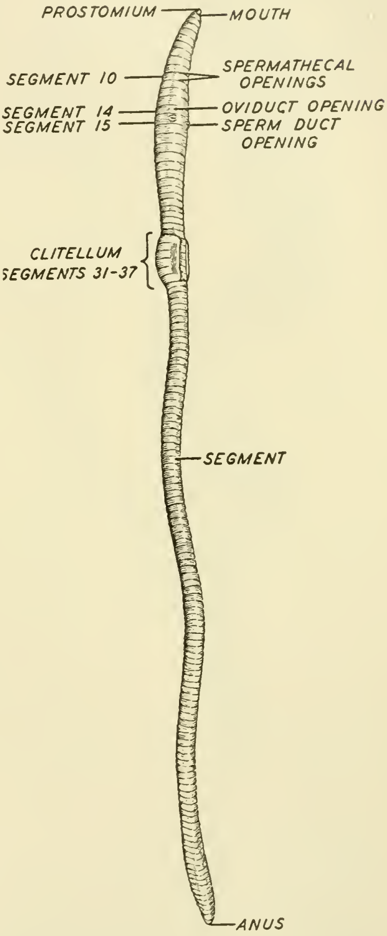


FIG. 83.—External appearance of the common earthworm.

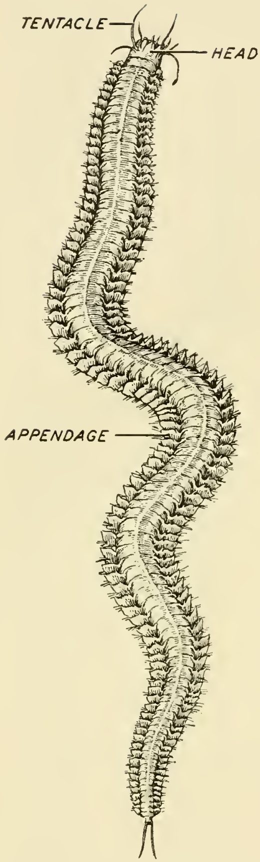


Fig. 84.—Nereis, the common sandworm of the sea shore. In the living animal four eyespots may be distinguished in the dorsal surface of the head. The broad appendages are composed of two lobes. The upper lobes, visible in the figure, contain many blood vessels and serve as respiratory organs. The lower lobes are traversed by stiff setæ and serve as organs of locomotion.

motion. No such ideal arrangement is found, for in all known metameric animals various segments are modified in various ways to serve special functions. For example, in the earthworm several of the most anterior segments that appear during the development of the animal fuse together to form the leading and correlating element, the head. This fusion of anterior segments into a single unit, the head, is termed CEPHALIZATION. The number of segments involved in forming the head varies in different varieties of annelids and among other segmental forms. The number of segments that have gone to form the human head is a matter of dispute, for the process of cephalization in this highly modified form is obscure, but indications are that the process has taken place.

The Principle of Homology. In some annelids, for example the sandworm, Nereis (Fig. 84), each segment, except the most anterior, is equipped with a pair of lateral appendages. Each appendage is comparable with the others, being derived in the same way from the same materials during development. Such structures that have the same origin are termed HOMOLOGOUS structures. Thus the cœlom is homologous throughout the series of forms in which it is developed; the wing of a bird and the fore limb of a cat, being derived from the same embryonic structures, are homologous (Fig. 85). Homologies furnish the basis of anatomical studies and are indications of relationships between groups. In fact, the entire science of Comparative Anatomy is a study of homologies. In meta-

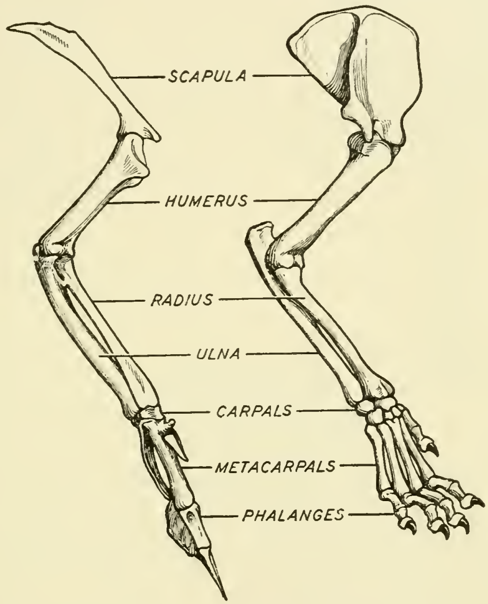


FIG. 85.—Bones of the forelimb of a bird (left) and of a cat (right). In the bird the carpals are reduced to two, the others being fused with the metacarpals. It will also be noted that the metacarpals and phalanges in the bird are reduced in number, but that in all regions of the limbs the bones of the two animals are comparable.

meric, or segmental animals, the parts of one appendage may be homologized with those of an appendage on another segment, as the parts of the maxillary appendage of a lobster are homologous with the parts of a walking leg (Fig. 86). In other words, within the same animal, particularly among segmented animals, homologies between segmental organs occur serially as well as homologies with structures found in other groups of animals.

Protective and Supporting Structures. Many and diverse types of protective and supporting structures occur among animals. Among the sponges supporting structures that consist of rods and spicules are developed in the ectoderm (Fig. 87). In some sponges these are composed of carbonate, in others of silicate; in the common bath sponge a peculiar substance called SPONGIN is formed as the supporting structure. In echinoderms integumentary plates containing calcium carbonate serve for protection and support (Fig. 88). In the molluscs the shell is essentially calcium carbonate, secreted by the cells of the outer layers of the body wall (Fig. 89). The arthropod body is enclosed in a series of tough movable plates composed of an organic substance called CHITIN (Fig. 90). These outer plates serve as fulcra for the attachment of muscles, so that in the insect for instance, the leg has its skeleton external and the muscles internal, the reverse of the relation between skeleton and muscles in the vertebrates. Surface and integumentary protective and supporting structures form what is known as the EXOSKELETON.

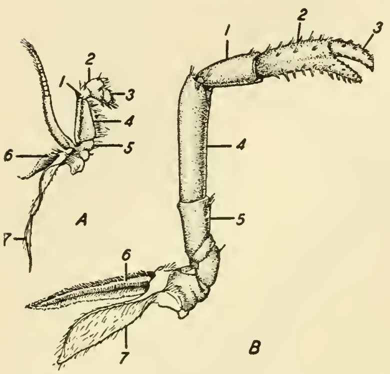


FIG. 86.—An illustration of serial homology. *A* is a mouth part (second maxilliped) and *B* the second walking leg of a lobster. Although quite different in appearance and employed by the animal for quite different uses, both represent modifications of a basic type of appendage. In the figures the homologous parts distinctly visible are numbered identically.

The Chordate Exoskeleton. Among the chordates, particularly in the vertebrates, the exoskeleton is frequently extremely well developed. The vertebrate exoskeleton consists primarily of scales. In its most primitive type, in the elasmobranch fishes of which the shark may serve as an example, the scale consists of two portions, an enameled spine formed by the metabolism of ectodermal cells, and

SOME INVERTEBRATE EXOSKELETONS

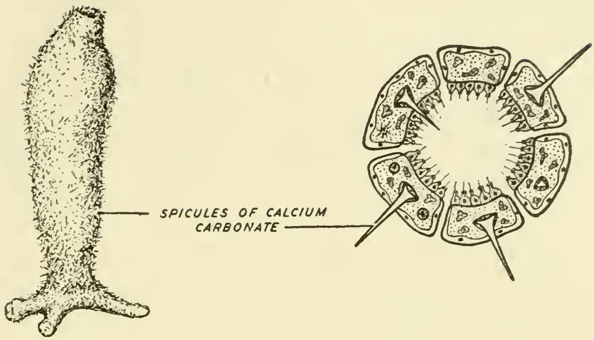


FIG 87 SIMPLE SPONGE AND SCHEMATIC CROSS SECTION (PORIFER)

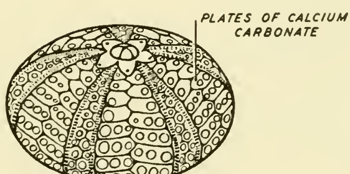
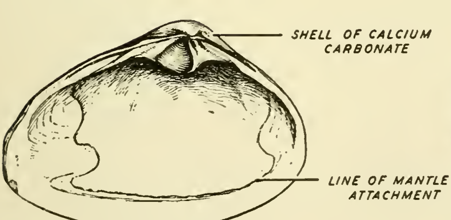


FIG. 88. TEST OF A SEA URCHIN (ECHINODERM)



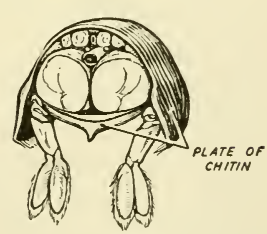


FIG. 89 SHELL OF A CLAM (MOLLUSC)

FIG. 90. SECTION OF ABDOMINAL SEGMENT OF LOBSTER (ARTHROPOD)

Figs. 87, 88, 89, and 90.—Some types of invertebrate exoskeletal and supporting structures. (Fig. 87 partly after Kühn: *Grundriss der allgemeinen Zoologie.* Georg Theime, Leipzig.)

SOME VERTEBRATE EXOSKELETONS

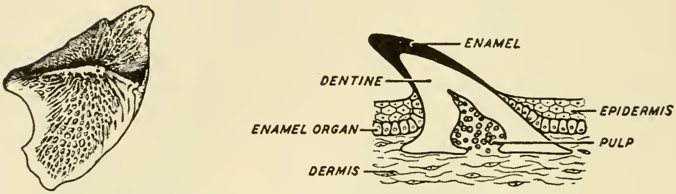


FIG. 91. PLACOID SCALE AND DIAGRAMMATIC SECTION

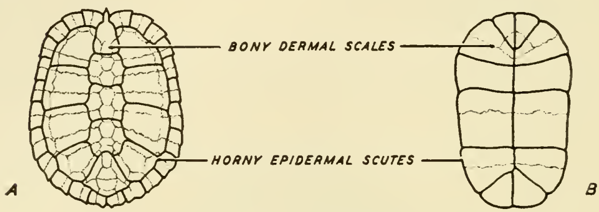


FIG. 92. CARAPACE (A) AND PLASTRON (B) OF TURTLE

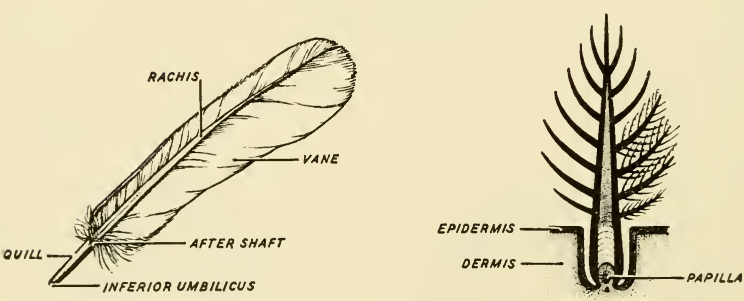


FIG. 93. CONTOUR FEATHER AND DIAGRAM OF FEATHER STRUCTURE

FIGS. 91, 92, and 93.—Some vertebrate exoskeletal structures. Placoid scales (Fig. 91) are characteristic of sharks and other elasmobranch fishes. A comparison of the diagram of the placoid scale structure with that of a human tooth (Fig. 103) shows them to be homologous. In Fig. 92 the horny epidermal scutes of the turtle are outlined in heavy lines; the deeper dermal bony scales are lightly outlined. (Part of Fig. 93 after Kühn: *Grundriss der Allgemeinen Zoologie*. Georg Theime, Leipzig.)

a bony basal plate derived from mesodermal elements (Fig. 91). The scales of common fishes are of mesodermal origin, the ectoderm forming a thin layer covering the scaly armor. None of our living Amphibia have scales, except as these are modified in the mouth to form teeth. In many reptiles, however, the exoskeleton is well developed. The scaly nature of the integument of snakes, lizards, and alligators is a matter of general information. The exoskeleton of the turtle illustrates an extreme development of scales. The turtle armor (Fig. 92) consists of two layers, a superficial layer of scutes derived from the ectoderm and a nether layer of bony plates of mesodermal origin. Beaks and claws are ectodermal and of separate origin. In the bird the ectoderm is the layer of origin of the scales on the legs and feet, of the beak and claws, and also of the feathers although a mesodermal organ is concerned in the nutrition of a growing feather (Fig. 93).

The exoskeleton of mammals consists primarily of hair, but scales occur in some; for example, on the tails of rats and of beavers and in the armor of the armadillo. The highest development of mammalian scales is found in the armadillo armor. It is composed of two layers of scales, the outer scutes of ectodermal origin and the inner bony plates of mesodermal origin. In the human body the only traces of an exoskeleton are the hair, the nails, and the greatly modified scales which form the teeth. The human skin (Fig. 94), like all vertebrate skin, consists of two layers, an outer EPIDERMIS of ectodermal origin and an inner DERMIS, or CORIUM, of mesodermal origin. The epidermis is made up of a considerable number of cell layers, the innermost of which consists of cells that are actively dividing throughout life. This active layer, termed the STRATUM GERMINATIVUM, is the source of the hair, of the SEBACEOUS or OIL GLANDS, and of the SUDIFEROUS or SWEAT GLANDS. The dermis, or corium, is composed ot loose connective tissue and contains minute blood vessels, nerve endings, and, in some regions, muscles. The relations of the layers of the human skin and the position of the hair and glands are best understood by reference to the accompanying figure (Fig. 94).

The Endoskeleton. The exoskeleton in the members of the phylum Chordata serves largely for protection. Support is provided by an internal framework known as the ENDOSKELETON, which is composed of shafts and plates of cartilage or bone, tissues that are

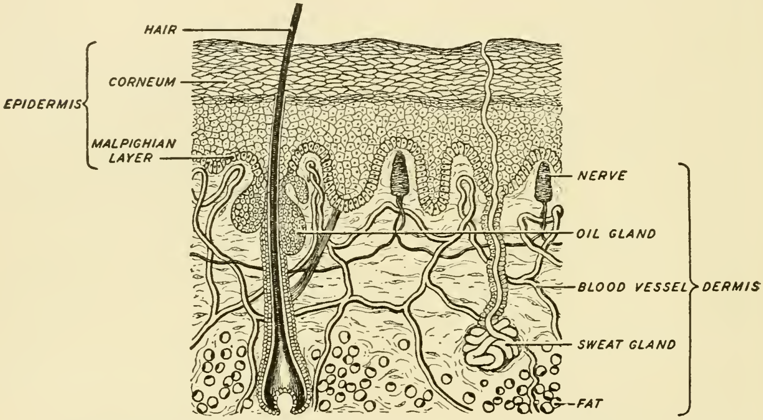


FIG. 94.—Diagrammatic section through the human skin. Note that the hair, sebaceous gland, and sudiferous gland are deeply embedded in the dermis and associated with the blood supply, but that they are derivatives of the epidermis.

peculiar to this phylum. Endoskeletons are unusual in achordates and never contain bone. The chordate endoskeleton always includes, some time during the life history of the animal, an axial rod of tissue known as the NOTOCHORD; hence the phylum name. It is situated in the body wall just dorsal to the cœlom and immediately ventral to the main nerve cord, or spinal cord (Fig. 95). In members of the sub-phylum Vertebrata the notochord appears in the embryo, but is more or less completely replaced by an axis consisting of a series of spool-shaped cartilages or bones, known as the VERTEBRAL COLUMN.

The sub-phylum Vertebrata constitutes a well-defined group with many similarities. They are in general so distinctly different from animals that lack a vertebral column that it is convenient to make two divisions of animals and to distinguish between the INVERTEBRATES and VERTEBRATES. The invertebrates include all animals of all phyla, including three chordate sub-phyla and excepting only the members of the sub-phylum Vertebrata.

In the more primitive types of vertebrates, for example, the shark, the skeleton is made up of cartilage, a tissue that has a great deal of

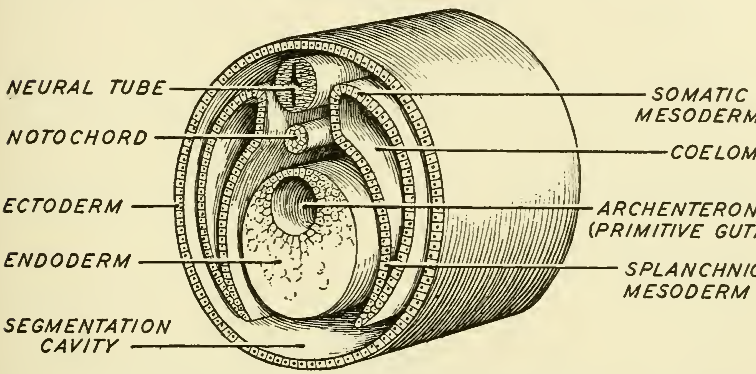


FIG. 95.—Diagrammatic section of a portion of a vertebrate embryo to show especially the position of the notochord.

rigidity but is also elastic (Fig. 96). In the true fishes many of the cartilaginous elements are replaced by bone (Fig. 97), by the replacement of the cartilage cells by bone cells, and the deposition of lime salts in the intercellular spaces. In the fishes also, some of the dermal bones of the exoskeleton become involved with the endoskeleton, particularly in the region of the head and jaws. The endoskeleton of the higher vertebrates is thus composed of bones of two different origins, CARTILAGE BONES, which are the result of the replacement of the primitive cartilages by bone, and DERMAL or MEMBRANE BONES, which are derived from the exoskeleton and do not pass through a cartilage stage during development.

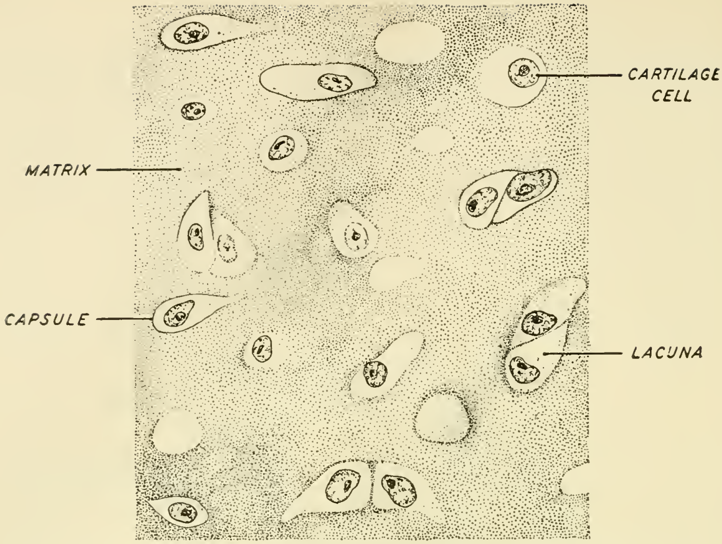


FIG. 96.—The appearance of cartilage under the microscope. Under suitable conditions the matrix can be shown to consist in large part of closely compressed fibres. Like bone, cartilage is a form of connective tissue.

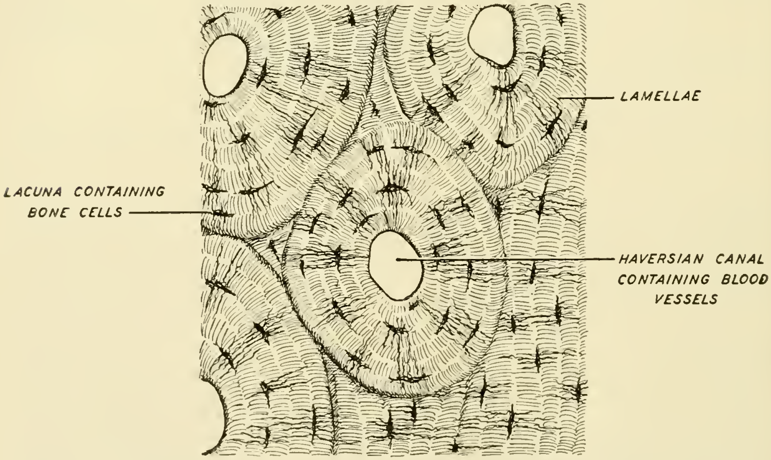


FIG. 97.—A very thin sheet of dried bone under a low power of the microscope. When bone is alive the lacunae contain living bone cells. The lacunae communicate by means of fine canals with the blood vessels that traverse the Haversian canals; they in turn communicate with the general circulation of the body.

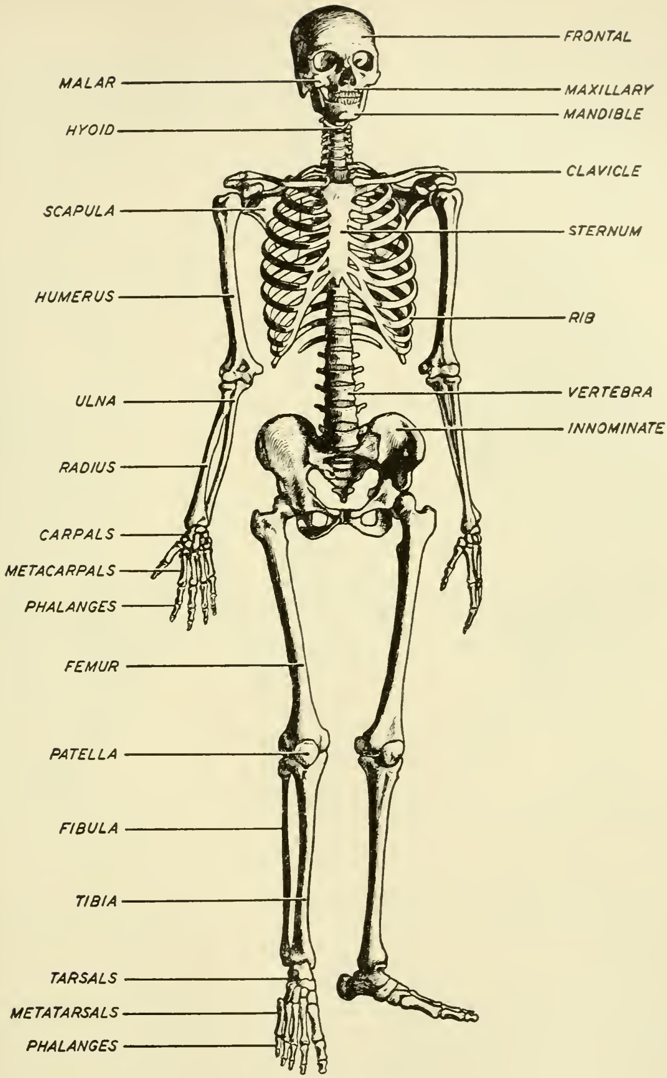


FIG. 98. **HUMAN SKELETON**

Fig. 98.—Human skeleton. The frontal, maxillary, and clavicles, as well as some bones not visible as the specimen is posed, are bones derived historically from exoskeletal dermal scales. The other bones are derived from a primitive cartilage skeleton.

The Human Skeleton. The human endoskeleton (Fig. 98) is composed of more than two hundred bones, some of which are of exoskeletal origin, being dermal bones, but most are cartilage bones. In fact, the human skeleton constitutes a most impressive record

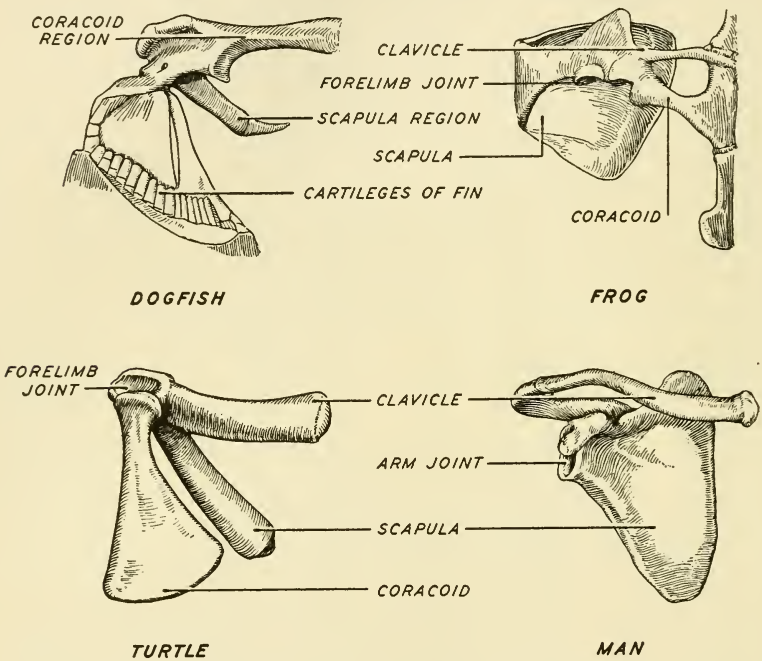


FIG. 99.—Shoulder girdles of some vertebrates. The scapula and coracoid are derived from the primitive cartilage girdle, shown in the dogfish. The clavicle is a membrane or dermal bone. In the human the coracoid exists as a small protuberance on the scapula.

of changes brought about by the incorporation of parts of the primitive exoskeleton into the endoskeleton; its various bones can be related to bones, cartilages, and dermal scales of lower forms. For example, the shoulder blade or SCAPULA is a cartilage bone of primitive origin among vertebrates, for its relation to a cartilage bar in the lower fishes may be traced with some accuracy

(Fig. 99). On the other hand, the large plate bone of the forehead, the FRONTAL, is a dermal bone. It is derived from two plates that may be traced to their homologues in the two broad exoskeletal scales of the head of certain fishes. The record shows that these scales, of mesodermal origin, have become associated with the carti-

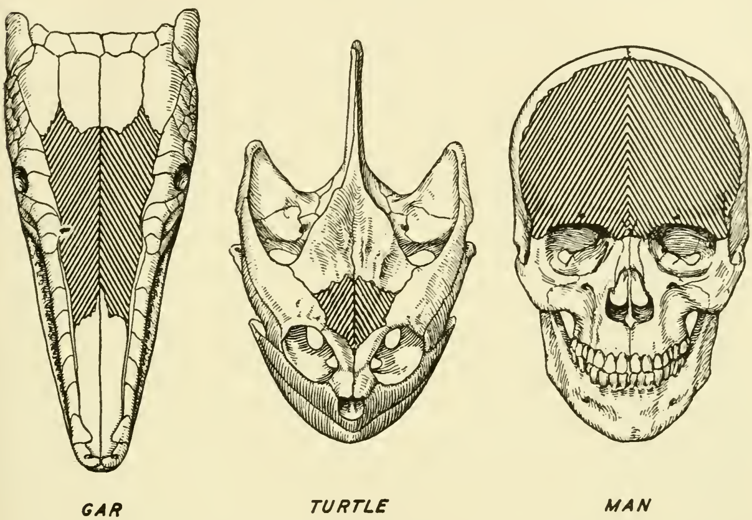


FIG. 100.—The head of a fish (short nose gar) to show the frontal scales; the head of a turtle to show the frontals, now a part of the endoskeleton; the human skull showing the homologous frontal elements.

lage bones to form the roof of the skull (Fig. 100); the cartilage bones form its floor.

The human skeleton for convenience in study may be divided into two main divisions, the axial skeleton composed of the skull, vertebral column, ribs, and sternum; and the appendicular skeleton, which consists of the bones of the legs and arms and of the two girdles, shoulder and pelvic. With the exception of the clavicle, which is a dermal bone, all the dermal elements of the skeleton are involved in the skeleton of the head. All the bones are invested closely by a tough membrane, which is anchored to the bone by fibres that are deeply rooted in the bone substance. This covering is the PERIOSTEUM; the muscles are attached to this membrane, so that it serves as the means of attaching the muscles to the bone. In case of injury to the bone, certain cells in the periosteum become active and invade the break and surround and fill it with a splice of bony tissue. It is to be understood that while bone to outward appearance is a rigid and solid substance, it is alive and contains living bone cells and the circulation of blood and lymph necessary to their maintenance. The appearance of a section of bone under the microscope is shown in an accompanying figure (Fig. 97).

The Human Architectural Plan. The indebtedness of the human body for its major architectural features may be briefly summarized. Bilateral symmetry appears very low in the scale of structural complexity; the most simple Metazoa that are built on this plan are the flatworms, the phylum Platyhelminthes. The three-layer, or triploblastic pattern also appears first conspicuously in this group. The body plan of a tube-within-a-tube with a cavity, the cœlom (see p. 137), between the two tubes and with the inner or digestive tube opening at both ends first appears in the round worms, the phylum Nemathelminthes. The partitioning of the cœlom into a pericardial sac and a peritoneal cavity occurs in fishes. The further division of the peritoneal cavity into the pleural and peritoneal cavities occurs in the lower mammals. The division of the body into segments of metameres is most highly developed in the Annelida and continues to be a characteristic in the Arthropoda and chordates. Various and diverse types of exoskeletal structures appear in the more simple animals, but true bone appears first in the lower vertebrates. The human endoskeleton appears to owe its origin to an association between exoskeletal elements and cartilage elements that first appear low in the phylum Chordata.

This closes a rapid review of the major characteristics of the animal as a whole. The next task is the examination of the various devices that serve the animal as mechanisms for the functions of nutrition, of irritability, of reproduction, of contractility, of excretion, and their various associated structures. The detail of the many types of organ systems is so great as to prohibit any extended treatment here; only the major facts will be discussed.

First and perhaps most important in the life of all organisms is the matter of nutrition, for on nutrition rests the whole complex of life; both energy and materials are wholly derived from the functioning of the mechanisms of nutrition.

Nutritive Mechanisms. Methods of obtaining nutriment are fundamentally different in plants and animals and may be regarded as largely responsible for their very different structure and life habits. In plants, particularly the green plants, the immediate source of energy is the energy of sunlight; materials for their subsistence are in a crude state as compared with the materials necessary for animal nutrition. Thus the green plant has only to be located in a soil containing relatively simple substances and to have available a supply of carbon dioxide and the presence of sunlight. None of these require extreme sensitivity to the environment, nor rapid motility, nor means of grasping and breaking up materials; hence plants are relatively non-motile and are able to thrive for long periods in the same location. On the other hand, the principles of holozooic nutrition impose on animals the necessity of feeding either on plants or of feeding on animals that have fed on plants. They require powers of locomotion, of sensing the presence of food, of grasping a nutritive material and of breaking it up, and of rejecting from the body those substances that are not available for assimilation into animal protoplasm.

Fundamentals of an Animal Digestive System. Methods of securing food vary widely among animals; some involve the development of complex traps for capturing edible forms, for example, spiders' webs; some require great muscular power and speed in effecting captures, for example, wolves, cats, or other Carnivora;

some, especially those which feed on plants, require only comparatively simple apparatus for dislodging and breaking off their food substances; for example, cattle. In general, animal foods are in solid form, or at least in chemical forms that require chemical change before the materials can be utilized by protoplasm or the energy in the food released. The conversion of this raw material into chemical and physical conditions that make it available to the cells of the animal body comprises the whole process of digestion. The details of the process differ in different forms; however, all animal digestive systems are designed to accomplish this common

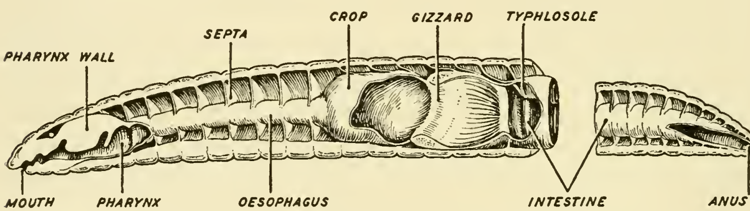


FIG. 101.—Digestive system of the earthworm.

result. They involve (1) machinery for obtaining and mechanically breaking up the food; (2) enzymes and other chemical agents for dissolving and altering the food chemically; (3) areas for the absorption of the finished products of digestion; (4) a mechanism for conveying these products from the site of digestion to all cells of the body. This fourth principle links the digestive system with the circulatory system and will be considered farther on.

Abrading Mechanisms. The first of these, mechanically breaking up the food, is accomplished by various devices usually, but not invariably, associated with that part of the digestive system which receives the food. In the diploblastic Porifera and Cœlenterata and in Platyhelminthes, a considerable proportion of the digestive process is accomplished within the endodermal cells, that is, intracellular, and no mechanisms are provided for grinding or otherwise fragmenting the food. In the Annelida, as in the earthworm (Fig. 101) the incoming food is diluted and softened by secretions from glands located near the mouth whose special function it is to manufacture certain digestive enzymes. It is broken up by abrasion with sand particles in a special region of the digestive tube called the gizzard. In the Arthropoda, particularly in such forms as the lobster (Fig. 102), hard, chitinous jaws grind the food,

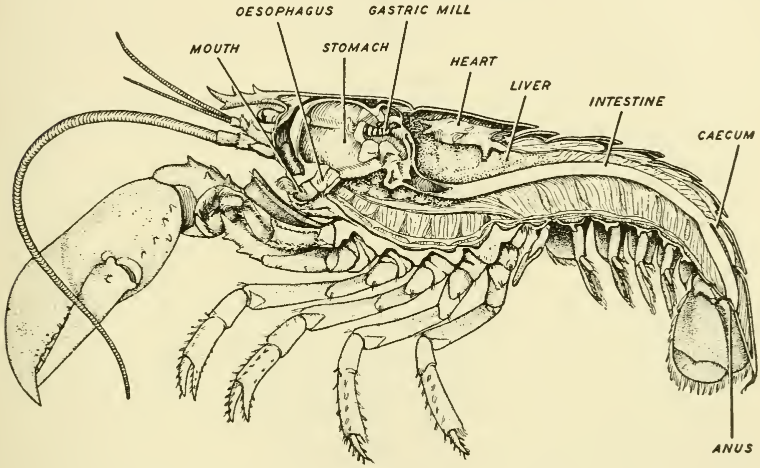


FIG. 102.—Digestive system of a lobster. Note the gastric mill, consisting of rough plates of chitin.

which is then subjected to a second abrading by file-like plates in the stomach (the gastric mill). In the vertebrates in many cases the mouth is equipped with modified scales, called teeth, that act in various ways in grasping and grinding foods.

The Human Tooth. The human tooth (Fig. 103) is homologous with the scale (Fig. 91) in the exoskeleton of the primitive fishes, for example, the shark. It consists of two portions, the ENAMEL, which is formed during development by the metabolism of the ectodermal cells, and the DENTINE, which is comparable to the bony plate of the shark scale and is formed by mesoderm. The enamel is the hardest substance in the body; it forms the cap on the dentine and after its formation the enamel-producing organ ceases to function, so that enamel of the human tooth once broken is never repaired nor replaced. The dentine resembles bone in many respects and is considerably softer than the enamel. It forms the

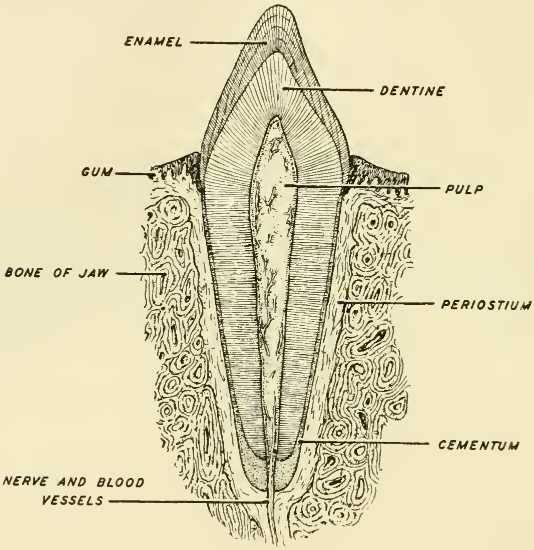


FIG. 103.—Section of a human tooth in its socket. Compare with the structure of a placoid scale (Fig. 91).

greater bulk of the tooth and its basal end is embedded in the bone of the jaw. The centre of the tooth contains the PULP CAVITY; it is filled with a form of connective tissue and contains minute blood vessels and nerves. The socket in the jaw is lined with the periosteum of the bone; the tooth is attached to its socket by a substance known as CEMENTUM. The enamel cap is discontinued at the level of the gum and the cementum then forms the contact layer down to the root of the tooth.

Digestive Enzymes. Since animal food consists essentially of three main types, carbohydrates, fats, and proteins, there are three main types of digestive enzymes required in conditioning the food. The DIASTASES act on sugars and starches; the LIPASES act on the fats; the PROTEOLYTIC enzymes digest the proteins. Their relative abundance depends on the type of food that forms the chief ingredient of the diet. In Man the digestive system contains all three types of enzymes apparently equally important, for the human food supply is most varied. Accessory to the activity of the enzymes is the presence in the digestive system of certain other agents. For example, the PEPSIN, a proteolytic enzyme in the human stomach, operates best in the presence of acid; hence the fluid of the stomach contains a quantity of hydrochloric acid. The percentage of HCl is considerably greater in the stomach of the dog, for in this animal it serves also to decalcify bone, which forms a part of the diet.

Absorption of Foods. All organisms are so adapted to their environment, including their food supply, as to solve and to take advantage of the principles and laws operating in non-living systems. Digested food passes out of the digestive system according to the principles of diffusion through a membrane and consequently the properties of the walls of the digestive tract are those of semipermeable membranes, which have been previously discussed (p. 32). In the passage of any substance through a membrane, three factors are concerned: (1) the condition of the penetrating substance; in other words, a food to be digested must be in the form of molecules that are small enough to pass through the pores of the membrane from a region of higher to a region of lower concentration; (2) the area; the greater the area of contact the more will pass through in a given time. In the case of digested foods, the amount that will pass through within a given time thus increases with an increase in the area of the walls of the digestive canal. In the earthworm the area for absorption is very greatly increased by a structure, the TYPHLOSOLE (Fig. 104), which is an extensive inward fold of the dorsal wall of the digestive canal, extending downward into the cavity of the stomach-intestine throughout its entire length. In the shark the food during digestion in the intestine passes around a SPIRAL VALVE (Fig. 105), which is a modified typhlosole and which

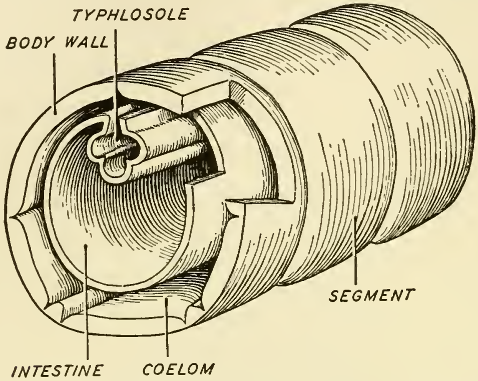


FIG. 104.—A portion of the intestine of the earthworm diagrammed to show the position of the typhlosole.

thus serves to increase the area for food absorption. In the human digestive canal the lining of the intestine, in which most of the food absorption takes place, is thrown into transverse folds, termed

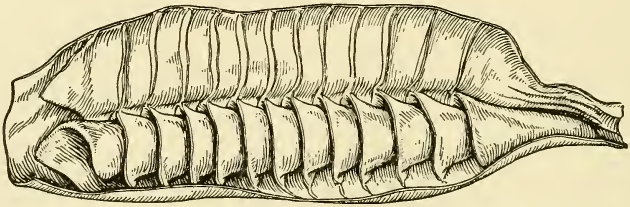


FIG. 105.—Diagram of the opened small intestine of a dogfish shark to show the relations of the spiral valve.

PLICÆ (Fig. 106) covered with smaller folds known as VILLI (Fig. 107); these also increase the area of the lining of the digestive canal and make for more complete absorption of the products of digestion. (3) A third factor is concerned in the completeness of food absorption, namely, time; more digested food will pass through the membranous wall of the digestive system the longer the time that the food remains in contact with the absorbing walls. In Man the digestive tube is quite long as compared with the length of the body wall, and the time required for food to traverse this tube more than twenty feet long permits almost complete absorption of the products of digestion.

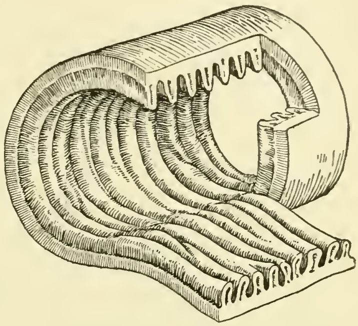


FIG. 106.—Diagram of the opened small intestine of Man. Note the folds and compare with the linings of the intestine of the dogfish and the earthworm.

The Human Digestive System. The human digestive system (Fig. 108) consists of the ORAL CAVITY, into which three pairs of SALIVARY GLANDS empty, the ŒSOPHAGUS, a narrow tube leading from the base of the ORAL CAVITY, the STOMACH, into which the œsophagus opens, the SMALL INTESTINE, with the glands that empty into it, the LIVER and the PANCREAS, the LARGE INTESTINE or COLON, the RECTUM, and the ANUS. The small intestine consists of three regions, the DUODENUM, which receives the food from the stomach through a valve called the PYLORIS and into which the BILE DUCT from the liver and the PANCREATIC DUCT from the pancreas open, the JEJUNUM, and the ILEUM, which opens into the large intestine through the ILEO-CŒLIC VALVE. The ileum does not open directly into the end of the colon, but at some distance from the extreme upper end. This leaves a sac at the upper end of the colon, beyond the ileo-cœlic valve, known as the CÆCUM. The end of the cæcum opens into a small blind tube, the VERMIFORM APPENDIX.

The walls of the digestive tube contain an intricate network of blood and lymph vessels and are composed chiefly of two layers of muscles, an outer longitudinal layer and an inner circular layer (Fig.

107). In addition to these, the wall of the stomach has a third, oblique layer. These muscles are derived from the inner sheet of mesoderm and are composed of plain or smooth muscle cells. They have the property of constant rhythmic contraction and are not under direct control of the will. Once food has been masticated in the oral cavity it is swallowed by a complicated automatic process, and

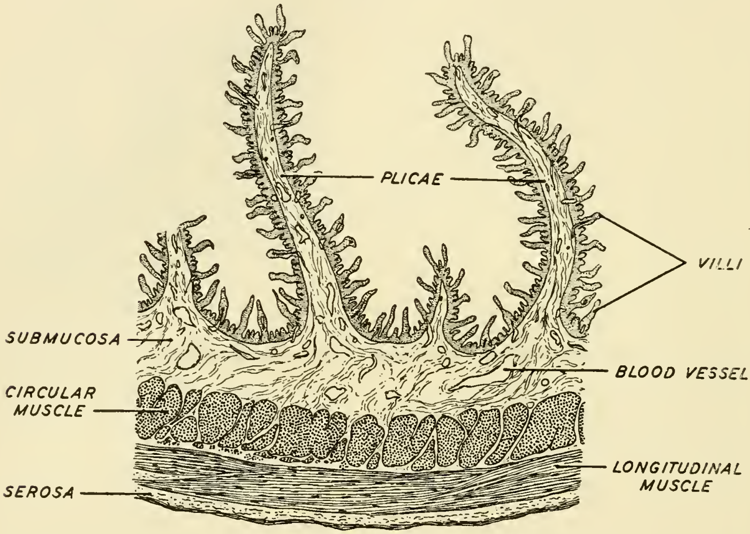


Fig. 107.—A diagrammatic section through the human intestine to show the relations of the muscle and other layers of the wall.

after entering the œsophagus it is moved along by the contraction of the smooth muscles in the wall of the canal, having passed out of control of deliberate efforts of the will. In the stomach the constant rhythmic contractions of the muscular walls impart a mixing action to the food. These movements of the walls of the digestive canal are termed PERISTALSIS. Thus by peristaltic action the materials in the canal are moved along. Most cathartic agents hasten the movement of the contents of the digestive canal by stimulating the smooth muscles and increasing peristalsis. Hunger distress appears to be caused by contractions of the walls of the stomach; it has been found that hunger pangs are relieved if the stomach is distended

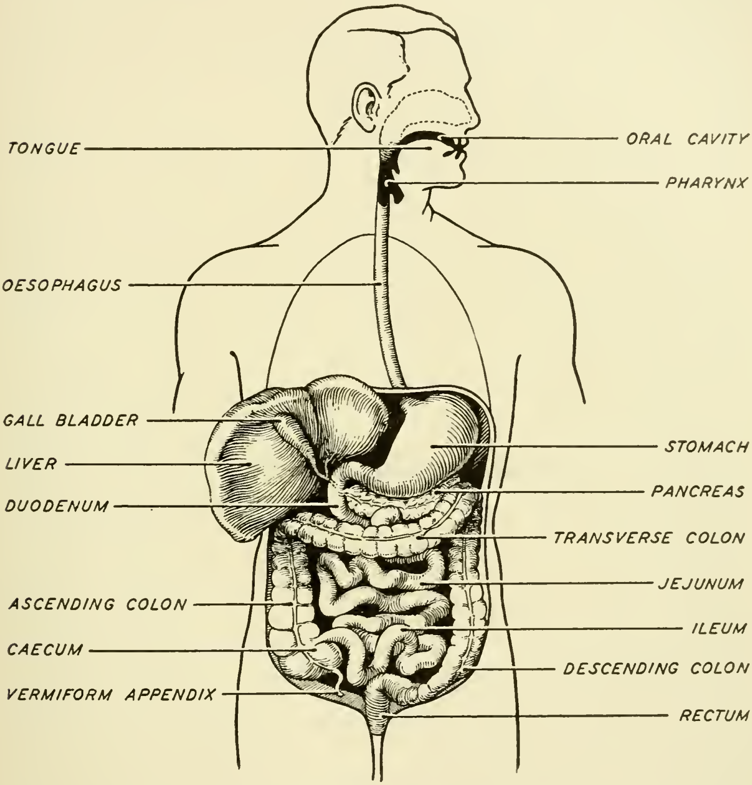


FIG. 108.—The human digestive system in diagram. The liver has been pulled aside to show the position of the gall bladder and of the bile duct. (Partly after Sobotta: *Atlas and Textbook of Human Anatomy,* published by W. B. Saunders Co.)

mechanically, for instance by the inflation of a rubber balloon that has been swallowed.

Digestion in the Mouth. Chemical changes in the food begin in the mouth. There the diastase, ptyalin, in the neutral or slightly alkaline saliva, acts upon starches. The reaction is a complicated hydrolysis (p. 12); its details do not concern us here. The process may be summarized as the conversion of a fairly large starch molecule into a simple sugar:

$C_6H_{10}O_5$ (as an aggregate consisting of n molecules) + H_2O (n molecules) $\rightleftharpoons$ n $C_6H_{12}O_6$ (maltose).

The process is only started in the mouth; it is considered certain that it is continued in the stomach.

Digestion in the Stomach. The digestion of proteins begins in the stomach. The fluid in the stomach, known as GASTRIC JUICE, contains two main ingredients, the proteolytic enzyme PEPSIN, and 0.5 per cent HCl. The action of these substances is largely to initiate the conversion of the proteins; the processes are completed by the juices in the intestine. In the stomach the complex, large protein molecules, or at least some of them, are converted into simpler and more soluble substances. Hydrolyses (p. 12) are involved and the reaction occurs in several steps. It was shown in an earlier chapter that protein molecules are composed of combinations of amino-acids (p. 14). In the ordinary diet of Man a very considerable variety of proteins is taken into the system but by the action of the proteolytic, or protein-digesting enzymes they may all be reduced to some simpler combinations of their essential amino-acids. In the stomach the proteins are first changed to PROTEOSES, a type that may be thought of as the first intermediate between proteins and amino-acids. Proteoses do not diffuse readily through animal membranes and hence are sparingly absorbed by the walls of the stomach. Proteoses are next split up into molecules that are still smaller, although not yet single amino-acids, known as PEPTONES. Peptones diffuse readily through animal membranes and consequently are absorbed by the walls of the digestive system. When the diet contains milk the digestion of its proteins is preceded by the curdling of the milk due to the action of another enzyme, RENNIN. Calcium must be present, else no curd forms. The action of the rennin is confined to the coagulation of the milk; the digestion of its proteins is accomplished by the HCl and pepsin. Fats are unchanged by digestive events in the mouth and stomach.

Digestion in the Intestine. In the small intestine the food, liquefied in the mouth and stomach (chyme), encounters secretions from three sources; the PANCREATIC JUICE, received from the pancreatic duct, the INTESTINAL JUICE, secreted by glands in the walls of the intestine, and BILE, secreted by the liver. In the pancreatic secretion are three enzymes; one, AMYLASE, acts on the starches; the second, TRYPSIN, acts on the proteins; the third, LIPASE, acts on the fats. The fats are changed chemically (saponified) by the action of the lipase and also physically by the action of the enzyme and the bile. The physical change in the fats occurs first and breaks them up into exceedingly fine droplets, a process known as EMULSIFICATION. The fats are converted to glycerin and fatty acids; they then pass into a set of fine tubules of the lymph system located in the wall of the intestine and from there drain into a large vein of the main circulation through the THORACIC DUCT. The secretions of the intestinal glands contain three chief enzymes that complete the simplification of the starches and sugars and one enzyme, EREPSIN, that completes the conversion of the proteins, proteoses, and peptones into their constituent amino-acids. Thus the amino-acids, first constructed by plant metabolism from inorganic materials and built up into proteins, are again resolved into amino-acids. The amino-acids are readily absorbed into the fine vessels of the venous system and are thence available for reconstruction into human proteins in the several tissues of the body. A summary of the digestive processes in the human digestive tract is given:

Enzyme	Where Found	Action
Ptyalin	Mouth	Converts starch to simple sugars.
Pepsin	Stomach	Converts proteins to proteoses and peptones.

Enzyme	Where Found	Action
Amylase	In small intestine, part of pancreatic juice	Converts starch to simple sugars.
Trypsin	In small intestine, part of pancreatic juice	Splits proteins into intermediate compounds.
Lipase	In small intestine, part of pancreatic juice	Splits fats to fatty acids and glycerin.
Erepsin	Small intestine	Splits intermediate compounds derived from proteins into amino-acids.
Invertase	Small intestine	Digests cane sugar.
Maltase	Small intestine	Converts products of salivary digestion to dextrose.
Lactase	Small intestine	Converts milk sugar to dextrose and galactose.

The absorption of the products of digestion is a continuous process. Since the chief changes are wrought in the small intestine, obviously it is the site of most of the absorption. Absorption of food is completed in the large intestine, where excess water is also absorbed, for the food entering the large intestine is quite fluid (chyle). In the large intestine the contents are normally fermented by bacteria that are always present. It is an open question whether or not the fermentative action in the large intestine is injurious to the human body; at least, the organism has so adapted itself to the presence of these saprophytes that under normal conditions no appreciable ill effects occur. The contents of the large intestine are undigested and unabsorbed food materials, indigestible and insoluble contents of the original food, products of putrefaction by bacteria, cells shed from the walls of the intestine, some few metabolic waste products, and water. The fæces are thus formed in the large intestine and pass into the rectum, a pouching distention of the end of the digestive canal. The evacuation of the fæces is brought about by the contraction of the walls of the rectum. In the very young these contractions are not under control of the will.

The Liver. Digested foods, except the fats, pass through the wall of the intestine into fine veins, which drain into a single large vein, and are then passed on into the liver (Fig. 108). Here the large vessel, termed the HEPATIC PORTAL VEIN, breaks up again into fine vessels. In the liver bacteria when present in the blood are taken up by the liver cells. But the chief function of the liver is the conversion of the carbohydrates after digestion back into large molecules of a substance known as GLYCOGEN. It is said to have the formula $(C_6H_{10}O_5)_n$, which, it will be noted, is also the formula of ordinary vegetable starch. It is therefore sometimes called animal starch. Glycogen is apparently not identical with ordinary starch, but the chemical differences do not concern us here. The essential point for consideration here is the fact that the large molecules of crude starch, which are taken in as food, are by digestion converted to a soluble form of sugar that passes through the walls of the digestive canal and in the liver is converted back again into large molecules that are stored there. Glycogen is the important source of energy in muscles and other activities of the body. It is released from the liver by being again converted by liver enzymes to a simpler form and is re-converted to glycogen again by enzymes in the body cells that eventually receive it.

The liver also acts upon blood proteins that have resulted from the breakdown of cell substances, and converts them into urea. The urea molecule has the formula $(NH_2)_2CO$; it passes through living membranes rather freely, and is the chief nitrogen-containing compound excreted by the body. Thus, in addition to its rôle in digestion the liver has an important function in excretion.

The BILE, which is a complex mixture of various substances, is secreted by the liver cells. In Man it is stored in a sac known as the GALL BLADDER and is excreted into the intestine through the bile duct. Some mammals, for example the horse, do not have a gall bladder.

Fundamentals of a Respiratory System. The importance of oxidations within the cell as the energy-releasing reaction in vital phenomena has already been emphasized (p. 58). For all aerobic animals some sort of mechanism provides for the reception of oxygen from the air, either directly or as oxygen from the air dissolved in liquids. In the single-cell animals and in the more simple Metazoa in which all cells are in direct contact with the water containing oxygen, the entire surface, wherever cells are in contact with the water, serves to receive oxygen and to dispel carbon dioxide. In more complex forms various types of respiratory mechanisms are to be found. All, however, have three characteristics in common: (1) a membrane freely permeable to oxygen and to carbon dioxide; (2) a relatively large area offered by such a membrane; (3) in many animals, some sort of mechanism for renewing the supply of air or water that is in contact with this membrane. The presence of a respiratory membrane is also associated with some means of transporting the absorbed oxygen to deep tissues.

Types of Respiratory Systems. It is possible here to mention only briefly how these provisions are made in various animals. In the Porifera, Cœlenterata, and Platyhelminthes no special respiratory apparatus is developed, the body walls serving for the interchange of gases. In Annelida with appendages, for example, Nereis, the sandworm (Fig. 84), one region of the flattened, oar-like appendages on each segment is specialized for the respiratory function, although the integument of the body wall also serves. In the earthworm (Fig. 83) the entire body surface constitutes a respiratory membrane, under which is the blood that receives the oxygen and gives off the carbon dioxide. Among the Arthropoda three types of respiratory systems occur. In members of the class Crustacea, the lobster (Fig. 109) and its allies, a set of feathery GILLS is attached to each of the walking legs. These gills are housed in a fold on either side of the thorax and are shielded by heavy chitinous plates. Anterior to this narrow shed in which the gills lie is a modified leg with a spoon-shaped extremity which by constant motion draws

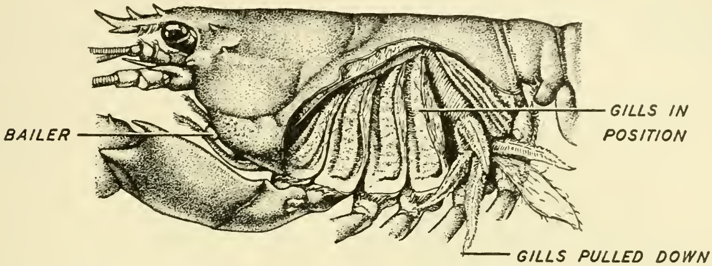


FIG. 109.—The gills and gill chamber of a lobster. The shield that covers the gill chamber has been cut away.

water through the gill chamber. In some of the members of the class Arachnida, the spiders, membranous folds in sacs, arranged like

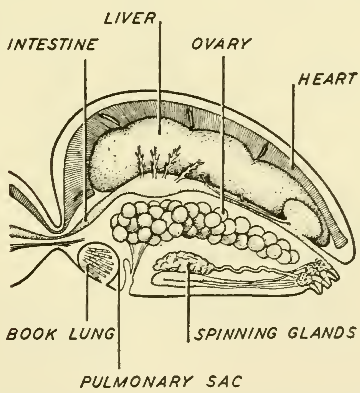


FIG. 110.—A diagrammatic long section through the abdomen of a spider to show the position of the book lungs. (After Leukart, with modifications after Warburton.)

pages in a book, form what are called BOOK LUNGS (Fig. 110). In the class Insecta, the insects, and in some spiders, an entirely different type of respiratory system occurs, consisting of a set of tubules that traverse the tissues of the body. In an insect on both sides in each segment are small apertures called SPIRACLES (Fig. 111). These openings lead into membranous tubes, termed TRACHEÆ, which subdivide and ramify throughout the insect body. Thus the air is plumbed directly to the tissues. Recent investigations indicate that

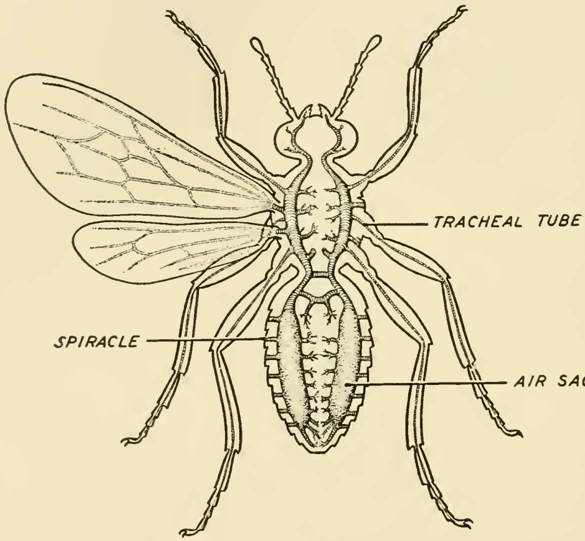


FIG. 111.—Diagram to show the position and distribution of the respiratory system of an insect. (After Kühn: *Grundriss der allgemeinen Zoologie.* Georg Theime, Leipzig.)

the more anterior tracheæ are incurrent, while the posterior are excurrent, so that the air follows an established course through the tissues.

Among vertebrate animals three main types of respiratory systems are employed. One of these, the skin, has a limited respiratory function in most forms, but in the frog and other Amphibia a very considerable proportion of the gas interchange between the blood and the environment takes place through the skin. In fishes, in some adult Amphibia, for example the salamanders, and in most larval Amphibia, for example frog tadpoles, the digestive canal is perforated on either side in the region of the pharynx by a series of slits (Fig. 112) equipped with gills. In the fishes water is taken in

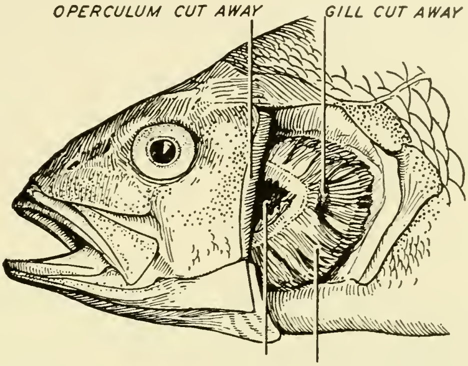


FIG. 112.—The respiratory system of the common perch. The operculum or shield has been cut away to disclose the gills and gill slits.

through the mouth and passes out through these slits, bathing finely divided filaments, which line the slits and are extensively invaded by blood vessels. In the adult Amphibia that have gills, for

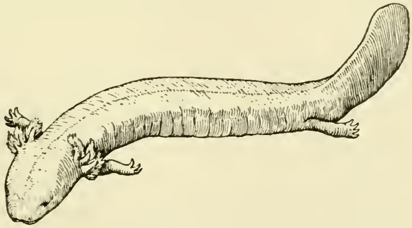


FIG. 113.—Necturus, the common mud puppy, found in the Mississippi River and its tributaries. In life the gills stand out about the head as a bright red ruff.

example Necturus, the mud puppy, the gills are extended like a ruffle into the surrounding water (Fig. 113). In the dipnoids, the so-called lung fishes of South America, of Australia, and of Africa, a sac connected with the pharynx by a narrow tube (Fig. 114), serves as an accessory respiratory device, enabling the fish to utilize air during those seasons when the water habitat is dried up or, in some forms, enabling the fish to leave its water habitat for a time. This sac is within the cœlom and by many is regarded as the forerunner of lungs.

Lungs. In the adult tailless Amphibia, for example the frog, in the reptiles, the birds, and the mammals, true lungs are formed. These are essentially sacs with thin membranous walls that are fur-

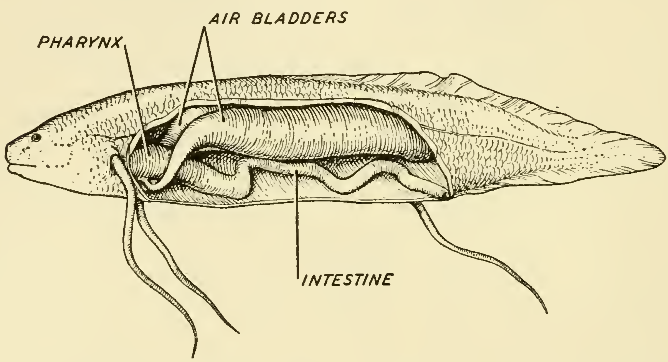


Fig. 114.—The African dipnoid or lung fish. The body wall has been cut away to show the position of the air sacs which under certain conditions serve as respiratory organs.

nished with a network of fine blood vessels. They lie in the anterior portion of the cœlom, which, as in Man, may be set off as separate compartments, the pleural cavities. In all air breathers these internal lungs are correlated with some sort of muscular device for drawing in and expelling the air. In Man this is accomplished by the periodic and automatic movements of the muscles of the diaphragm and of the chest and abdomen. The air enters the NARES where it is conditioned by moist membranes. By way of the internal nares the air passes through the LARYNX, a cartilaginous box-like structure containing two membranous folds, the VOCAL CORDS.

The vocal cords are in reality membranes continuous with the wall of the larynx that stand over and partially obstruct the passage. In ordinary breathing they are relaxed and permit passage of air without any vibration whatever. When the voice is produced these membranes are tautened and the air is forced against them with some pressure so that they vibrate, the frequency of vibration being regulated by the degree of tautness. The cavities of the thorax, the column of air in the trachea, and the cavities of the nose and sinuses of the bones of the face constitute resonating cavities. Motions of the tongue, jaws, lips, and soft palate modify the sounds produced. In general, the vocal cords vibrate only while air is being expired, but in some mammals sounds are produced on inspiration also, for example in the bray of the donkey.

The TRACHEA (Fig. 115) leads from the larynx, and is composed of rings of cartilage, so that it is always open. It branches into two BRONCHII, one leading toward each lung. These further subdivide into BRONCHIOLES, which divide repeatedly, becoming smaller and smaller, finally ending in small air sacs, termed ALVEOLI. Normally the alveoli always contain some residual air. The air having rushed in by the increasing of the capacity of the pleural cavities by the lowering of the diaphragm and the raising of the ribs, the interchange of gases takes place in the alveoli with great rapidity, and the air is expelled by the contraction of the muscles of the body wall and diaphragm. The walls of the trachea and bronchii are lined with cells that are ciliated. These by constant and correlated beating maintain an outward flow of viscous liquid secreted by some of the cells lining the passages. This current serves to remove dust and bacteria that have entered with the air.

The exchange of gases in the alveoli is considered as a simple diffusion through the membranous walls. It is estimated that the total area of the alveoli in the human lungs is in the vicinity of 90 square yards. The diffusion of gases in the lungs is not respiration; it is merely the introducing of oxygen into, and the passage of carbon dioxide from, the blood. The fundamental processes of respiration whereby energy is transformed occur in the tissue cells of the entire body. While at rest the demand of the body cells for oxygen and their output of carbon dioxide are fairly constant. But with

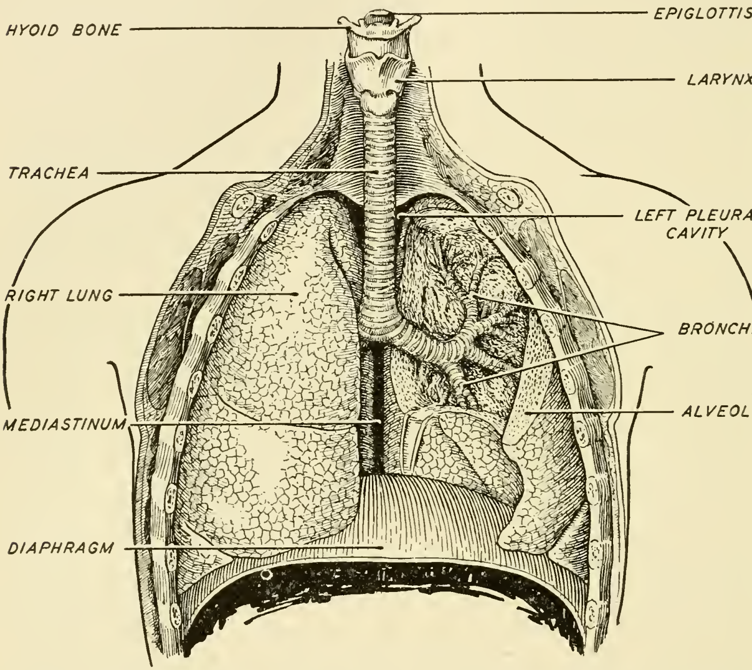


FIG. 115.—Diagrammatic representation of the human respiratory system. The wall of the thorax has been removed and a portion of the left lung cut away. (Partly after Sobotta: *Atlas and Textbook of Human Anatomy,* published by W. B. Saunders Co.)

exercise the oxygen demand and the carbon dioxide output are increased. The rate of inhaling and exhaling is controlled by a nerve centre located in the MEDULLA OBLONGATA, the most posterior region of the brain. The increase in carbon dioxide output and the oxygen deprivation during exercise alters the blood chemically and thus stimulates this centre, which in turn by stimulating the proper muscles increases the rapidity of ventilation of the lungs. The increased rate of breathing continues after exercise, until the chemistry of the blood returns to normal. Many other events may stimulate the respiratory centre of the brain, for example, fright, injury, and shock; it is also under voluntary control.

Food and Oxygen Transport Systems. The distribution of nutritive materials from the digestive system and of oxygen from the respiratory system, and the collecting of carbon dioxide and of nitrogenous and other wastes for expulsion are effected by orderly currents of liquids within the tissues. The complex system of trans-

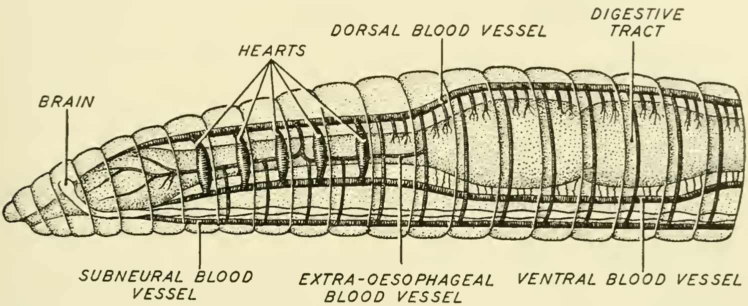


FIG. 116.—Diagram of the circulatory system of the anterior region of an earthworm. (Partly after Stephenson: *Oligochaeta*. Oxford University Press.)

portation that constitutes the human circulatory system appears to be the summation of various processes which take place in more simple forms. The direct respiration and excretion in Protozoa and in the simple diploblastic animals renders a circulatory medium unnecessary; the surrounding water serves that purpose. In triploblastic animals with deep tissues, watery circulatory liquids serve. In the flatworms, Platyhelminthes, and in the Nemathelminthes the circulatory liquid consists of a watery cœlomic fluid that does not appear to be exceptionally highly developed for carrying oxygen. In most Mollusca, for example, the common oyster, and in Arthropoda, the circulatory liquid is in part confined in tubes and contains a green compound, HÆMOCYAN, containing copper, which by reaction with oxygen serves to increase the oxygen-carrying property of the liquid. In the annelid worms the system of tubes that plumb the circulatory liquid about the body is fairly complex (Fig. 116). The blood contains a red coloring compound containing iron in solution in the liquid portion of the system. This red substance is HÆMOGLOBIN; its chemical reaction with oxygen increases the oxygen-carrying power. This same substance, in solution in the annelid blood, is the substance that colors vertebrate blood, but in vertebrates is entirely confined in certain blood corpuscles.

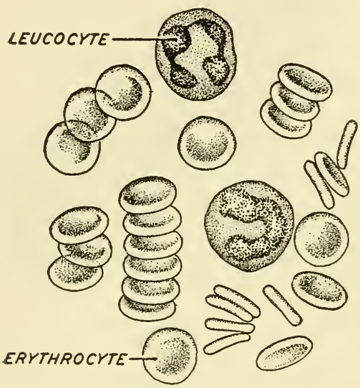


FIG. 117.—Human blood cells.

Human Blood. In Man and in other vertebrates the circulatory system includes two types of liquid media, the BLOOD and the LYMPH. The human blood is composed of a liquid PLASMA and two types of blood cells, one a highly modified cell, lacking a nucleus in the mature stage and containing the red substance, hæmoglobin. The red blood cells are known as ERYTHROCYTES (Fig. 117). The erythrocytes number about 4,500,000 per cubic millimeter of blood in women, and about 5,000,000 per cubic millimeter in men. The white blood cells, known as LEUCOCYTES (Fig. 117), are not so numerous, the number being normally between 5,000 and 7,000 per cubic millimeter in both sexes. There are several varieties of leucocytes, one of which, the PHAGOCYTES, ingests bacteria and other foreign particles in a manner similar to the feeding process of amœba; hence phagocytes are highly important in the defense of the organism against infection (p. 83).

The liquid plasma of the blood is a complex colloidal system. It is slightly alkaline and the degree of alkalinity does not alter materially in health, for it contains substances, chiefly carbonates, that form acid if excess alkali enters, or form alkali if excess acid is taken in. Such substances are termed BUFFERS; in the blood plasma they are most important in maintaining the chemical balance of the system. The osmotic pressure of the human blood is given as equal to between 5 and 7 atmospheres. The viscosity varies within limits, depending on the amount of liquid taken into the body or lost. It is generally thought that foods and wastes are carried by the blood in solution in the plasma. The plasma also contains salts of Ca, Na, and K, the immunity bodies, antitoxins and bacteriolysins, and minute quantities of substances secreted by glands. An important feature of the blood is its ability to form solid masses or clots. Normally this occurs only when the blood is exposed to air. The blood plasma contains small BLOOD PLATELETS, which enclose a substance known as PROTHROMBIN, that, on contact with surfaces, particularly oil-free surfaces in the presence of air and calcium ions, becomes chemically changed into a different substance, THROMBIN. Thrombin then acts on another plasma constituent, FIBRINOGEN, converting it into an insoluble protein, FIBRIN. Fibrin in air-exposed blood forms masses of fibres; these entrap the blood cells, the whole forming a blood clot. Calcium is necessary for the clotting reaction for it will not take place if the blood calcium salts are removed. The formation of the clot is therefore the result of a series of enzyme actions set in motion by the bursting of the blood platelets. Clotting is a very important defense mechanism; in cases in which it is lacking, even a minor injury results in continuous and profuse bleeding. Inability of the blood to form clots, HÆMOPHILIA, is a hereditary character in some human families. Its inheritance is sex linked; mothers are not usually bleeders but their sons may be (Chapt. IX).

Transportation of Gases by the Blood. The chief function of the red blood cells is the transportation of oxygen from the respiratory apparatus to the tissue cells and the conveyance away of the carbon dioxide. The hæmoglobin that colors the erythrocytes is a complex iron-containing compound. This substance unites readily with oxygen, forming an unstable molecule, an oxide of hæmoglobin known as OXYHÆMOGLOBIN. The oxyhæmoglobin, being unstable, readily yields its oxygen in the presence of substances with a greater affinity for oxygen. Thus it is converted back again into hæmoglobin. The usefulness of this substance in the conveyance of oxygen by the blood of Man is briefly this:

The liquid plasma of the blood is composed chiefly of water. Now oxygen dissolves in water and in watery liquids, but in the presence of air at ordinary temperature and pressure pure water is saturated when it contains approximately 0.6 per cent of dissolved oxygen. The temperature of the bodies of mammals is much higher than that of the room and since the solubility of gases such as oxygen in liquids decreases as the temperature increases, the solubility of oxygen in the plasma of the human blood is materially less than 0.6 per cent. The solubility is further reduced by reason of the colloidal nature of the blood plasma, for the solubility of gases is less in solutions of salts and in colloids than in pure water. Consequently, if the cells of a complex animal body such as Man were dependent for their oxygen supply solely on the oxygen that dissolves in the liquid portion of the blood, their energy-transforming metabolism would be carried on at a very low rate, due to inadequate oxygen supply. But the hæmoglobin in the blood cells very much increases the oxygen-carrying power of the blood by reason of its reaction with oxygen. Thus the supply of oxygen for consumption in the metabolism of the tissue cells is raised to a quantity adequate for the maximum activity of which the tissue is at the moment capable. So during its course through the exceedingly fine blood vessels in the tissues the oxyhæmoglobin is deprived of its oxygen, reduced to hæmoglobin and during its circulatory course in the respiratory membranes it comes in contact with free oxygen and is again oxidized.

The carbon dioxide that is produced as a waste product of oxidation within the cells is also carried away by the blood in chemical combination with blood substances, including hæmoglobin, and not primarily as merely a solution of the gas in the liquid portion of the blood. The process of carbon dioxide conveyance is somewhat more obscure than that of oxygen; it is known that in this process too the hæmoglobin plays a rôle, as do other blood substances, particularly $NaHCO_3$, sodium bicarbonate.

Lymph. In many animals lower than the vertebrates the circulation of fluids within the body is unorganized, taking place in and among the tissues without being confined within a definite tubular system. A similar unorganized or open liquid circulation occurs in vertebrates; since the blood is always confined within the blood vessels, some medium is necessary to convey foods to, and wastes away from the tissue cells and into and out of the blood vessels. Earlier it was pointed out that all active animal cells are aquatic; that is, each is surrounded by a watery liquid. This liquid in the more complex animals is called the LYMPH; it serves as the solvent which bathes the cells and in turn the walls of the fine tubules of the blood system. Lymph is substantially equivalent to the blood plasma minus the blood cells and clotting mechanism. Through the walls of the blood vessels materials pass by diffusion into the lymph and from the lymph into the tissue cells. The lymph is not in general enclosed within tubular walls. However, small lymph vessels do serve to collect this liquid draining through the tissues and to return it to the veins. Chief among these lymph vessels in the human body is the THORACIC DUCT, which receives all the lymph that is returned into the blood vessels and empties into the great vein near the heart (Fig. 123). It also receives the digested fats derived from the small lymph vessels, LACTEALS, that are distributed in the wall of the intestine, so that fats are not passed through the liver after digestion but are short-circuited, so to speak, and taken directly to the main circulation. The other products of digestion pass into fine vessels of the hepatic portal vein and are rectified in the liver (p. 163).

Propulsion of Blood. The propulsion of the lymph about the body is effected in part by gravity, but chiefly by the motions of the body and the pressure and expansion of the various tissues and organs that are muscular and active. The blood within the blood vessels is propelled by a muscular organ, the HEART. In the annelid worms (Fig. 116) certain segmental blood vessels serve as hearts and exhibit the property of periodic contraction and relaxation, which motions propel the blood. In the Arthropoda, for example the

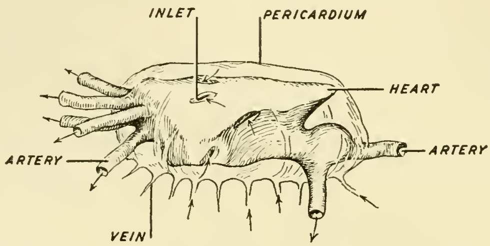


Fig. 118.—Diagram of the heart of a lobster. Veins drain into the pericardial sac. Inlet valves in the heart allow this blood to enter the ventricle, or heart proper. When the walls of the ventricle contract the inlet valves close and the blood is forced out through the arteries, as indicated by the arrows.

lobster (Fig. 118), a quite different contractile organ or heart is located in the dorsal region of the thorax. It is enclosed in a chamber, the PERICARDIAL CAVITY, that receives the blood, which has been oxygenated in the gills, and by a system of one-way valves and muscular contraction and relaxation expels the blood into well-formed blood vessels, the inlet valves closing and the outlet valves opening with each contraction. When it relaxes the appropriate valves open as it again fills.

The Vertebrate Heart. In the vertebrates the heart is always ventral to the digestive canal. In the fishes it consists of three chambers set in series (Fig. 119). The most posterior chamber receives the blood from all regions of the body. The beat or contraction

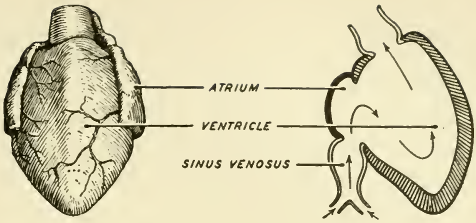


FIG. 119. FISH

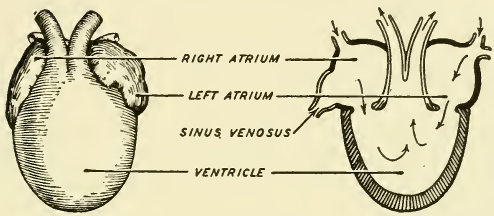


FIG. 120. AMPHIBIAN

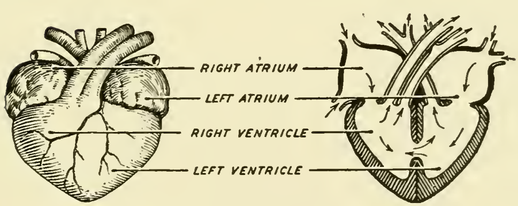


FIG. 121. REPTILE

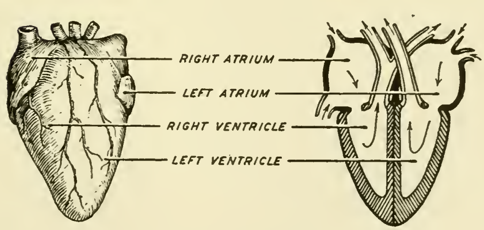


FIG. 122. BIRD

FIGS. 119, 120, 121, 122.—A series of vertebrate hearts and diagrams to show the paths of the blood. The reptilian heart represented in Fig. 121 is that of a lizard; in many other reptiles the wall separating the ventricles is complete. Note the progressive steps in the organization of parts of the heart to provide for the propulsion of the blood to, and the reception of blood from, the lungs.

begins in this chamber, the SINUS VENOSUS, and propels the blood into the next chamber, the ATRIUM. From the atrium it is passed into the VENTRICLE, a compartment with thick muscular walls. The wave of contraction from the sinus venosus passes to the ventricular walls and their contraction drives the blood out into the distributing vessels. In the Amphibia (Fig. 120), the intermediate chamber, the atrium, is divided into two compartments, one receiving the blood from the lungs and the other the blood from the large veins of the body by way of the sinus venosus. The ventricle is a single chamber. The large vessel that leaves the ventricle very shortly divides into two paths, one leading to the lungs and skin and the other to the remainder of the body. In reptiles (Fig. 121) a partition partially or completely divides the ventricle into two chambers, one of which propels the blood to the lungs, and the other to the remainder of the body. In birds and mammals (Fig. 122) with an efficient air-breathing system and the complete change from an aquatic habitat, the heart has absorbed the sinus venosus into the right atrium, or auricle, and is completely divided into four separate chambers, the auricles and the ventricles. Technically it is more correct to speak of the receiving chambers of the heart as atria. Vessels that conduct blood away from the heart are called arteries; vessels containing blood flowing toward the heart are veins.

The Human Heart. The human heart (Fig. 123) is not different from that of other mammals in any important respect. The large veins, VENA CAVÆ, empty into the right atrium, having received the blood from all tissues of the body, including blood from the liver containing digested foods contributed by the liver mechanism, and the fats that are picked up by the lacteals and collected in the thoracic duct. The blood passes to the right ventricle, impelled by the wave of contraction originating in a small node in the right atrium that represents the remnants of the sinus venosus. The same wave of contraction drives the blood out of the right ventricle through the pulmonary arteries to the lungs where it passes through exceedingly fine capillaries. It is collected again as these capillaries drain together and passes by way of the pulmonary veins to the left atrium. The beat or contraction of the walls forces it into the left ventricle and out anteriorly through the largest vessel in the body, the aorta. Shortly after leaving the left ventricle this vessel arches dorsally and then turns posteriorly. At the arch of the aorta large arteries to the head, face, and shoulders are given off. As the main trunk passes posteriorly in the dorsal wall of the cœlom

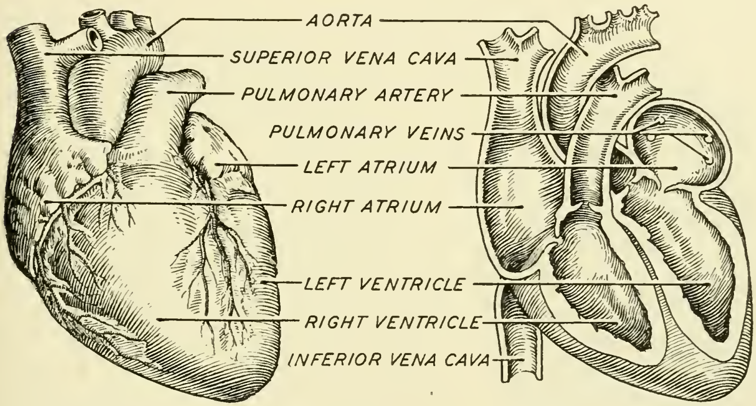


FIG. 123.—The human heart. (After Sobotta: *Atlas and Textbook of Human Anatomy,* published by W. B. Saunders Co.)

arteries are given off to the digestive and other organs of the cœlom, and to the body wall. Posteriorly it divides into large vessels that supply the legs. The blood in the heart and in the vessels is kept from flowing in the wrong direction by a system of valves.

The muscle cells of the heart (Fig. 124) are different in structure and in functional characteristics from smooth muscle cells of the intestinal wall and from the cells of large muscles attached to the skeleton. Heart muscle contracts periodically, automatically, and obtains its necessary rest during the relaxation intervals between contractions. The heart is connected with two sets of nerves, one which acts to accelerate and the other to inhibit the rate of beat. Two different brain centres are involved. A variety of conditions may affect rate of beat by acting on one or the other of these centres. Acceleration of beat normally accompanies exercise. We have seen how exercise changes the chemical composition of the blood. In some way this blood change acts to stimulate the nerve centre that increases heart beat, and thus assures an increase in the blood supply to the tissues as well as a more rapid flow through the lungs and an increase in tissue oxygen supply. This accelerated beat continues after the exercise has ceased, until the normal composition of the blood is restored. While the rate of heart beat may be affected by emotional states, it is not under voluntary control.

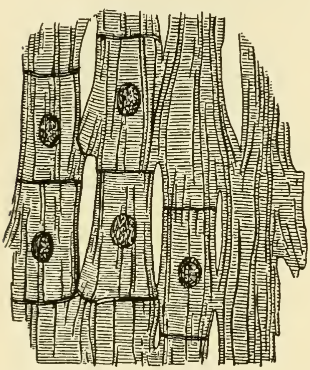


Fig. 124.—Muscle cells from the wall of the human heart. (After Schäfer: *Essentials of Histology*. 12th ed. Longmans, Green and Co.)

Blood Pressure. As the left ventricle contracts it sends an amount of blood equal to its capacity out into the great aorta with considerable suddenness. A series of contractions thus sets up a corresponding series of waves in the arteries, each wave indicating a ventricular contraction. This regular sequence may be noted at regions where arteries are near the body surface and is commonly called the PULSE. As the blood proceeds to smaller vessels the pulse becomes less marked and disappears in the capillaries, where it becomes dissipated by the resistance offered by the walls and the back pressure of blood already filling the tiny vessels.

The walls of the arteries consist largely of circular muscle fibres, together with connective tissue and a lining of thin cells known as an endothelium. In the vein walls the muscle elements are almost or completely lacking (Fig. 125). Within the closed system of vessels the confined blood exerts an appreciable pressure. Particularly noticeable is the pressure in the arteries, as the heart is constantly adding to their contents. The elastic walls of the arteries yield to each pulse wave and thus tend to absorb the increase of pressure. Arterial blood pressure is dependent on four conditions: (1) The quantity of blood in the whole circulatory system; (2) The resistance offered the flow of blood in the capillaries, small arteries

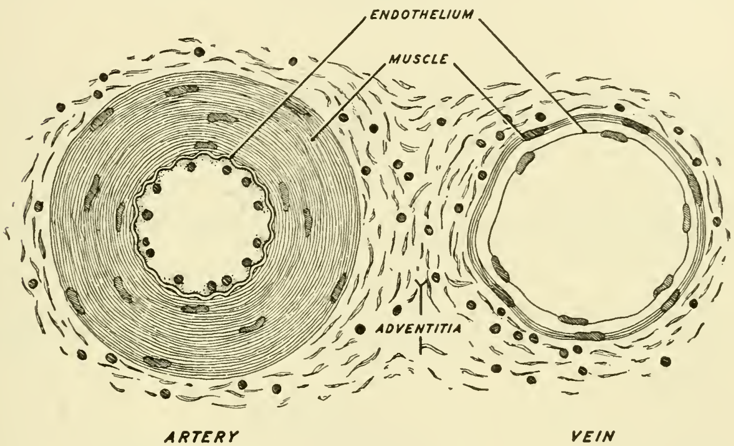


FIG. 125.—Diagram of a cross section through an artery and a vein. Note the very great difference in the muscle layers.

and small veins in the tissues; (3) The force and rate of heart beat; (4) The elasticity of the walls of the arteries. If any one of these is disturbed, the result is a disturbance of the blood pressure. On occasion a blood vessel may rupture as a result of excessively high pressure.

Disposal of Wastes of Metabolism. Among other functions performed by the liver is the conversion of nitrogenous wastes in the blood to UREA ($CO\langle\begin{matrix}NH_2\\NH_2\end{matrix}$), which is the final chemical form assumed by nitrogenous materials as they are expelled from the body. It is appropriate at this place to consider the mechanisms whereby the non-gaseous wastes of metabolism are finally expelled from the animal body. In unicellular animals and in the simple Metazoa the wastes are excreted directly by osmosis, for each cell is in direct contact with the water in its environment. But with the development in animals of deeply situated tissues and the appearance of hard or tough surface and supporting layers, this direct

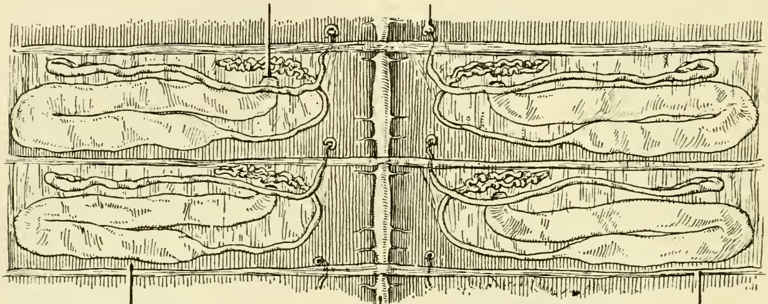


FIG. 126.—The nephridia, excretory organs of the earthworm, diagrammed to show position and nature.

excretion cannot be effected. Therefore associated with this increasing complexity is the appearance of organ systems whose special function it is to collect and rid the animal of such wastes. Animal excretory systems occur in a variety of forms; we shall mention only a few for the sake of contrast and to indicate the stages in increasing complexity which precede the system as found in mammals.

In the earthworm and like animals each segment is equipped with a pair of excretory tubes, termed NEPHRIDIA (Fig. 126), the inner ends of which are somewhat funnel-shaped and open into the cœlom. The process of abstracting non-gaseous wastes occurs in the contact between these structures and the cœlomic fluid. The nephridial tubules pass forward and open out through the ventral body wall of the next anterior segment. In Crustacea, the lobster and its allies, a pair of GREEN GLANDS (Fig. 127) located at the bases of the

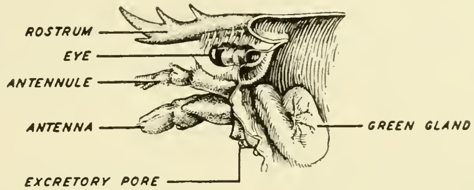


FIG. 127.—The green gland, excretory organs of a lobster.

antennæ abstract the non-gaseous wastes from the circulation and expel them. In insects a series of fine MALPIGHIAN TUBULES are found in the body cavity (Fig. 128). These tubes open into the intestine,

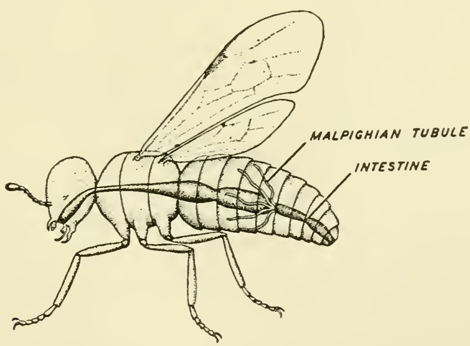


FIG. 128.—Diagram representing the Malpighian tubules, the excretory organs of an insect, and their position. (After Kühn: *Grundriss der allgemeinen Zoologie*. Georg Theime, Leipzig.)

into which the wastes from metabolism are collected together with the fæcal materials, and expelled. It may be remarked that this close association between excretory system and digestive system is unusual; in general, the two systems are widely separated and have no structures in common. In the lower vertebrate animals there is a common receptacle that receives the fæcal material and the excretory wastes, known as the CLOACA; it is emptied through the anus.

Vertebrate Excretory Systems. In vertebrate animals three different excretory systems appear, the head, middle, and hind kidneys, or more properly, the pro-, meso-, and metanephros. The first to be formed in all vertebrates is the PRONEPHROS (Fig. 129),

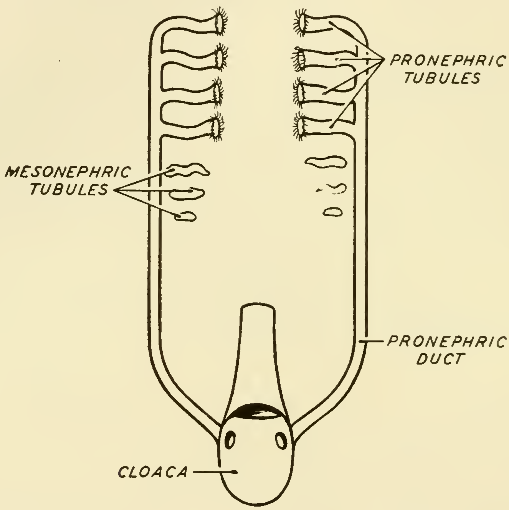


FIG. 129.—Diagram of the vertebrate pronephros. (After Patten: *Embryology of the Chick*, published by P. Blakiston's Son and Co.)

which may be roughly compared with the series of nephridia found in the earthworm, modified so that a common tube, the PRONEPHRIC DUCT, receives each segmental duct and opens into the extreme posterior end of the digestive canal. The pronephros and the nephridia of the annelids are not homologous, however, for the vertebrate pronephros is of mesodermal origin, while the nephridia of the earthworm are derived from ectoderm.

The pronephros is the only type of excretory system developed in the lowest of the vertebrates, the cyclostomes or lampreys. In the fishes it appears in the embryo but is replaced by the second development, the MESONEPHROS (Fig. 130). This consists of a considerable number of collecting ducts, each with a special excretory organ, the GLOMERULUS. The collecting ducts open into a MESONEPHRIC DUCT, which is in reality the reorganized pronephric duct; it delivers the wastes into the common receptacle, the cloaca. In vertebrates higher

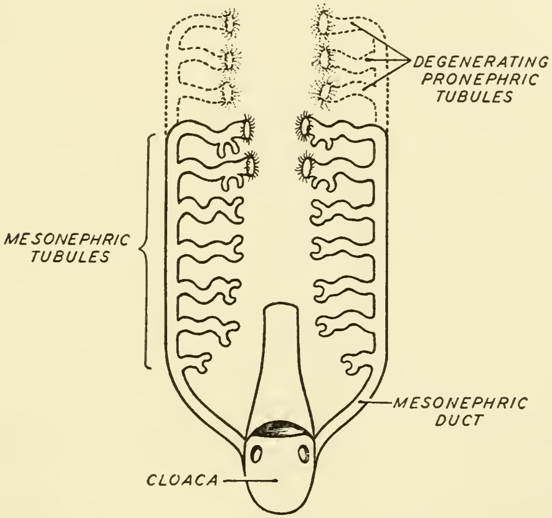


FIG. 130.—Diagram of the vertebrate mesonephros. (After Patten: *Embryology of the Chick*, published by P. Blakiston's Son and Co.)

than the fishes, except mammals, both pronephros and mesonephros appear during development, but the pronephros disappears, except for its duct, and the mesonephros becomes the functional kidney. In mammals, both pro- and mesonephros appear. The pronephros disappears; the mesonephros either largely disappears as in females, or becomes involved as an important structure of the male reproductive system. The definitive kidney or METANEPHROS arises and becomes the functional excretory organ. The cloaca, which in the fishes, Amphibia, reptiles, and birds, is a common receptacle for the contents of the colon and for the wastes from the excretory organs, is separated in the higher mammals into urinary and rectal organs.

The Human Kidney. The chief organ of excretion in Man and other mammals is the kidney (Fig. 131). In the human body a pair of these are located closely associated with the dorsal wall of the peritoneal cavity on either side of the mid-line. The human kidney is composed of two regions, an outer, known as the CORTEX, and an inner region, the MEDULLA. The cortex contains great num-

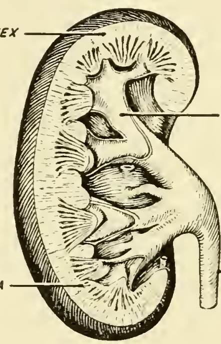


FIG. 131.—The gross anatomy of the human kidney in diagrammatic section. (After Sobotta: *Atlas and Textbook of Human Anatomy,* published by W. B. Saunders Co.)

bers of excretory units, each of which consists of a small structure shaped much like a champagne glass, termed the GLOMERULUS (Fig. 132). Within the hollow of the glomerulus is a small artery and a small vein. The stem of the glomerulus consists of a duct; a short distance from the glomerulus the duct is thrown into convolutions and the walls of this convoluted portion also receive an artery and a vein. The nitrogenous wastes of metabolism diffuse out from the body cells into the lymph and blood stream. In the liver they are converted into urea. In the glomerulus of the kidney this substance, together with other waste materials, is filtered out of the blood and into the duct that drains the glomerulus. In the region of the CONVOLUTED TUBULE certain important salts and water are resorbed back into the blood. The remainder of the contents are carried along, and the duct joins with other ducts. These pass through the medullary portion of the kidney and empty into a receptacle, termed the RENAL PELVIS. From the renal pelvis a tube, the URETER, leads downward to enter the base of the urinary bladder.

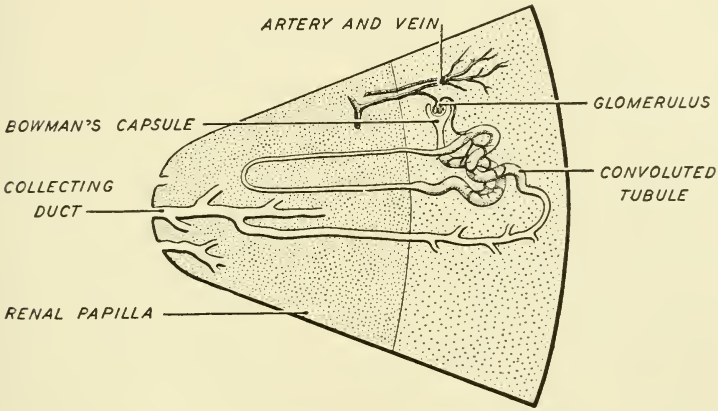


FIG. 132.—The essential excretory organs in the cortex of the human kidney, the glomerulus, convoluted tubule, and collecting duct. Diagrammatic.

Thus many hundreds of glomeruli and convoluted tubules are constantly rectifying the blood, the resulting excretion accumulating in the bladder, to be expelled through a short tube known as the URETHRA. The more than a quart of urine that is excreted each twenty-four hours is the sum of the excretory activity of all of these small units.

As the contents of the blood stream vary in health and disease, so the constituents of the urine vary. It is thus possible to diagnose disease by a chemical analysis of the urine, for characteristic changes in the urinary constituents are symptoms of certain diseases. The adjustment between blood constituents and the amount and nature of the substances excreted by the glomeruli is a delicate one; it may be disturbed by many conditions in addition to disease. Violent poisons may alter the permeability of the glomerulus to excretory substances; other agents, for example narcotics, accelerate the activity of the excretory processes. And since the glomerulus acts primarily as a filter, changes in the blood pressure bring about corresponding changes in the excretory activity of the kidney.

Excretion by Skin. A second organ of excretion important for the human body is the skin. Both the sweat glands (Fig. 94) and the oil glands excrete substances from the blood but the former are much more prominent excretory organs. The control of the activity of the sweat glands is a function of the nervous system. Many drugs and some diseases by their effect on the nervous system cause the glands to excrete rapidly. The substances excreted by the skin include NaCl, the chief salt constituent of perspiration, water, and traces of other salts and fatty acids. The sudiferous glands are constantly active, so that there is a constant loss of weight even when the body is at rest. With increase in the temperature of the surroundings or with exercise the glands excrete more or less profusely.

Fate of Heat in the Animal Body. Constant evaporation of watery perspiration on the body surface means that heat is being constantly absorbed. Skin excretion is therefore an important factor in regulating the temperature of the human body. This leads us to a consideration of body temperature in general throughout the animal kingdom.

All oxidations are exothermic reactions, that is, energy is released. In the protoplasm some of this energy is utilized as work, some in the synthesis of compounds, the formation of which requires energy; some is degraded into heat. In the simple animals this heat is almost immediately dissipated and even in forms as complex as the reptiles no provision is made for conserving it. In birds and mammals it is retained and devices provide for controlling the rate of heat loss. Thus animals according to whether or not they retain heat are divided into two rather sharply defined groups, the warm- and the cold-blooded animals, or more properly, the POIKILOTHERMAL and the HOMOIOTHERMAL. The body temperature of the cold-blooded animals is therefore very nearly that of their environment. Now the rate of a chemical reaction depends on the temperature, the higher the temperature the more rapid the reaction, the rate being slightly more than doubled for each rise of ten degrees. The general metabolism of the cold-blood animal is therefore at the mercy of the environmental temperature. Hence at low temperatures they become quiet, for their metabolic processes transform energy slowly. On the other hand, warm-blooded animals are independent of the surrounding temperature and their rate of energy transformation is fairly constant. One may with some accuracy think of a warm-blooded animal as producing an excess of heat and maintaining a constant temperature by means of varying a release mechanism, while the cold-blooded animals have no heat-retaining power nor any control over their temperatures. Obviously the warm-blooded animals are better equipped to cope with temperature changes in their environment.

Regulation of Body Temperature in Man. Control of body temperature in the human body is effected by heat-releasing mechanisms that are constantly dissipating heat. Most important of these is the skin, which constantly radiates heat when the environmental temperature is lower than that of the body. When the surrounding air is warmer, the sudiferous glands excrete sweat that by evaporation tends to lower the temperature. Also under such conditions the walls of the fine capillaries in the corium of the skin expand and more blood is brought near the surface where heat loss may take place. When the air temperature is low these vessels are contracted and thus the heat in the blood is conserved. Moreover, low temperature is said to set up a stimulation by way of the skin that is carried by a nerve mechanism to these glands whose products accelerate oxidative metabolism.

A second avenue of heat loss in the human body is by means of the warm air that is expired from the lungs. Not only is the air warmed by its stay in the lungs but in this air the water on the moist surfaces of the respiratory apparatus evaporates; the process of vaporizing water absorbs body heat. In the dog, which has no sweat glands, this is the chief method of cooling during exercise or on warm days. Another avenue of heat loss is by way of the urine and fæces. The specific heat of water is high; ridding the body of more than a quart of water at body temperature daily involves a considerable loss of heat. In mammals that lack sweat glands loss of body heat is by radiation from the skin, by ventilation of the lungs and by the heat loss in excretory and fæcal materials.

The striking difference between the homoiothermic birds and mammals and the poikilothermic lower forms inclines one to search for intermediate conditions. Not many animals are known to be intermediate between warm- and cold-blooded. It is true that some mammals during the cold season HIBERNATE and that during their winter stupor the body temperature decreases considerably. Some old observations on the body temperature of an incubating female python (a snake) indicate that during this period the reptile does conserve heat, for the body temperature is twenty or more degrees above that of the air. Recent observations of the body temperature of newly hatched birds show that they at this time resemble cold-blooded animals in that their temperature varies with that of the air.

Reproduction. Animals reproduce in two ways, sexually, involving the union of two types of cells, and asexually, involving a single cell or group of cells. They are more properly termed GAMETIC and AGAMIC. In plants and in animals that reproduce asexually, various sorts of organs are specialized for the purpose of developing the reproductive element. For examples, the SORI on the leaves of the fern (Fig. 174) are the organs of development of the reproducing spores; in the cœlenterate hydroids the reproductive

HYDRANTH (Fig. 176) is the organ that gives rise to buds that develop asexually into free swimming forms. But the term reproductive system in Animal Biology is usually confined to those structures that are concerned in gametic reproduction.

Fertilization. In animals the two cells that unite to initiate the process of gametic reproduction are observably different. The ovum is a relatively large, inactive cell (Fig. 133) containing more or less stored-up food materials in the form of yolk. The individual or organs that produce such cells are known as female. The spermatozoa (Fig. 133) are relatively small, active cells, devoid of yolk, produced in male organs. It is necessary to distinguish not only individuals but also organs by sex, for in some animals both types of sex cells are produced in the same individual. The spermatozoa, actively swimming about, come in contact with, and penetrate the ova, the nuclei of the two cells joining. This union is known as FERTILIZATION and the resulting fertilized egg is the ZYGOTE.

Fertilization may be brought about in two ways. In many animals, for example, the starfish, aquatic annelids, and jelly fish, both eggs and spermatozoa are shed into the surrounding water; the meeting of sperm with egg is therefore largely a matter of chance. Assurance that sperm and eggs are in close proximity is provided in most of these forms by the close association of males and females during the period of egg and sperm deposition. This is the case in the fishes and Amphibia during the spawning season. Fertilization occurring outside the female body is termed EXTERNAL FERTILIZATION.

The second method of fertilization is accomplished by the deposition of spermatozoa within the body of the female and is known as INTERNAL FERTILIZATION. Its nature requires that the female be provided with structures for the retention of eggs and the reception of sperms. Internal fertilization much increases the probability of meeting between egg and sperm; usually associated with the character is a very much reduced number of eggs as compared with the number shed by females whose eggs are externally fertilized. While fertilization is internal in the highest animals, it cannot be said

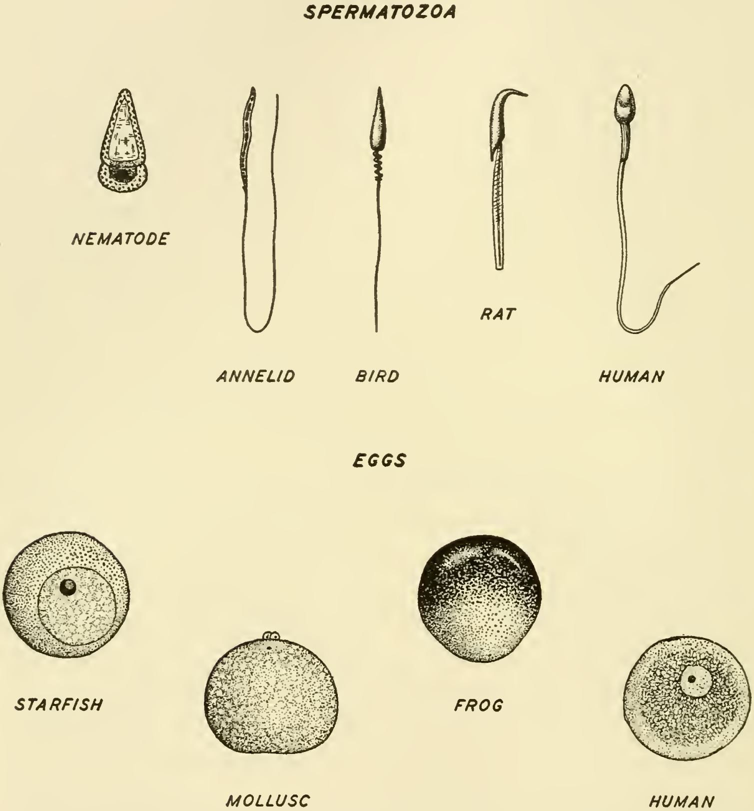


Fig. 133.—Some types of animal germ cells. All of the spermatozoa and the human ovum have been greatly enlarged. (From preserved materials and various authors.)

that this character is an evidence of advance; for fertilization is also internal in many lower forms, Arthropoda, some Annelida, Nemathelminthes, and even in Platyhelminthes. As regards the location of the developing zygote, animals are either egg-laying, or OVIPAROUS, or give birth to living young, or VIVIPAROUS. Again it cannot be said that because the higher mammals are viviparous this character is advanced serially throughout the scale of animal complexity, for the lowest mammals lay eggs while some fishes give birth to living young.

Reproductive Organs. The sex cells are located and matured in special organs known as GONADS, that producing eggs being termed the OVARY and the sperm-producing structure the TESTIS. Testes and ovaries are temporary structures in a few animals; for example, in forms like the sandworm, Nereis, the gonads appear during certain seasons of the year and consist of masses of maturing gametes. But in most animals the gonads are permanent organs. The basic sex structures that are common to all gametic animals are the gonads; the accessory structures in most cases include a set of tubes in the male that collect the matured sperms and lead these products to the outside by means of a sperm duct. In species in which fertilization is internal the male accessory structures usually include some sort of intromittent organ. The accessory female structures usually include tubes that conduct the ova away from the ovaries and serve as avenues of exit from the body. In those animals in which the eggs develop inside the body, these tubes undergo more or less modification to provide a chamber or UTERUS in which development takes place. In many lower animals the sexes are not separated, both ovaries and testes and accessory sex organs of both sexes occurring in the same individual. Such forms are known as HERMAPHRODITES. The most common example is the earthworm (Fig. 134), in which both sets of sex organs are always present and functional at the same time. A copulatory process, which insures the presence of sperms of another individual, tends to prevent self-fertilization.

The gonads together with the tubes and ducts that conduct the sex cells may be termed PRIMARY SEX ORGANS. In addition to these, a more or less complicated set of SECONDARY SEX ORGANS or characters may occur; for example, the spurs, head furnishings, and coloration of male birds, the thumb pad of the male frog, the body form and mammary glands of female mammals, are secondary sex characters. There are wide variations and differences in both primary and secondary sex characters; to review them in detail is beyond the purposes of this discussion. It is not possible to establish a series

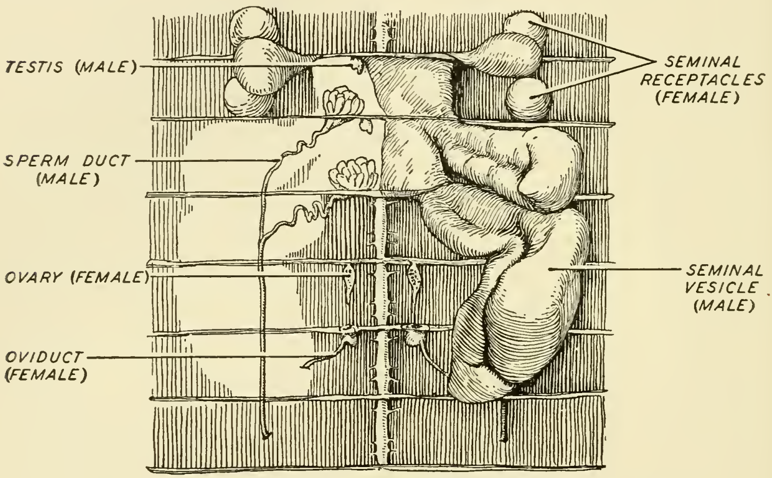


FIG. 134.—Diagram of the reproductive organs of an earthworm.

of increasing complexity nor to generalize concerning the principles of organization of reproductive systems. For example, in such dissimilar forms as worms, arthropods, birds, reptiles, and the lower mammals, the walls of the egg ducts or associated glands secrete and deposit shells about the eggs as they pass. In invertebrates the shell is composed of chitin; in vertebrates it is largely calcium carbonate. On the other hand, within a phylum the arrangement of the sex organs may differ widely between classes. For example, within the phylum Arthropoda, in members of the class Crustacea, lobsters, crayfish, *et cetera,* the gonads are largely located in the cephalothorax. The genital opening in both sexes is on the ventral posterior region of the CEPHALOTHORAX (the unit consisting of the head and thorax) and in the male the appendages of the adjacent anterior abdominal segments are modified to form the intromittent organ. In members of the class Insecta the gonads and ducts are situated in the abdomen and the genital opening is at the extreme posterior end of the abdomen. In many species of insects the appendages of the posterior segment are modified to form a stout or complex instrument for depositing the eggs. Obviously, among invertebrates there is no apparent relationship in the arrangement of the reproductive organs, nor do any of them appear to be the basic type from which the reproductive systems of vertebrates may have been derived.

The Vertebrate Reproductive System. Among the vertebrates the reproductive systems all represent modifications of a single basic plan, which is best described by diagrams (Fig. 135). The primary female organs, the ovaries and oviducts, are situated in the peritoneal region of the cœlom. The ova, when mature, are shed directly into the cœlomic cavity, and the oviducts open into this cavity to receive them prior to fertilization. In mammals the ovaries are closely associated with the internal open ends of the oviducts; their situation reduces the probability of escape of the ova into the peritoneal cavity. The outer ends of the oviducts form the uterus, which may thus be double, or single, depending on the extent of fusion of the ducts. The mesonephros is always incorporated into the male reproductive system. For example, in the frog the mesonephric duct in the male serves to carry away both the wastes from the mesonephros and the spermatozoa from the testes. In the higher animals the excretory function of the mesonephric duct is dispensed with; the mesonephric tubules of the anterior region are retained as ducts that collect spermatozoa and the mesonephric duct serves as the main sperm duct. In mammals the gonads migrate posteriorly during development, but still retain

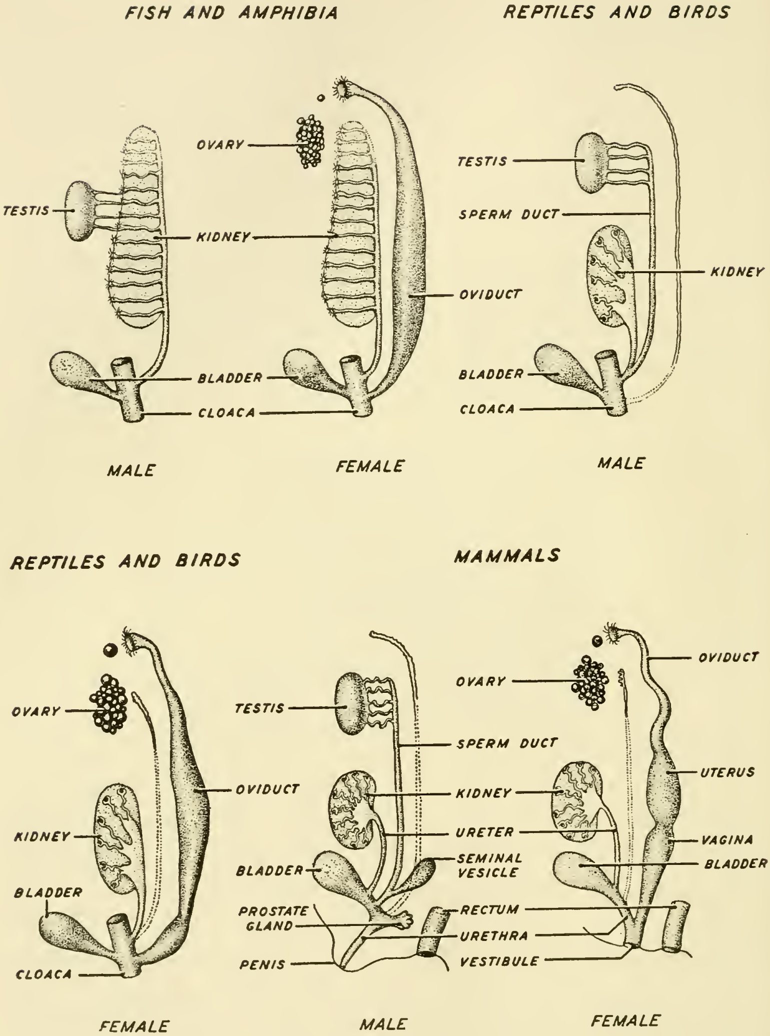


FIG. 135.—Diagrams showing comparatively the homologous parts of the excretory and reproductive organs of vertebrates. One side only is shown. It will be noted that in the higher mammals the cloaca does not exist in the adult; its place is taken by urinary and reproductive canals and the posterior end of the digestive canal, the rectum. (After Kühn, slightly modified: *Grundriss der allgemeinen Zoologie.* Georg Theime, Leipzig.)

their circulatory and mesenteric connections with their primitive position in the anterior region of the peritoneal cavity.

Reproductive System of the Human Male. The human testis (Fig. 136) consists of a considerable number of contorted SEMINIFEROUS TUBULES that lead into a series of ducts known as the RETE TESTIS. The rete tubules communicate with another set of tubes, the VASA EFFERENTIA, derived from the mesonephric tubules:

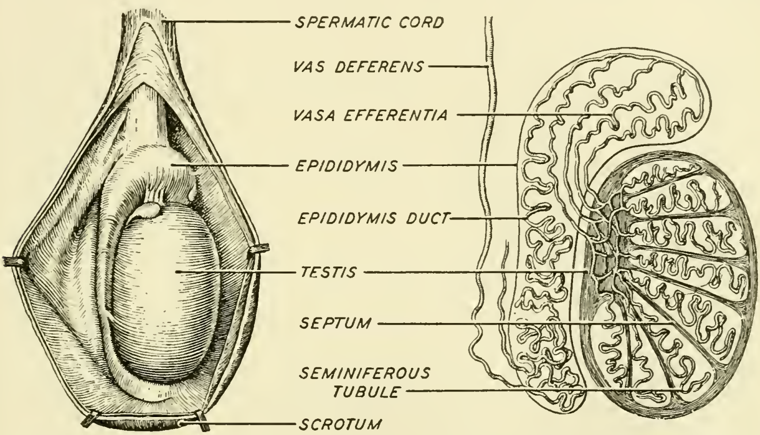


FIG. 136.—A partially dissected human testis and a diagram showing the relations of its parts. (Partly after Sobotta: *Atlas and Textbook of Human Anatomy*, published by W. B. Saunders Co.)

the vasa efferentia deliver their contents into the single main duct, the VAS DEFERENS, the mesonephric duct of lower forms. The vas deferens is joined near the base of the urinary bladder by a sac termed the SEMINAL VESICLE and also receives the duct from a large PROSTATE GLAND. The vas deferens then empties into the urethra. In this region the vas deferens is called the ejaculatory duct. The urethra thus serves a double function, an outlet from the urinary bladder and an outlet for the products of the testes.

The long, contorted seminiferous tubules in the testes are the site of origin and of maturation of the spermatozoa. The walls of the tubules are composed of two types of cells, spermatozoa in various stages of maturation, and large nurse cells known as SERTOLI CELLS. Spermatozoa are being continuously matured during adult life and are stored in the seminal vesicles.

Reproductive System of the Human Female. The human ovary (Fig. 137) consists of two portions, a core or MEDULLARY PORTION and the CORTEX. The ova originate in connection with the

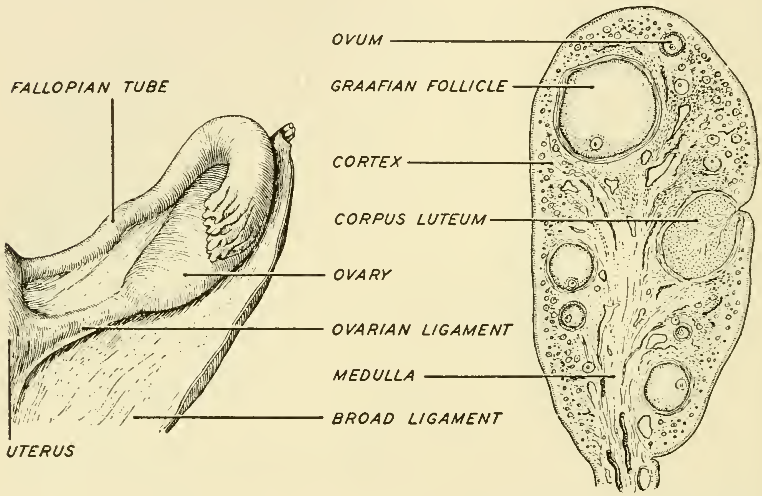


FIG. 137.—The position and structure of the human ovary. (Partly after Sobotta: *Atlas and Textbook of Human Anatomy,* published by W. B. Saunders Co.)

epithelium of the cortex and as they mature sink deeply into the cortical tissue. The epithelium and cortex appear to contain many thousands of primordial ova but only a few hundred mature during the life of the individual. Around each maturing ovum a special organ is formed, known as the GRAAFIAN FOLLICLE (Fig. 137). The cells forming the follicle have a glandular function and secrete a liquid that fills the cavity of the mature structure. In some mammals at least, the follicular liquid contains hormones (p. 203) that have to do with certain psychical sex attributes and with body changes during the reproductive cycle. When the ovum attains an appropriate stage of maturation the follicle opens on the surface of the ovary and the ovum is freed. The ovary is closely invested by the open end of the oviduct, called in mammals the FALLOPIAN TUBE. The Fallopian tubes from both ovaries open into a triangular-shaped cavity, the uterus, which is normally collapsed except during the development of the embryo. The single posterior outlet of the uterus is termed the OS UTERI and is normally closed by circular contracted muscles. The os uteri opens outward through a short canal, the VAGINA. A comparison of these adult structures with the basic sex structures of vertebrates (Fig. 135) shows that the oviducts are exclusively reproductive in function in all vertebrates and that the human system differs from that of other vertebrates only in relatively minor details. Only traces of the mesonephros are to be found in the adult female.

Suggested Readings

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Chapter VI

THE STRUCTURE AND FUNCTIONS OF MULTICELLULAR ANIMALS

II. Correlating Systems

Correlating Systems. The body of a multicellular animal is unified and correlated so that it behaves as an individual and not as an association of independent tissues. This correlation is provided for by two distinctly different types of mechanisms. One transports materials to all regions so that all receive, or are in contact with the same sort and quantity of food, of oxygen, and of the products of metabolism. The other system is one of conduction of impulses or excitations rather than of transportation of materials. The former is one of the functions of the circulation, the latter primarily of the nervous system, although tissues other than nervous have important transmissive correlative functions.

Rôle of Body Fluids as Correlating Agents. For convenience we may consider the rôle played by the circulatory fluids as correlating agents under two headings: (1) Passively, the circulation serves to regulate and correlate the various tissues and organs by reason of the fact that it exposes each to the same constituents. For example, in Man the oxygen content of arterial blood is much the same in all regions, so that all tissues have the same quantity available; any differences in their rates of oxygen utilization are due to specific tissue differences in oxygen requirement. In warm-blooded animals the temperature of the blood is fairly uniform in all regions, a condition that in part determines their rates of metabolism. (2) Actively, the blood serves as a correlating agent by distributing special substances, the hormones.

The Endocrine Glands. Hormones. In recent decades it has been found that, in higher animals at least, there is an intricate system of special glands (ENDOCRINE GLANDS) whose function it is to release into the blood stream minute quantities of special chemical agents that activate other tissues. These substances are termed HORMONES; their study has become a separate branch of Biology known as ENDOCRINOLOGY. Attention has focused chiefly on vertebrates; comparatively little is known concerning hormones in invertebrates.

The endocrine glands are sometimes called the ductless glands, because they possess no ducts; their excretions are passed directly into the blood from the cells by osmosis. Intensive study of the chemical nature and structure of the hormones and of the effects of removal of such glands and subsequent treatment with gland extracts have brought about marked progress in the understanding of body functions and in the control of disease. In the mammalian body these glands are widely separated and their products act in various ways to control many of the vital processes.

The Thyroid. The chief endocrine glands are (Fig. 138): The THYROID, the PITUITARY, the PANCREAS, the ADRENALS, the PARATHYROIDS, and the GONADS. The thyroid is a large gland of endodermal origin situated in mammals in the base of the neck. Its product is known as THYROXIN, and is an iodine-containing compound, the structure of which is known. In the frog tadpole thyroxin brings about the metamorphosis from the water-living tadpole to the air-breathing frog. In Man this hormone is a regulator of the rate of oxygen utilization by the body; in other words it controls the pace at which oxidative metabolism transforms energy. When the production of thyroxin is excessive the result is an increase in the rate of oxidative metabolism accompanied by general body disturbances. If the thyroid is deficient during early life, the individual may develop as a mental and physical defective of a distinct type known as a CRETIN. Defective thyroid in later life may result in various disturbances, such as excess fat, nervous depression, weakness, and impaired mentality.

The Pituitary. The pituitary gland is situated in a depression in the base of the skull, in Man almost directly above the posterior

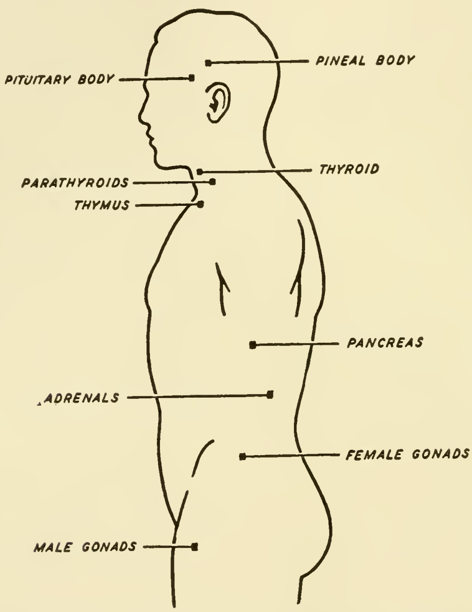


FIG. 138.—Diagram to show the approximate levels in the human body at which are located the chief endocrine glands.

portion of the roof of the mouth. It consists of two chief parts each of which has a different hormonal function. The hormones from the more anterior lobe of the gland appear to be important regulators of the rate of growth; excessive or deficient activity of the gland results in giantism or dwarfism. They also have to do with the normal development and functioning of the reproductive organs. The hormones from the posterior lobe affect the muscles of the walls of the blood vessels, causing contraction, affect similar types of muscles in the reproductive system, apparently are also concerned in the activity of the kidneys, and have still other effects.

The Pancreas. The pancreas varies in form among vertebrates. In Man it is a large lobed gland located posterior to the stomach. It contains two sorts of tissues. One type is glandular tissue which secretes the pancreatic juice that is employed in digestion. These secretions are passed to the duodenum by means of the pancreatic duct opening with the bile duct from the liver. In the mammalian pancreas the other type of tissue is scattered as islets among the tissue concerned with digestive enzyme production. The products of these islets are passed directly into the blood as in other endocrine glands. The islet hormone is known as INSULIN and regulates the sugar content of the blood. We have seen how the liver converts the digested starches into glycogen, the so-called animal starch, and stores it within the liver cells. We have also noted that this starch, glycogen, is again converted into a sugar and released into the blood for the use of muscles and other tissues. Insulin appears to be the chemical agent which controls this release of sugar into the blood. Deficiency in the activity of the pancreas brought about by disease or degeneration of the islets produces a serious condition known as diabetes mellitus, which is characterized by a constant loss of sugar from the blood into the urine, with resulting breakdown of body functions. A remedy, at least temporary, is afforded by the administration of insulin.

The Adrenals. The adrenals are glands located very near the kidneys, in mammals just anterior and slightly medial. Each adrenal consists of two portions which secrete different hormones. The central or medullary portion of the gland secretes ADRENALIN, a substance that affects blood pressure, causes an output of muscle sugar from the liver into the blood in emergencies, and affects the sympathetic nervous system which in turn affects many automatically controlled body functions. The outer portion of the gland, the cortex, supplies a hormone that controls or at least has much to do with the acidity-alkalinity level of the blood by reason of its effect on the elimination of acid by the kidneys.

The Thymus. The thymus, in mammals situated in the upper thorax, has been commonly regarded as an endocrine gland, but its function is not definitely known. In the human it disappears with the approach of maturity.[1]

The Parathyroids. The parathyroids consist of a number of small glands in the neck region. Although in Man their total mass is quite small, they have a very important function and their destruction or removal results fatally. The hormone from these glands in some way regulates the utilization of calcium by the body. Calcium is an absolute essential to cell life, although the quantity utilized is quite small except in the case of bone formation.

The Gonads. The gonads of both sexes have a double function. In addition to the production of spermatozoa, the male gonad or testis, secretes a hormone that appears to induce and to maintain the secondary sex characters which make the body of the male observably different from that of the female. In Man the changes in body form, voice changes, and other characters, both physiological and psychical, that accompany maturity result from the effects of this hormone on the metabolism of the several parts of the body which undergo change. A section through the testis (Fig. 136) shows that between the seminiferous tubules are masses of cells of characteristic appearance, known as INTERSTITIAL CELLS; these are regarded as the portion of the gonad that is endocrine in function.

In the female gonad or ovary (Fig. 137) are found similar masses of interstitial tissue that secrete the female hormone. All the characters of the body that are distinctly female are regarded as due to the influence of this hormone. In addition to the female hormone, certain temporary structures develop in the adult ovary that have to

[1] The pineal gland, dorsal to the brain stem, appears to be concerned with the delay of sexual maturity.

do with the secretion of other hormones. One group of these, found in the fluid of the GRAAFIAN FOLLICLE surrounding the maturing ovum, has an influence on the mating impulse of the female and causes histological changes in the wall of the uterus in preparation for the reception of the fertilized egg; another, secreted by the follicular cells after the ovum has been shed and fertilized activates the mammary glands prior to and during lactation and has other functions concerned with the development and birth of the young.

General Considerations. Certain general characters of the hormones of vertebrates are worth further discussion. In the first place, some of these endocrine glands represent rather extreme modifications of some simple structures which occur in the other chordates and lower vertebrates. For example, the thyroid is found to be homologous with a small gland in the floor of the pharynx of a primitive chordate, Amphioxus. In Amphioxus this gland secretes a slimy ribbon of material which, floating free in the pharyngeal cavity, entraps particles of food from the water and carries them down the digestive canal. In Man this gland originates from the endoderm in the same relative position. In the embryo it has a tubular connection with the floor of the pharynx but later this connection is closed and the adult gland has no outlet except through the absorption of its products by the blood. The wide adaptability and remarkably efficient characters of the higher animals have been profoundly influenced by the development of the endocrine function of these glands, controlling, as they do, the type of growth and development, of physical and psychical characters, and the maintenance of life in such a complicated body system.

Secondly, the hormone from one vertebrate when placed in the body of another type has the same action as the hormone produced by that animal's own gland. For example, if a bit of the thyroid of an ox is planted in a frog tadpole from which the native thyroid has been removed, it causes the tadpole to metamorphose into an adult frog in a typical fashion. Advantage is taken of this interchangeable property in the preparation of hormones for use as treatment in various human diseases. Insulin may be obtained from islet tissue in the fish and employed in the treatment of diabetes in Man; adrenalin for human use is likewise prepared from the adrenal glands of other animals. The most obvious explanation of this interchangeability of hormones among vertebrates is that all have been derived from a common ancestry. At least the evidence is clear that all of the group are chemically related.

Lastly, the effect of any hormone is the result of an interaction between the hormone and certain cell protoplasms. For example, the blood stream of a pregnant female mammal contains a hormone from an ovarian structure that induces activity in the mammary glands and the secretion of milk, but milk is secreted only by these glands and not by other tissues. In other words, certain tissues may be considered as attuned to these chemical influences and by their response to the hormones act for the benefit of the animal as a whole. Thus the hormones, transported by the blood, serve to unify the organism, inducing such reactions in gland, brain, nerve, and other tissues that serve the whole individual.

The discovery of the existence of this intricate and sensitive system of hormones in the human body has within recent years brought a profound change in the concepts of human physiology. As is so frequently the case with new discoveries, there has been a tendency to overemphasize the endocrines and to ascribe to their deficiency or overproduction all sorts of psychological and personal traits. They have been called the glands of personality. While it is undoubtedly true that abnormalities in the functioning of endocrine glands have effects on these characteristics of the individual, it is equally true that the abnormal functioning of other structures have similar effects. Many diseases are characterized by rather definite mental and psychological symptoms; cheerful optimism accompanies tuberculosis; on the other hand mental depression and irritability are frequently associated with digestive disturbances. That complex of human behavior commonly called personality is the sum of many characters, including the state of the endocrine glands.

Transmitted Correlations. The production of a hormonal substance by a gland, its transportation, and its effect are time consuming. For immediate response and rapid unification the organism is equipped with a system for transmitting correlating impulses. The principal agent in transmitted correlation is the nervous system.

Irritability is one of the fundamental properties of living material. Irritability in the organism consists of three phases: First, excitation. Thus if the finger is placed on a hot object the heat excites a certain type of specialized nerve tissue. Second, transmission. If only the region in contact with the hot object were excited, there would be no response and the excitation would serve no useful purpose. Some sort of influence is propagated along the nerve to other tissues. Third, response. The propagated impulse passes along the nerve path until it reaches a muscle, and sets in motion a response that results in the contraction of the muscle and a consequent withdrawal of the finger. Thus in the highly organized irritability mechanism of the human body the necessary structures are: RECEPTOR, TRANSMITTOR, EFFECTOR, in the order named. But even in the most simple animals these three components are always concerned in any response to an outside stimulus.

Primitive Excitation-Transmission Systems. We have seen how in certain Protozoa, in the genus Diplodinium for instance, there are definite paths over which pass correlating stimuli, a NEUROMOTOR system. In such forms as the genus Amœba, however, no specialized system has been detected. We are forced to conclude that in such simple types the properties of receptor, transmittor, and effector are properties of the cell as a whole, with no special differentiations or localizations, except that the surface of the cell must be the locus of reception for all stimuli. In the members of the phylum Porifera, the sponges, the cells that serve to receive and to transmit stimuli are not clearly differentiated, although a primitive receptor-effector mechanism exists in the functions of some of the ectodermal cells. The most primitive of the nervous mechanisms of Metazoa occurs in the members of the phylum Cœlenterata, particularly in the Hydrozoa. In these forms, hydra for instance, some of the ectodermal cells are linked together by means of protoplasmic processes, to form a sort of NERVE NET (Fig. 139). The contacts between the processes that form the net are said to be direct, the cytoplasms being fused. The net is therefore a continuous cytoplasmic structure and a stimulus set up in one region may be transferred elsewhere without crossing a cell boundary. Some of the processes of the net communicate with the contractile cells of the ectoderm; the nerve net together with these epithelio-muscular cells constitutes the most primitive type of nerve-muscle operating unit.

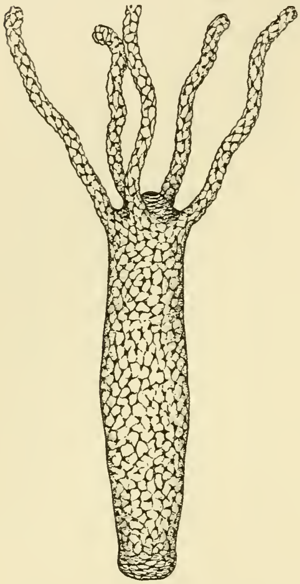


FIG. 139.—Diagram illustrating the distribution of the nerve net in the ectoderm of a hydra.

The Neuron. The nerve cell of other Metazoa in general is so markedly different in both structure and function from other types of cells that it is known by a separate name, NEURON. A neuron consists essentially of a cell body containing a centrally placed nucleus and equipped with one or more long extensions of the cell substance which may be referred to as NERVE FIBRES. If the fibre is one that conducts stimuli toward the cell body, afferent, it is known as a DENDRITE. If the fibre is efferent, that is, conducts stimuli away from the cell body, it is designated as an AXONE. In some cases the dendrites and axones may be quite long; for instance, the cell bodies of the nerves that receive sensations in the human hand are located in groups adjacent to the spinal cord, the fibres from these cells reaching from approximately the middle of the back to the surface of the hand.

There are three types of neurons, distinguished by the number and arrangement of the axones and dendrites (Fig. 140). The

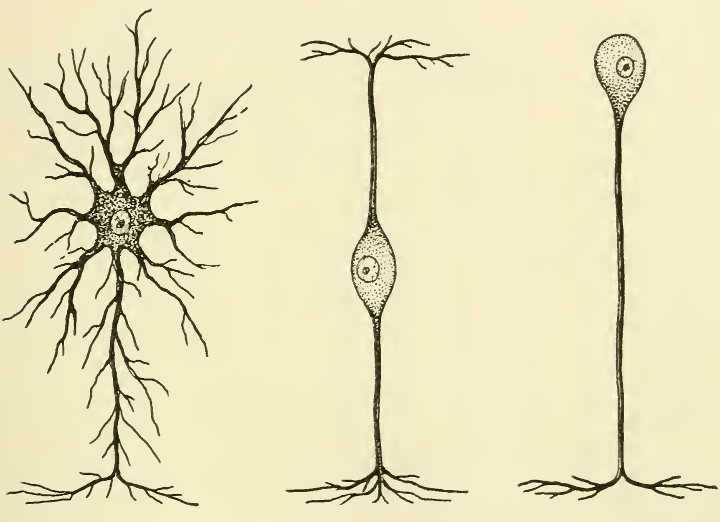


FIG. 140.—Monopolar, bipolar, and multipolar neurons.

most primitive type, the MULTIPOLAR NEURON, may be compared with the branching cells of the nerve net of cœlenterates, in that it consists of a cell body with several fibres. The BIPOLAR NEURON has but two fibres; the MONOPOLAR NEURON has only one fibre leaving the cell but that fibre is usually divided into two branches very near to its origin. The nerve fibres of all types end in a more or less numerous set of branches. In the case of nerves that receive stimuli, or, the SENSORY NERVES, each branch of the dendrite, the afferent fibre, is connected with some sort of receptor mechanism, for example, a taste bud, and each branch of the efferent fibre, the axone, communicates with the dendrite of one or more other neurons. The arrangement of the fibres of neurons that conduct stimuli to the

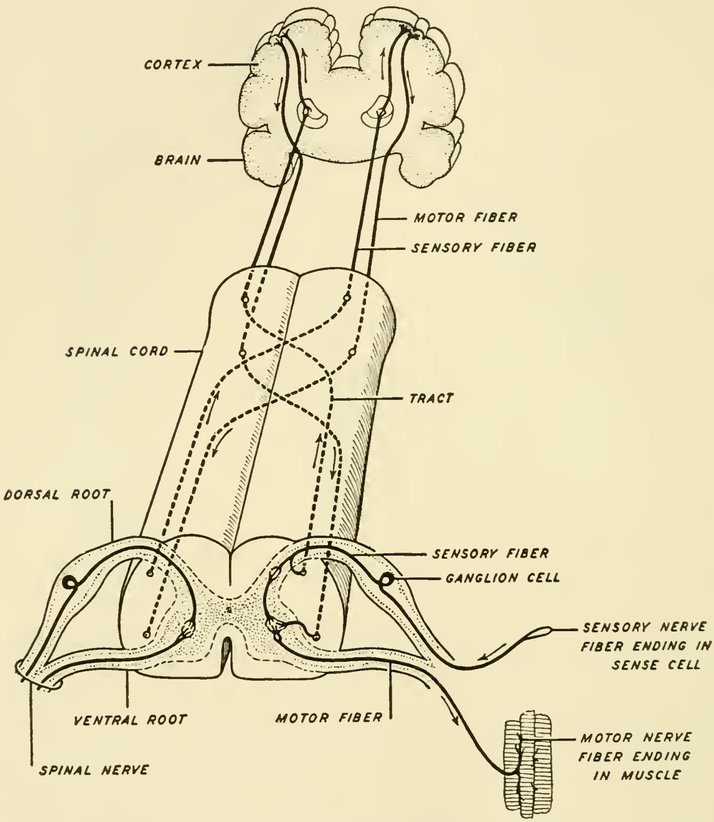


FIG. 141.—Scheme of nerve tracts in a mammal. (After Woodruff: *Animal Biology,* published by The Macmillan Company.)

muscles, or, MOTOR NERVES, is similar but reversed. Dendrites of motor nerves communicate with the axones of other nerves, while the axones finally communicate with muscle cells. A TRACT (Fig.

141) is composed of a series of nerve cells that form a chain, the axones of one being in contact with the dendrites of the next, and so on. In the cœlenterate nerve net the protoplasm of the cells is continuous, but in the more advanced types the communicating axones and dendrites are in contact through a special structure termed the SYNAPSE. The synapse is not thoroughly understood, but it is known that impulses pass through in one direction only.

Nervous Systems of Invertebrates. In general, the nervous systems of animals higher in the scale than Cœlenterata consist of more or less centrally located groups of nerve cells whose fibres ramify to all regions of the organism, either as receptors or associated with muscles or other effector organs. An aggregation of nerve cells is called a GANGLION. In animal forms that are not segmental there is no regularity in the position of the ganglia in the different types. For example, in the starfish many nerve cells are located among the ectodermal cells; others form nerve trunks in each arm, which are in communication with a central nerve ring encircling the mouth (Fig. 142). In a clam the nervous system consists of three pairs of ganglia, one pair near the œsophagus, one in the foot, and one just under the large posterior muscle that pulls the shell shut (Fig. 143). Pairs are connected with each other, and with the body tissues by fibres. In the segmental invertebrates, Annelida and Arthropoda, the ganglia occur in pairs, one pair in the ventral body wall of each segment, except in the most anterior segments, in which the ganglia are dorsal. In the earthworm, for instance (Fig. 144), there is a pair of ganglia dorsal to the pharyngeal cavity. Nerve tracts connect these ganglia with a pair just under the pharynx. The sub-pharyngeal ganglia are the most anterior pair of a chain of segmental ganglia that are all connected with each other and with the body tissues by nerve fibres. In addition, giant fibres traverse the entire chain of ganglia. It is thought that these giant fibres control the rapid contractions of the whole animal,

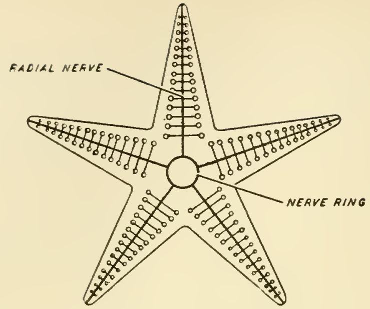


FIG. 142. ECHINODERMATA

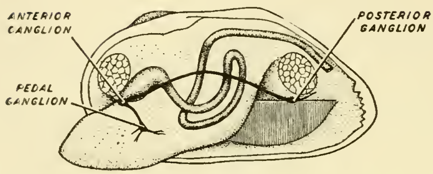


FIG. 143. MOLLUSCA

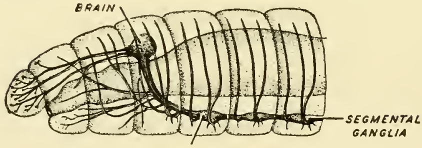


FIG. 144 ANNELIDA

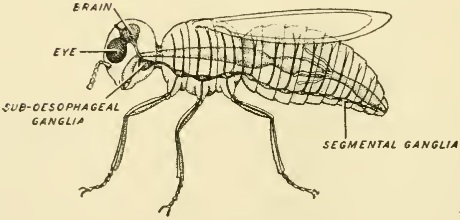


FIG. 145. ARTHROPODA

FIGS. 142, 143, 144, and 145.—Some types of invertebrate nervous systems. Diagrammatic. Note the similarity between the systems of the annelid and the arthropod.

while the fibres of the segmental ganglia control the slower crawling movements.

A similar arrangement consisting of a ventral chain of paired segmental ganglia, with larger ganglia dorsal to the pharynx, constitutes the nervous system of the Arthropoda (Fig. 145). The ganglia above the pharynx are relatively larger and more complex than in the Annelida; fibres from these ganglia communicate with the antennæ and eyes, thus establishing an elaborate sensory system. The dorsal anterior ganglia in both annelids and arthropods constitute primitive brains.

The Vertebrate Nervous System. In vertebrates the nervous systems all represent modifications of a single basic plan. The vertebrate nerve plan may be divided for study into three rather distinct systems, the CENTRAL, consisting of the BRAIN and SPINAL CORD, the PERIPHERAL, consisting of the nerves from the central system that extend to the muscles and sense organs, and the SYMPATHETIC, or autonomic system, consisting of ganglia and nerves that are more or less independent of the central and peripheral systems. The sympathetic system is concerned in the automatic control of the visceral organs, the circulatory system, and various other functions, glands for instance, that are not directly under control of the central system.

The central and peripheral systems in reality constitute an operating unit and are the elements that receive, transmit, and effect responses to stimuli received from the environment.

Developmental Origin of the Vertebrate Nervous System. In connection with the description of the ectoderm of cœlenterates (p. 132) it was stated that the ectoderm of all animals is the layer of origin of all purely nervous elements of the metazoon body. To accomplish this so that all the deeper tissues of the complex adult vertebrate body are in contact with nerve fibres, requires an invasion by that portion of the ectoderm destined to form nerves, at some time during development. This is brought about early in

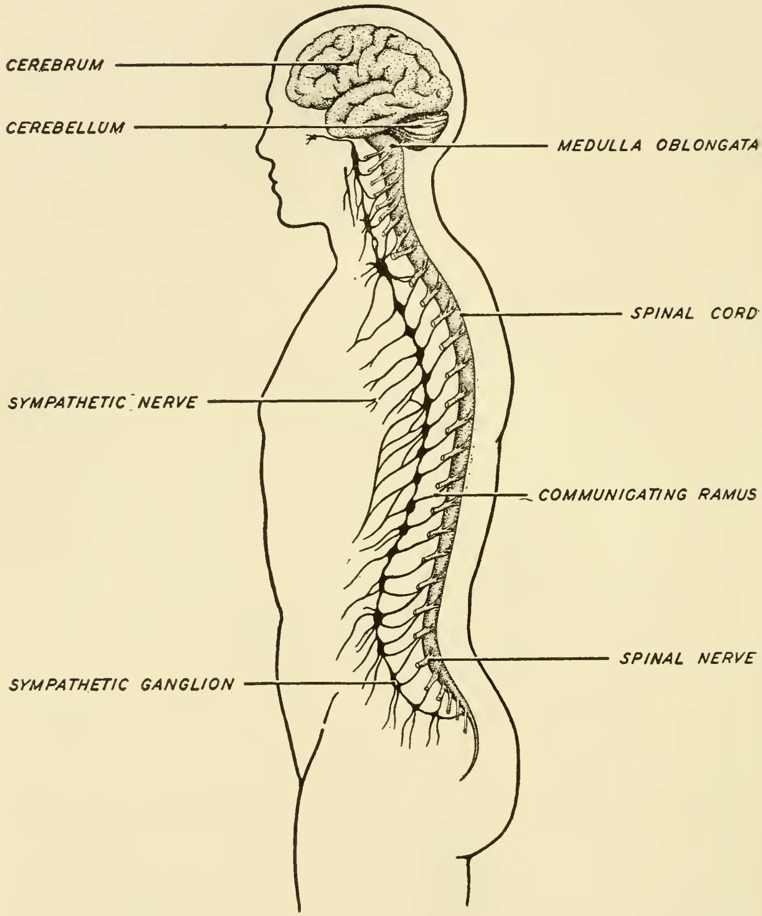


FIG. 146.—The relative positions of the central and sympathetic nervous systems in the human body. The distance between the two systems has been somewhat exaggerated in order that their forms might be more distinctly shown.

the development of the vertebrate embryo by the sinking inward of a plate of ectoderm along the dorsal mid-line of the newly established body. This plate soon becomes a distinct groove, the margins of which approach each other and finally fuse together, thus forming a tube of ectoderm embedded in the surrounding mesoderm (Fig. 147). So the NEURAL TUBE is established early in the life of the individual; by differentiation of various regions of this tube the central nervous system is set up. Dorsal and lateral to the primitive

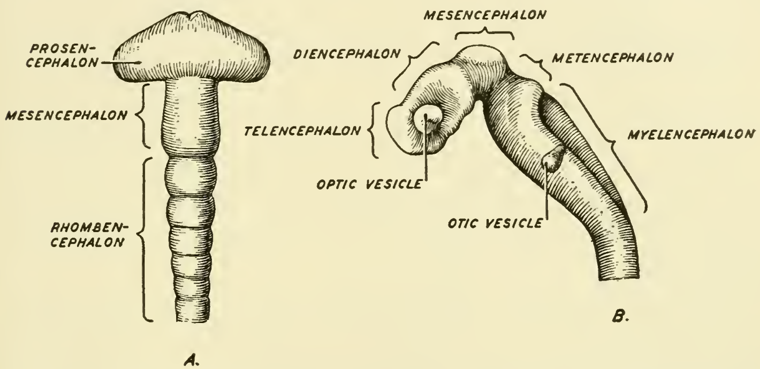


FIG. 147.—Two early stages in the embryonic development of a vertebrate brain. In *A* the view is dorsal and the brain consists essentially of three parts. In *B* the view is lateral and the differentiation of five parts is clear.

neural tube there remain masses of ectodermal cells that are not incorporated into the tubular central nervous system but are destined to form ganglia associated with the neural tube and the ganglia of the sympathetic system. These masses of potentially nervous ectodermal cells are spoken of as the NEURAL CREST.

The Central Nervous System. Essentially then, the central nervous system of the vertebrates is a tube situated dorsal to the cœlom, the walls of which are composed of nerve cells and associated connective tissues. During development in all vertebrates the anterior region of the tube, by unequal growth, dilates to form three primary expansions, the fore-, mid-, and hind-brains, or, more properly, the PROSENCEPHALON, MESENCEPHALON, and RHOMBENCEPHALON. Subsequently these divisions are further modified (Fig. 147). The prosencephalon forms anteriorly and dorsally the TELENCEPHALON from which the CEREBRUM of the adult arises, and the DIENCEPHALON, which is the origin of the RETINA of the eye and of the OPTIC NERVE, of a portion of the PITUITARY gland, and other structures. The mesencephalon does not divide; it gives rise to the OPTIC LOBES of the adult brain and to various tracts and paths of communication between the fore- and hind-brains. The rhombencephalon is the origin of two regions, the METENCEPHALON, from which the adult CEREBELLUM arises, and the MYELENCEPHALON, which becomes the MEDULLA OBLONGATA of the adult. These five portions vary as to their relative size and degree of development in various vertebrates, but all adult brains are derived from these basic parts. The relative development of the parts in the brains of the five classes of vertebrates is shown in the accompanying figure (Fig. 148).

The remainder of the neural tube posterior to the myelencephalon becomes the SPINAL CORD of the adult. In the wall and floor of the primitive tube the cells increase in number; the outside diameter of the tube increases and at the same time the walls encroach upon the opening of the tube so that the inside diameter decreases. The tubular character of the spinal cord is never completely obliterated, however; a section through the adult human spinal cord shows a small central canal still present.

The potential nerve cells within the wall of the tube develop axones and dendrites that traverse the cord anteriorly and posteriorly to establish the nerve tracts that characterize its adult anatomy. Some cells in the ventral region of the cord send out axones that extend to the body muscles and constitute the motor elements of the peripheral nervous system.

The Sympathetic Nervous System (Fig. 146). For convenience here the sympathetic system is next to be considered. Dur-

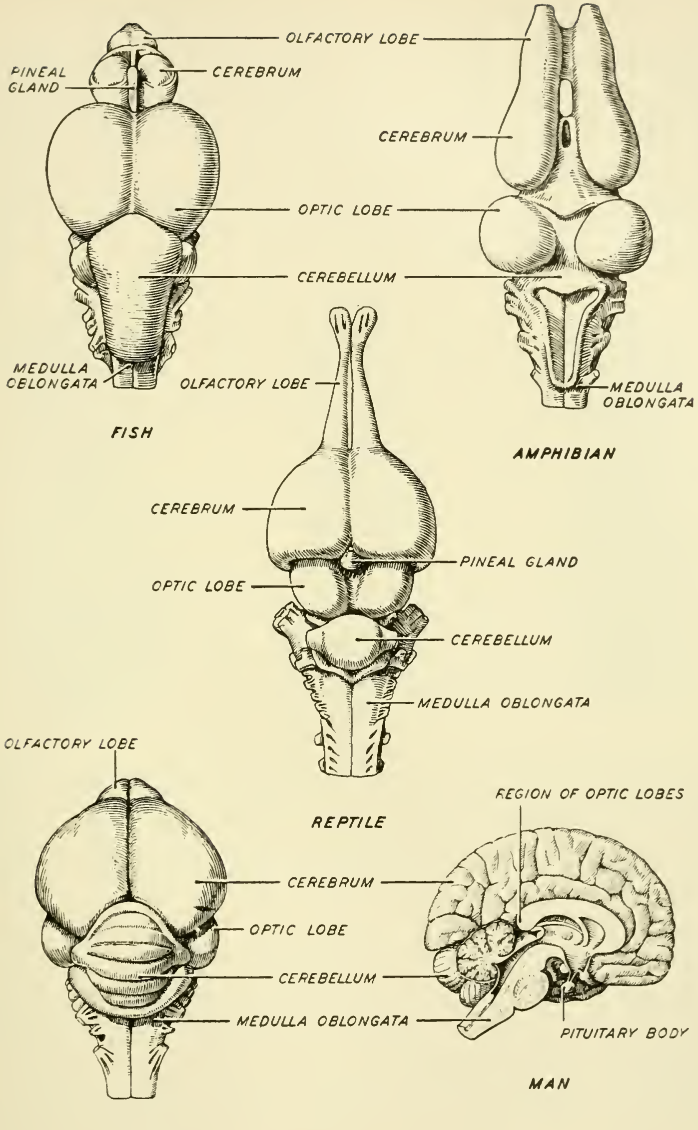


FIG. 148.—Comparison of vertebrate brains. Dorsal views, except that of the human brain, which has been sectioned longitudinally. Compare the relative size of the various parts throughout the series.

ing embryonic development some of the cells of the neural crest migrate ventrally and take up permanent position in the viscera and elsewhere to become the ganglia of the sympathetic system. The most conspicuous sympathetic ganglia form a chain in the dorsal wall of the body, just ventral to the vertebral column. Fibres from these ganglia ramify to the various organs and tissues, estab-

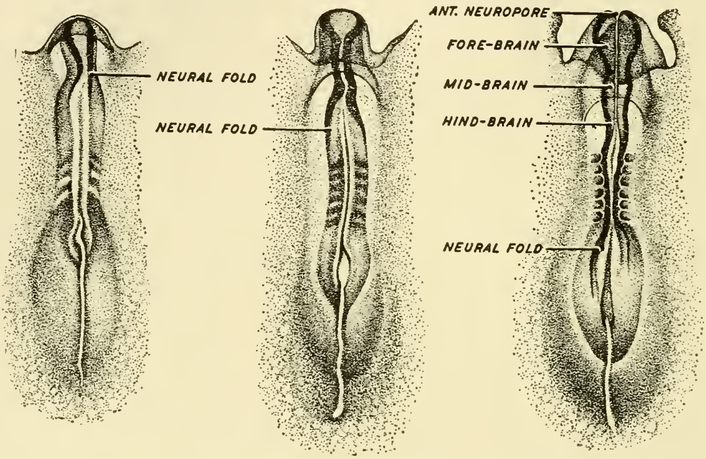


FIG. 149.—Three stages in the early development of the spinal cord and brain as illustrated by the development of the chick. The egg was opened and the early chick embryos examined under a low power of the microscope. In the first figure on the left the head bud is just forming; in the last figure the three primitive divisions of the brain are indicated. The neural tube, the primordium of the adult spinal cord, has not yet closed posteriorly. A thin line visible along the mid-line in each figure represents the notochord, which disappears later. (After Duval.)

lishing a most surprisingly complete network of sympathetic fibres associated with glands, walls of blood vessels, and tissues in general. Other fibres grow back, so to speak, to establish connections with the central nervous system. By means of these returning rami or fibres the sympathetic and central systems are in communication so that a disturbance in the central system may affect the sympathetic and the organs which it reaches, and stimuli from the viscera may become recognized by the central system. Other ectodermal cells from the neural crest also migrate elsewhere and become associated with mesodermal elements to form endocrine glands; for example, the adrenal glands are in part derived from such cells.

Spinal Nerves (Figs. 141, 146). But the greater number of the cells that are in the embryonic neural crest on both sides of the newly organized neural tube remain in their original position with reference to the tube and form a series of ganglia on either side and slightly lateral to the dorsal region of the spinal cord. These ganglia correspond to the primitive segments and so in the adult human are vestiges of primitive segmentation. Nerve fibres, that is, the dendrites, grow out from the nerve cells in these ganglia and innervate the surface and other regions of the vertebrate body. All the endings of these fibres are associated with organs for the reception of stimuli; hence the spinal ganglia are sensory in function. Other fibres, axones, grow centrally from the ganglia and penetrate the dorsal region of the spinal cord to establish connections with the nerve tracts within. Thus a continuous communication is set up between the sensory nerve endings on the surface of the body and the spinal cord and brain (Fig. 141).

The motor fibres growing out from the cells of the ventral region of the spinal cord on either side become associated with the sensory fibres growing out from the dorsal ganglia to form nerve trunks. The ventral fibres all carry outward bound impulses and as they branch off from the nerve trunks they pass to muscles. Thus a spinal nerve is composed of sensory and motor fibres, associated with the communicating fibres from the sympathetic system.

Reflex Arc. Because of the numerous communications existing between sensory and motor fibres within the wall of the spinal cord an impulse may be received and traverse a sensory fibre, enter the cord, be transferred to a motor fibre, and finally activate a set of muscles without passing up the cord through the complex association of nerve fibres that make up even the most simple of vertebrate brains. A response to a stimulus that follows such an abbreviated path is known as a REFLEX ACT and the path over which it travels is termed a REFLEX ARC (Fig. 150).

Cranial Nerves. A number of nerves enter directly into the vertebrate brain without any association with the spinal cord. These are termed the CRANIAL NERVES. There are ten pairs in fishes

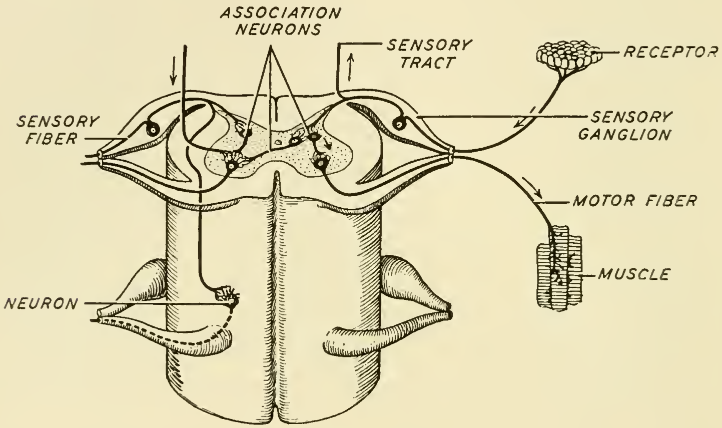


FIG. 150.—Scheme of a reflex arc. (After Kühn: *Grundriss der allgemeinen Zoologie.* Georg Theime, Leipzig.)

and Amphibia and twelve pairs in reptiles, birds and mammals. The fibres that compose them are outgrowths from the nerve cells of the brain and nearby ganglia, but in the case of the optic and of the olfactory nerves the developmental origin is from specialized regions of the fore-brain that during development grow out to become parts of the nares and the eye. The cranial nerves are not segmental structures. Some are purely sensory, some are purely motor, and some are made up of both sensory and motor fibres. A tabulation is given showing the name of each cranial nerve, its region of connection with the brain, its distribution and function in Man.

Cranial Nerves

Name	Origin on Brain	Terminus	Function
Olfactory	Cerebral hemispheres	Membrane of internal nares	Sense of smell
Optic	Floor of diencephalon	Retina of eye	Sense of sight
Oculo-motor	Base of mid-brain	Eye muscles	Motor. Movement of eyeballs (p. 226)
Trochlearis	Anterior margin of hind-brain	Superior oblique eye muscle	Motor. Movement of eyeballs (p. 226)
Trigeminus	Medulla oblongata	(1st branch) Integument of forehead, eyelids, lachrymal glands	Sensory
		(2nd branch) Upper jaw, upper teeth, roof of mouth, etc.	Sensory
		(3rd branch) Masticatory muscles, lower jaw and teeth, lower lip	Motor and sensory
Abducens	Medulla oblongata	Lateral eye muscles	Motor. Movement of eyeballs (p. 226)
Facial	Medulla oblongata	Facial muscles	Motor
Auditory	Medulla oblongata	Organ of equilibrium and organ of sound reception in ear	Sensory
Glossopharyngeal	Medulla oblongata	Pharynx, part of tongue, parotid gland	Sensory and motor
Vagus	Medulla oblongata	Pharynx, trachea, œsophagus, viscera	Sensory and motor
Spinal accessory	Medulla oblongata	Muscles of neck, viscera	Sensory and motor
Hypoglossal	Medulla oblongata	Muscles of tongue	Motor

Receptors: Chemical Senses. While a nerve may be stimulated by artificial means at any place along its course, for the reception of outside stimuli the sensory nerves of the animal body end in specialized sense or receptor organs. In general, in the higher animals these receptors are grouped into five main types and their responses are known as the Special Senses. The sense of smell, olfactory sense, and the sense of taste, gustatory sense, are considered together as chemical senses, since both are activated by chemicals, in the air, water, or materials entering the mouth. The nerve endings that receive the stimuli recognized as smell and as taste are equipped with specialized structures; those of smell are constituted of a single sensory cell (Fig. 151); those of taste are multicellular and are termed TASTE BUDS (Fig. 152). The olfactory nerve endings are localized in areas of epithelium in the nasal pas-

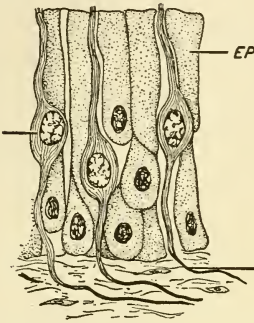


FIG. 151.—Olfactory nerve endings in the olfactory epithelium in the human nose. Diagrammatic.

sages. In many lower vertebrates and in many mammals the areas are prominently placed so that the tidal air as it enters the nares is in direct contact with these sense organs. In Man, however, the

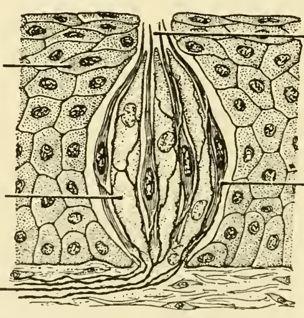


FIG. 152.—Diagram of a taste bud from the human mouth.

olfactory areas are in the base of folds or crypts so that in order for a stimulus to be set up, the chemical in the air must be penetrating or an effort be made by sniffing. The acuteness of the sense of smell in Man is much less than in many other vertebrates. The taste buds are located chiefly on the tongue in the human adult but in the very young they are also found elsewhere in the mouth.

Light Receptors. The reception of a stimulus by light presupposes the presence in the animal of some sort of substance that is light-sensitive, affected chemically by light rays. In certain Protozoa, for example euglena, the light-sensitive substance is localized in a visible spot, the STIGMA, seen as a pink body near the reservoir (Fig. 29). This spot must not be regarded as an eye similar to the

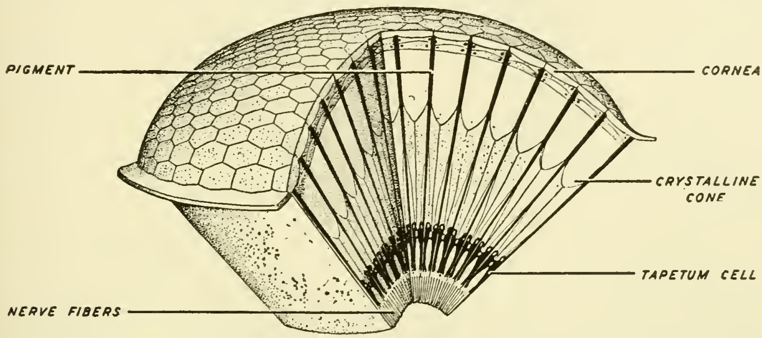


FIG. 153.—Diagram of the compound eye of an insect. (Partly after Kühn: *Grundriss der allgemeinen Zoologie*. Georg Theime, Leipzig.)

image-forming structures of higher animals, but merely as a region of light sensitivity. In the eyes of invertebrates the light-sensitive substances are located in association with the endings of nerves. In some forms structures occur that have the properties of convex lenses and converge light on these endings. In insects and other Arthropoda the eyes are compound, consisting of a considerable number of tubes shaped like inverted cones. In the apex of each cone is a nerve ending, with associated light-sensitive structures; the base of each cone contains a lens which serves to converge light rays on the apex (Fig. 153). It is said that this type of eye, by reason of the mosaic image which it forms, is peculiarly suited to the detection of movement.

The Eye of Vertebrates. The essential features of the vertebrate eye are: A spherical cup at the base of which are the nerve

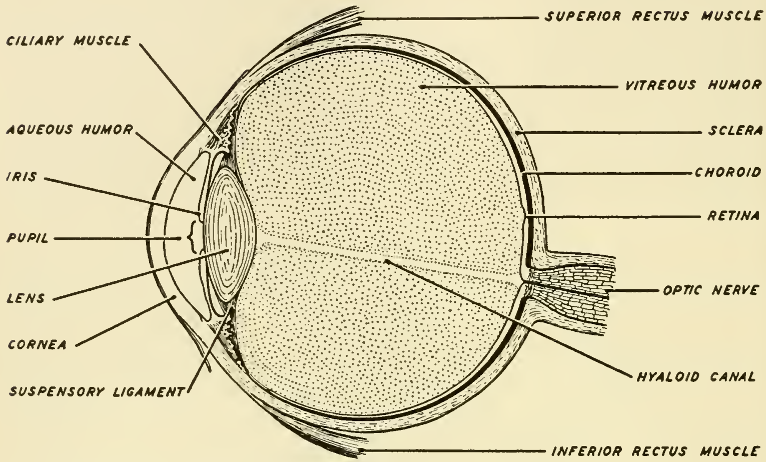


FIG. 154.—Diagram of a longitudinal section through the human eye.

endings and the receptors with the light-sensitive substances that, when affected by light, activate the nerves; a lens suspended in front of the nerve endings in such a way as to converge the rays of light and to form an image on the sensitive area of RETINA. As the source of light is moved farther away or nearer to the eye, the lens is accommodated to the changing distance. In the eye of the fish this is accomplished by means of a mechanism that moves the lens forward or backward, as one focuses the lens of a camera.

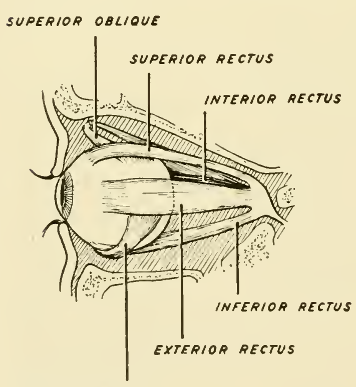


FIG. 155.—The arrangement of muscles which operate the human eye.

The mammalian eye (Fig. 154) accommodates to near and far vision by changes in the curvature of the lens. It is thought that the lens substance is quite elastic and tends to assume the shape of a sphere. It is suspended by a ligament and is enclosed in a capsule of transparent tissue. The lens ligament is anchored to the crest of the ciliary muscle, the fibres of which are chiefly at right angles to the pull exerted by the ligament (Fig. 156). When an object is brought near the eye, the ciliary muscles contract, thus shortening the base attachment of the lens ligament. This allows the ligament to loosen,

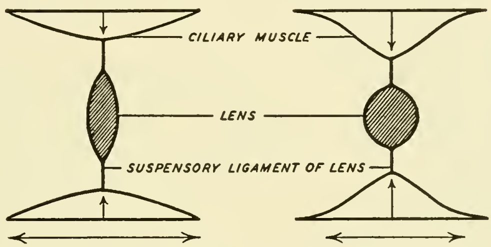


Fig. 156.—Diagram to illustrate the theory of accommodation of the human eye to changes in distance. In the first figure the eye is at rest and is said to be focused at infinity. When vision is accommodated to observe a near object the ciliary muscles contract. This lessens the tension on the suspensory ligament of the lens. Then the lens, being elastic, tends to become spherical. It will be noted that in this state the ciliary muscles are expending energy; hence prolonged close vision causes fatigue.

since the crest of the ciliary body is thereby raised. The relief of tension on the ligament and lens capsule allows the elastic lens to assume a more spherical shape by taking up the slack in the ligament. Thus the curvature of the lens is increased. At rest the ciliary muscles are relaxed but by reason of their elasticity and that of associated tissues there is a draw exerted on the lens capsule which flattens the lens. Thus the resting eye is set for far vision, that is, focused at infinity. The mechanism of accommodation is very sensitive and constantly in action during waking hours.

Defects in Vision. The most common defects in human vision are near-sightedness, MYOPIA, far-sightedness, PRESBYOPIA, and ASTIG-

MATISM. Near-sightedness may be the effect of an abnormally shaped eyeball, the lens being thus advanced too far forward. Or, as is frequently the case, the tension on the lens is not sufficient to reduce the curvature for far vision. Presbyopia, or old-, or far-sightedness is said to be the effect of decreased elasticity of the lens so that no matter how vigorously the ciliary muscles may contract the lens does not assume a correspondingly greater curvature. This disorder commonly occurs in Man after the age of forty, and as old age comes on the whole mechanism of accommodation may fail, although acuity of vision may not be seriously impaired. Astigmatism is caused by imperfections in the curvature of the lens so that all the rays of light are not converged on the retina. The result is that the image is blurred in some regions, the regions corresponding to the defective regions of the lens. For near-sightedness the correction is made by the use of suitable concave lenses; for far-sightedness convex lenses are employed; for astigmatism lenses are so ground that they compensate for the imperfections in the lens of the eye.

A complex mechanism, consisting of two sets of muscles, opens and closes the aperture of entrance of light, thus regulating the amount of light that reaches the lens. This IRIS DIAPHRAGM is extremely sensitive to changes in the intensity of light and is constantly responding to the changing shadows and lights of the environment. The opening in the iris diaphragm (Fig. 154), the PUPIL, has different shapes in different mammals. In the cat it forms a perpendicular slit; in cattle it is a transverse oval; in Man it is circular.

The mammalian eye is moved about in its socket by six muscles, attached to the heavy SCLEROTIC COAT of the eyeball and anchored to the bony walls of the socket (Fig. 155). They are called the RECTI MUSCLES; one is above, one below, one internal, one external, one obliquely set above, and one lower oblique. The perfect correlation between these muscles accounts for the fact that the normal eyes move synchronously in the socket and that both eyes are directed at the object of vision. If there is an unbalance between the members of any pair of these muscles, that eye will be out of symmetry with its fellow, either a crossed or a wall-eye. Correction may be made by the use of lenses, or by operation to correct the difference in tension between the muscles.

The Ear of Vertebrates. The sense of hearing is essentially a sensitivity to vibrations of certain frequencies. Many of the simple animals are sensitive to sound frequencies, but whether their re-

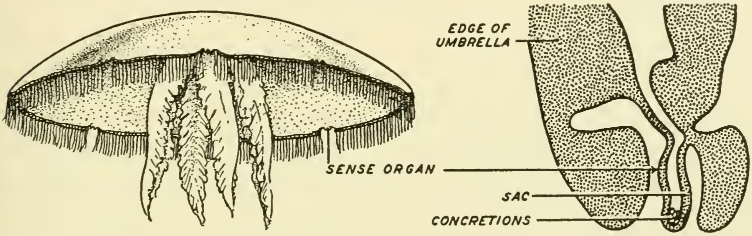


FIG. 157.—Statocysts, the balancing organs in a jelly fish. (After Parker and Haswell: *Textbook of Zoology,* published by The Macmillan Company.)

sponse is due to reception of mechanical vibrations or to sounds as distinct from mechanical effects is difficult to determine. Special organs for sound reception find their highest development among the higher vertebrates. The essentials of the vertebrate ear are: A membrane under such tension that it vibrates with the vibrations of the air or water of the environment; a mechanism consisting of a bone or a series of bones which transfers these vibrations to an organ that analyzes the vibrations so that they activate the appropriate nerve ending. The organ of hearing is associated with an organ which detects changes in position by the dislocation of fluids and small concretions; when the animal changes position these stimulate appropriate nerve endings. Similar organs that function in maintaining position and equilibrium occur in invertebrates (Figs. 157 and 158).

The mammalian ear (Fig. 159) consists of an outer canal surrounded by a more or less funnel-shaped structure of cartilage and

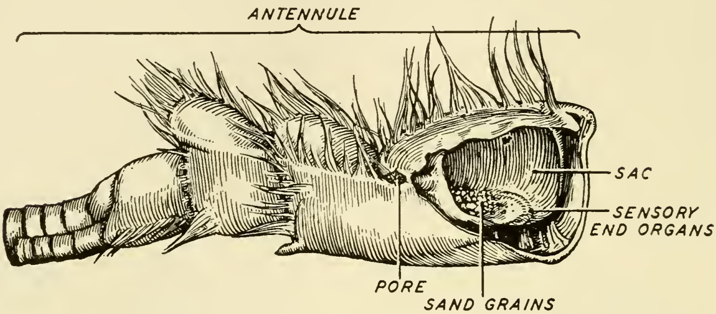


FIG. 158.—The balancing organs of a lobster.

integument. At the base of this canal is a membrane, the TYMPANUM, stretched over a TYMPANIC CAVITY that serves as a resonating

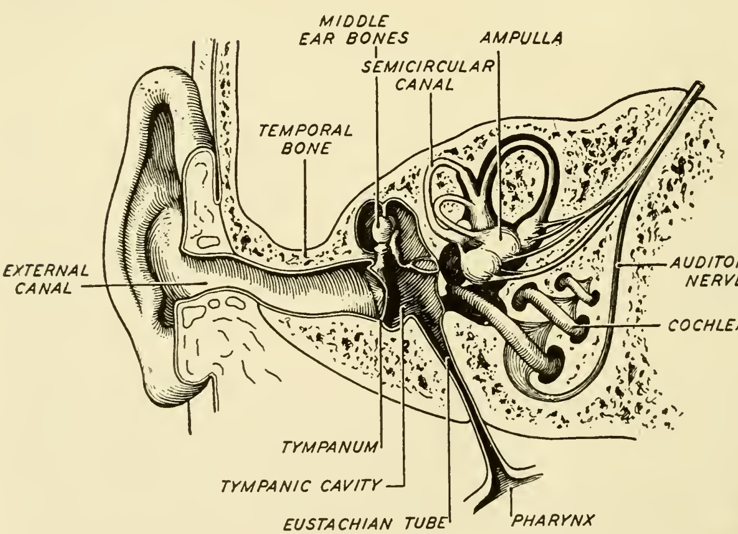


FIG. 159.—Diagram of the human ear. (After Haggard: *The Science of Health and Disease,* published by Harper and Brothers; original by Tschermak.)

cavity. The tympanic cavity is connected with the oral cavity by means of the EUSTACHIAN TUBE, the connection serving to maintain equal air pressure on each side of the tympanum. From the tympanum inward across the tympanic cavity is a chain of bones, named respectively the MALLEUS, INCUS, and STAPES. These bones are so set together that they transfer the vibrations of the tympanic membrane with increased intensity but without change in fre-

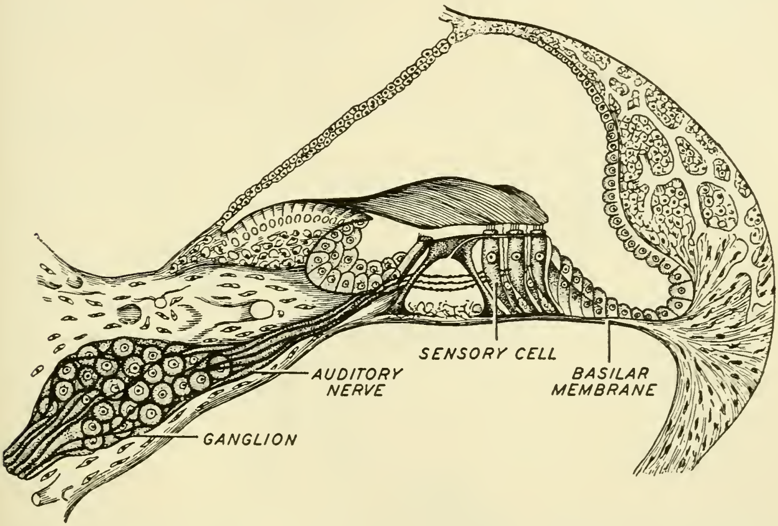


FIG. 160.—Scheme of the organ of Corti, the end organ of the human ear sensitive to sound. (After Wiedersheim.)

quency, to a window. Behind this window, the FENESTRA OVALE, is a liquid, the PERILYMPH. This liquid efficiently transfers the vibrations to another liquid, called the ENDOLYMPH, which is enclosed in a membranous spiral structure termed the COCHLEA. In the membranous spiral cochlea is a shelf that bears the distributed ends of the auditory nerve. This shelf with associated structures is called the ORGAN OF CORTI (Fig. 160); it is generally regarded as an analyzing organ, so constructed that certain nerve endings are stimulated by certain definite frequencies. The length and number of nerve endings on the organ of Corti provide for the recognition of a wide range of sound frequencies.

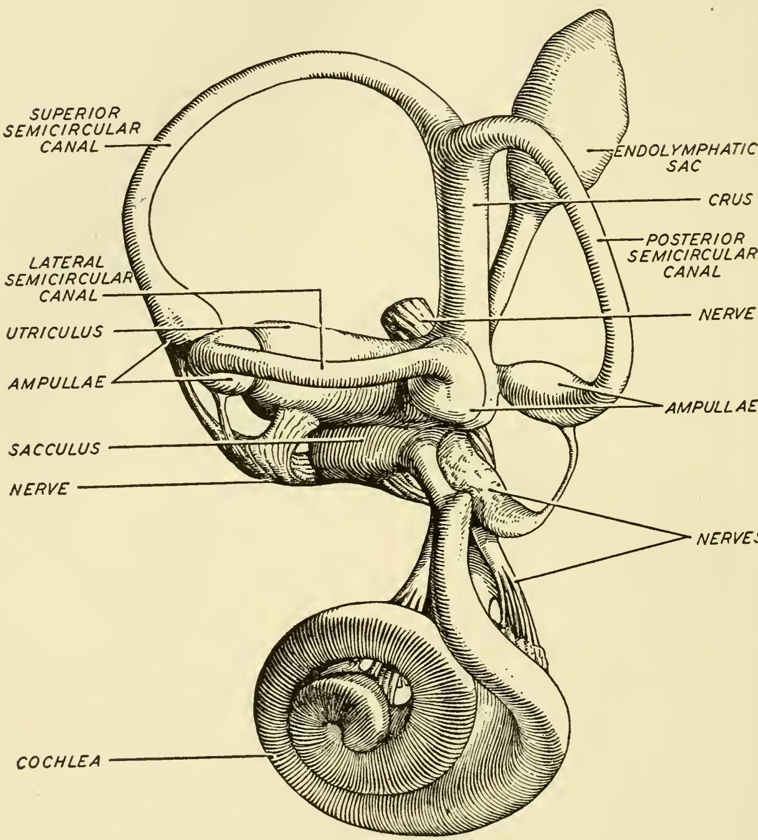


FIG. 161.—The membranous labyrinth of the human ear.

The membranous cochlea containing the organ of Corti is continuous with three membranous tubes roughly arranged as horizontal, transverse, and perpendicular, called the SEMICIRCULAR canals. When the animal is turned about the endolymph within the canals by reason of its liquid nature and inertia exerts pressure in certain bulbs or ampullæ (Fig. 161). The ampullæ are fitted with nerve endings that give the sense of change of position when stimulated by the pressure of the endolymph. In the ampullæ are small organic dense bodies known as otoliths. When the position of the animal with respect to gravity is changed, the otoliths are correspondingly dislocated and thus register their change of position by stimulating nerve endings; from this mechanism arises the senses of orientation and balance. The whole auditory and orientation apparatus consists therefore of three regions; the outer ear consisting of the external ear and external canal, the middle ear consisting of the tympanum, tympanic cavity, ear bones, and Eustachian tube, and the inner ear consisting of the membranous tubes and structures of the cochlea and the semicircular canals, embedded in corresponding bony cavities.

The nerve endings that give rise to sensations of temperature, pain, pressure, and so on, are fairly generally distributed over the mammalian body. A detailed account of their structure and functioning is beyond the purposes of this discussion. Very much less is known concerning their occurrence and distribution in invertebrate forms.

The Nerve Impulse. The excitation and transmission of the impulse in a nerve fibre is a remarkable phenomenon and has attracted a great deal of inquiry. Just what is the nature of the disturbance set up when a nerve is stimulated, and just what is the impulse that is propagated along the fibre, with the extraordinary power of setting in motion the contraction of a muscle or initiating activity in a gland, or inducing other effector responses? A final answer cannot be given now, but as new facts are discovered the characteristics they reveal serve to indicate something of the physical and chemical nature of the process.

Under the most simple conditions the first immediate effect of a stimulus upon a cell is electrochemical in nature. Let us imagine a cylindrically shaped cell that is inactive (Fig. 162). Its boundary, as we have seen, is a semi-permeable membrane that permits the passage of some molecules and ions but holds back others. It is known that the boundary of such a cell allows positive ions to escape from the underlying cytoplasm but does not allow negative ions to pass out. Due to the electrostatic attraction between opposite charges, the positive ions cannot leave the outer surface of the membrane, being held back by the attraction of the negatives that cannot escape through the boundary. The cell boundary is therefore elec-

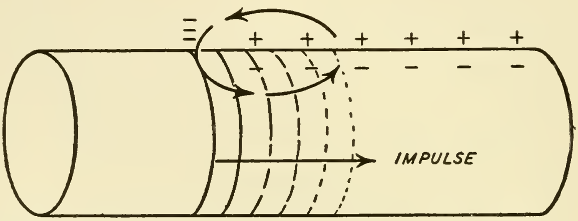


Fig. 162.—Scheme to represent an interpretation of the nerve impulse. (Slightly modified, after Gerard.)

trically polarized, bearing an outer positive charge and an inner negative charge, so long as the cell is undisturbed. If a stimulating agent is brought into contact with the cell boundary, its permeability to negative ions is increased at the point stimulated and they escape. The result of the stimulus is to increase the number of negative ions at the point of contact and thus to set up a potential difference between that point and adjacent regions of the membrane, which are still positively charged (Fig. 162). Whenever two regions with different electrical potentials are connected by an element that will admit of electrical change, then a current flows from one to the other. In the cell boundary, the electrical disturbance at the point of stimulation causes a re-arrangement of the electrical conditions elsewhere on the surface of the cell; thus the excitation is responsible for some sort of transmission.

But the nerve impulse that traverses a nerve fibre appears to be more complicated than a redistribution of electrical charges at the boundary of the fibre. According to present views the propagation of the impulse is conditioned upon both electrical and chemical changes in the boundary of the fibre. The electrical changes are regarded as essentially a sweep of depolarization of the membrane, as indicated in the preceding paragraph. The metabolic changes are thought to be oxidative chemical reactions initiated in the substances of the fibre surface by the changes in its electrical condition. This double nature of the impulse is revealed by its physiological characteristics; for purposes of illustration we may list the more important ones here:

Characteristics of the Nerve Impulse. A stimulated nerve gives off more carbon dioxide and consumes more oxygen than a resting nerve. Moreover, the impulse causes a slight rise in temperature, somewhat less than one ten-millionth of a degree. These facts show that oxidative metabolism is in some way associated with the impulse. Further evidence appears in the fact that in the absence of oxygen the nerve soon loses its ability to transmit stimuli.

The speed at which the impulse travels varies between different types of animals and between different nerves in the same animal. In human nerves the maximum rate of propagation reaches 125 meters per second. Obviously the nerve impulse is not an electrical current in the ordinary sense, for the speed of electricity is approximately 186,000 miles per second.

The speed of the impulse varies with the temperature of the nerve fibre in much the same way that temperature influences chemical reactions. Moreover, if the fibre is crushed, the impulse will not pass the broken region, even though the crushing be done by tying the nerve with a copper or other metallic wire. Here again is evidence of the metabolic nature of the impulse and of its dependence on the peculiar structure of the nerve, not merely an electrical conductor.

The impulse is accompanied by a wave of electrical negativity, measurable by a galvanometer set in circuit between the passing impulse and a resting portion of the nerve. This fact reveals the changing electrical conditions of the boundary as the excitation is propagated along the fibre. That the impulse is primarily a phenomenon of the surface of the fibre is shown by the fact that the speed of the impulse is proportional to the surface and not to the volume of the fibre.

A nerve is either totally stimulated, or else does not react at all. This characteristic is known as the All-or-None Law. Moreover, a succession of stimuli, each too weak to set up a response, will, if applied in rapid succession, initiate an impulse. These characteristics are regarded as evidence that the excitation at the point the impulse is initiated must set up a difference of potential of a certain value before the excitation is propagated, but once that value is reached, the entire mechanism is totally engaged. A nerve fibre will transmit stimuli in either direction, but in the living animal the functioning nerve tracts will transmit stimuli in one direction only. The single direction transmission in a reflex arc is known to be due to the properties of the synapses between the axones of one nerve and the dendrites of the next. The synapse may then be compared with a one-way valve. The mechanism of the synapse is still elusive; little is known of its nature.

Anæsthesia. Since the middle of the last century the relief of pain has been accomplished by the administration of certain anæsthetic agents. The subject of anæsthesia is so important from both the theoretical and practical points of view that it merits discussion here. Anæsthesia may be defined as a reversible decrease of irritability. It may be accomplished by a wide variety of agents and conditions, fat solvents such as ether, chloroform, and the alcohols, water-solvent substances, as chloral and magnesium salts, alkaloids such as the derivatives of opium, low temperature, and other conditions. An ideal anæsthetic is one that produces a complete loss of irritability from which recovery is prompt and without injury or poisonous effect. No perfect anæsthetic has yet been devised, but progress is being made; modern Chemistry has lessened the injurious action of anæsthetics without impairing anæsthetic qualities.

The discovery of the perfect anæsthetic awaits the complete solution of the problems of the physico-chemical nature of excitation and transmission. Present views are that the action of the anæsthetics now employed is to stabilize the surface membrane of the nerve fibre so that the electrical and metabolic phenomena that constitute excitation and transmission are prevented.

If we employ as an anæsthetic some given substance, for instance ether, on a series of animals ranging from Protozoa to mammals, it is found that in general the animals lowest in the scale are least readily anæsthetized. Thus not only are the nervous mechanisms of the higher animals structurally more complicated and efficient but also their properties of excitation and transmission are more highly refined, more sensitive to environmental conditions and more readily extinguished by anæsthetics.

A clinical terminology of anæsthesia that is generally employed has the virtue of commonly accepted usage and accuracy in a broad sense, but may be misleading unless the facts are understood. Thus in the case of a major operation the patient is given what is called a general anæsthetic. But the actual effect of such an anæsthetic is merely the anæsthesia of certain local regions of the brain. Should this local anæsthesia extend to complete and general anæsthesia of the brain, as sometimes accidentally happens, the centres that control respiration and heart beat are inactivated. So a clinical general anæsthesia is in reality a local anæsthesia of the regions of consciousness in the brain. On the other hand, when in minor operations a so-called local anæsthetic is used, the effect is a general anæsthesia of all tissues within the region of its diffusion. Thus it is local only in the sense that its effect is limited as to region and not as to tissues affected.

Neuroid Transmission. The phenomenon of excitation-transmission takes place in more than one type of tissue. The more familiar and the more striking effects are those involving the nervous mechanism, which is highly organized, and, so far as known, has no other function. Less familiar are the correlative influences transmitted by other tissues; they are less prominent but none the less important. Transmission over tissues other than nerves has been called NEUROID TRANSMISSION. Several examples will serve to illustrate its rôle in unifying the organism.

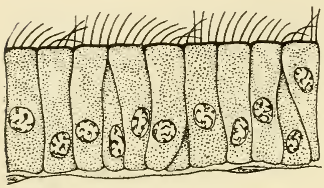


FIG. 163.—Diagram showing the passage of coordinated waves of ciliary beat along a ciliated epithelial layer.

The lining of the respiratory passages of air-breathing vertebrates is composed of a layer of epithelial cells, the exposed surfaces of which are ciliated. The cilia all beat toward the nares, thus assuring an outward flow of the liquid that

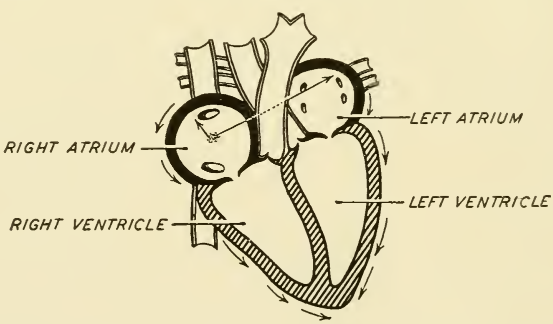


FIG. 164.—Diagram to show the order of contraction in the beat of the human heart. The region of the right atrium in which the beat is initiated is the homologue of the sinus venosus of the hearts of lower vertebrates.

moistens the passages. This ciliary beat is a coordinated effort but the ciliated cells have no direct connections with the nervous system. It is generally thought that the coordination of beat is effected by the cell-to-cell contact throughout the epithelium (Fig. 163).

The beating of the vertebrate heart is effected by a harmonious contraction and relaxation of the muscle cells, the impulse traveling from cell to cell so that the order of contraction is first sinus

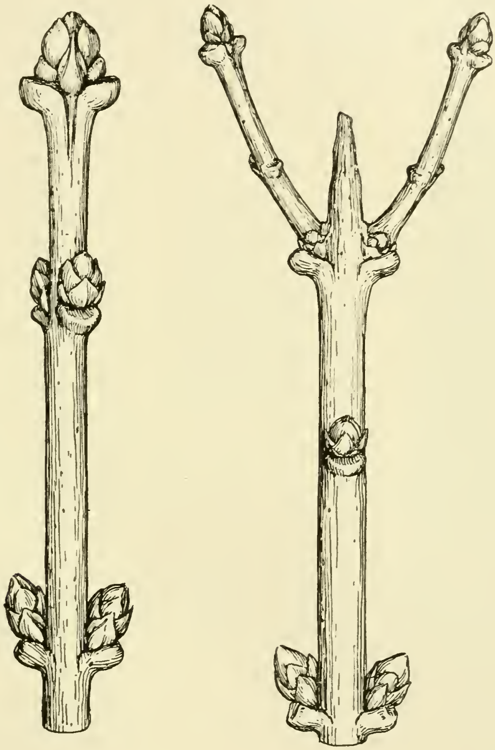


Fig. 165.—A, branch of the privet; B, axillary buds developing after removal of the terminal bud.

venosus (or its remnant, the sino-auricular node in the mammalian heart), then the atria, and lastly the ventricles (Fig. 164). Although the rate of heart beat is under control of the nerves, the beat itself does not originate by nerve stimuli. Coordinated beating occurs in the embryonic heart long before any nervous connections are established.

A somewhat different aspect of coordination through tissues other than nervous is shown during the development of the embryo. The form and pace of development appear to be regulated by influences arising in a series of dominant regions that exercise control over the fate of adjacent regions long before any nervous connections are established. A similar type of coordination is shown in the relation between the terminal bud and the lateral or axillary buds of a growing plant. Ordinarily the lateral buds are quiescent unless the terminal bud is pinched off or otherwise isolated. Then the lateral buds, freed from the dominance of the terminal bud, start developing (Fig. 165). The rôle played by this type of neuroid transmission, this action-at-a-distance, in regulating form during development constitutes one of the most important, and at the same time one of the least understood problems of Biology.

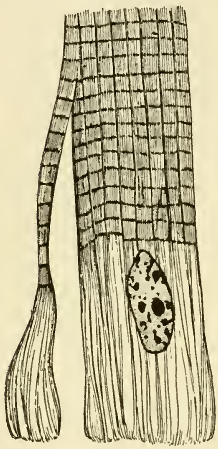
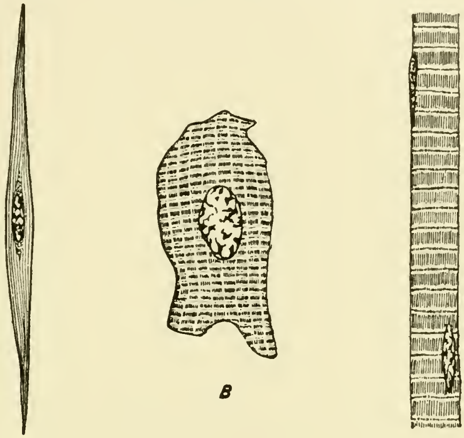


Fig. 166.—A muscle cell from the wing muscle of a wasp. Only a portion of the whole cell is shown and a strand has been separated to show its fibrous character. (After Jordan.)

Effectors: Muscles. The effector member of the series receptor-transmittor-effector may be a muscle or a gland. The most prominent effect of a stimulus is the response of muscles; glandular responses are usually more obscure. The most primitive of the contractile cells are the contractile elements in the ectoderm of the sponges and the epitheliomuscular cells in the ectoderm of the cœlenterates. But in general the muscle cells of tripoblastic animals are of mesodermal origin. One finds them functionally highly developed very low in the scale of animal complexity; a long neck clam withdraws its siphon with great rapidity; an oyster holds its shell shut with considerable firmness. The muscles (Fig. 166) of insects are considerably more powerful than those of vertebrates. They appear to be more gelatinous and are colorless as compared with the vertebrate muscle, but they are capable of great power and speed. We are told that if Man were equipped with muscles equivalent to those of the grasshopper he could jump many times as far as his best records; and that the



A C

Fig. 167.—Human plain, cardiac, and striated muscle cells. Diagrammatic. Compare the striated muscle cell with that of the insect muscle in Fig. 166. (Partly after Kühn: *Grundriss der allgemeinen Zoologie,* published by Georg Theime, Leipzig, and partly after Shäfer: *Essentials of Histology,* published by Longmans, Green and Company.)

wings of certain gnats beat 15,000 times a second. The high state of functional efficiency of muscles in lower forms is understandable, for it is as important for these animals to withdraw from danger or move from place to place as it is for vertebrates.

Vertebrate muscle cells are of three sorts, smooth cells forming the muscular elements of the digestive and reproductive systems and the walls of the arteries; cardiac muscle cells, confined to heart muscle; striated or striped muscle cells, forming the large muscles attached to the skeleton. The accompanying figures show the differences between these three types (Fig. 167). Muscles are also inaccurately classified as voluntary and involuntary, the striated muscles being regarded as voluntary and the smooth and cardiac muscles as involuntary. Since many striated muscles are not under voluntary control and since all may occasionally contract involuntarily, the classification is of limited value.

Energy and Fatigue in Muscles. The contraction of a muscle cell is essentially a change of shape, the long dimension being shortened and the diameter being increased. By the shortening of the long dimension work is done. This requires energy. The energy of muscle contraction is known to come from the breakdown of muscle sugar, GLYCOGEN, into lactic acid with the release of energy in the form of heat. It is known that with prolonged exercise and the reduction of the amount of carbohydrate available, proteins and fats may also furnish the energy. Some of the lactic acid that is produced (about one-fourth) is oxidized into water and carbon dioxide; the remainder is converted back to glycogen. The relation between the chemical events that occur in muscle contraction and the actual mechanical shortening of the cell has not yet been made clear. The lactic acid that is recovered as glycogen after the contraction is available for the energy of succeeding contractions. Recent work has indicated that the fatigue of a muscle is due to two factors, the accumulation of lactic acid in the cells and the disappearance of the glycogen.

Muscle Work Units. A striated muscle cell is a multinuclear, long, cylindrical fibre. Fibres are bound together by connective tissue as bundles and the bundles form the separate muscles. Muscles occur in antagonistic sets and work is done by the contraction of one set accompanied by the relaxation of the other. For example, the forearm is flexed by the contraction of the muscles on its anterior face accompanied by the relaxation of the muscles on the back of the arm; when the arm is extended the contracted muscles relax and the arm is pulled straight by the contraction of the muscles on the back of the arm. It is perfectly clear that such an arrangement of antagonistic muscles is the only practical one, for in the absence of an antagonistic muscle a joint once flexed could not be straightened again.

Glands. Glands respond to nerve impulses by forming and expelling secretions. In a broad sense all living cells secrete substances, but here we are confining our attention to those concerned in the activities of specialized glands. Glandular secretions cannot well be arranged in related groups, for they are most diverse, ranging from

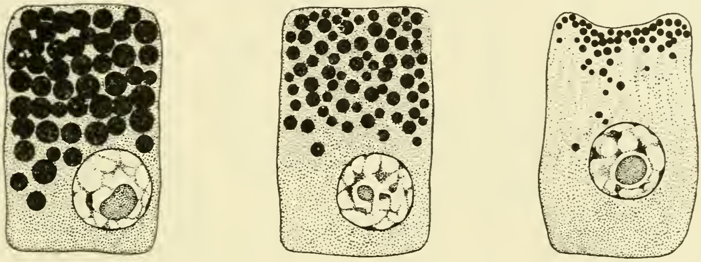


Fig. 168.—Fully charged, partially discharged, and almost completely discharged secretory cells in the pancreas of a toad. (After Child: *Senescence and Rejuvenescence*, published by the University of Chicago Press.)

such simple substances as hydrochloric acid to exceedingly complex organic molecules. It is not yet understood how a nerve impulse sets in motion the physical and chemical processes of glandular action. Secretory activity represents the expenditure of energy, for active glands absorb more oxygen than do resting glands. It is also known that electrical factors are involved, for an active gland is electro-negative to adjacent tissues. The secretions are apparently formed in connection with certain plastids in the cytoplasm; furthermore, resting glands often contain stored-up materials that are seen to disappear when the gland becomes active (Fig. 168). Some glands secrete constantly; others are active only during stimulation. The activity of the gland may be a response to a nerve impulse or to some chemical activator. For example, the salivary glands become active in response to nerve stimuli set up by foods or by the sight of foods; they may also be activated by chemicals, such as ether.

According to their structure, glands may be unicellular or multicellular (Fig. 169). Multicellular glands may be simple tubes with walls composed of gland cells, or compound tubular arrangements, or they may be simple sac-like or alveolar structures. Unicellular glands are quite commonly distributed in the animal body, in the

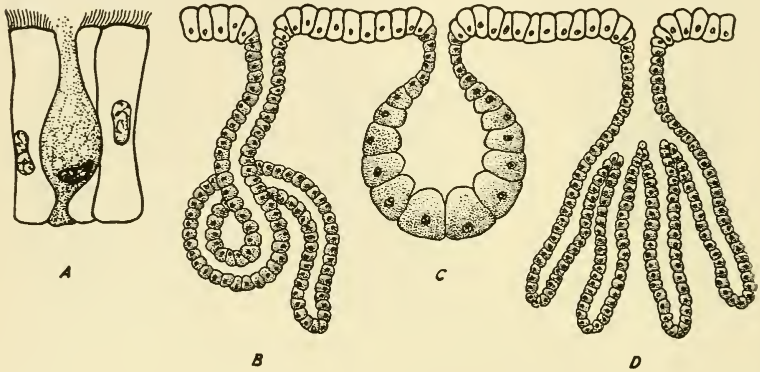


FIG. 169.—*A*, unicellular gland; *B*, *C*, and *D*, multicellular glands. *B*, simple tubular. Compare with sudiferous gland, Fig. 94. *C*, simple bulb; compare with sebaceous gland in Fig. 94; *D*, compound tubular; compare with Fig. 11. All are diagrammatic.

integument of many invertebrates, in the walls of the respiratory and digestive systems of vertebrates, and elsewhere.

According to the type of outlet, glands perform either internal or external secretion. Glands of internal secretion are known as endocrine glands; their functions have been discussed elsewhere (p. 204). Their products appear to pass into the appropriate blood capillaries by osmosis through the cell walls. The glands of external secretion (exocrine glands) pass their products to collecting ducts that lead to the surface of the body, or to some organ that is in communication with the external; for example, the sweat glands lead to the surface of the skin; the liver and pancreas deliver their products into the intestine. The question as to how such gland cells extract certain materials from the blood, form them into secretions and expel the secretions into the collecting duct is not wholly answered. In some glands, for example in the tubules of the kidney (p. 189), the secretion passes from a region of lower osmotic pressure within the tubule into the blood, which has a higher osmotic pressure. Likewise the gland cells of the salivary gland secrete water from the blood to form saliva. Now the blood has a higher osmotic pressure than that of the saliva; so in forming the gland product water is withdrawn against osmotic pressure. It is necessary to assume that in such cases work is done by the cells of the gland wall in accomplishing the expulsion of products against osmotic pressure.

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Chapter VII

REPRODUCTION AND DEVELOPMENT

Types of Reproduction. One of the most striking and perhaps the most universal distinction between living and non-living objects is that the former are invariably capable at some time during their life history of taking part in producing another living object nearly identical with its parent. We have seen that this is accomplished in two ways: Either by the independent development of a cell or group of cells (that is, a bud or a fragment) into a new adult organism, or by the development of a zygote, which results when an ovum and a sperm cell, usually derived from separate individuals, have united. The former, agamic reproduction, results in an individual that shows no differences from the parent. On the other hand, an animal that results from the development of a zygote may, and usually does, resemble both the parents.

Agamic Reproduction. Agamic reproduction is very common among both plants and animals. In its simplest form in animals, among the Protozoa, it first involves a division of the cell nucleus, followed by a separation of the cell body into two or more daughter cells, each with the structural and functional characteristics of a young animal. In most Protozoa only two daughter organisms result from each division. In the Sporozoa, however, a considerable number of nuclear divisions precede the division of the parent cell; division results in as many daughter organisms as there are daughter nuclei (Fig. 31). Among Protozoa that form colonies, for example volvox (Fig. 27), the products of a division may not be completely separated, the daughter organisms becoming a part of the colony.

Similar conditions are found among the single cell plants. In the yeast plant a modified form of cell division occurs, in which the new organism is distinctly smaller than the parent, a characteristic known as BUDDING. The buds may remain attached to the parent cell and themselves give rise to buds. Thus a colony of yeast cells may be formed by the budding of daughter cells that adhere to the parents (Fig. 24). When, as in a paramœcium, the two daughter cells are equal in size and both have the characters of young animals, the parent disappears in the reproductive process. If one of the members is distinctly smaller than the other and it alone has the characters of a young organism, as in the yeasts, one may distinguish between parent and offspring.

Agamic reproduction occurs quite commonly in many phyla of the Metazoa. In the diploblastic forms, Porifera and Cœlenterata (Figs. 32 and 33), buds are formed in the body wall; in colonial types these may continue to develop attached to the parent, thus forming colonial groups. Colonial forms may therefore be thought of as incomplete or partial agamic reproductions.

Agamic reproduction among the free-living Platyhelminthes is accomplished by the fission or fragmenting of the parent body. This process is illustrated in a most striking fashion by the life histories of two rather common fresh water planaria. In the Spring one may find, in water-filled ditches and pools of the Middle West, considerable numbers of a small, active planarian, *Planaria velata.* When brought to the laboratory and kept in basins of water for some time the animals become less active. An individual creeps slowly across the floor of the container. The tail is broken off and left behind; then another fragment breaks off from the posterior end; then another, until only the head of the original animal remains. Eventually the head dies. Each fragment secretes a capsule as a covering and within this capsule the tissues of the fragment develop into a small planarian. The walls of the capsule resist drying; so in Nature the developing young are protected and life is carried over until conditions are suitable for the breaking of the capsule and the release of the young animal.

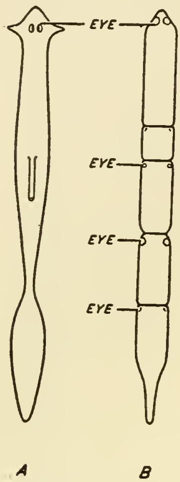

FIG. 170.—*A*, a planarian worm about to undergo fission; the posterior region is potentially a new individual. *B*, another type of free living flatworm, *Stenostomum*, showing new individuals already distinctly formed before separation from the parent. Compare with the agamic reproduction in plants shown in Fig. 172 and with agamic reproduction of yeast plants, Fig. 24. (*B* after Child.)

Planaria dorotocephala is another fresh water flatworm found in spring-fed pools in the Middle West. So far as is known it never reproduces sexually in Nature. In fact, animals with mature sex cells have never been collected. Its method of reproduction together with its characteristics of growth and starvation comprise a most interesting adaptation to its environment. It is known to feed on the blood and juices of injured or freshly killed animals. In the late Summer the food supply is abundant and the planarians grow to their maximum natural size. They become sluggish and eventually pull into two parts (Fig. 170), the posterior fragment developing a new head and the anterior fragment developing a new posterior end. The two products of this fission soon become identical and by the growth resulting from feeding again assume a size that brings about another fission. Thus the number of individuals is increased during the Summer. But in Autumn the food supply decreases and largely disappears during the Winter. During this season the animals subsist largely upon their own body contents, decreasing in size with prolonged starvation. Thus in the Spring one ordinarily collects only small animals and during this season fission occurs infrequently in Nature. With the appearance of adequate food supply these starved forms. which are essentially young animals, grow larger and again the phenomenon of fission occurs.

In forms like *Planaria velata* and *Planaria dorotocephala* almost any region of the body may serve as a reproductive mass, undergoing, when separated from the animal, the changes necessary to develop a normal adult. In fact, in some flatworms exceedingly

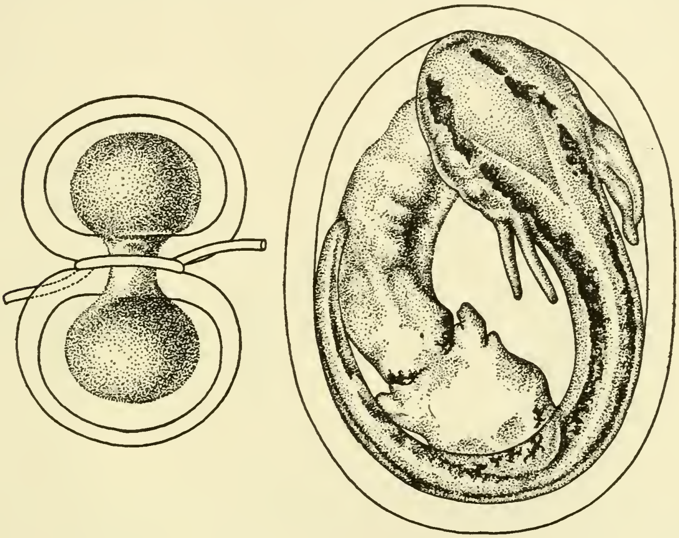

Fig. 171.—Twinning in a salamander embryo brought about by dividing the early embryo by a knot. (After Spemann.)

minute portions possess this property. This is not a universal attribute of the phylum, however, for some Platyhelminthes do not undergo fragmentation or fission, reproducing solely sexually.

The property of reproducing an adult from a fragment is also found among Annelida and Echinodermata, but is absent in Mollusca and in adult Arthropoda. It occurs in some of the lower chordates, however. The property is entirely absent in the adult vertebrate but a type of agamic reproduction may occur in the embryo. The embryos of some vertebrates may be divided experimentally at certain stages of development (Fig. 171) and each portion give rise to a normal form. It is extremely probable that identical twins in mammals are the products of the division of a single embryo at an early stage.

Agamic reproduction by budding is a common but not universal property among plants. The usual method of artificial propagation of many plants is by the separation and proper handling of a bud or cutting. In Nature it is most strikingly illustrated by creeping stems

Fig. 172.—A strawberry plant and its daughter plants agamically produced. Compare as to general character with agamic reproduction in animals as illustrated in Fig. 170. (After Child: *Senescence and Rejuvenescence*, published by the University of Chicago Press.)

that develop independent root and shoot systems and become separate plants, for example, the strawberry runner (Fig. 172). The common potato is an underground stem in which is stored large quantities of starch and other materials and on which are developed latent buds known as eyes. Under suitable conditions these buds give rise to root and shoot systems. This modified stem is the chief method of propagation and is obviously an organ for agamic reproduction.

Gametic Reproduction. Gametic reproduction is effected by the development of a new individual from a single cell, the zygote, which results when two gametes or sex cells unite. This fusion of two specialized sex cells occurs among the Protozoa, for example in the life cycle of Sporozoa, as previously described (p. 75). In animals the two uniting cells are different in appearance and nature (Fig. 133). The ovum, formed in a female organ, is the passive, quiescent member that contains the food materials and is the site of development of the new individual. The other member that enters into the unity, the spermatozoon, is usually active and relatively smaller, consisting largely of nuclear material. An individual or organ which produces this type of gamete is known as a MALE. In some of the lower plants the two sex cells are not distinguishable, a characteristic which is known as ISOGAMY. Distinguishable differences between the two types of gametes are the rule, however, a characteristic known as HETEROGAMY. With few exceptions (some Protozoa) all animals are heterogamous.

The union of the two gametes is called FERTILIZATION (p. 193). Its functions are several. In the first place, the union of the two nuclei derived from different parents provides a mechanism of inheritance from both, a subject which will be discussed in more detail farther on. Secondly, fertilization in some manner provides a stimulus for development of a new individual by the ovum, since, with certain exceptions to be mentioned presently, neither egg nor sperm ever develops into an adult unless fertilization has occurred. Thirdly, in some forms of animals the completion of maturing of the egg is not effected until after the sperm has entered. The essential events which follow fertilization will be discussed farther on.

Metagenesis. At this point it is desirable to discuss those forms which in their life cycles regularly exhibit an alternation in reproductive method, sexual and asexual methods succeeding each other. This character, METAGENESIS, occurs among both plants and animals. As it is impossible to treat of biological phenomena in one type of animal without reference to other types, it is similarly impossible to consider Animal Biology adequately without examining also some features at least of the broad outlines of Plant Biology. In previous pages emphasis has been placed on the distinctive characters of the metabolism of plants and animals and on some of the features of organization that are common to the two groups. Metagenesis constitutes another character that both exhibit to a greater or lesser extent. Three of the four phyla of plants, the Bryophyta or mosses, the Pteridophyta or ferns, and the Spermatophyta or flowering plants, pass through sexual and asexual generations alternately in their life cycles. Only the Thallophyta, the single-cell and exceedingly simple plants, have single life histories, reproduction in these forms being either sexual, asexual, or both, without regular sequence. So before examining the phenomena of metagenesis in animals we may with profit familiarize ourselves with the chief features of plant-life cycles.

Life Cycle of Moss. As indicated above, in the Bryophyta, the mosses and their allies, the life cycle comprises two phases. The green leafy moss plant with which we are all familiar is a sexual generation, that is, produces gametes or sex cells (Fig. 173). In the tip of such a green plant is found a vase-shaped structure, the ARCHEGONIUM, in which is the ovum. In nearby tips are sperm-producing organs, the ANTHERIDIA, club-shaped structures that produce considerable numbers of sperms. In moisture, that is dew or rain, the active sperms swim down the neck of the vase-shaped archigonium; there fertilization takes place. The fertilized egg remains in its original position and develops there, growing into a long spike, which contains no chlorophyll but draws its subsistence from the green plant in the fashion of a parasite. This is a new asexual generation of the moss. A spindle-shaped SPORANGIUM, in which great numbers of single cells termed SPORES are formed, develops on the upper end of this spike. When the sporangium ripens the spores are released and, falling on the ground, develop as independent green moss plants that produce only ova and sperm, never spores. Spores, then, are single cells capable of developing without being fertilized. True spores are produced among animals only by Protozoa. The green moss plant is a sexual generation

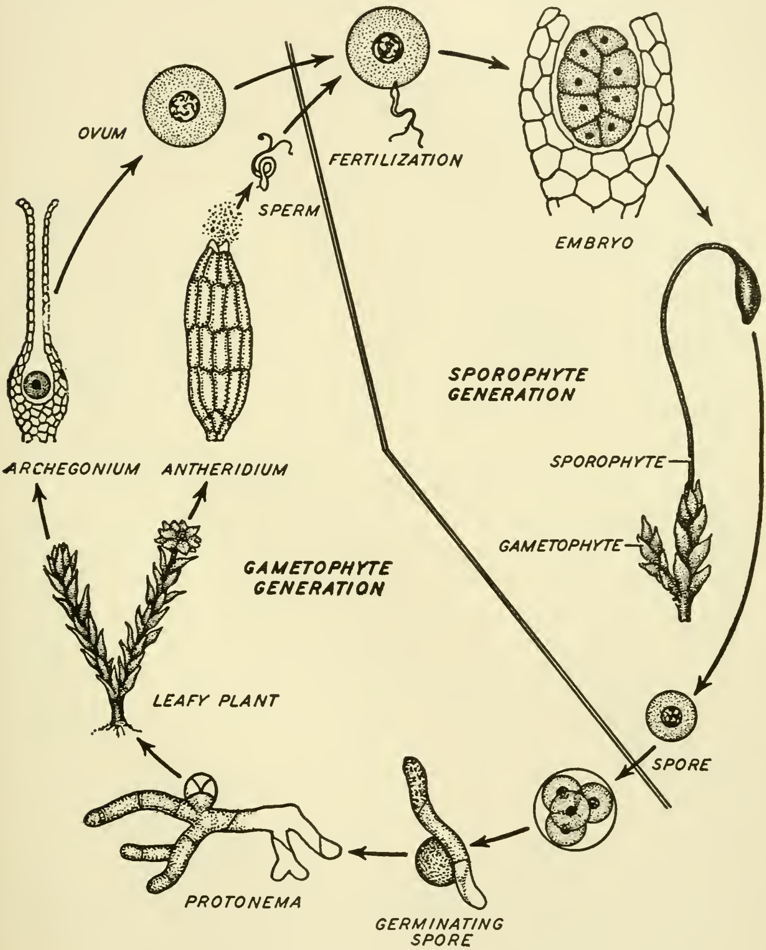

FIG. 173.—Diagram of the life cycle of a common moss.

which never reproduces itself but always produces an asexual generation from its fertilized egg. The parasitic asexual generation never reproduces another spore-bearing generation but always a gamete-bearing green plant. The gamete-bearing plant is known as

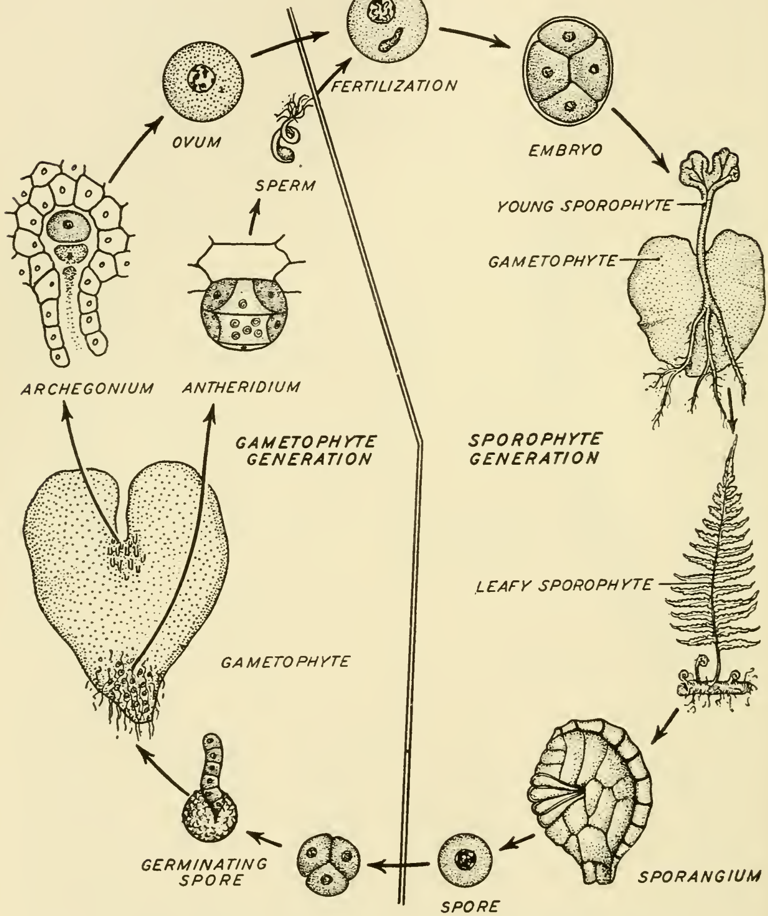

Fig. 174.—Diagram of the life cycle of a common fern.

the GAMETOPHYTE, while the brown, parasitic, spore-bearing generation is termed the SPOROPHYTE.

Life Cycle of Fern. Alteration of generations, or metagenesis, is modified in the ferns, the phylum Pteridophyta (Fig. 174). The large fern plant with which we are familiar is a SPOROPHYTE, a spore-bearing generation. If one examines the leaves of a fern at certain seasons, some of them will be found to bear on their under surfaces crescentic shaped brown bodies, known as SORI. In these are the SPORANGIA. When mature the capsules of the sporangia open and release spores. In the ground these spores develop into small, heart-shaped, flat green plants known as PROTHALLI. In a prothallus there develop both archegonia and antheridia, the sperm from the antheridia fertilizing the ova in the archegonia. Development of the fertilized eggs occurs in the archegonia and results in the large green fern, the sporophyte generation. Thus in the Pteridophyta the GAMETOPHYTE generation has been reduced to an obscure structure, but is not done away with completely; asexual generation is necessary in the life cycle.

Life Cycle of Flowering Plant. In the spermatophytes, the flowering plants, the gametophyte generation has been still further reduced (Fig. 175). The ordinary flowering plant is the sporophyte generation. The FLOWER is a complex of modified leaves, which gives rise to two types of spores; one, the MEGASPORE, develops in the base, RECEPTACLE, of the flower and there gives rise to a gametophyte generation, which produces only an ovum. This MEGAGAMETOPHYTE consists usually of not more than eight cells, one of which is the egg cell. Rising from the centre of the flower is a shaft, the PISTIL, consisting of a group of tubes that spread out at the upper end to form the STIGMA. Each of these tubes leads into a separate chamber containing a megagametophyte in the base of the flower. Around the base of the pistil are attached a series of modified leaves known as the STAMENS. At the tip of each stamen is an ANTHER, which is the origin of another type of spore, the MICROSPORE, capable of producing only a MICROGAMETOPHYTE generation that develops only the male cells or sperms. The ripened micro-

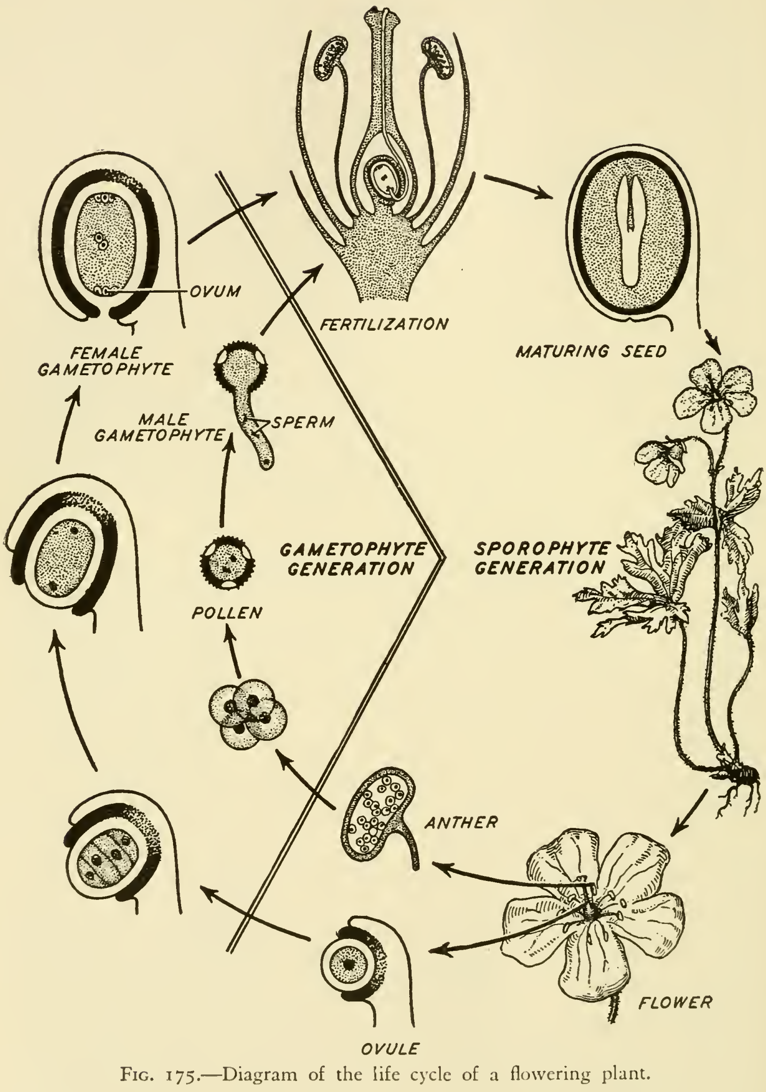

Fig. 175.—Diagram of the life cycle of a flowering plant.

spores are commonly known as POLLEN. By one means or another pollen is transferred from the anthers to the stigma at the upper end of the pistil. Here the microspore germinates and produces the microgametophyte; it consists of but three cells. One of these develops a long tube that passes down the pistil into a chamber containing an ovum. The sperm nucleus traverses this tube and fertilizes the ovum. The walls of the chamber and of the base of the flower become modified to form the seed coats and parts of the fruit at the same time the fertilized egg within is developing. Development proceeds until the fundamentals of a root and shoot system appear, when development stops. Thus a seed contains an embryo sporophyte in an arrested condition, together with a certain amount of reserve food material.

Here in the Spermatophyta is a separation of the spore-producing organs of the sporophyte into those that produce egg-forming, and those that produce sperm-forming gametophytes, a condition known as HETEROSPORY. In most plants both types of spores develop in the same flower, but their separation is not unusual. In the common corn, maize, for instance, the silk represents the pistils of many compartments containing egg-producing macrospores, forming megagametophytes, while the dust of the tassel is made up of microspores, which when they germinate produce the sperm-yielding microgametophyte. The whole series from the Bryophyta through the Pteridophyta to the highest flowering plants shows a great reduction in the relative size of the gametophyte generation, but it is not abolished completely. Metagenesis is therefore the order of the life cycle of three of the four plant phyla.

Metagenesis in Animals. The common nature of life processes among plants and animals is emphasized by the fact that among animals one also finds metagenesis. Alternation of generations in the life history of the malarial parasite has been described elsewhere (p. 75). It is sufficient here to call attention to the occurrence of this characteristic in some of these single cell animals.

Among the Metazoa it occurs conspicuously in certain Cœlenterata. The essentials, namely the order of sexual and asexual generations in a life cycle is as among plants but the details are quite different. Only one class of the phylum (Hydrozoa) exhibit distinct metagenesis; because this character in a way marks this class as intermediate between it and another class we may review the characters of the Cœlenterata in some detail.

Cœlenterata in General. Cœlenterata are characterized by the fact that they are diploblastic and by the further fact that all members are equipped with a special sort of defensive mechanism in the ectoderm, consisting of a coiled, spring-like structure with a barbed end, embedded in a cell containing a poisonous substance (p. 100). This structure is called the NEMATOCYST and the cell in which the mechanism is formed is known as a CNIDOBLAST. They are most numerous on the tentacles, which surround the mouth, and not only serve as defensive organs but assist in the capture of smaller animals for food. Cnidoblast cells are very sensitive to contact and rapidly discharge the nematocyst. This impales the prey which is rendered less active by the poison and thus more easily passed into the mouth by the tentacles.

There are three classes of Cœlenterata; the Hydrozoa, the Scyphozoa, and the Actinozoa. The most familiar of the Hydrozoa is the fresh water hydra, a simple sac-like organism, consisting of a basal disk, which is usually attached to some object, a two-layered body, containing an endodermal cavity by which the food is digested, and an upper end consisting of a series of tentacles surrounding a mouth set on an eminence in the centre of the cluster of tentacles. Between the ectoderm and endoderm are some interstitial cells called MESOGLEA. The animal is usually attached but may become detached and carried through the water, or it may turn end over end and thus move slowly from place to place. It has no organs for propelling itself through the water. It reproduces either sexually, the eggs or sperms being formed from mesoglea cells in an ovary or a spermary on the same individual, or by budding, the bud becoming detached to form a separate individual.

The Hydroids. The hydroids are mostly marine Hydrozoa and exhibit metagenesis. The asexual form is attached to rocks or other material and consists of a branching, diploblastic tube (Fig. 176). The walls of the tube in many varieties are covered with a transparent non-cellular layer secreted by the ectodermal cells, known as the PERISARC. Some branches end in a structure much like a single hydra, consisting of an expanded bell-shaped HYDRANTH around the rim of which are tentacles armed with nematocysts. The mouth is in a central eminence known as the HYPOSTOME. This constitutes a feeding hydranth. On other branches are hydranths, quite different in structure, which are specialized as reproductive hydranths. The reproductive hydranth consists of a central shaft, the GONOSTYLE, on which develop a number of flat plates of cells known as MEDUSA BUDS. It is covered with a layer known as the GONOTHECA, which is continuous with the perisarc of the stem. At the extreme end of the reproductive hydranth is a pore, the GONOPORE. When the medusa buds are mature they separate from the gonostyle and escape through the gonopore into the water. Here they develop into free swimming forms known as MEDUSÆ. The processes of medusa bud formation and the development of medusæ are entirely asexual.

The free swimming medusæ are sexual animals (Fig. 176). Their general shape is similar to that of an umbrella. The tentacles are suspended from the rim. The mouth is at the end of a short tube suspended in the cavity formed by the concave under surface of the animal, similar in position to the handle of an umbrella. This tube is continuous with four radial alimentary canals, the position of which may be compared with that of the ribs of an umbrella. At the rim these four radial canals enter a circular canal that traverses the entire circumference of the animal. The sex organs develop on the walls of the radial canals. The sexes are separate. An individual

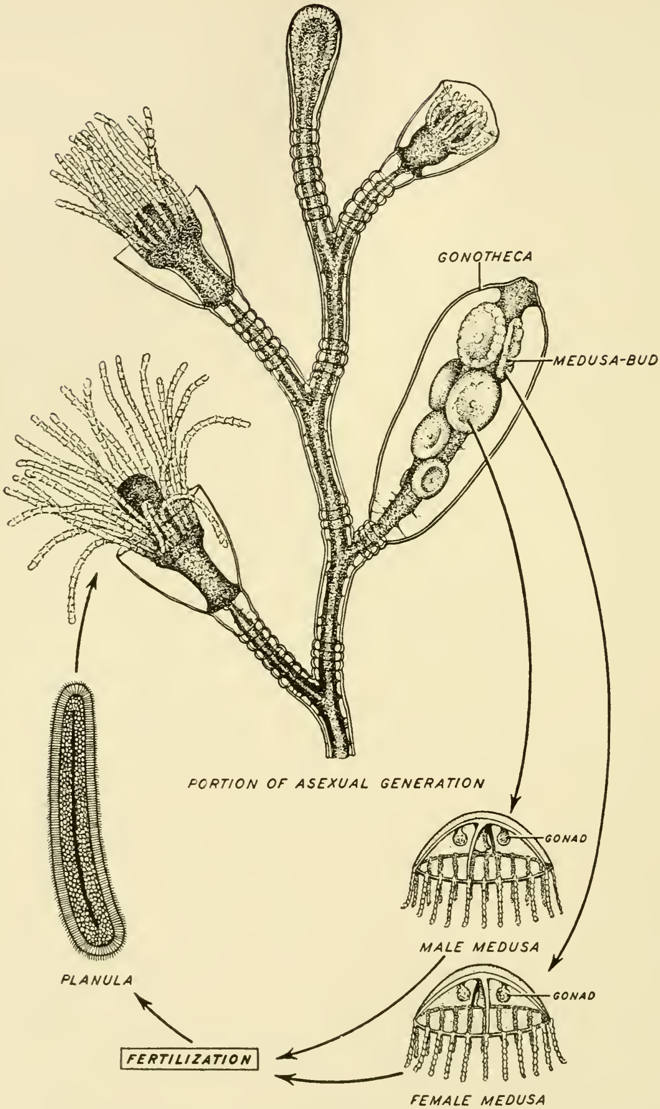

FIG. 176.—Diagram of the life cycle of an animal exhibiting metagenesis, the hydroid *Obelia.*

medusa sheds the mature eggs or sperms into the water where a chance meeting with the germ cell of the opposite sex results in fertilization. The fertilized egg by cell divisions becomes a two-layered flat PLANULA, which then develops into the attached branching asexual hydroid. Thus the cycle is complete. The description here given applies in detail to the hydroid species *Obelia*, but the essential features apply to all other species.

The Scyphozoa. The free swimming medusa, sexual generation of the hydroid, very closely resembles a jelly fish. The jelly fish constitute the second class of Cœlenterata, the class Scyphozoa. In general the jelly fish are larger than the sexual generation of the Hydrozoa, have a somewhat more complicated set of radial canals, and more clearly defined nerve elements. The sexes are separate and in most species the fertilized eggs develop directly into free swimming forms; a few species exhibit a sort of metagenesis and some have stalks that serve as hold-fasts.

The Actinozoa. The members of the class Actinozoa are attached marine Cœlenterata, the endodermal cavity being divided by a number of partitions into radial compartments (Fig. 35). The sea anemone is a member of this class, but perhaps the most familiar form is the coral, of which there is a wide variety of species. Corals are colonial forms, composing large masses. True metagenesis does not occur among the Actinozoa. The attached animal is sexual, the sexes being separate. The gonads are located in the cavity and the sex cells are expelled into the surrounding water. After fertilization the eggs develop into planulæ which in turn become the attached animals.

Viewing the Cœlenterata as a group it is seen that the hydra is the most simple; hydroids resemble the hydra in many respects but by specialized buds give rise to a free swimming sexual generation, which in turn resembles the class Scyphozoa. In the Actinozoa there is a return to the attached form; the gonads, however, are internally placed as in the free swimming Scyphozoa.

Metagenesis in Other Metazoa. A true alternation of sexual and asexual generations is found in various other Metazoa; certain parasitic Nemathelminthes, some of the Platyhelminthes, and in some lower chordates. Metagenesis also occurs in some insects. In some ichneumon flies, a type of insect related to bees, wasps, and ants, the eggs of the female are laid in the larvæ of other insects. In some species a single egg in the process of development gives rise to a great number, several hundred, larval parasites in the body of

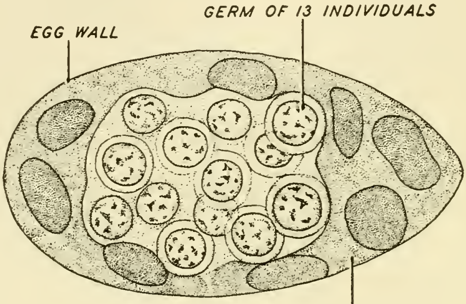

Fig. 177.—Polyembryony in the development of an insect, *Platygaster vernalis*, order Hymenoptera, parasitic in the eggs and larvæ of the Hessian fly. Sixteen new individuals may hatch from a single fertilized egg; thirteen are shown as early germs in the figure. (After Patterson, after Leiby and Hill.)

the host larva. There occurs here by multiple divisions of the germ, an agamic reproduction of the developing parasite, a phenomenon known as POLYEMBRYONY (Fig. 177). Essentially it is a process of metagenesis, for a sexual process of reproduction is followed by an asexual fragmentation of the embryo of the new generation.

Sufficient has been said here to emphasize the fact that alternation of sexual and asexual generations is a very common type of life cycle in both plants and animals. Plants have developed this type of reproductive phenomenon as a major feature of the highest and most complicated plants; animals have continued the sexual type of reproduction as the method in the most highly developed forms.

Metagenesis may be regarded as a very general characteristic of living objects and is one of the many facts that show a real relationship between plant and animal types of protoplasm.

Parthenogenesis. It was stated previously that in most cases eggs require the activating influence of the sperm cell in order to initiate and undergo development into an adult individual. The eggs of some animals, however, normally develop without being fertilized. This phenomenon is known as PARTHENOGENESIS. Clear examples are to be found in the life cycles of some insects. For illustration, the life cycle of one common species of plant lice, an aphid, may be described.

The form that winters over is known as the stem mother. In the Spring she lays eggs which develop parthenogenetically. This brood is made up exclusively of females. In turn the eggs of these females are also parthenogenetic and so in the Spring and Summer generations no males occur. In late Summer or early Autumn, however, broods are produced which are of both sexes in approximately equal numbers. Succeeding late broods are derived from fertilized eggs and the stem mother which winters and starts the series of maleless broods the following Spring is herself the result of the development of a fertilized egg.

Parthenogenesis normally occurs in some members of the phyla Nemathelminthes and Platyhelminthes and among the class Insecta of the phylum Arthropoda. It may be artificially induced in a variety of eggs. It is accomplished most easily with the ripe eggs of certain Echinodermata (starfish eggs). Appropriate treatment of the eggs with a wide variety of chemical agents, with brief exposure to high temperature, with hypo- and hypertonic solutions, by mechanical shaking, and other methods will cause a normal development of the embryo. Frog eggs have been activated by pricking with a needle first dipped in a salt solution. Adult frogs without any male parent have been reared from such eggs.

Development. The development of an adult animal from an egg constitutes one of the most interesting and at the same time one of the most puzzling of the processes characteristic of living material. An egg is alive and consequently carries on metabolism and the transformation of energy into life processes. One may measure the amount of oxygen taken in, the carbon dioxide given off, the nitrogenous waste output, and other characteristics of the egg and from the data obtained calculate with fair accuracy the efficiency of the egg in transforming energy, the materials being used, and other physiological characteristics of the life of the egg. Like physiological characters of later stages of development may be determined with some assurance. Thus a series of determinations may be made, each revealing information as to the nature of the vital processes at any given stage. But the results give no clue whatever to the answer to the problem of why these stages succeed each other nor as to how one stage is transformed into the next. Consequently the facts of development as a physiological process are but little known; it constitutes one of the most intriguing and at the same time one of the most difficult fields of biological investigation. Study and description of the changes in the form of the organism from the egg to the adult are much less difficult and have been accomplished in a great many animals. Details of development vary greatly; it is not the purpose of this discussion to enter into such details nor does space permit. Certain basic similarities are found throughout animal development, however, and attention will be confined here to the events of development that are general, and to useful comparisons.

Following the union of the egg and sperm nuclei in the fertilized egg, the events that follow may be divided into two main categories: (*a*) Chemical changes in the transforming protoplasm, which gradually convert the more or less generalized substance of the egg toward the characteristically different types of protoplasm found in the specialized tissues of the adult, are spoken of as DIF-

FERENTIATION. (*b*) Cell divisions, mechanical foldings of the cell layers, and the migration of cells are in normal development carefully and accurately adjusted to the time of differentiation of the several types of cells, so that development is an orderly process. Cell divisions and mechanical changes in position of the cells, and differentiation are, however, independent processes. Experimentally one may interfere with, and prevent cell divisions without arresting the chemical changes of differentiation. With these facts of the normal concurrence of differentiation and changes in position of the cells and cell layers in mind, the description to follow will be largely confined to descriptions of change in form during development.

Cleavage. The first period of development is marked by a series of cell divisions and is known as the cleavage period. Division into two, then into four, then into eight and more cells, results in a hollow sphere of cells known as the BLASTULA (Fig. 178). Essentially this process takes place in all forms of animals, but with considerable modification in some. The cavity of the blastula is called the BLASTOCŒLE. The truly spherical blastula of the lower invertebrates resembles the general structure of the colonial protozoon, volvox, which was described elsewhere (p. 89; p. 90). Biologists permit themselves to speculate as to whether this resemblance indicates that the ancestor of the Metazoa was a colonial protozoon of the structural type of volvox, or whether the resemblance is due to the possibility that this sort of hollow sphere is a necessary stage in the development of an adult animal regardless of its ultimate ancestry.

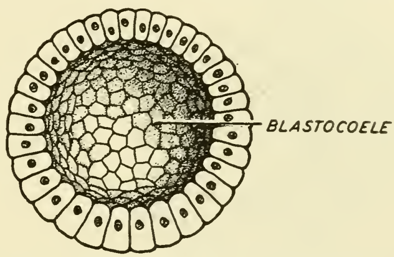

FIG. 178.—The blastula stage of the cephalochordate, Amphioxus.

Gastrulation. The blastula is a single layer; the next step in development is the formation of a diploblastic form from the hollow sphere. In the simplest cases this is effected by differences in growth that cause the impinging of one hemisphere of the blastula into the other, a process which may be roughly compared to the impressing of one half of a hollow rubber ball into the other half so that the result is a double-walled hemisphere, the inner and outer layers being continuous around a rim (Fig. 179). This process in development is called GASTRULATION and establishes the two primary layers, the ectoderm and the endoderm, continuous around the lips of the circular opening, the BLASTOPORE. The blastocœle is thus partially obliterated. The inner, sac-like cavity formed by the endoderm is the rudiment of the alimentary tube, the ARCHENTERON. Again there are grounds for comparing this stage in the development of higher animals with the adult of the lower forms, for it will be recalled that the cœlenterate, hydra, consists of a two-layered hollow sac.

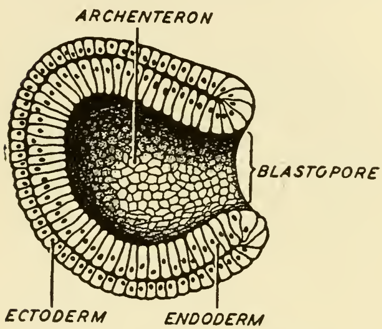

FIG. 179.—The gastrula stage of Amphioxus.

Cleavage and gastrulation as described for the simplest cases take place in this fashion only in eggs with a relatively small amount of yolk fairly equally distributed throughout the egg, or ISOLECITHAL eggs. In eggs with more yolk unequally distributed the processes are much modified. Such eggs are termed TELEOLECITHAL eggs. The amount and distribution of yolk varies among teleolecithal eggs. For the egg organization and cleavage of a teleolecithal egg containing a relatively small amount of yolk a study may be made of the early development of the frog's egg. Because of their intermediate yolk character, such eggs are sometimes known as MESOLECITHAL.

Gastrulation in the Frog Embryo. Examination of the undivided fertilized egg of the frog shows that it may be roughly divided into two hemispheres, one darkly pigmented, the other a light yellow (Fig. 180). The yolk content of the yellow hemisphere is much greater than in the pigmented hemisphere. This is known as the VEGETAL HEMISPHERE and its geometrical pole is called the VEGETAL POLE. The black hemisphere is the ANIMAL HEMISPHERE, its pole being the ANIMAL POLE. The presence of yolk appears to slow up cell divisions, so when the fertilized egg of the frog divides, the division planes start at the animal pole and first separate the animal hemisphere. Internally in such eggs the blastocœle is dislocated toward the animal pole, being partially filled by the large, slowly dividing cells of the vegetal hemisphere (Fig. 181). A frog blastula then consists of cells of different sizes, the smaller actively dividing cells of the animal hemisphere and the large, slowly dividing, yolk-containing cells of the vegetal hemisphere.

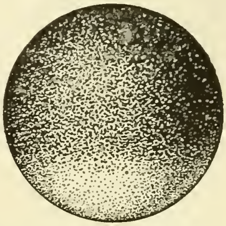

FIG. 180.—An unsegmented frog egg.

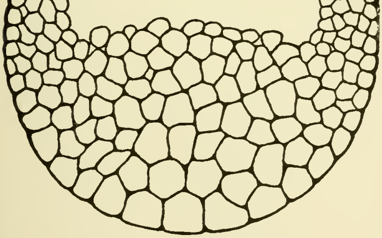

FIG. 181.—Section through the blastula of the frog embryo.

Gastrulation is also affected by the amount and distribution of the yolk. Gastrulation in the frog blastula begins as a crescentic shaped notch near the equator between the animal and vegetal poles (Fig. 182). Here some cells are tucked in to form the roof of the archenteron;

the floor is formed by the large yolk cells of the vegetal hemisphere. The pigmented cells of the animal hemisphere increase in number and migrate downward over the vegetal hemisphere, thus incorporating the yolk-containing vegetal hemisphere cells within as the floor of the archenteron. The blastopore is then first indicated by the crescentic shaped notch where the endoderm is first turned inward. This is the dorsal lip of the blastopore, the lateral

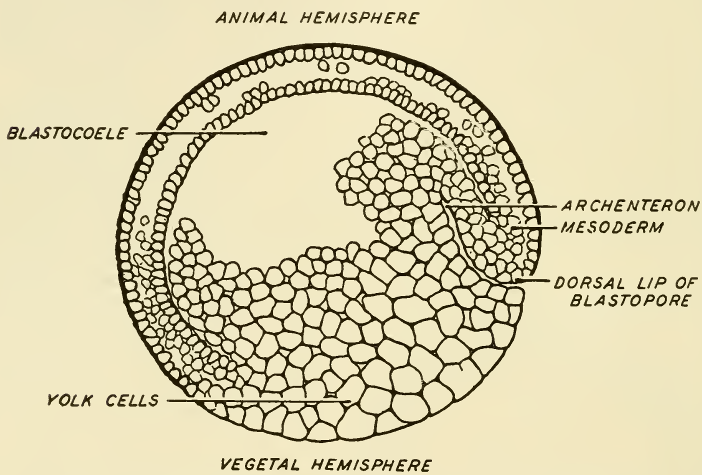

Fig. 182.—Section through the gastrula stage of the frog embryo.

and ventral lips being the line formed where the animal hemisphere cells are advancing over the vegetal hemisphere to converge and form a circular blastopore under the dorsal lip.

In the distinctly teleolecithal eggs of fishes, reptiles, and birds the yolk-containing vegetal hemisphere does not cleave. Cell divisions are at first confined to a region in the vicinity of the animal pole, the cells forming a cap. Gastrulation is much modified. In birds it is reduced to the inward growth of a wedge of cells, which forms the endoderm by increasing in area by cell divisions and by additions of cells cleaved from nucleated cytoplasm that underlies the

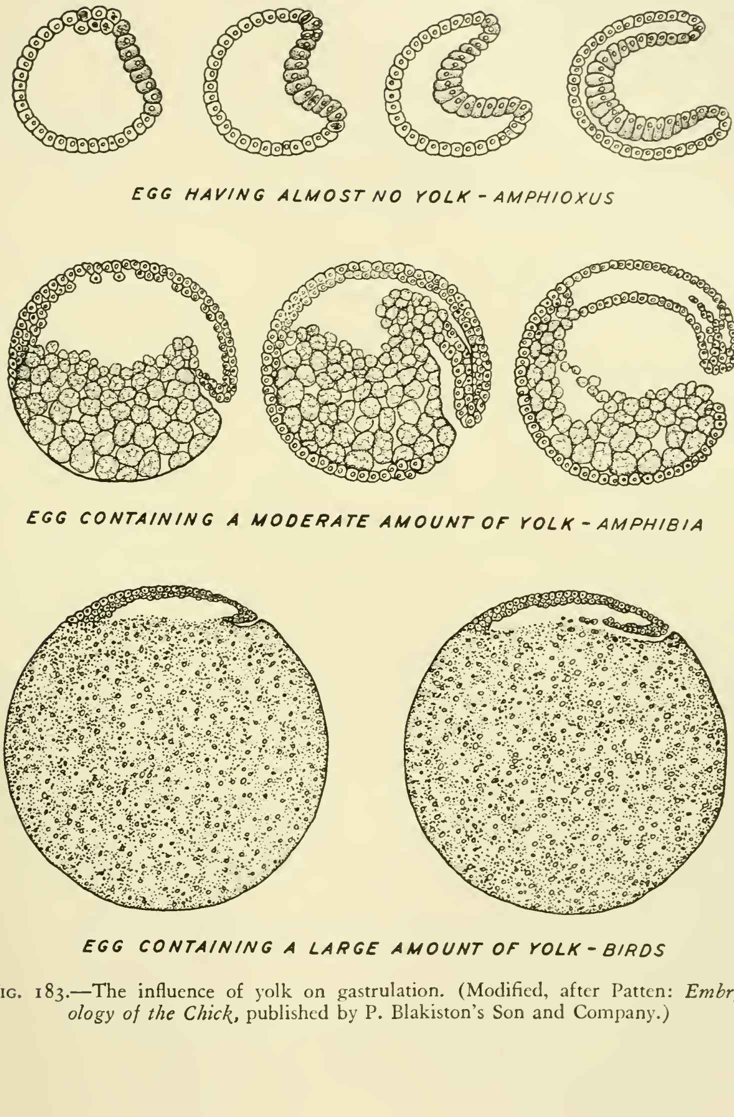

FIG. 183.—The influence of yolk on gastrulation. (Modified, after Patten: *Embryology of the Chick*, published by P. Blakiston's Son and Company.)

cap of dividing cells. The influence of the amount and distribution of the yolk on cleavage and gastrulation is shown in the accompanying figure (Fig. 183).

Mesoderm Formation. Cleavage and gastrulation are followed by the rise of the intermediate layer, the mesoderm. In vertebrates the chief source of the mesoderm is from cells of the vicinity of the lips of the blastopore, particularly the dorsal lip (Fig. 179). It extends forward and laterally between the two primary layers. Its lateral sheet on either side the mid-dorsal line splits into two layers; the inner becomes closely applied to the endoderm, the outer lines the ectoderm. The cavity set up between the two layers of mesoderm is the cœlom (Figs. 81 and 179). Meanwhile the embryo has been elongating, the blastopore becoming smaller and forming an aperture in the posterior end of what is now a more or less cylindrically shaped body. These processes of germ-layer formation and accompanying changes in shape are modified in many forms but the essential features can always be recognized.

At the close of the period of gastrulation and mesoderm formation the embryo presents the basic structures of the adult organ systems laid down in their permanent relation in external, intermediate, and internal layers. Shifts of position occur in later development but do not involve any change in the relative relations of ectoderm, mesoderm, and endoderm. Immediately following the formation of the three germ layers as described, the embryos of most invertebrates develop rapidly into free swimming or moving larvæ of various sorts. Many types of invertebrate larvæ carry on independent feeding and some become sexually mature and reproduce a new generation before they themselves have become adult. Some invertebrates (for example, Annelida) pass through several larval stages.

All of the sub-phyla of the chordates except the vertebrates pass through a larval stage that is free swimming and somewhat similar in shape to the frog tadpole. In the sub-phylum Vertebrata, however, only the members of the class Amphibia pass through a free swimming larval stage that feeds on plant materials in its environment. In all others development is direct toward the adult form; nutrition is carried on in various ways that will be described farther on.

Fate of the Primary Layers. Development consists of chemical differentiations, of cell divisions, and of growth of the various primordia (p. 286) of adult structures, of foldings of layers and dislocations produced by unequal increase in relative size of the developing structures, and finally of the perfection of the tissues so that they may carry on their respective functions in the adult. In normal development all these processes are accurately synchronized. In vertebrates from the ectoderm are derived the outer layers of the integument, integumentary glands, for example, sweat and other skin glands, exoskeletal structures such as feathers in birds, the hair and enamel of teeth in mammals, parts of scales in lower vertebrates, and also all the nervous elements of the nervous system. The ectoderm is also involved in the formation of two important endocrine glands, the pituitary and the adrenals (p. 204). From the mesoderm are derived the nether layer of the integument, connective tissues, the muscles, the excretory, reproductive, and circulatory systems, and supporting structures such as bone and cartilage. From the endoderm are formed the lining of the digestive system, digestive glands, parts of the urinary and genital systems, and the lining of the trachea and lungs in air-breathing vertebrates. The endoderm is also the origin of important endocrine glands, the thyroid, the parathyroids, and the pancreas (p. 205).

The Neural Tube. The development of the nervous system is accomplished by the greatest shifting of parts of layers in the whole process of development, for it involves the penetration of ectodermal derivatives deep into mesodermal and endodermal structures. In vertebrate embryos (Fig. 184) very soon after the beginning of mesoderm formation the ectoderm anterior to the dorsal

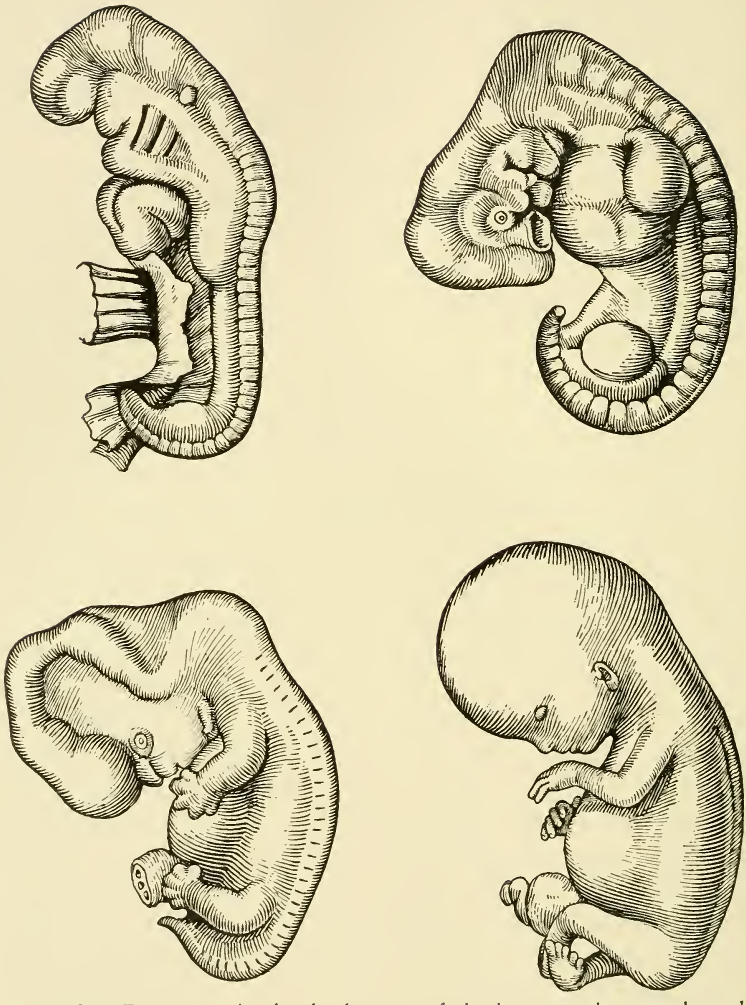

Fig. 184.—Four stages in the development of the human embryo to show the relatively earlier appearance of anterior structures. See also Fig. 147 and Fig. 149. (After McMurrich: *Development of the Human Body,* published by P. Blakiston's Son and Company.)

lip of the blastopore becomes differentiated into a plate that sinks downward to form a groove. This plate of ectodermal cells is destined to form practically the entire nervous system (Fig. 149). The boundaries of the groove close over and fuse, leaving the future nerve elements as a tube, under the ectoderm and surrounded by mesoderm. The dilations of the anterior end of this neural tube to

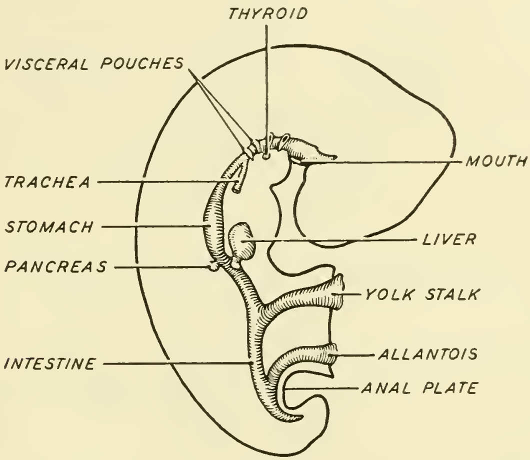

Fig. 185.—The primitive digestive system of the chick embryo after 4 days' incubation of the egg. (After Patten: *Embryology of the Chick*, published by P. Blakiston's Son and Company.)

form the basic portions of the brain have already been described (p. 217), as have also the origin of the ganglia of the spinal cord and of the sympathetic nervous system, and other parts of the adult vertebrate nervous mechanism.

The Alimentary Canal. The endoderm in invertebrates becomes rapidly differentiated into a functional alimentary tract. In diploblastic forms and in the more primitive triploblastic animals, for example the Platyhelminthes, it does not acquire a second opening. But in the more advanced invertebrates and in all chordates a contact forms between the ectoderm and the anterior end of the endodermal tube which breaks through to form the mouth. In some cases the anus is developed from the original blastopore but in the higher animals where a definite open blastopore does not form during gastrulation the anus develops as a break in the contact area between the posterior end of the endodermal tube and adjacent

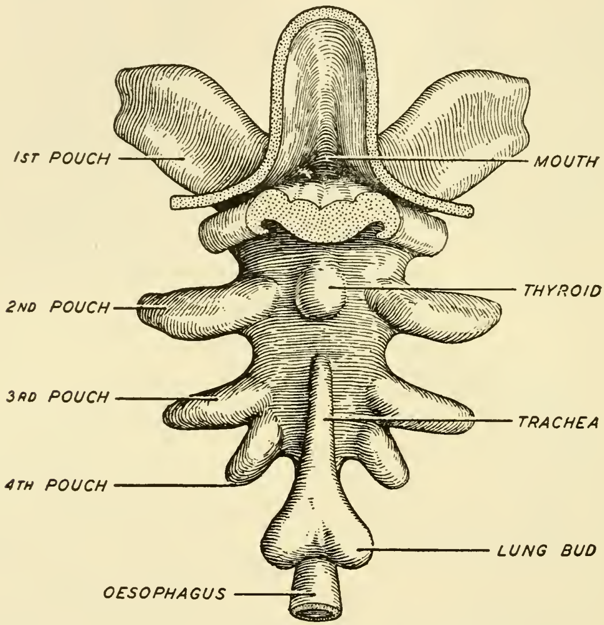

FIG. 186.—Visceral pouches in the embryo of a vertebrate.

ectoderm (Fig. 185). Thus is established the characteristic tube-within-a-tube structure, the outer wall being developed from the ectoderm and the outer or SOMATIC layer of mesoderm and the inner tube being formed by the endoderm and the layer of SPLANCHNIC mesoderm which immediately surrounds it, anterior and posterior openings forming as apertures in the area of contact between ectoderm and endoderm.

The Visceral Pouches. In vertebrates six pairs of bays or grooves form in the endodermal wall of the anterior end of the archenteron (Fig. 186). In the fishes the posterior four or five of these break through and on their walls develop the filamentous gills. In air-breathing vertebrates, the fate of these visceral or endodermal pouches is very different. In Man (Fig. 187), for example, portions of the first or most anterior pouch become involved in the development of the ear and form the tympanic cavity and the Eustachian tube which connects it with the roof of the adult

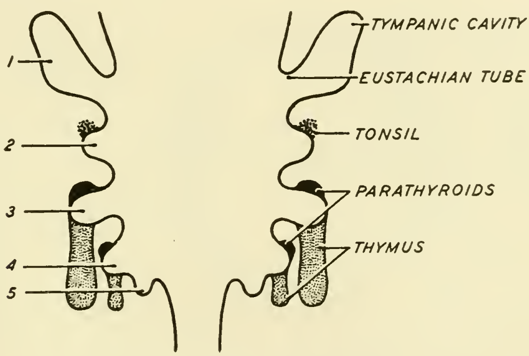

Fig. 187.—Fate of the Visceral pouches in Man.

pharynx. The thyroid gland develops from the floor of the endodermal region between the first and second pouch. The true tonsils, the thymus, and the parathyroids develop from the endoderm of the second, third and fourth visceral pouches. In the floor of the embryonic pharynx just behind the site of origin of the thyroid a groove develops from which arise the trachea and lungs, the linings of which are of endodermal origin; the circulatory and connective tissues of the lungs are derived from the adjacent mesoderm.

Nutrition of the Embryo. The development of an adult from a fertilized egg is accompanied by a relatively enormous increase in quantity of living material; furthermore, new and different types of protoplasms arise during the developmental process. It is therefore plain that the newly forming animal must have at its disposal an abundance of food to provide both energy and materials for development. All types of eggs that are fertilized outside the body of the female obviously develop independent of the maternal body. Of eggs that are fertilized within the female, some are expelled before development proceeds very far, and some spend the entire period of development within the maternal body. The former type is described as OVIPAROUS and the latter as VIVIPAROUS animals. In ovi-

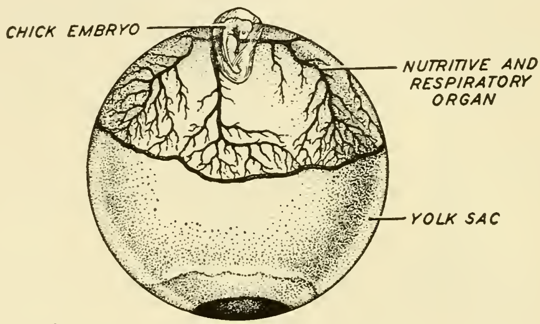

FIG. 188.—An embryo chick with its yolk sac, showing the circulation of the blood over the yolk area. (After Duval.)

parous forms that do not develop into free swimming or feeding larvæ, for example the chick, the energy and materials required for the processes of development are, except for oxygen, contained in the egg as yolk and other materials. Embryos in such eggs as the chick develop a sac which encloses the yolk; blood vessels and blood cells develop in the wall of the yolk sac and transport the food materials into the embryonic body and carry outward to the surface of the yolk the gaseous wastes of metabolism (Fig. 188). The wall of the yolk sac thus serves as the chief respiratory and nutritive organ during much of the period of development.

The Placenta. Some viviparous animals merely incubate the eggs in the maternal body during development, the food supply being within the egg and independent of the maternal food supply. In other viviparous forms, for example in certain viviparous fishes, the quantity of yolk available appears to be insufficient for the processes of development and the young embryo develops organs that adhere to the ovary or wall of the oviduct and absorb foods from the blood stream of the adult. In the mammals, the egg is almost devoid of yolk and other reserve foods, the major portion of its nutriment being derived from the blood stream of the mother during development. For this function as well as for obtaining an oxygen supply and for ridding the developing embryo of the wastes of metabolism a special organ is developed, consisting in large part of membranes arising from the embryo but also involving modifications of the maternal uterine wall. This organ is the PLACENTA. A true placenta is developed solely in the higher mammals; hence the class Mammalia include both PLACENTAL and APLACENTAL mammals, grouped according to whether or not a placenta is formed. Man is a placental mammal; marsupials (for example, the opossum) and monotremes (example, the duckbill) are aplacentals.

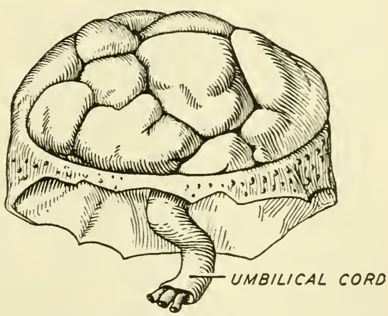

FIG. 189.—A human placenta. (After McMurrich: *Development of the Human Body*, published by P. Blakiston's Son and Company.)

The Human Embryo and Its Nutrition. In the placental mammals the transfer of food and oxygen from the blood stream of the mother to that of the embryo takes place through the membranes of the placenta. The human placenta is a disk-shaped structure (Fig. 189). The face of the disk apposed to the wall of the uterus has fronds which penetrate deeply into the tissues of the uterine wall, bringing the blood vessels of the embryo into intimate contact with the blood of the mother. The maternal and embryonic bloods are, however, always separated by a membrane (Fig. 190), so that any substance or influence in the body of the mother can affect the development of the offspring only by being in solution in the maternal blood and diffusing through a membrane, obeying the

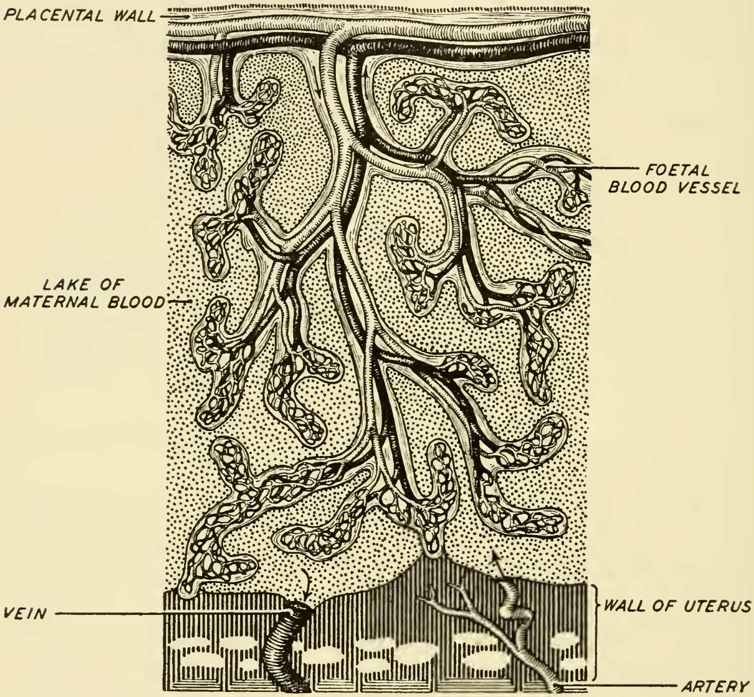

Fig. 190.—Diagrammatic section through the human placenta in position. Note that the blood vessels of the foetus dip into the lakes of maternal blood and that they do not receive blood directly from the mother. Note also the absence of nerves in the foetal portion.

principles of membrane permeability set down in a previous chapter (p. 32). Many erroneous ideas are current concerning the influence of mother on the offspring during development; some of these explain birth marks as the results of fright or other emotional experiences of the mother; others attribute mental traits of the offspring to mental states of the mother during the intra-uterine life of the offspring. It may be set down definitely here that there is absolutely no direct connection between the nervous system of the mother and that of the embryo; the relationship is similar to that of parasite and host. Many of the superstitious and pseudo-scientific ideas concerning prenatal influence are therefore purely imaginary and have no basis in anatomical nor physiological facts; any school of pseudo-science that includes prenatal influence as one of its doctrines is utterly worthless so far as that basis is worked into its teachings. In order for a maternal factor, a food, a poison, or an emotional state, to affect the development of the embryo it must affect the chemistry of the mother's blood in such a manner as to influence the transfer of materials through the membranes in the placenta. It is unthinkable that a fright by a mouse, for instance, could be transformed into a blood ingredient that would pass through the semi-permeable membranes of the placenta, traverse the long vein that conducts the blood from the placenta to the embryo, and in the embryo be transformed into a pattern in the skin that resembles a mouse.

It is possible for certain types of bacteria to penetrate the membranes of the placenta, enter the blood stream of the embryo and infect it. Disease acquired in this way is not strictly speaking an inherited disease; it is merely an intra-uterine infection not different in principle from infections of adults.

Embryonic Membranes. The embryos of birds and of mammals are enclosed in a sac derived from the ectoderm and outer layer of mesoderm during the early period of development. This sac is the AMNION and is filled with the amnionic fluid (Fig. 191). During development, then, these embryos are immersed in a liquid, the principal ingredient of which is water. At the ventral mid-region the walls of the sac turn toward the embryo forming a tube, the UMBILICAL CORD. The human umbilical cord may be several feet long (Fig. 191). It is traversed by the blood vessels that connect the placenta with the embryonic circulation and by the stalk of the yolk sac and the stalk of the endodermal structure that in early embryonic life is the origin of the embryonic portion of the placenta. The

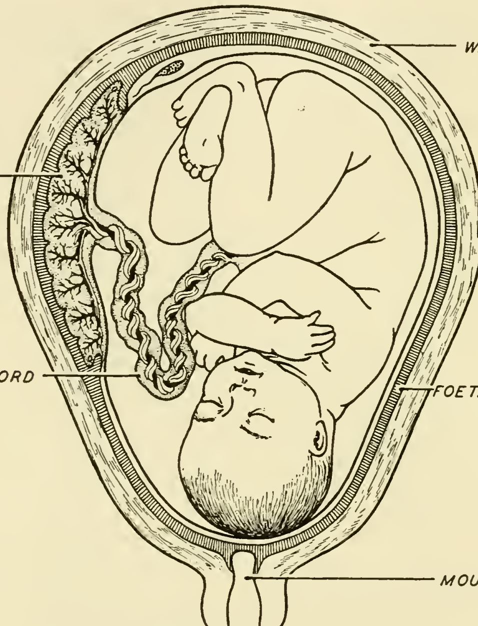

Fig. 191.—Diagram to show the position of the human foetus in the uterus, the umbilical cord, and the position of the placenta. (After Ahlfeld.)

large amnionic cavity and the relatively long umbilical cord permit considerable movement of the developing offspring. The amnionic fluid serves to equalize pressure on the embryo and as a protection against contact between the rapidly growing embryo and extra-embryonic structures.

Embryonic Vestigial Structures. Recapitulation. The adult of higher animals has a considerable number of structures that are without function. For example, the vermiform appendix of Man is a small blind tube continuous with the cæcum, a pouch at the junction of the large and small intestine, and is without function in the digestive process. Such structures are called vestigial organs, for they appear to be vestiges of functional structures of lower animals. In the rat and the rabbit there is no vermiform appendix, the cæcum being long and including at its end the portion that is homologous with the appendix of Man.

Similarly, some of the structures that function in one fashion in lower animals are partially obliterated during the development of higher forms and modified to assume quite different functions. For example, the visceral pouches in the aquatic vertebrates become gills and are the chief respiratory organ; in mammals these pouches appear in the embryo, but some of them are obliterated while others are transformed as organs of quite different function, none of them being concerned in the development of the respiratory organs. The appearance during development of a considerable number of such vestiges has led to the formulation of a BIOGENETIC LAW, which states that the development of an individual repeats the history of the species as derived from ancestral types.

Without going into the great mass of facts of anatomy and of development that agree with the principle of biogenesis, or RECAPITULATION, and the facts that appear to make it of limited application, it may be stated with accuracy that the occurrence of vestigial structures and the conversion of structures to new uses are most rationally explained by this law. However, the application of the law must be made only in the most general way, for in no case is any developing stage of an embryo identical with the adult of a lower species. There is frequently a resemblance which is highly suggestive that in the development of the individual we are witnessing a sort of historical panorama, but there is no absolute identity of higher embryo and lower adult. Human embryos develop endodermal pouches which are similar in position and structure to the endodermal pouches in the fish embryo. In the fish they develop into gills; in Man they develop into a number of structures. Human embryos do not develop gills.

Form and Symmetry in the Developing Animal. It has been possible here to consider only the high lights of the essentials of development of the body layers and organ systems of the animal. The account would be still more incomplete if we did not consider the question of the manner and mechanisms by which the new individual is organized into an animal having a definite antero-posterior axis, an anterior and a posterior end, with organs and limbs appearing at definite places along this axis and with right and left halves essentially mirror images of each other. This controlling and determining nature of the developmental process always interests the professional biologist; it may be that the general reader will be similarly intrigued once the nature of the problem is made clear.

To begin with, protoplasm is not a chaotic association of water, proteins, fats, carbohydrates, salts, *et cetera,* but is, as we have seen (Chapter I) a highly and intricately organized polyphasic colloidal system. Moreover, the cell is a similarly highly organized unit composed of this complex colloid, each type of cell being somewhat differently organized although all cells have features in common. The adult animal is likewise not a fortuitous association of cells, tissues, and organ systems no more than a house is a mere mass of bricks, mortar, wood, and iron. One may therefore speak of the type of organization of the animal as its structural pattern. Attention will be confined here to the type of pattern that is exhibited by the higher animals, characterized by an anterior-posterior axis and bilatetral symmetry.

When the fertilized egg starts to develop the first signs of division are noted in the upper, more active, animal pole. The cleavage planes are initiated there and hence this region acts as a leading element during the early stages of development. Similarly, throughout the developmental period, the embryo exhibits a region or regions that lead in the appearance of new structures and seem to act as dominant elements, controlling and coordinating the initiation of developmental processes of other regions. In the gastrula the dorsal lip of the blastopore is such a dominant element. If the dorsal lip of an early gastrula of a salamander embryo be cut out and transplanted to an abnormal position on another gastrula of approximately the same stage of development, it in some way causes the cells of the host in its vicinity to develop into neural plate cells and eventually to form an abnormally situated neural tube. This action of a bit of tissue foreign to the developing host is rather amazing, for the ectodermal cells that otherwise would normally develop into the superficial layer of the skin, under the influence of the transplanted tissue become differentiated into nerve tissue with the extremely specialized characters that distinguish that tissue (Fig. 193).

When the neural plate has formed, apparently under the influence of the dorsal lip of the blastopore, the antero-posterior axis of the new animal has been definitely established. The anterior end of the neural plate and subsequently developing neural tube now appears to become the leading element; the blastopore either closes or becomes differentiated into other structures. Development is now marked by the fact that the anterior regions of the embryo lead in undergoing the chemical and structural transformations of growth and differentiation. Thus the features resembling the adult form of the head are first to appear; the anterior limb buds form first (Fig. 184). The anterior end of the nervous system differentiates into the parts of the embryonic brain and assumes an advance over more posterior nervous tissue. This character of development is known as the Law of Antero-posterior Development; briefly stated, the law is, that, in general, in the development of the animal or of any of its organ systems the most anterior region is first to appear. These facts constitute visible evidence of an underlying principle of animal organization, namely, the principle of dominance and subordination. More specifically, anterior regions, or certain of them at least, are leading elements that in some way control and influence the developmental fate of adjacent and more posterior regions.

In recent years careful studies of the nature of the differences between such dominant regions and subordinate parts have shown that the dominant regions are more active physiologically; they undergo differentiation sooner, they grow more rapidly, and are first to be poisoned by powerful toxic substances. In the comparatively few cases where it has been possible to make the test, it has been found that dominant regions consume oxygen more rapidly than do subordinate regions; furthermore, when connected through a sensitive galvanometer, it is found that a dominant region bears a positive electrical charge in relation to the charge of the subordinate region, very probably because of its more rapid oxidative metabolism. A sufficient number of facts are not yet at hand to permit us to conclude definitely that the control of form and organization is effected by the electrical relations between parts, but the facts suggest the possibility that this may be the basis of the mechanism. As regards the development of form in the human body, we have at hand only a few general facts, largely relating to the more rapid growth and development of the anterior end and demonstrating that the law of antero-posterior development applies. In the absence of other evidence it would not be sound science to assume without qualification that the mechanism that causes the human body to assume antero-posterior organization and bilateral symmetry is electrical in nature; the possibility is suggested, however, by the facts known concerning the nature of dominance in simple forms.

As organ systems in the embryo develop, the form characteristic of that particular animal begins to appear. The process is gradual and during the early period of development all embryos within the phylum look very much alike. Thus a human embryo strongly resembles that of a bird or of a fish during its early stages; presently it may be distinguished as a mammalian embryo, but it must progress to still more advanced conditions before one can distinguish the characters that are distinctly human. Here, again, the evidence suggests some sort or path of relationship between Man and other animals.

Abnormalities. Human interest is usually stirred by the appearance of monstrosities and abnormalities in young animals, particularly in infants. Explanations based on superstitions have sometimes been cruel. To the student of Embryology, it is considerably more of a marvel that so many individuals of the same species resemble each other so closely and that abnormalities are so infrequent. For, as has been emphasized, protoplasm is highly susceptible to all sorts of conditions in its environment, and in addition, the protoplasm of a developing embryo is involved in an accomplishment that depends on a number of accurately adjusted mechanical and chemical events. Cell divisions, growth, differentiations, foldings, and changes of position are phases of development that are coordinated with great exactness. It is not difficult to imagine that minor changes in the environment of a developing embryo at a critical stage may effect departures from the usual course of developmental events and produce an abnormal form. When this is put to test by subjecting embryos to abnormal environments, just these results ensue. What we call a normal form in an animal is the result of the usual shifting of layers, of the usual growth of parts in relation to each other, of the spacing of structures, and the usual undercurrent of chemical changes that produce the appropriate tissue at the proper time.

The most common abnormalities are duplicities, double heads, double posterior parts, or double limbs. The origins of these are to be sought in the properties of the embryonic parts which normally give rise to a single structure. The region or bud that ordinarily develops into a single limb, is composed of embryonic tissues that possess the general property of limb formation. A region or bud of this sort that has the potential to form a definite adult structure is spoken of as the PRIMORDIUM of the adult structure. If a limb primordium is divided before these properties are realized, then each of the divisions possesses the property of limb formation and two or more limbs may develop, depending on the number of divisions of the original limb primordium (Fig. 192). The division can be accomplished in several ways. Experimentally, the bud may be divided by an incision, or by planting a piece of some other tissue in such position as to divide the structure.

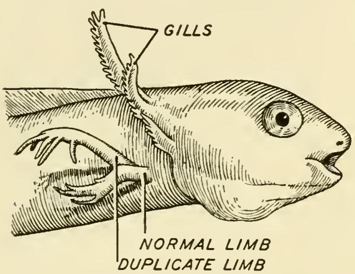

FIG. 192.—A salamander larva with a duplicate forelimb experimentally produced by an operation on the primordium of the normal limb. Note that the duplicate limb is the mirror image of the normal. (After Harrison.)

Similarly, the origin of double heads or double tails may be referred to accidental separations or divisions in the primordia of these structures before their developmental processes have become fixed and determined. Experimentally this has been done by mechanical means and by the obliteration of the physiological organization of the organism or a part, that is, by suppression of the dominant-subordinate relations. This has been accomplished in the embryos of lower forms by obliterating the normal differences in rate of metabolism with various agents, low temperature, absence of oxygen, and chemicals that have a depressant action. If the functioning of the leading or organizing region is interfered with during critical periods of development, dominance no longer is complete and parts undertake more or less independent development; abnormalities result. The principle is illustrated most strikingly by some experimental work with adult hydra. If hydra are placed in a weak solution of alcohol, they eventually lose their vase-shaped form; the tentacles and mouth region are resorbed and the body appears to melt down to form a flattened round mass of cells. Now if the alcohol is removed before the injury is fatal, new mouths equipped with tentacles appear at several points around the edge of the flattened mass. It is interpreted to mean that the depressant action of the alcohol has extinguished the relation of dominance and subordination that obtains between the apical or mouth region and the remainder, and that new dominant regions arise when this depression is removed.

One of the most common human congenital defects is harelip. It results from the failure, or partial failure, to fuse on the part of

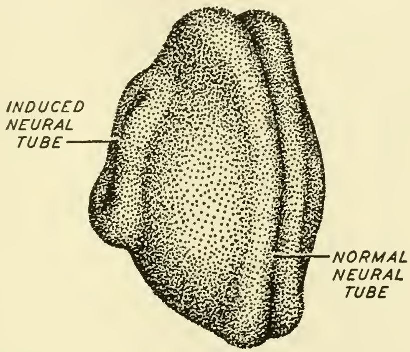

Fig. 193.—An early salamander embryo with a normal neural tube and one induced to form by a small portion of the lip of the blastopore of another embryo transplanted into the side region. (After Spemann and Mangold.)

the two processes that grow out from the primordium of the lower jaw on either side. Normally these two maxillary processes meet at the mid-line and fuse to form the upper jaw, upper lip, and palate. Harelip has no significance whatever, except the incomplete fusion of these two processes; it is not possible to state exactly the cause of this growth deficiency.

While much of the detail of the nature of the processes that regulate normal form in the development of the individual, and of their upset by environmental conditions, is yet obscure, in a general way abnormalities can be accounted for in terms of abnormalities in differentiative and growth metabolism, that is, in terms of mechanism rather than vitalism. They are visible evidences of aberrant physico-chemical events that have interfered with the controlling and correlating properties of leading elements or have divided regions before the inherent developmental potentials have been realized. In no sense do such abnormalities of form represent punishments or mental impressions of the parent; nor are they "freaks," for they are the consequence of the operation of mechanistic principles and not of supernatural laws.

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Chapter VIII

GROWTH, AGE, AND DEATH

Age and the Passage of Time. We watch the animals with which we are familiar in everyday life grow to maturity, eventually reach a stage of decreased activity which we call old, and finally, even if they have escaped accident and disease, die. Consequently there is a general interest in what constitutes growth, what is the significance of age or SENESCENCE, and why does death ensue. One's interest is the more acute because the human body goes through exactly these experiences.

Recent investigations on the development of some invertebrates have indicated that within a very brief time after an animal egg is fertilized it begins to consume oxygen very rapidly. After soon reaching a maximum, the rate of respiration in proportion to mass starts to decline, rapidly at first, then more and more slowly until in adult life the decline, if it continues at all, is very slow indeed. The deceleration in rate of respiration is not steady but fluctuates with temporary events in the life of the animal; the general trend is downward, however. The rate at which oxygen is being utilized by protoplasm is an index of the rate of energy transformation; hence more energy is being utilized by the developing egg in proportion to mass of living protoplasm than at any other time of life. If we think of age not in terms of lapsed time but in terms of ability to transform energy, an animal grows old much more rapidly as an embryo than as an adult.

Growth. Similar rules hold true with rate of growth. GROWTH, in general, is increase in size as a result of metabolism. It is most rapid in relation to the size of the organism in early embryonic

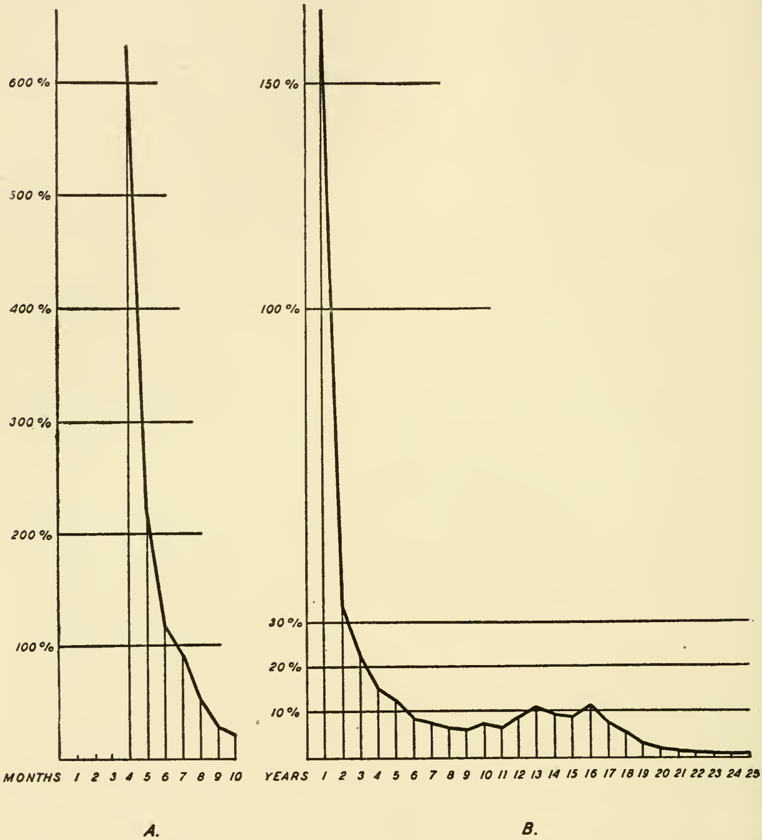

FIG. 194.—*A*, graph showing the decrease in rate of weight gain in the human embryo from the fourth lunar month of development until birth. *B*, graph showing the decrease in rate of weight gain in humans from the first to the twenty-fifth year. (After Minot.)

life, and declines, with fluctuations, as development proceeds (Fig. 194). In Man growth ceases altogether when all the principal tissues are completely differentiated. In animals that reproduce agamically, growth of differentiated tissues is a more or less continuous process, for as maximum size is reached the animal divides. Thus in the planarian worm fission occurs when growth slows and instead of one old animal there are two young animals entering a period of more rapid growth.

Growth rate varies with a number of circumstances. In the first place, rapidity of growth fluctuates normally during the developmental period. Secondly, the various organs of the animal body do not all grow at the same rate; some, for example the human brain, attain their final size earlier than others. Moreover, some tissues continue to grow indefinitely after the growth of others has ceased. For example, the surface of the human skin that is being constantly worn off is replaced by the continuous growth and cell divisions occurring in the lower layers of the epidermis. Growth of this sort in the adult is essentially the replacement of lost cells; the total tissue so produced does not increase the size of the animal.

Third, size is an inherited character; hence because of inherited qualities some individuals in a species grow more rapidly than others. Fourth, the supply and quality of food and the general vigor of the organism are important not only in determining rate of growth but also in regulating the final size.

The basis of all organic growth is the holophytic metabolism of green plants, converting inorganic substances into forms that may be used in constructing plant and animal protoplasm. All growth is then initiated by plant metabolism; all living forms are thus linked together, from the minute nitrogen-fixing bacteria to the most advanced animal, as a consequence of the complete dependence of animals on plants for the materials and energy for growth. Animal growth is dependent upon a food supply containing complex compounds, proteins, fats, and carbohydrates. In the development of the embryo these are supplied by materials stored in the egg, or by the maternal blood. With the development of the organs of nutrition in the oviparous animals and after birth in the viviparous forms, the food available for growth is dependent upon the efforts of the animal and the supply in its surroundings. Rapidity and extent of growth may therefore depend to a considerable degree upon environmental conditions.

The Vitamins. It has been found in recent years that not only quantity but also certain qualities of food are necessary for growth. Growth in the young and the maintenance of normal metabolism in the adult are dependent, in part at least, upon the presence in the food of small quantities of substances termed VITAMINS. Five of these have been detected, all apparently necessary to normal life. Their exact chemical structures are not yet known. They have been named in the order of their discovery.

Vitamin A is found in fats, particularly cod liver oil, butter, and in the leaves of plants. When it is absent from the diet, young animals fail to grow. Its absence from the diet of adults in some way causes the degeneration of epithelial tissues, resulting in ulcerations of various types.

Vitamin B is water soluble and occurs in green plants, germinating seeds, fruits, eggs, milk, and other foods. In its absence beriberi, a serious degenerative disease, develops.

Vitamin C is found in fruits, particularly the citrous fruits, lemons and oranges, and in most vegetables. When it is absent from the diet, scurvy, a degenerative disease, formerly common among sailors on long voyages and among explorers in polar regions, will develop.

Vitamin D, like Vitamin A, is found in cod liver oil and elsewhere with Vitamin A. It is concerned with the metabolism of bone and in its absence bone growth and maintenance are interfered with, a condition known as rickets.

Vitamin E is found in green leaves and germinating seeds. In its absence growth and general health appear to be normal but degeneration of the gonads occurs, particularly those portions which have to do with the maturing of the germ cells. Its deficiency is one of the causes of sterility.

Disorders produced by the lack of any of these substances are rather promptly relieved by the addition of the proper vitamin to the diet. Vitamin deficiency, however, renders the animal more susceptible to infection by pathogenic bacteria; consequently serious results may flow from deficient diets. Ordinarily, the varied diet of civilized Man provides all necessary vitamins, so long as moderate attention is paid to the constituents.

But it must not be supposed that the studies of growth have ceased with the discovery of the facts that have just been outlined. The final word has not yet been said, for investigations of growth and of the nature of growth-promoting and growth-inhibiting substances go on continuously. Particular attention is being paid to the chemical nature of certain proteins or protein-like substances that are concerned in growth; also the nature of the vitamins and their action are being subjected to further analysis. Moreover, growth is being studied from the standpoint of the energy required and the manner in which the supply of energy is transformed, particularly during the early period of development of the animal, when growth is most rapid.

Growth and Differentiation. The property of continuous growth is exhibited by embryonic tissues, so long as differentiation does not occur. This is illustrated in a most striking way by the behavior of tissues that have been removed from the embryo and induced to live in an artificial medium. More than twenty years ago in a prominent research laboratory, a fragment of heart tissue was removed from an embryo chick and placed in a suitable nutrient solution at the proper temperature. The culture is still continued. Growth and cell divisions take place but there is no differentiation; it is today still embryonic heart tissue. At intervals of several days fragments are removed and the nutrient solution renewed. This culture has been carried on continuously; the amount of embryonic heart tissue that might have been formed during the many years of cultivation is tremendous, exceeding by many million fold the total heart tissue of an adult chick. There is no reason to expect it to cease to grow; barring accidents of the environment this tissue is immortal, so long as it does not differentiate and form adult heart tissue.

Differentiation, the process of specialization of tissues during development, confers certain properties of structure and function, but these are apparently antagonistic to growth and cell divisions. In general the older the embryo the more sharply are the tissues defined; and the higher the animal in the scale of complexity the more completely does differentiation terminate growth and cell divisions. For example, the nerve cells of the human body are frequently regarded as one of the most highly organized types of cells. Increase in nerve cell number is said to cease during the first year after birth and the brain reaches its maximum growth very early. Once a human nerve cell body is destroyed, it is never replaced.

Tumors and Cancers. The antagonism between growth processes and differentiation is also exemplified in abnormal growths in the adult animal body. Such adventitious growths are commonly called TUMORS and CANCERS; by scientists they are known as NEOPLASMS. There are many types of cancerous tissue but in general they form two classes, MALIGNANT and BENIGN. Malignant cancers consist of cells that carry on a continuous process of growth and cell division, without differentiating into anything resembling normal tissue. Benign growths contain differentiated tissues such as epithelium or fibrous tissue. Such tumors attain a maximum size and often cease, or very nearly cease, to grow. Malignant neoplasms, on the other hand, increase incessantly.

Regeneration. We have seen that highly differentiated tissues are incapable of increase. In last analysis, this means that cells that are highly specialized and differentiated have lost the ability to undergo division and to produce other cells like themselves. When such tissues are injured and parts removed. no replacement occurs unless the new part or tissue is derived from some less specialized type of cells. For example, the nerve cells of the human brain do not undergo division; an injury in which some brain cells are destroyed results in a permanent loss of the nerve cells of that particular region. No other type of cell is capable of being transformed into a brain, or a nerve cell. Similarly, human muscle cells from such muscles as those of the arm cannot undergo division and if destroyed or removed are not replaced; their place is taken by a type of connective tissue that forms a scar.

The replacement of a part which has been lost is known as REGENERATION. Ability to regenerate lost parts, in general, decreases from the lower to the higher types of animals, and in general decreases with the age of the individual animal. But there are many exceptions to this rule and many factors other than position in the scale of animal life and age of the individual are concerned in this ability to regenerate.

If an amœba is cut into two parts, the part which contains the nucleus usually will re-form and in time regain its normal size, while the part lacking a nucleus may initiate but never completes regeneration; parts that lack the nucleus or any part of the nucleus always die. This is also true of other Protozoa. One may state it as a general rule that parts of cells that lack nuclear material do not regenerate and live only a brief time.

The Porifera and Cœlenterata exhibit the most extensive powers of regeneration. If certain species of sponges are cut into small pieces and the tissues pressed through silk bolting cloth, some varieties of cells in the resulting minute fragments will assemble and develop into adults. In some cœlenterates also, small fragments will regenerate the whole. If the stem region of many species of hydroids (p. 102) is cut into sections, the feeding and reproductive hydranths having been removed, each section will regenerate into a new individual. Curiously enough, most free-swimming Cœlenterata have very little or no power to regenerate. Ability to regenerate is high in some of the free-living flatworms (Platyhelminthes) but is very low in most of the Nemathelminthes. Annelida and Echinodermata, or at least certain members of these phyla, are able to regenerate a whole from a part, but regeneration in Arthropoda is limited to the replacement of appendages by some members of the group; for example, a new claw will develop on the leg of a lobster when one has been broken off. In some of the lower members of the phylum Chordata, the sea squirts, a separated portion may regenerate the whole animal. Among the Amphibia, some salamanders (tailed Amphibia) will regenerate a lost leg, but the frogs and toads (tailless Amphibia) are unable to do so. In the higher animals only certain tissues retain the power of regeneration. In the human body, the epidermis, the blood, and a few other tissues are capable of regeneration.

In forms like planarians, nemertians, and similar simple forms that will regenerate a whole animal from a small fragment, the processes of regeneration are in some respects like those of the development of an adult from an embryo, although the tissue at the start of regeneration is adult, that is, old tissue. Thus to begin with, regeneration in such forms involves a renewal of the characters of young animals, a rejuvenescence. In general, animals which possess the power of regenerating a whole animal from a piece are also animals that reproduce asexually, by budding or fragmentation, but this is by no means invariably true. For example, *Phagocata gracilis,* a small flatworm closely similar to Planaria reproduces solely by the sexual process of fertilization of eggs by sperms; but a very small portion of the adult animal will regenerate into a normal whole.

If a cross piece is taken from the body of hydra or from the body of a planarian, the new hydranth or the new head develops at the end which was most anterior in the whole animal. In other words, the piece retains the polarization that it possessed while in the intact animal, the same relation of dominance of the anterior over the more posterior regions. The principle of dominance and subordination in regulating development of form (p. 282) then applies to the processes of regeneration as well as in the development of the adult from the embryo. Curiously enough, fragments of some planaria, and of other forms as well, may be made to develop two heads, one at each end of the regenerating fragment (Fig. 195). In such cases the polarization, that is, the relation of dominance and subordination which ordinarily determines that one region shall become the head because of its higher metabolic activity, has been obliterated, and both cut surfaces, being equally independent and equally active, regenerate heads.

It has been set forth that the anatomical characteristics of an animal are determined by the degree of complexity of its various organ systems (Chapters V and VI). Similarly, many of the physiological characteristics of an animal are determined by its relative properties of growth, differentiation, regeneration, and agamic reproduction. When differentiation in the adult is sharp, the other three properties are reduced or lacking; differentiation in an adult human is high and the animal no longer grows nor regenerates nor reproduces agamically. Thus Man and other mammals in general are regarded as the most highly differentiated forms of

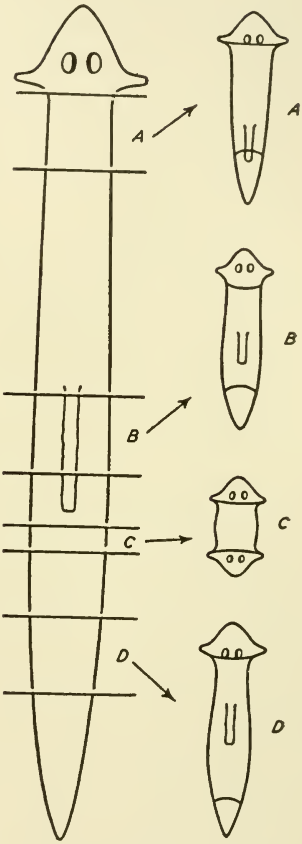

Fig. 195.—Regeneration of pieces from different regions of a planarian worm. *C* is a biaxial form; the piece was cut in such fashion that neither end dominated the other during the regeneration of the head; hence two heads were formed.

animal life, but this high degree of differentiation has been at the expense of ability to grow continuously and to regenerate lost parts. In animals which may reproduce agamically a physiologically young condition is restored to the products of the reproductive division; rejuvenescence by this method is denied the mammals, lost in the high differentiation and specialization of the tissues. Individual mammals grow old; only the mammalian fertilized eggs become young again.

Rejuvenescence. When animals grow old their metabolic processes slow down, the denser products of metabolism accumulate in the cells and intercellular substance, and anabolism, the constructive phase of metabolism, becomes less and less conspicuous, while the katabolic phase becomes more prominent. Eventually as a result of this shift from a predominantly constructive to a destructive metabolism, the protoplasmic structure is altered, energy transformation decreases below that necessary for continued maintenance, and a disorganization familiarly called death ensues.

From the beginnings of human intelligence men have sought to reverse the process of growing old and to attain immortality of the human body. For "the most familiar imperfection of Mankind is growing old." We have seen that chemical reactions constitute the important part of metabolism and that growth, differentiation, and senescence are some of the consequences of metabolism. According to commonly accepted chemical theory, all chemical reactions are reversible. Are growth, differentiation, and senescence chemical processes that are reversible in the human body? If so, rejuvenescence and restoration of youth to an old person should be possible.

In some of the lower invertebrates it is possible to demonstrate the reversibility of these processes. If a well-fed large flatworm is starved it becomes smaller and smaller. A planarian three-quarters of an inch long may be reduced by several months' starvation to an animal approximately one-eighth of an inch in length and having the physiological and structural characteristics of a young animal. Accompanying the reversion of growth is a corresponding reversion of differentiation. In other forms that reproduce agamically there is a similar reversal of tissue condition from an old to a young state. But these methods of rejuvenescence are not to be applied to complex vertebrates nor to mammals. The mammalian body represents a very complete differentiation of tissues and an extremely closely correlated mechanism in which the continuation of life in one tissue depends on the normal activities of all other tissues. Not all tissues and organ systems have the same energy requirement; hence starvation of a tissue may reach a degree fatal to its function before others are extensively affected. The whole mechanism breaks down when undergoing starvation as a result of the failure of one or more parts and death results. There is no reversing of growth nor of differentiation.

Two other concepts of the nature of old age have attracted some attention. According to one theory, the human body poisons itself by reason of the absorption of toxic substances produced by bacteria from the contents of the digestive system; the long-continued accumulation of effects of such absorption is said to be responsible for senescence. There is sufficient fact to lend some weight to this theory, for the blood stream does continually absorb substances that result from the fermentation of foods in the intestine. However, while this may be contributory to the onset of various infirmities that characterize old age in Man, it can hardly be regarded as the cause of age; senescence is a metabolic phenomenon, not a bacterial disease. According to another theory that has attained some prominence with the growth of knowledge of the endocrines (p. 203), senescence is a consequence of decline of the normal activity of certain endocrine glands, particularly of the gonads. Attempts have been made to restore bodily vigor by implantations of glands from various sources. The results have not in general afforded support for the theory; the fact that senescence is metabolic and general has again been lost sight of, or ignored.

Duration of Life. Duration of life, barring accident or disease, varies greatly among animals. Accurate data of the maximum age reached by common animals are not easily obtained, but we are familiar with the fact that some insects may live but a few days, some of the smaller mammals for a few years only, and that very exceptionally does a human live for more than a hundred years. We are also familiar with the fact that duration of life is greater among some human families than others. Thus duration of life is a diagnostic feature, a part of the attributes of the several phyla, and is an inheritable character within the species. So, the length of a human life is determined at its very beginning, within certain limits, by inheritance.

Death in an animal body may result from one of two conditions: An accident of the environment, including destruction by disease, and the ceasing of the fundamental metabolism by reason of changes brought on by time. Mammals are thus in double jeopardy; accident, disorders, or infection may destroy at any time in life; if these are avoided death due to gradual arrest of metabolism is inevitable. But in a complex animal body all cells do not cease to function simultaneously. Experimentally one may, by proper handling, keep some tissues and organs alive for a considerable time after they have been removed from the body. The ultimate death of a metazoon body is reached when all the cells have died; life, then, may persist for some time after the body as a whole has ceased to exhibit the characters that are commonly recognized as evidence of life. The maintenance of life is therefore conditioned upon the interdependence of the cells, an expression of organization. Death must represent some sort of disorganization.

Death of Protoplasm. In last analysis death means the death of cells and cell death is brought about by protoplasmic disorganization. As we do not know the exact organization of living protoplasm beyond that revealed by the highest powers of the microscope and by such other observations as are available, so we do not know the exact nature of the processes that result in the irreversible cessation of protoplasmic activity, that is, death. But as a matter of fact, much that is known concerning the vital processes has been gained by studies on the processes of disorganization preceding death. The fact that protoplasm is a colloid and hence is subject to the laws governing colloidal behavior suggests the probabilities that underlie death of the cell. By definition a colloid consists of matter suspended in a finely divided state. Many sorts of agents cause the finely divided particles to clump together, a process known as coagulation. The coagulation of a colloid represents its disorganization, its change from one type of structure to another. In some colloids coagulation is irreversible; for example, the coagulation of egg white by heat or by alcohol. Conditions similar to this type of coagulation are observed when protoplasm dies, and some biologists have expressed the view that death is primarily an irreversible coagulation of protoplasm.

The physical changes that mark the irreversible disorganization of dying protoplasm are accompanied by chemical changes. But some of the chemical processes of metabolism are not extinguished by the destruction of the living structure of the cell. If a cell is ground up with sand or otherwise crushed and mechanically disintegrated, the remaining formless mass continues to consume oxygen for a time. From such preparations it is possible to extract enzymes that remain active. But enzymes, the organic catalysts, are not alive; their activity merely plays a part in the total metabolism of the protoplasm. Again we are impressed with the evidence that life is a consequence of organization, not of specific chemical processes nor specific substances.

Let us return for a moment to the subject matter of the first chapter. In the light of the facts outlined in the present discussion one may add still another characteristic of life to those listed in

Chapter I, namely, that all living organisms endeavor to avoid death, either actively by the functioning of the property of irritability and by escape, or passively by reason of its powers of adaptation to environmental circumstances. Protoplasm was described as a complex colloidal system in which the laws of physics and chemistry operate; but we know of no non-living colloidal system that either actively or passively changes character to avoid coagulation or other disintegrative influence.

Cycles. So far as the life of any particular animal is concerned, death closes and extinguishes its existence as living matter. But the species is perpetuated through the rejuvenescence of the zygote during reproduction and much of the energy expended during individual life is devoted to this continuation of the species. Thus the continuity of the species is all important; the life of the individual is of secondary importance. With the fertilization of the egg a new individual is initiated and continues as the carrier of life to succeeding generations. From the general picture thus presented one obtains the view that the path of an animal species through time is a succession of cycles; egg, development, adult, egg, development, and adult succeeding each other as the centuries pass. One also thinks of an individual animal in terms of its life cycle and notes that in some species a life cycle may include several varieties of form. For example, the hydroids exhibit an alternation of sexual and asexual generations; various parasitic worms assume several forms within the life cycle (p. 260).

Cyclic successions characterize many phases of animal life. We are already familiar with the cycles of nitrogen and of carbon in Nature. Cells pass through division cycles. Individuals pass through reproductive cycles and life cycles. Is it possible that the species of animal life with which we are familiar are passing through species cycles, that they are destined to be succeeded by other species in the future?

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Chapter IX

HEREDITY

Species. Biologists look upon all living objects as forming a great unity made up of a wide variety of more or less remotely related groups, each group being divisible into smaller groups within which the resemblances are closer; increasing preponderance of similarities mark still more closely related subdivisions, until the ultimate indivisible unit is an individual animal or plant. The forms that most closely resemble an individual animal or plant are its parents or immediate offspring. A group within which the resemblances are so close that the various members may stand in the relationship of parent and offspring, or brother and sister, is commonly called a SPECIES. This is a general definition and is generally applicable, but within some groups commonly recognized as species some varieties are so distinct that they may be, and often are, legitimately regarded as separate species. Moreover, interbreeding sometimes occurs between recognized species.

Offspring always resemble parents but also always differ in some respects. To discuss the question as to the nature and mechanism of inheritance of parental qualities and as to the origin and nature of the differences between offspring and parent involves us in a whole series of other questions that constitute the complicated subject of heredity. Here we shall concern ourselves with inheritance within the species; hence it has been necessary to repeat and enlarge the definition of the word. The origin of species will be discussed elsewhere.

Galton's Law. Many years ago Galton, studying by means of statistics the inheritance of various traits, set down a law which was widely discussed and is still occasionally quoted. In brief, Galton's law holds that an individual inherits half its characters from each parent, one-fourth from each grandparent, one-eighth from each great grandparent, and so on back into its ancestry. The law attempts to state in quantitative terms what in a general way is the common observation of everyone, namely, that resemblances between parent and offspring are closer than between grandparent and grandchild, and that offspring resemble both parents. But it tells us nothing of the mechanism of inheritance, and, as will be apparent later, is definitely applicable only under conditions that are rare indeed.

The Cell Nucleus and Inheritance. Perhaps the most striking contribution of the present century to biological knowledge is the success attained in working out the fundamental principles of inheritance within the species. Obviously, the machinery of transmission of characters from parent to offspring is in some way associated with the reproductive cells. Spermatozoa and ova are very different in appearance and in physiological nature, yet both carry inheritable qualities. Ova consist essentially of a relatively large quantity of cytoplasm, more or less heavily charged with yolk, and contain a nucleus; spermatozoa have but a very small proportion of cytoplasm and no yolk, the cell being largely nucleus. The nucleus being the most distinctive feature common to both egg and sperm, attention centres on it as the seat of the inheritable qualities. Therefore in studying the nature and mechanism of inheritance, most minute attention must be given the nucleus and its changes during the passage from one cell generation to the next.

Cell Division. No one knows just why a cell divides. In growing tissues there appears to be some critical relation between the volume of the cell and the area of its surface, so that when a certain ratio of volume to surface area is reached, division into smaller cells restores a greater area in proportion to volume, but this is certainly not the whole cause of cell division. Nor are the physical and chemical processes that cause the nuclear phenomena about to be described, known. We are limited therefore to descriptions of the process as seen under the microscope.

Amitosis and Mitosis. In the final division of cells in the differentiation of some tissues during development, and under certain other conditions, the nucleus divides by separating into unequal fragments which then become the nuclei of daughter cells. This form of cell division is known as AMITOSIS; it is said that a cell having once divided by amitosis does not again divide in any other way. Its occurrence is, to say the least, infrequent and in all observed cell divisions concerned with the establishment of the individual, cell nuclei do not divide in this irregular and simple fashion. The usual division process is much more complicated. The indirect type of division, involving a regular and equational division of nuclear materials, is known as MITOSIS. Since inheritance in the last analysis depends on this type of cell reproduction, it is necessary to become familiar with the details of the process.

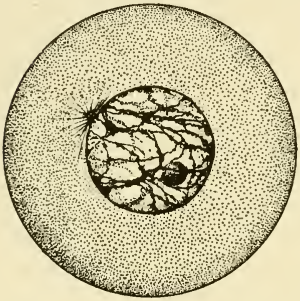


Fig. 196.—A cell; nucleus not undergoing any phase of cell division. Note the distribution of the chromatin.

Chromatin. In the nucleus of all cells may be found a number of different materials; chromatin (Fig. 196) is a type of substance that is common to all. Study of the mechanism of inheritance has closed in on chromatin as the material which plays an all important part and is apparently the container of inheritable qualities that are transmitted from generation to generation. As yet the chemical property of the chromatin that is responsible for its extraordinary powers is unknown; nothing that is very significant is revealed by the analyses which show it to be composed of NUCLEO-PROTEINS. Our chief interest here is in its behavior, first, during mitotic cell division. The account given is in general applicable to mitosis in all sorts of animal cells.

When the description of a typical animal cell is recalled, it will be remembered that the nucleus is surrounded by a thin membrane, outside of which is a small body, the centrosome, that was said to play a part in the division of the cell. Within the nuclear membrane the chromatin is scattered. Seemingly the quantity of chromatin in a cell not undergoing mitotic division is often less than appears later; either it is not in the chemical form necessary to accept the stains that are used in distinguishing it, or it is dissolved, or diffused in bodies too small to be visible. For convenience in treatment, the whole process through which the chromatin passes during mitosis is divided into four stages or phases.

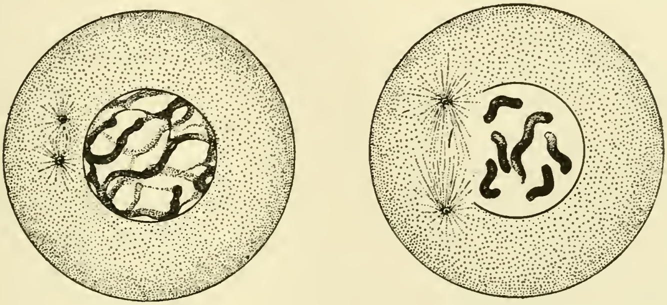


FIG. 197.—Two steps in the prophase stage of mitotic cell division.

The Prophase (Fig. 197). Approaching division is first indicated by the division of the centrosome into two units. Each acquires in the cytoplasm around it a set of radiating fibres, so that each presents a somewhat star-like appearance; these are now known as the ASTERS. The nucleus being essentially a sphere, the asters now move around on arcs toward opposite poles of the sphere and come to rest in positions exactly opposite each other, the nucleus between them. While the asters are thus migrating the chromatin granules within the nucleus become arranged into a distinct thread, known as a SPIREME because of its coiled arrangement, and the membrane around the nucleus begins to disappear, being transformed by some unknown process of metabolism. The spireme presently is resolved into a number of rods or other shaped units of chromatin known as CHROMOSOMES. As the nuclear membrane disappears these chromosomes that have resulted from the breaking up of the spireme come to position halfway between the asters. Meanwhile fibres have formed between the asters, which gives the whole complex of asters, fibres, and chromosomes the appearance of a spindle with a scattered group of dense bodies distributed about on a plane (the equatorial plane) at right angles with the long axis of the spindle and halfway between the two poles. This is known as the MITOTIC SPINDLE; its appearance marks the close of the PROPHASE.

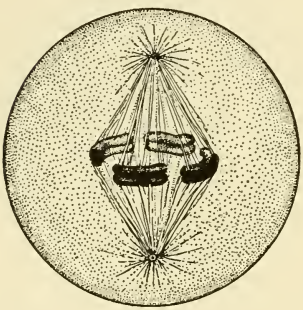


Fig. 198.—The metaphase.

The Metaphase (Fig. 198). **Chromosomes.** The second stage is the METAPHASE. Before describing it, however, it is necessary to give some attention to the chromosomes that have become so distinct during the prophase. Each species has a fixed number of these bodies in each cell during mitosis, except as will be seen later, in certain stages of the development of the gametes. Some chromosomes are rods, others are the shape of open hooks, others are spherical; all have characteristic shapes and it is possible to identify the chromosomes that descend from specific chromosomes through generation after generation of cell divisions. Thus, although the chromatin is scattered in a non-dividing cell, chromosomes always appear during the prophase in their characteristic form and number in each variety of organism. This number is called the SOMATIC or DIPLOID number, or merely designated as S. From this point on, it will be convenient to distinguish between the reproductive or germ cells and those of all other tissues of the body, designating the gametes as GERM PLASM and all other tissues as SOMA. For example, the somatic chromosome number is S and that of the germ plasm is $\frac{S}{2}$. The terms DIPLOID and HAPLOID are also used to refer to S and $\frac{S}{2}$.

Chromosomes are in pairs. That is to say, for example, the forty-eight chromosomes in the soma of the human female consist of twenty-four pairs, each member of a pair having been derived from a separate parent. Members of a pair are spoken of as HOMOLOGOUS CHROMOSOMES, or SYNAPTIC MATES. One pair in the human female is composed of two chromosomes that are concerned with the development of the female sex characters. These are designated as the X CHROMOSOMES; the other twenty-three pairs are referred to as AUTOSOMES. In the human male there are twenty-three pairs of autosomes, and one X or sex chromosome, whose synaptic mate is distinguishably different from an X chromosome and is designated as the Y chromosome. In the males of many of the lower forms the Y chromosome is completely lacking, so that in these organisms the chromosome number of the male is always one less than that of the female. The number of chromosomes is a species character. Thus in Man the number is forty-eight; in certain grasshoppers the females have twenty-four and the males twenty-three chromosomes; in some of the Nemathelminthes there are but four chromosomes. In moths and butterflies, in birds, and in some varieties of fish the male has two chromosomes which correspond to the X chromosomes, while the female has but one X and a synaptic mate which corresponds to the Y chromosome.

For convenience in this account the two members of a pair of autosomes are designated according to their parentage, as *p* and *m* (*p* having been inherited from the male parent and *m* from the female parent). Thus at the end of the prophase in mitosis in the human female there are at the equator of the spindle twenty-three *p* and twenty-three *m* chromosomes, that is, autosomes, and one *pX* and one *mX* chromosome. In the male the arrangement is twenty-three *p* and twenty-three *m* chromosomes, one *mX* and one *pY* chromosome.

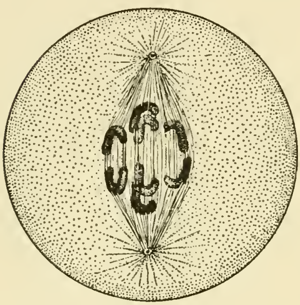


Fig. 199.—The anaphase.

The prophase is followed without pause by the metaphase (Fig. 198), which is brief and includes only the lengthwise splitting of each chromosome into exactly equal halves. If at this time one passed a plane exactly between the members of divided pairs, on each side of the plane would be a somatic number of chromosomes, each one-half the size of the original *p* or *m* chromosomes that have appeared during the prophase.

The Anaphase and Telophase (Fig. 199). The ANAPHASE follows at once. The new *p* and *m* chromosomes that result from the splitting during the metaphase now move toward the nearest centrosome, each product of the original *p* and *m* members going to opposite poles of the spindle. Rod-shaped chromosomes often appear drawn out into a V during this migration. At this time the surface of the cell flattens around an equator exactly opposite the equator of the spindle. Then a groove appears in the cell boundary. The groove becomes deeper as the chromosomes move nearer the centrosomes, and appears to constrict the cell. Sometimes the groove is wide and the dividing cell appears dumb-bell shaped. Presently the cell separates into two daughter cells, the actual division immediately preceding the last stage of mitosis, the TELOPHASE (Fig.

200). Each cell now contains adjacent to the centrosome the *S* number of *p* and *m* chromosomes. The telophase is a period of nuclear reconstruction. The nuclear membrane appears and within it the chromosomes lose their distinctness, the chromatin becoming again a spireme, then scattering and remaining so until the prophase of the next mitosis.

It has been found that in addition to the nuclear phenomena that characterize mitotic cell divisions, there are distinct changes in the physical nature of the cell contents. By centrifuging cells at various stages of the division cycle and noting the effect of centrifugal force in dislocating granules in the cell it became apparent that the viscosity of the cytoplasm changes during the cycle. At the time of the onset of separation of the two daughter cells the viscosity is greater than at any other period of the division cycle. By introducing exceedingly fine glass needles into the cell it was found that the whole mitotic spindle is considerably more rigid than its surroundings; it can be pushed about with the needle. From these and other facts it is perfectly clear that mitotic cell division involves profound changes in the metabolism and the physical nature of the cell substance; the process is not solely the changes which, with the aid of the microscope, may be observed to occur in the nucleus. But our interest here must be confined entirely to the nuclear phenomena.

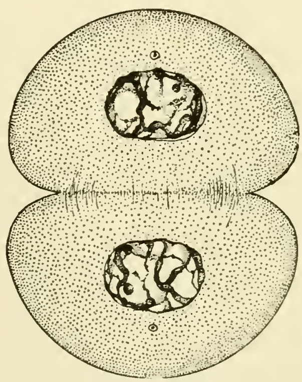


FIG. 200.—The telophase.

Mitosis is a most striking and regular performance and one who observes it cannot but be impressed with the equal distribution of the chromatin and the preservation of the identity of each *p* and *m* chromosome as synaptic pairs in the daughter cells. And so the quantity of chromatin and the identity of the chromosomes are kept constant throughout the numerous cell generations as the individual develops and grows from the fertilized egg to the adult. The manner of transmitting chromatin from parent to offspring is the critical process in the passing of inheritable characters from one generation to the next; our discussion of this process will complete the account of the essentials of the history of the chromosomes within the species.

The Chromosomes of the Zygote. Fertilization of the egg by the spermatozoon combines cells from two individuals. If both gametes were to contain the S number of chromosomes, the number in the new individual would be twice S, and with each succeeding generation doubled again. Shortly the number of chromosomes in the species would approach infinity, unless some sort of process reduced the chromosome number in the gametes. This reduction actually occurs in the ripening and maturing processes through which both sperm and ova pass before they are capable of fertilization. Consequently, when two gametes unite, each has but one-half the S number of the species $\left(\frac{S}{2}\right)$; the union of the egg and sperm nuclei thus restores the normal number of the soma. The process through which the chromosomes pass during the maturing of the germ cells is complex, but in order to understand the basic principles of inheritance it is necessary to comprehend it in some detail. The maturation of the spermatozoa will be described first.

Spermatogenesis (Fig. 201). The germ cells are set aside very early in the life history of the organism; in some animals they may be identified during the very first stages of cleavage. In the male mammal the primordial germ cells come to be placed in the walls of the seminiferous tubules; in lower forms they are located in other types of testicular tubes or follicles. Here by ordinary mitotic cell divisions they increase in number. During this period of multiplication they are known as SPERMATOGONIA. Presently, however, they cease to divide and enter a period of extensive nuclear change

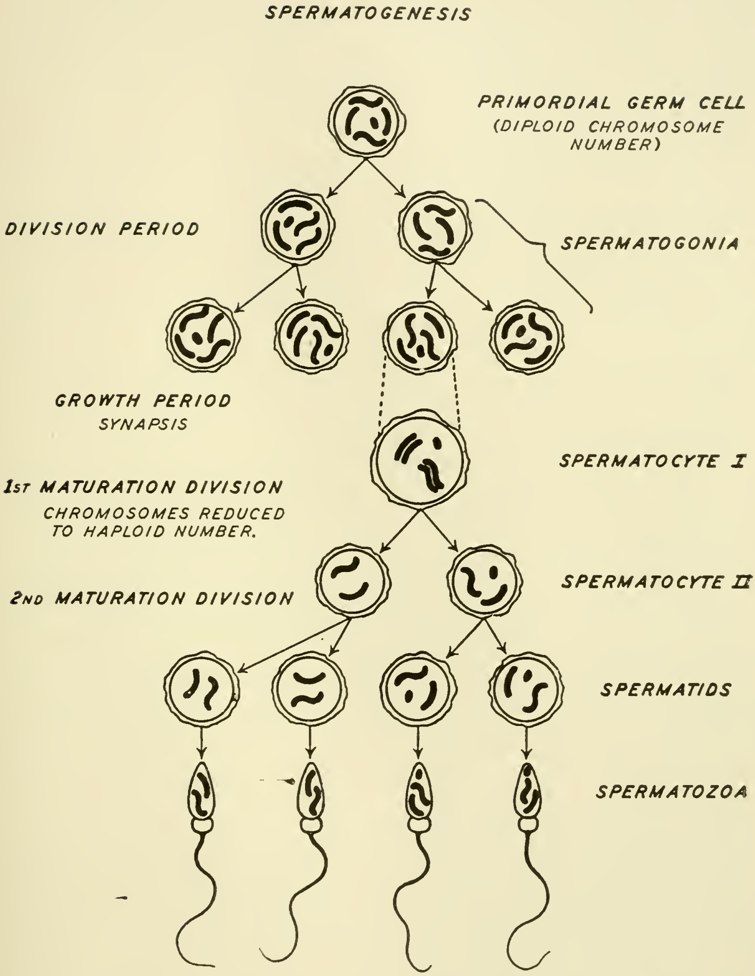


FIG. 201.—Diagram of the maturation of spermatozoa. Note the ~~two~~ types of sperms, one with and one without an *X* chromosome. One of each type is introduced in Fig. 203. For convenience the *Y* chromosome is omitted.

of great importance in determining the nature of the inheritable characters to be conveyed by the mature sperms. Cells undergoing these changes are known as PRIMARY SPERMATOCYTES; the stage is marked by an increase in nuclear size and an absence of cell division.

The nuclear material at the close of the telophase of the last spermatogonial division is similar in arrangement to that in any nucleus that has undergone a recent mitosis. At the beginning of the primary spermatocyte stage the chromatin becomes organized into a long thread, the spireme. Presently this spireme appears to be a double thread and then severs into a number of double chromosomes, the number being one-half the somatic number, or $\frac{S}{2}$. At this time these chromosomal bodies are in reality paired chromosomes, p and m being now united for the first and only time during the life history of the animal. The paired chromosomes are during this period either fused side by side or entwined together, and as they separate during the later stages of the primary spermatocyte, p contains a part of m and m contains a part of p. In other words, substances have crossed over and been exchanged between the two members of a pair. This contact period is known as SYNAPSIS. When the chromosomes separate, p is no longer the original p but a new mixture of chromosomal materials which may be designated as P; m is no longer m, but another mixture, not identical with P, which we may designate as P'.

The primary spermatocyte now passes through a modified metaphase in which all P chromosomes are on one side the equatorial plate and all P' chromosomes on the other side. On one side is the mX which we may now call PX and on the other side is the PY. In the succeeding anaphase all P chromosomes and PX go to one, and all P' chromosomes and PY go to the other centrosome. The division of the cell, which now follows, thus divides the chromosomes so that one of the daughter cells contains one set of the separated synaptic mates and the other cell the other set. The daughter cells of this division are known as SECONDARY SPERMATOCYTES, and, as we have seen, are of two sorts, one with X and one with Y sex chromosomes. The division of the primary spermatocyte is therefore a REDUCTIONAL DIVISION; secondary spermatocytes have half the S number of chromosomes. Consequently, all cells in stages following the secondary spermatocyte are haploid.

The secondary spermatocytes then divide without any further reduction or change in chromosome number. The division is in many respects a typical mitotic division, each P or P' chromosome splitting lengthwise during the metaphase, to contribute one-half itself to each of the resulting cells. These cells are the SPERMATIDS, one-half of which have all the P chromosomes, the other half having the P' chromosomes. One-half the spermatids contain PX chromosomes and the other half PY chromosomes. The spermatids become transformed by a complicated process but without further division into mature, active spermatozoa. There having been two generations of cells between the spermatogonia and the mature spermatozoa, one spermatogonium is the origin of four spermatozoa, two with X chromosomes and two with Y chromosomes. The spermatozoa of most animals are therefore of two sorts in equal numbers; in Man one contains twenty-three unpaired autosomes and one X chromosome, the other sort containing twenty-three unpaired autosomes and one Y chromosome.

Oogenesis (Fig. 202). The processes undergone by the chromosomes of the ovum during maturation are in many respects similar to corresponding stages in sperm maturation. The earliest female germ cells are the OOGONIA, corresponding to the spermatogonia of the male. After the mitotic divisions of this period of multiplication are ended they are PRIMARY OOCYTES, which correspond to the primary spermatocytes. During the primary oocyte stage, synapsis between p and m chromosomes of each synaptic pair occurs and the result is two new chromosomal elements, desig-

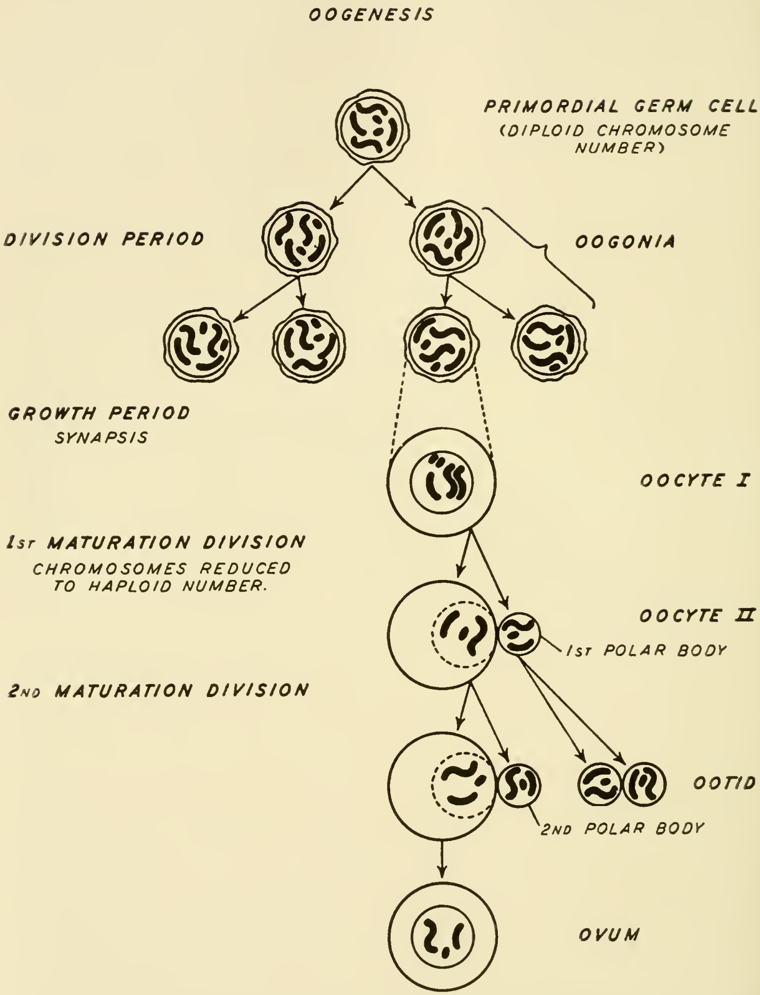


Fig. 202.—Diagram of the maturation of ova. The mature ovum shown appears again in Fig. 203. For convenience the *Y* chromosome is omitted.

nated here as M and M'. When the primary oocyte divides, reducing the number in the SECONDARY OOCYTE to $\frac{S}{2}$, one of the two daughter cells is not a functional secondary oocyte, but an abortive small cell called the FIRST POLAR BODY, OR FIRST POLOCYTE. It contains either all M or all M' chromosomes, which are thereby lost, for, although the first polocyte usually divides again, it never becomes functional nor seems to serve any useful purpose. It must be remembered that the polocyte also contains an X chromosome. The loss of chromatin represented by the nucleus of the first polocyte means that some of the inheritable characters may be dropped at this point in the chromosome cycle, for only those in the functional secondary oocyte ever have an opportunity to realize the characters of an adult.

The secondary oocyte, with $\frac{S}{2}$ chromosomes, then divides again by ordinary mitosis to form OOTIDS. But again one of these is an abortive, small SECOND POLAR BODY, OR SECOND POLOCYTE. The remaining ootid is now the only functional cell derived from the original oogonium, a marked contrast in number with the four spermatids derived from a single spermatogonium in spermatogenesis. The chromosomes of the ootid are one-half the somatic number, either all M or all M' elements, one of which is an X chromosome, destined to become the synaptic mate of the PX or PY chromosomes in the sperm. The ootid now becomes transformed into a mature egg, the transformation including an increase in size and usually the secretion of considerable quantities of food reserves, commonly known as yolk.

Composition of the Nucleus of the Zygote (Fig. 203). When the egg is fertilized by the spermatozoon the somatic number of chromosomes is restored and P and M chromosomes become the synaptic mates in the soma cells of the resulting new organism. If the sperm that fertilizes the egg happens to be one of those which contain the PX chromosome, the PX of the sperm and the MX

of the egg become synaptic mates and the chromosome complex, containing two *X* members, is that of the female of the species. If the fertilizing sperm is one which contains the *PY* chromosome, then the new animal has the chromosomal makeup of the male.

We may now think of *p* and *m*, and of *P* and *P′*, and *M* and *M′*, as representing paternal and maternal chromosomes. To analyze, *P*

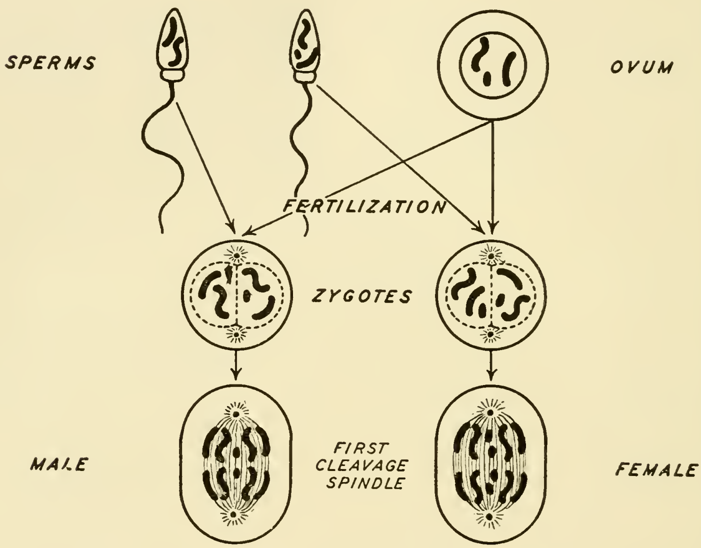


Fig. 203.—Diagrams of fertilization and the formation of the diploid number of chromosomes in the dividing egg. Note that two possibilities as regards the *X* chromosomes are shown. Compare with Fig. 201 and Fig. 202.

in the new generation contains chromatin from both *p* and *m* of the male parental nucleus, and *M* contains elements from both *p* and *m* of the mother. To go back another generation, *p* of the male parent and *m* of the male parent both contained *p* and *m* elements from his parents; similarly, in previous maternal generations, *p* and *m* members of synaptic pairs were derived from synaptic pairs of previous generations. Thus there is a continuity of chromatin material from generation to generation and by the mechanism of synapsis, there is an interchange and mixing of chromatin materials, so that the germ cells of the parent contain and transmit chromatin derived from many lines of ancestry.

This brief account leaves out much that is known concerning mitosis, maturation, and fertilization, and is only in a generalized form; there are many variations. Our account is sufficiently complete to show that in the nucleus of the fertilized egg are chromosomes, one-half the total number having been derived from each parent, that include chromatin from previous generations. It also shows that a chromosomal condition underlies sex differences, for femaleness is associated with the presence of two X chromosomes, and maleness with an X and a Y chromosome, or merely a single X chromosome. It will be necessary to refer to these facts repeatedly in connection with the study of inheritance; variations that are significant will be discussed in their proper place.

Inheritable Characters. With the essential facts concerning the machinery of inheritance before us, we have next to examine the nature and behavior of the characters of the adult animal as they are passed from one generation to the next. The characters of an individual may be grouped into three categories, the first two of which are related or merely different treatments of the same sorts of characters. (1) Characters that distinguish the animal as a member of the species. For example, the common cat is recognized as *Felis domesticus* because of the size, nature of the coat, number of digits, shape of claws, *etc*. These features are transmitted from one generation to the next, for the offspring of cats are always cats. Species distinguishing characters appear to be fundamental properties of that particular type of protoplasm. The problem of the origin of species will be discussed farther on in connection with the subject of evolution. (2) Characters that distinguish the animal as a variety within the species. For example, cats differ as to coat color, depth of coat, and in other ways. Characters of this sort are transmitted from generation to generation. For convenience we will designate such differences as VARIATIONS. New variations which appear within the species that are inheritable are spoken of as MUTATIONS. It is with this group that the present discussion will deal. (3) The third group of characters are those caused by environmental factors. In cats such differences are largely confined to differences in heaviness of coat, mutilations as the result of injuries, *etc.* In Man these characters include training and education. All these are not of themselves inherent in the germ cells but are acquired by the individual through contact with its environment. To distinguish such features from variations we may designate them as MODIFICATIONS, or ACQUIRED CHARACTERS.

Mendel. The fundamental laws now known to govern the inheritance of variations within the species were first discovered by an Austrian monk, Gregor Mendel, and published in a little known journal in 1863. Mendel's work was practically unknown until the close of the nineteenth century, when, during the increased impetus given to the study of inheritance by Darwin, Weismann, and others, DeVries, a Dutch investigator, came upon Mendel's paper and presented it anew to the scientific world. The current century has seen the development of the principles set down by Mendel as results of his breeding experiments, and the growth of Mendelism as a science of far-reaching academic and economic importance.

Alternative Characters. While not the first to use the method of direct experiment, nor the first to analyze his results by means of mathematics, Mendel's clear-cut methods and the success which he attained in revealing important principles of vital phenomena gave a strong impetus to the employment of similar methods in the study of a wide variety of problems. He recognized the necessity of confining attention to single facts among the maze of inheritable characters, and of tracing in detail the events surrounding these facts. His breeding materials were peas and he confined his attention to seven characters that varied between parent and offspring through several generations. These variations he recognized as ALTERNATIVE; that is to say, in peas Tall and Dwarf are alternative height characters; Yellow and Green, Smooth and Wrinkled are alternative seed characters, and so on. We recognize alternative characters in human inheritance; for instance, blue and brown eye color are alternative.

Monohybrid Cross. We will discuss here only illustrative cases which will serve to demonstrate the principles that Mendel's work uncovered. First, attention will be confined to a single pair of alternative characters, Tall and Dwarf. Mendel found that when two plants of these varieties were crossed, the first generation, designated as F_1, were all Tall. The progeny of the crossing of two varieties are called HYBRIDS. Since in this case the varieties differed in only one character, height, the offspring are termed MONOHYBRIDS. The first filial generation being all like the Tall parent, we note at once that Galton's law, that offspring inherit equally from both parents, does not appear to be valid. When two of these monohybrids of the F_1 generation were crossed, the second filial generation, F_2, consisted of a large number of individuals of different sorts. Three-fourths of the number were Tall like one grandparent, and the remaining fourth were Dwarf. When two of these Dwarfs were crossed, all their progency were Dwarf in all succeeding generations, Tallness having dropped completely out of that line of descent. Nor were these Dwarfs in any way different from the original Dwarf parent used in the first cross. In other words, the one-fourth that were Dwarfs in the F_2 generation (that would be the grandchildren in a human family) were pure for this character and Dwarfness had been introduced into a generation (F_1) and extracted again without change (Fig. 204).

Breeding experiments with the other three-fourths of the F_2 generation showed that they consisted of two types, genetically, although all appeared alike outwardly. One out of every three, when self bred, gave progeny that were all Tall and continued to breed Tall through succeeding generations. Therefore, one-fourth of the F_2 generation were pure for the character of Tallness, as one-fourth had been shown pure for Dwarfness. The remaining half, when bred, behaved like the F_1 generation, separating out in the F_3 generation as Tall and Dwarf in the proportion of 3:1. The Dwarfs of the F_3 generation again proved to be pure and the re-

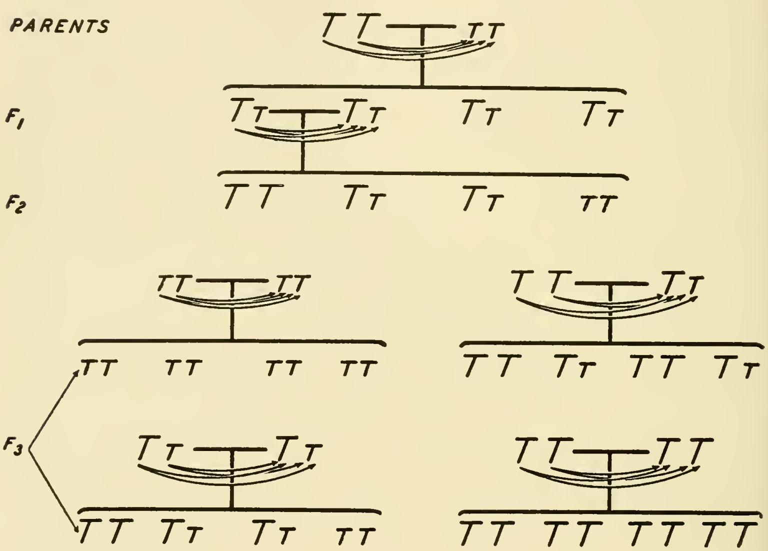


FIG. 204.—Chart showing the behavior of Tallness (T) and Dwarfness (T) in a monohybrid cross in peas.

maining three-fourths of the F_3 generation that were Tall again proved to be of two sorts, Tall, and Tall with the potential of throwing Dwarf offspring.

Mendel's Laws. We now may analyze a monohybrid cross: The F_1 generation are all Tall. To outward appearance the F_2 generation is in the proportion of three Tall to one Dwarf; in potential for characters in future offspring, the ratio is one Tall : two Tall with Dwarf hidden : one Dwarf. By this experiment with monohybrids Mendel demonstrated two rules governing the behavior of inheritable characters. (1) The law of Dominance and Recession. Alternative characters are either DOMINANT OF RECESSIVE, which means that in the case just given, all the peas in the F_1 generation were Tall because Tall is dominant over Dwarf, Dwarfness remaining latent in the presence of the character for Tallness. This law has been found to apply to some characters but not to others. (2) The law of SEGREGATION. In the F_2 generation in the example Tallness and Dwarfness separate out again after both have been present together in the F_1 generation. Moreover, neither character has been changed because of its having been associated with the other. This law has been found to be altogether sound in all cases.

Mendelian Laws and the Behavior of Chromatin. The Gene. For an explanation of the mechanism and manner in which these characters segregate we must now direct our attention to the behavior of the chromosomes. The process is understandable if it is supposed, to begin with, that the germ cell of one of the parents carries a chromosome, *P,* with the character for Tallness on it. This character determiner is called a GENE. Suppose also that the germ cell of the other parent carries a chromosome, *M,* on which is the gene for the alternative character Dwarf. Genes which produce alternative characters in the adult are termed ALLELOMORPHS, or COMPLEMENTARY GENES. Now when fertilization occurs *P* and *M* become members of a synaptic pair in the newly developing plant. *P* has the gene for Tall and *M* the gene for Dwarf, but Tallness for some unknown reason overshadows the gene for Dwarfness, that is to say, Tallness is dominant. The resulting plant is Tall. But in its chromosomes it carries Dwarfness on the *M* member of a synaptic pair. Two terms are used to distinguish between what such a plant or animal is in outward appearance, and what it contains as its chromosomal constitution. The outward appearance is called the PHENOTYPE; in the F_1 generation here the phenotype is Tall. The chromosomal constitution that describes the type of genes present is spoken of as the GENOTYPE; in the F_1 generation in the example, the genotype is Tall dominant with Dwarf recessive. It is customary to represent the dominant of an alternative pair of genes by a capital letter and the recessive by a small letter. Thus the genotype of F_1 is written as Tt (Fig. 204).

When the germ cells of the F_1 generation mature, a gamete, having the $\frac{S}{2}$ number of chromosomes, can have either *M* chromosomes or *P* chromosomes, not both; hence only the gene for Tall or the gene for Dwarf, not both, since the other allelomorph goes either to the other secondary spermatocyte or to the first polocyte at the time of the reductional division, as a part of the synaptic mate. Thus when maturation is completed as far as the distribution of allelomorphic genes, there are two types of sperms and two types of eggs. When fertilization takes place, the union between the eggs and sperms occurs at random and the fertilized egg which develops into the F_2 generation may contain one of three possible combinations of genes. If the egg with the chromosome that contains the gene T unites with a sperm containing T, then there will be no gene for Dwarfness present; such individuals are Tall and continue to breed true for Tallness throughout succeeding generations. If the egg with the chromosome that contains the gene for Dwarfness unites with a sperm containing the Dwarfness gene, then the new individual will be pure for that character and all its future progeny will be Dwarf. But if the egg contains the gene T and the sperm the gene t, or the egg contains t and the sperm the gene T, then the synaptic mates constituting a pair of chromosomes in the new individual will contain different genes, T and its alternative for Dwarfness, t. Since T is dominant, the phenotype will be Tall. But such an individual is capable of producing a Dwarf; the genotype is exactly that of the F_1 generation. Individuals which contain genes for both of the alternative characters are known as HETEROZYGOUS; when both genes are for the same quality of character, as TT for example, the individual is termed HOMOZYGOUS. Since the heterozygous type may result in two ways, either by union of an egg with T and a sperm with t, or by an egg with t and a sperm with T, it occurs twice as often as either of the homozygous types, tt and TT. This accounts for the ratio of genotypes in the F_2 generation of a monohybrid cross, 1 TT : 2 Tt : 1 tt. The dominance of Tallness over Dwarfness accounts for the phenotype ratio of 3 Tall : 1 Dwarf (Fig. 204). These ratios are always obtained from a simple monohybrid cross if the number of progeny is large enough to constitute a fair sample.

It is thus possible to refer the segregation of alternative characters in inheritance to the processes which take place during the reduction of chromosome number in the maturing of the gametes and to account for the Mendelian ratios on the basis of chromosomal behavior during mitosis, maturation, and fertilization. The involved processes leading to equal distribution of chromatin and to the maintenance of chromosome number and integrity, as well as the various steps in maturation, now have an important significance and their functions are clear. But Mendel knew nothing of chromosomes; his interpretations were wholly independent of any structural basis.

The case, which we have given, of a monohybrid cross with the complementary genes truly dominant and recessive, located on members of a single pair of homologous chromosomes, is comparatively simple. In fact, Mendel's laws are in themselves simple. But, like so many natural laws that are simple in their fundamentals, their application in some cases becomes exceedingly complicated and abstruse. Each chromosome in the nuclear complex in the organism contains a great number of genes for alternative characters located on its synaptic mate. In Man, with forty-eight chromosomes, it may be assumed that there are twenty-four such groups of pairs of alternative characters; the number in each group, that is, the number of pairs of characters is unknown and may be very great.

Dihybrid Cross. If a cross is made between two individuals involving two pairs of alternative characters located either on the same or on different chromosomal pairs, it is known as a DIHYBRID

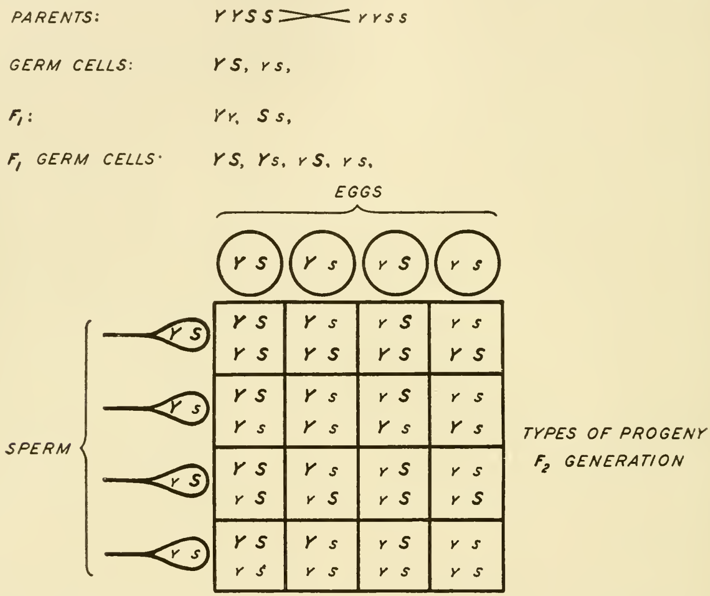


FIG. 205.—Scheme to show the segregations of yellow color (Y) and its alternative character, green (y); and of smooth seed (S) and its alternative, wrinkled (s), in a dihybrid cross in peas. Capital letters represent the dominant, and small letters the recessive characters. Posterior germ cells and their combinations are shown as ova across the top of the table and as sperms along the side. Verify the Mendelian 9:3:3:1 ratio.

cross; when three alternative characters are employed, it is termed a TRIHYBRID; when many are used the cross is a POLYHYBRID. We continue to follow Mendel's original work as examples; the next case is that of a dihybrid cross (Fig. 205). For this he used two individuals which differed in two characters, the color and smoothness of the seed. Alternative characters for seed color were Yellow (Y) and Green (y) and Yellow is dominant over Green. Characters for seed smoothness were Smooth (S) and Wrinkled (s) and Smooth is dominant over Wrinkled. The inheritance of either pair may be considered alone, in which case they are exactly like the first example of a monohybrid cross. But when considered together the number of genotypes and phenotypes of the F_2 generation is greater than in a monohybrid cross. If it is assumed that in a pair of chromosomes the gene Y is on one and y on the other, and that a second pair of chromosomes contain the genes S and s, then in the F_1 generation all the phenotypes are Yellow and Smooth, for these are the dominant characters. When the germ cells of the F_1 generation mature, each may contain one of the following combinations, since each contains one member of every pair of chromosomes: YS, Ys, yS, ys. In the fertilization of the eggs which produce the F_2 generation, the possible combinations are shown in the accompanying diagram (Fig. 205). The letters in the columns across the top represent the possible types borne by the egg, those in the columns along the side represent the genes borne by the sperms. Each block within the diagram represents a possible association of genes in an offspring, that is, its genetic constitution. It is conventional to represent dominant characters by capital letters and recessives by small. From the diagram it is clear that there are phenotypically 12 Yellow (Y) and 4 Green (y), which is the 3:1 Mendelian ratio for a single pair of characters. Likewise there are 12 Smooth (S) and 4 Wrinkled (s). Counting all phenotypes, there are 9 Yellow (Y) Smooth (S), 3 Yellow (Y) Wrinkled (s), 3 Green (y) Smooth (S), and 1 Green (y) Wrinkled (s). Thus in a dihybrid cross the F_2 generation extends the 3:1 ratio of phenotypes of a monohybrid to 9:3:3:1. It should be clear that these figures represent ratios, that is, the distribution of characters among the offspring. Reliable ratios are obtained only when there is a large number of offspring in a generation. With small numbers reliable ratios do not appear. For example, if one tosses a coin a great number of times, the number of times that heads are tossed will be 50 per cent of the number of tosses. But the first three or even more tosses may turn heads. If there are only six individuals in an F_2 generation, all six might by chance be phenotypically Green Smooth. Thus, while the table enables one to predict accurately the ratios that will appear, it does not enable a prediction of the characters of a single offspring.

The letters in the blocks show that genotypically the ratios of homozygous individuals for one or the other of the genes is 1:1:1:1. If one employs any of these as a parent in a mating with another homozygous for the same character, it is found that all progeny in turn are homozygous. It is therefore possible to extract a pure recessive out of a cross with a dominant, or *vice versa.* But suppose an individual that is heterozygous for both characters is crossed with one that is homozygous for both the recessive genes. The germ cells possible and the ratios of occurrence of phenotypes are as follows:

Parents—YySs × yyss
Germ cells—YS, Ys, yS, ys × ys
Offspring—YySs, YYss, yySs, yyss
Phenotypes—1 YS: 1 Ys: 1 yS: 1 ys

Similarly, crosses may be made between individuals homozygous for both dominants and heterozygous for both characters, with corresponding ratios. We may then conclude that, given a dominant character, or a number of dominant and recessive characters, it is possible to predict the frequency of occurrence among the offspring of any given type we may desire.

Polyhybrids. To follow the detail of inheritance in a polyhybrid cross is unnecessary here. It is sufficient to state that in a trihybrid cross the 3:1 ratio of phenotypes is again advanced as is shown in the accompanying diagram (Fig. 206) representing three pairs of allelomorphic genes in the germ cell chromosomes, to 27:9:9:9:3:3:3:1, 64 possibilities in all. A moment's consideration will now indicate the complexity of human inheritance, where there are twenty-four synaptic pairs of chromosomes, with a probably very great number of pairs of allelomorphic genes. If we were to

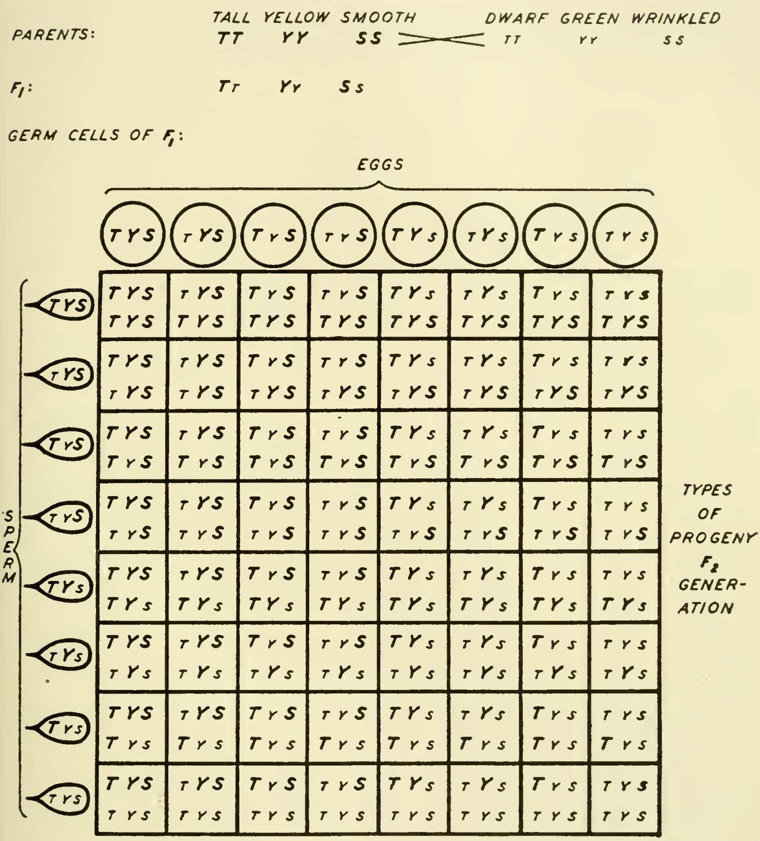


FIG. 206.—The segregation of genes in a trihybrid cross in peas: Tall (T) and its alternative Dwarf (t); Yellow seed color (Y) and its alternative Green (y); Smooth seed coat (S) and its alternative Wrinkled (s).

consider the probability of occurrence of a triple recessive in a human cross involving three pairs of characters, Fig. 205 indicates that it will occur but once in sixty-four chances. Since the number of human offspring from a mating is extremely limited, the probability of occurrence of such an individual becomes somewhat remote.

No Dominance. Still other facts complicate the problems of inheritance. Earlier it was stated that Mendel's law of dominance and recession does not always hold. In some cases neither gene of a pair is dominant or recessive; they appear to exert equal influence. In which case both are apparent in the F_1 generation. For example, blue Andalusian fowls are the F_1 generation of a cross between blacks and whites splashed with blue and are a mixture of white and blue areas, giving a mosaic effect. Such fowls do not breed true for color; in order to obtain them a cross between black and white splashed with blue is necessary.

Multiple Genes. Another complication arises from the fact that in many characters the activity of more than one pair of allelomorphic genes is involved, some of which are truly dominant or recessive, but others may show incomplete dominance, or no dominance. This is said to be the case in Man in crosses between the White and Black races. More than one pair of genes for color are involved; the result in the F_1 generation is a pigmentation that is neither White nor Black but a blend of the two, due presumably to incomplete dominance of some of the multiple genes involved in determining pigment of the skin.

Sex-limited Inheritance. Heretofore it has been assumed in the examples given that the genes are located on autosomes, chromosomes that do not have to do with sex determination. But the X chromosomes, in addition to their rôle in determining the sex of the individual, also carry genes. The peculiarity of certain types of inheritance in which the female does not show the character but her sons frequently do is readily explained when it is understood that the genes for such characters are located on the X chromosomes and are recessive to the usual character, or normal. For example, White eye is a character that occurs in certain flies which have been widely used in the study of inheritance. It is a sex-limited character and is recessive to Red, which is the normal eye color. The manner in which this recessive character is segregated and the explanation of the fact that it is usually found only in males are clear from the diagram (Fig. 207). A male with White eyes is

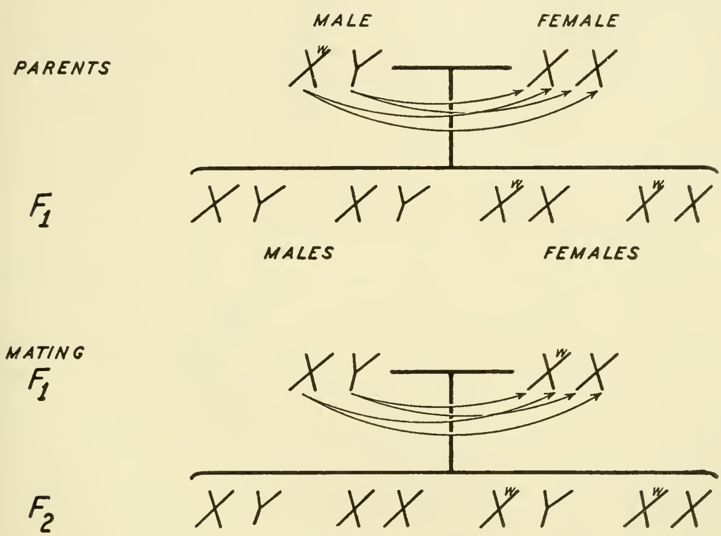


Fig. 207.—Chart showing the behavior of genes that are associated with the sex chromosomes. The example given is that of White eye, a sex-linked character in the fruit fly. It is recessive to the normal eye color, Red. See also Fig. 201, Fig. 202, and Fig. 203.

mated with a normal Red-eye female, homozygous for Red. The F_1 generation then, as usual, are male and female in equal numbers. The females derive one of their *X* chromosomes from the father, which contains the gene for White eye, and one from the mother, which contains the normal allelomorph, Red. The females are therefore heterozygous for eye color; since Red is dominant, the phenotype is Red eye. The males of the F_1 generation derive their *X* chromosome from the mother and are therefore Red eye, homozygous for that character and cannot transmit White eye to future generations. Now if the heterozygous female is mated with a normal male, the F_1 generation consists of phenotypically normal females, one-half of which are genotypically heterozygous, and males, one-half of which are White eye and one-half Red eye. In the two crosses so far given, all the females of the F_1 generation are phenotypically Red eye. One can obtain a White-eye female, however. If a female heterozygous for eye color is mated with a White-eye male, as in crossing two from the F_1 generation of the preceding example, the resulting offspring will include males that are in equal numbers Red and White eye and females that are in equal numbers White eye and Red heterozygous.

A certain type of color blindness in Man, known as DALTONISM, is, according to the most reliable data, a sex-linked character. If one substitutes in the diagrams given above a symbol for color blindness and another for normal, and then analyzes the table, it is clear why women are rarely color blind and why color blindness is transmitted through the mother. To obtain a color-blind female, a mating between a heterozygous normal woman and a color-blind man is necessary and since color blindness is comparatively infrequent in Man, this mating is unusual. A physiological character which is marked by an absence of the blood-clotting process (p. 175), known as HÆMOPHILIA, is also a human sex-linked character and is apparently transmitted as is color blindness.

Linkage. In all that has preceded it has been assumed that in synapsis in gamete maturation the allelomorphic genes of a character are interchanged between synaptic pairs according to chance. But when the genes for two characters are on the same chromosome they tend to be inherited together. This is known as linkage. It means that during synapsis these genes, being located near each other on one or the other of the synaptic mates, remain together during the interchange of materials that occurs at this time (Fig. 208). In a similar fashion, sometimes the chromosomes do not break cleanly after synapsis and a fragment of one may remain attached to the other. Offspring from such gametes show either the total

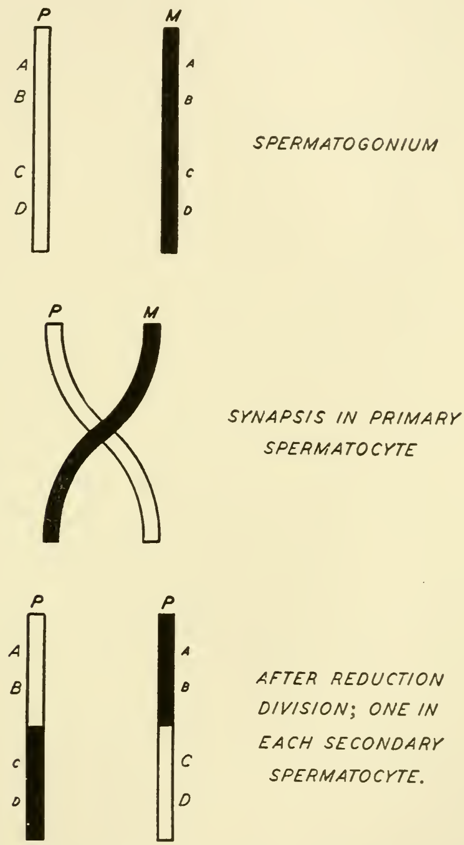


FIG. 208.—Diagram illustrating a simple case of an interchange of materials between two homologous chromosomes during synapsis. Obviously, all genes, such as *C*, *D*, and *c*, *d*, that are detached and assumed by the synaptic mate are passed into the succeeding generation together. Likewise all genes located in regions not detached, such as *A*, *B*, and *a*, *b*, are inherited together.

absence of a character, or else an exaggeration of the character. This appears to be the cytological basis of one class of mutations.

Sex Determination. From what has been said concerning the X chromosomes and their difference in number in males and females, it would seem to be obvious that the factor which determines sex is the presence or absence of one of the X chromosomes. According to this point of view, sex itself is a Mendelian character, the female being homozygous and the male heterozygous. But the problem is not so simple. It has been found that the sex chromosomes do not function as expected if certain allelomorphic genes are absent from some of the autosomes. Moreover, there is a long chain of developmental events, both structural and physico-chemical, between the elemental condition when the fertilized egg receives into its nucleus a sperm nucleus, for instance containing an X chromosome, and the completion to the adult female body. Nothing whatever is known as to how this extra X chromosome so controls the physico-chemical events that development results in femaleness, nor why in its absence the chain of developmental processes results in a male. Furthermore, there is substantial evidence that hormones, derived from the interstitial cells (Figs. 136, 137) of the developing gonads, influence sex development. By proper administration of such hormones, either by injection or by grafting into the animal functional glands of the opposite sex, it has been found possible to divert a potential female toward maleness and, more rarely, to divert a potential male toward femaleness. Complete sex reversal has been accomplished experimentally in poultry and in Amphibia. A natural demonstration of partial sex reversal in cattle is shown in the case of the FREE MARTIN. A female calf born co-twin with a male is known as a free martin and is almost always sterile. It has been found that its sterility is due to a more or less complete reversion during development of its reproductive apparatus toward the male type. Even the ovaries exhibit certain structural characters that resemble testes. An examination of the relation between these twins in cattle showed that during the developmental period the embryonic circulations are fused and continuous and that the bloods intermingle.

Further examination showed also that the interstitial cells of the male gonad are differentiated earlier than those in the female co-twin, so that the bloods during the early period of development contain only the male sex hormone. The cause of the diversion of the female sex apparatus toward maleness is thought to be due to the activity of the male hormone prior to the development of the interstitial cells of the ovary of the free martin. It is sometimes stated that human female twins born co-twins with males are sterile, but this is an error. In the development of human twins the embryonic circulations do not fuse, as they do in cattle.

In addition to the principle of sex determination by the sex chromosomes, and the principle of hormonal action in realizing adult sexuality, there are probably other principles that have not yet been established so clearly. In some invertebrate animals, for example in certain small aquatic Arthropoda, it appears that sex development is associated with metabolic rate; when the rate of metabolism of the female is high, her eggs yield a preponderance of male offspring; when it is low, females predominate. If over-ripe frog eggs are fertilized, the majority of the offspring are females. Numerous other examples of sex control that appear to be based on something else than the *X* chromosome distribution could be cited. So the whole answer to the problem of sex determination has not yet been found.

Questions of Human Inheritance. Human interest in heredity has always been intense and has centred chiefly around the following questions: Can the sex of the offspring be predetermined or controlled? How may family traits be transmitted? May a character acquired by reason of education or training be transmitted? Is disease inherited? Does mating between individuals that are closely related produce degenerate offspring? With the facts of the mechanism of heredity before us and with some knowledge of the behavior of genes in determining the character of the offspring, the subject of human inheritance may be discussed with an appreciation of the problems involved. The general principles of genetics have been derived from experimental matings using as material a considerable variety of plants and of animals. Particularly important has been the study of inheritance in the fruit fly, Drosophila, and in the guinea pig. The progeny of a single mating in Drosophila are ordinarily several hundred. Guinea pigs reproduce quite rapidly, so that a character can be followed through several generations in a relatively short time.

In order to work out with accuracy the behavior of an inheritable character, a number of conditions are necessary that are wanting or imperfect in Man. In the first place, it must be possible to control matings at will in order to test the nature of the genes by appropriate crosses. This is obviously impossible in human society. Secondly, numerical ratios are reliable only when large numbers are involved, and, as has been illustrated, one of the fundamental methods of genetics is a statistical treatment of the data. The comparatively few offspring in a human family do not afford ratios that permit definite conclusions. Third, in order to determine the behavior of a genetic character it must be studied through several generations. The interval between generations in human families is approximately two decades; to follow a character through more than two generations is usually beyond the opportunity of personal observation of an investigator. Consequently, conclusions arrived at concerning inheritance in Man are by inference from the studies of similar characters in lower forms, or are derived from statistical studies among populations and an occasional family history that has been recorded with some accuracy. The study of human inheritance is called EUGENICS; in the popular mind it is frequently distorted as a sort of non-social program in some cases and over-socialization in others. In general, the actual program looks toward collecting data on human inheritance so that the facts may become known for individual guidance or for assistance in the solution of medical, legal, and social problems.

In the comparatively short period of time during which data on human inheritance have been collected with an accuracy looking toward testing the application of Mendelian principles, a considerable mass of evidence has accumulated and many human traits have been studied. Unfortunately, however, most of the records are incomplete. This, together with the fact that many traits and charac-

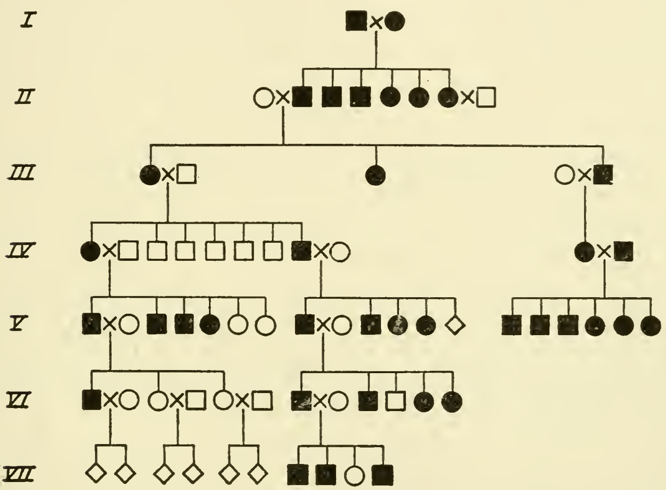


Fig. 209.—Chart showing the inheritance of closely curled hair in a human family through seven generations. Squares represent males; circles represent females. Solid black indicates that the individual had the character; blank indicates the lack of the character. Diamonds represent individuals concerning which nothing is known. (After Gates: *Heredity in Man*, published by The Macmillan Company.)

ters are not sharply defined and that many are undoubtedly the result of more than one pair of allelomorphic genes, has thus far rendered it impossible to assemble data necessary to anything like a complete knowledge of human genetics. From a wealth of more or less incomplete data we may select a single example that plainly shows the inheritable character of a human feature, namely the inheritance of close curly hair in a German family history extending back to the sixteenth century. The data show the Mendelian dominance of the character in this family, but one should not reach the generalization that curly hair is dominant in all families. The nature of the hair of the first generation, I in Figure 209, is not known but since the six children all had curly hair and since in the fifth generation, V in Figure 209, two curly-haired parents had six curly-haired children, it is presumed to have been curly.

Many other human characters are known to follow Mendelian principles. It has been shown before (p. 332) how Daltonism and hæmophilia are sex linked. In addition, it is definitely known that

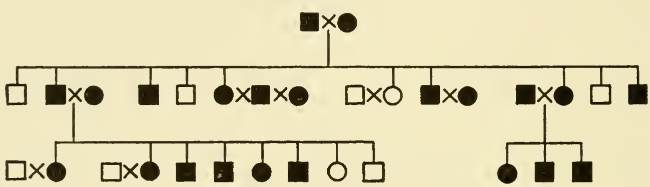


FIG. 210.—Inheritance of feeble-mindedness in the descendants of Sam Sixty. Squares represent males; circles represent females. Blacks represent feeble-minded individuals; blanks represent normals. Abner, the male parent in the first generation shown, was the feeble-minded son of the feeble-minded Sam Sixty. Abner married Rose, who was also feeble-minded. Their children and grandchildren are represented. (From *Publication No. 8*, Ohio Board of Administration, by Kostir.)

certain anatomical abnormalities, such as the presence of double thumbs, susceptibility to tuberculosis and other diseases, stature, eye color, and other characters are inherited in accord with Mendelian rules, although the data are incomplete and the details have not been worked out. Wide studies have been made of the inheritance of feeble-mindedness; fairly complete family histories have been traced by skilled investigators, which reveal that this, too, is a Mendelian character, in some families apparently a dominant (Fig. 210). In this case the control of the frequency of occurrence of this type of defective mentality is possible, within limits; progress has been attained by legal enactments designed to prevent the mating of feeble-minded. The nature of inheritance of many human characters, including defects in mentality, as shown by collected family histories, illustrates two important principles: (1) Many mental and physical traits are inheritable and appear to obey Mendelian laws; (2) the desirability of the acquisition of more complete data on human inheritance in general, to serve as a guide in various sociological, legal, and medical programs.

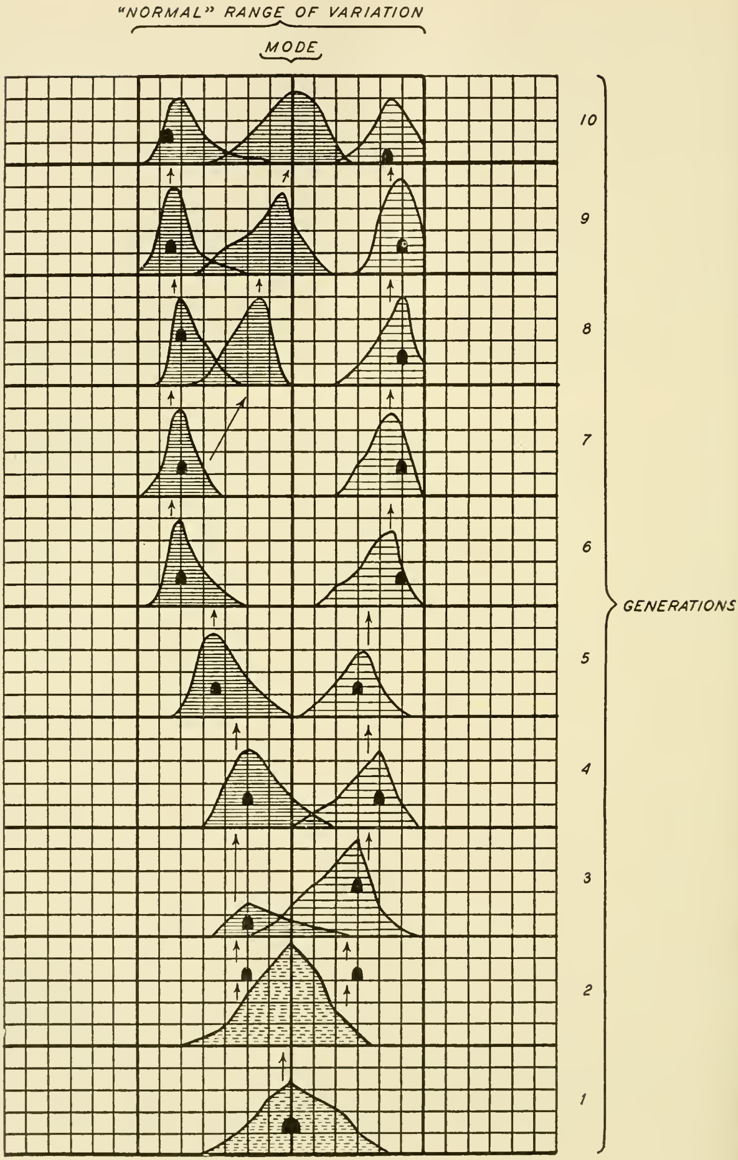
Concerning the possibility of predetermining sex, the facts at present known indicate that the chief factor in determining sex is the presence or absence of an *X* chromosome. Since in Man the spermatozoa are of two sorts in equal numbers, one-half containing and the other half lacking the *X* chromosome, and since the union of the egg and sperm is a chance contact in which the probabilities of one or the other type of sperms fertilizing the egg are exactly equal, the possibility of predetermining sex is remote. It would involve controlling the type of sperm that is to reach the ovum first.

Characters Not Represented in the Zygote Are Not Transmitted. One of the prominent questions raised by biologists of the nineteenth century, and earlier, that is still prominent in many fields of human thought, is the problem of the inheritance of acquired characters, characters that are acquired by the soma and not in any way derived from parents. With the facts of the rôle played by the chromosomes before us, a preliminary statement may now be made; more complete discussion is reserved for a later chapter. In order to be transmitted, a character must be represented on the chromosomes by genes. Therefore the only way in which a character acquired by the soma, for example proficiency in a trade, education, bad habit, crippling by injury, and so on, can become a part of inheritance is by effecting changes in the genes, either causing chemical processes to occur which construct new genes, modify genes already present, or destroy genes. With an exception noted farther on, in no case has it been possible to demonstrate by experimental methods that somatic characters or the influence of the environment affect the quality and behavior of the genes. Confusion has arisen from failure to recognize the distinction between inherent capacity for developing a somatic property and the property itself. Particularly is this true in the recognition of the nature of the source of skill or mental properties and of the source of disease. It has been demonstrated that high susceptibility to certain diseases (for example, cancer and tuberculosis) are genetic and transmitted according to Mendelian principles. But the disease itself is not transmitted; it is a somatic character that may or may not appear, depending on environmental conditions. Similarly, capacity to develop skill, or facility with instruments, or for acquiring knowledge, may be genetic, but whether or not the individual ever realizes such capacities depends on the opportunities of the environment.

Inbreeding. Mating between closely related individuals is known as INBREEDING. In most human societies it is forbidden by statute, but is a common procedure in breeding domestic animals and plants and occurs widely in nature. In the behavior of the genes of a monohybrid cross between Tall and Dwarf (p. 322), we may substitute for one of this pair of allelomorphic genes another which, for the purposes of an illustration, is an undesirable character or defect of some sort. Further, suppose that this gene is recessive to a normal, or desirable character. Then in brother-sister matings in the F_1 generation the segregation of this character results in the appearance of one-fourth the F_2 generation as pure for this undesirable, with one-half the progeny heterozygous and capable of transmitting the character. Thus inbreeding tends to segregate characters as homozygous in the next generation. If, as in the example given, the character is an undesirable, inbreeding is undesirable. If, on the other hand, it is a desirable character, inbreeding is also desirable. But due to the tendency of undesirable characters to accumulate in homozygous form, it is a common practice to break them up again by occasional outbreeding with an unrelated line. There is no reason for regarding human inheritance as an exception to these laws.

Mutations. Although it has not been possible to cause new genetic characters to appear by the application of some environmental change, new characters do appear in animal and plant populations. These are called MUTATIONS and their cause is at present unknown. Not all varieties of animals or plants are alike in this respect; in some, mutations occur with considerable frequency; in others their occurrence is rare. In the fruit fly, *Drosophila melanogaster,* which has served as excellent material for the study of inheritance, mutations have occurred with some frequency in stocks kept in the laboratory for experimental purposes. Other species of this same genus appear to be much more stable and mutate but rarely.

The facts that are known concerning the causes of origin of new characters are few indeed. Mention has been made of the fact that sometimes in the maturation of the germ cells the members of a synaptic pair of chromosomes do not sever equally, thus leaving an excess of chromatin on one and a defect on the other. This results in somatic effects that are inheritable. It is also known that certain environmental conditions, for example high temperature, affect the process of synapsis and result in changes in the cross-over of genes located on the same chromosome. The most clear-cut effect of environment on germinal constitution is the recently demonstrated fact that when a race of Drosophila (the fruit fly) is exposed to radioactive substances, mutations occur distinctly more frequently than in races that have not been exposed. Such changes may be referred to some unknown physico-chemical action of the ray on the genes. Conjectures have been made that the effect of radioactivity may account for the origin of many new characters in animals and plants in general. But no conclusions can be drawn at present. The nature of the relations of the chromosomes during synapsis affords an opportunity for a wide variety of recombinations that may account for genetic changes which appear from time to time.


"NORMAL" RANGE OF VARIATION
MODE
10
9
8
7
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4
3
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1
GENERATIONS

Effect of Selection. Would it be possible to develop a race of supermen by carefully selected matings? For illustration let us select one character, height. The height of any human is the sum total of a number of influences. Unquestionably one of these factors is included in the inheritance he derived from his ancestral line, but in addition nutritive conditions and disease during growth, and the activity of the pituitary hormone act on this genetic factor so that the eventual height may be influenced in both directions and amount to the algebraic sum of the effects of these influences. In plants it has been shown that selection is effective in increasing the frequency of occurrence of tall individuals in a population, so that the general average of height increases for a number of generations as selection is continued. But selection soon ceases to be effective; the maximum has been reached. Fluctuations around this maximum are due to non-genetic conditions. This maximum height represents a pure line for all the allelomorphic pairs of genes that have to do with height of the offspring. When all these are homozygous no increase in height is accomplished by further selection. A new height character can arise only as a mutation and so far as is known, selection in breeding does not induce a mutation in the character selected. Going back to the original question, a human race might possibly be produced by selection, the average height of which is distinctly greater than that of the present races, but there is no reason to regard it probable that a race of giants could be so developed (Fig. 211).

The Nature of the Gene. In the preceding discussion of the principles of heredity we have used the term *gene* freely. It is endowed with powers of continuing itself unchanged through genera-

Fig. 211.—Graphs showing the effects of selection and breeding for size through ten generations of potato beetles. Black areas indicate the sizes selected for mating in each generation. Thus in the second generation a pair smaller than the average and one larger than the average were mated. This was practiced throughout. Note that after the sixth generation the average size did not increase further. In the smaller line in the seventh generation a random mating was made. Note that its descendants returned to the normal for the species in the tenth generation. (After Tower.)

tion after generation, of so directing and controlling development that a specific quality always appears as a consequence of its presence. It apparently has a fixed position on the chromosome so that no matter how widely chromatin material may disperse when the cell is not dividing, the genes always assume their proper position when the chromatin becomes organized as chromosomes. On occasion one of the members of an allelomorphic pair of genes undergoes some sort of change, the result of which is a mutation. After the mutation has occurred the changed gene may be introduced into a generation and there be associated with its normal allelomorph without being changed. The question that constantly comes to the fore in any discussion of heredity is: Just what is the nature of a gene? No answer is possible at present. Two sets of facts are known: Unities of some sort, for convenience termed genes, are located on the chromosomes; as a result of their action the adult animal or plant exhibits certain characters. Between these two sets of facts there is a wide gap in our knowledge. Inserted between the existence of genes in the nuclear makeup of the fertilized egg and the characters of the adult is a long series of intricate physical and chemical events of development concerning which little is known, and concerning how the chromosome makeup directs these events nothing at all is known. Attempts have been made to identify the gene as a molecule, but this does not help us much, for no molecule now known to the chemist has the properties of self-reproduction nor the other powers that have been ascribed to the gene.

The term gene then represents an hypothesis; its nature and mode of action are unknown, but the concept has been useful. Based upon the theory of the gene, accurate prediction of offspring characters can be made. Moreover, great progress has been attained in practical animal and plant breeding and in the more important abstract understanding of heredity. These facts alone justify the use of the hypothesis.

Preformation and Epigenesis. Having sketched the outlines of development and traced the chief principles of inheritance, we are now in position to appreciate the two opposite interpretations of development. Begin by facing the problem in a simple statement. Before us is an egg; after a rapid series of changes, before us is an individual consisting of millions of cells, highly organized and intricately constructed. Is this highly organized adult present in miniature in the egg? Or is development a progressive process, as a chain of technical processes in a factory convert in an orderly fashion crude materials into an end-product? The first interpretation is known as PREFORMATION and the second as EPIGENESIS.

These two views both have long histories and both have colored and still influence biological theory. A moment's thought will convince one that only these two interpretations are possible; either development is an unfolding of the egg potencies, or it is a series of reactions that are initiated by fertilization, which build up the adult from outside materials. In their earliest forms both concepts partook of the ridiculous. Early preformationists claimed to have observed a miniature human in a sperm cell. One early worker calculated the possible number of miniature human bodies in the ovary of the Hebrew mother Eve. The earliest form of the doctrine of epigenesis was primarily vitalistic, holding that an outside supernatural power governs the formation of the adult from the egg.

Preformation in modern Biology takes the form of the self-evident fact that the protoplasm of a species is peculiar, that only the adult of a particular species can arise from the species ovum. It recognizes the importance of the fact that the egg is organized and that the organization of the adult is accomplished by reason of this basic organization. In the hands of some biologists the gene theory of inheritance becomes primarily a preformationist doctrine; it is held that the genes are in some way actual representatives of adult structures.

Epigenesis in its modern form regards development as a serial metabolic phenomenon, analogous to the series of metabolic steps in the origin of proteins in a cell from the crude proteins of the food. This point of view places emphasis upon the *metabolic processes* of differentiation; preformationism emphasizes the physico-chemical and organismic *organizations* that characterize development. Both are associated in the developmental process.

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Chapter X

THE ORGANISM AND ITS ENVIRONMENT

Types of Adaptations. Protoplasm can function as the physical basis of life only when it is so adjusted to its surroundings that a more or less constant supply of energy and materials enter, and only when no external conditions interfere with its energy-transforming processes. Constant changes in the environment compel an animal to expend energy in making corresponding adjustments. Moreover, the obtaining of materials for nutrition, the safeguarding of the organism from injury, and the assurance of perpetuation of its kind by reproduction require energy expenditure. So all animals are constantly engaged in a struggle with the environment; life is perpetuated and maintained for a longer or shorter time in spite of the adverse conditions they encounter, and at the expense, in some animals at least, of tremendous losses. Fish and frogs, for instance, spawn enormous numbers of eggs, of which only a very few ever reach the adult stage. Starfishes shed countless numbers of eggs and sperms into the water, from which chance meeting of sperm and egg results in the development of comparatively few adults.

A character that fits the organism to cope with the environmental difficulties it faces is termed an ADAPTATION. According to their origins, adaptations may be classed as SPECIES ADAPTATIONS, that is to say, adaptations which are a part of the inheritable features and characters of the species and are possessed by all members of the species; and INDIVIDUAL ADAPTATIONS, which are characters peculiar to individual members. According to their nature, adaptations fall into two classes, STRUCTURAL and FUNCTIONAL ADAPTATIONS. Structural adaptations in an animal may be compared with the thread in a nut to engage and follow the thread on a bolt; functional adaptations may be thought of as the energy expenditure both as to direction and quantity, required to advance the nut along the bolt. As the thread of a nut is not perfectly fitted to that of the bolt, so the adaptations of the organism do not fit perfectly with the demands of the environment, and as energy is absorbed by friction as the nut advances, so energy is expended as the organism overcomes its obstacles.

The Preservation of Mutations. Present views are that species adaptations, whether structural or functional, have their origin in chance germinal mutations and that their continuance as a part of the inheritance of the individual and of the species is conditioned upon the fact that some mutations better fit, and others unfit the organism for its struggle to maintain existence; some tend to true the thread, others to distort it. By the constant pressure of the environment the unfit are eliminated; the fit are preserved. Thus, according to this point of view, the adaptive characters of the species are determined, in last analysis, by the environment and the survival value of mutations; the unfit fail in competition for food, are destroyed by enemies, or are unable to perpetuate the species. The principle is illustrated by an example. The fruit fly, Drosophila, has given rise to several hundred mutations in the two decades that it has been reared for experimental purposes. Some of these mutations are obviously of a nature that makes it difficult for the animal to compete for food, and for mating. For example, one mutant race is wingless. In Nature this mutant would be promptly stamped out, or at least obscured in a heterozygous state.

Adaptive Structural Species Characters. Adaptive structural species features in animals include all those anatomical characters that are characteristic of the species and fit it for its environment; for examples, the fins and gills of fishes, the human hand, the various types of beaks in birds, and so on. It is unnecessary to enumerate more. It is profitable, however, to discuss in detail the structural adaptations of certain animals. The bird body will serve to illustrate the principle of the unity of adaptive features within the individual; other examples will illustrate special cases.

The Bird As an Example of Fitness for Habitat. The exoskeleton of the bird (Fig. 93) consists essentially of a set of greatly modified scales, the feathers. The lightness of the feather coat with its entrapped air makes for buoyancy, as well as providing effective insulation against loss of heat and a protection against weather. The beak, together with the bones of the head, forms a stream-lined unit with a minimum of resistance against the air. The vertebræ of the neck have saddle-shaped joints, allowing wide freedom of movement and when in flight the neck forms a straight column back of the extended head. The skeleton of the body is a compact light frame forming the shape of a projectile. Buoyancy is added by the fact that the shafts of many of the bones contain air sacs continuous with the lungs. Teeth have been dispensed with, which decreases the weight of the head. Their function is performed by a modified stomach, commonly called the GIZZARD (Fig. 212). The voice-producing apparatus has been shifted out of the head back to the region where the trachea divides to form the bronchial tubes. Here the trachea is modified to form a voice box known as the SYRINX. It contains a vibratory member (pessulus) suitably controlled by muscles. Sounds are produced by the passage of air over this structure.

All unnecessary weight is dispensed with. The large intestine and rectum are much reduced in size; there is no urinary bladder. Wastes are expelled promptly. The shifting of the voice apparatus from the head into the body, the elimination of teeth, the shortening of the tail, the habit of drawing the feet and legs against the body when in flight, all centralize the weight into the body proper. The centre of gravity is low and the vertebral column rigid in the body

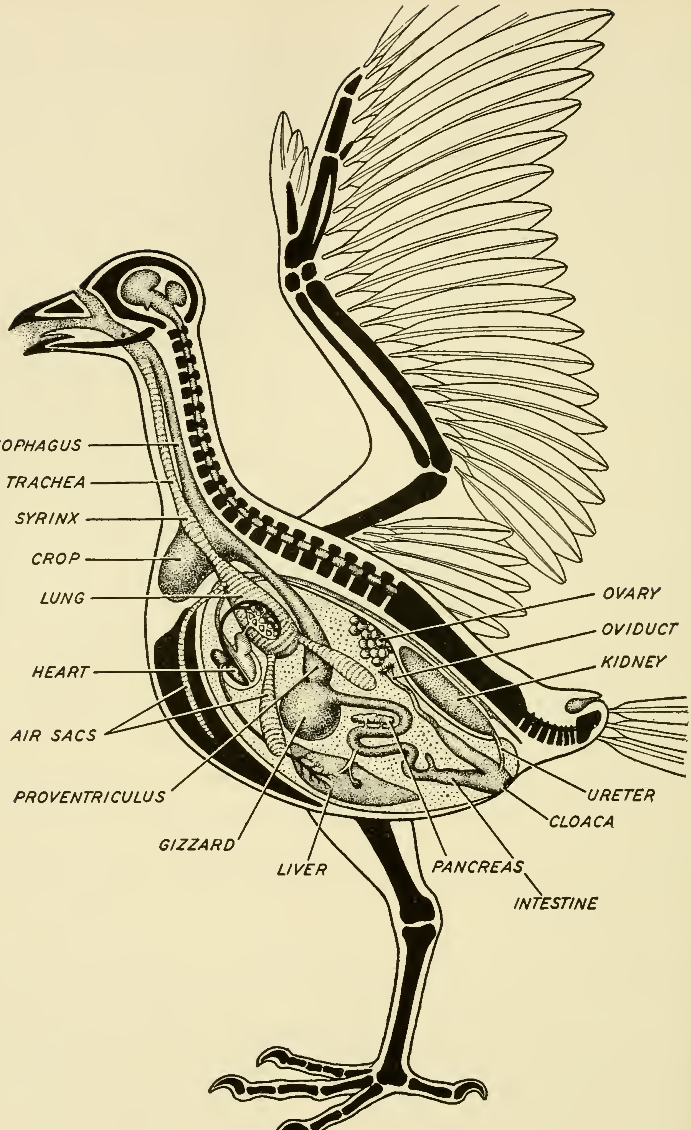

FIG. 212.—Diagrammatic figure of the structure of the bird body. (After Kühn: *Grundriss der allgemeinen Zoologie,* published by Georg Theime, Leipzig.)

region. The lungs are large to provide for a rapid exchange of gases. The body temperature is high, which makes for more rapid oxidative metabolism with a consequently more rapid transformation of energy. The rate of energy transformation is high in proportion to weight, a relation necessary for the flight of a heavier-than-air object. The lungs are somewhat different from those of other air breathers, in that the bronchioles communicate with each other. Thus when air is drawn in, it circulates through the various passages in a more or less continuous stream; the fine tubules do not end in blind alveoli as in other air-breathing vertebrates (p. 171). The bird in flight breathes by the action of the large muscles of flight, their contraction and relaxation operating the lungs somewhat in the fashion of a bellows. By this arrangement energy is conserved, for the effort put forth in flying also serves to ventilate the lungs; the muscular act of flying includes the muscular act of breathing.

An examination of the structure of the wing (Figs. 212 and 85) shows that by a reduction of the bony framework of the vertebrate forelimb and by a marked increase in the size of the feathers, an effective propelling structure, consisting of a broad surface with a light framework, has been derived from the same essential features which in other vertebrates develop into fins, forelegs, or forearms. The flight of a self-propelled, heavier-than-air object requires great power in proportion to weight, broad surfaces, a proper distribution of weight with respect to such surfaces, and the reduction of wind resistance to a minimum by stream-lining. The body of the bird represents just this sort of structure, apparently modified from ancestral land types whose characteristics were quite otherwise. The bird body constitutes a most striking example of the modification of the vertebrate body plan to adapt for a special type of locomotion. This unified adaptation is impressive because it confers powers that the human body does not possess. But from the standpoint of the general subject of adaptations, all animals are similarly adapted for their special methods of locomotion and special habitats and possess structures that represent wide alterations from a basic type. For example, the bird body contains no structure that is more strikingly fitted for its function than is the human hand.

Special Types of Adaptive Structures. Although the adaptive features of the bird, of the human hand, of the frog and fish, and so on, are as illustrative as any, yet the animals are so well known that they arouse no particular interest and are accepted as commonplace. One's curiosity is usually much more stirred when attention is directed to exotic and bizarre forms that are not commonly met with, and to organs that are either lacking in Man or else are very different from their human analogues. Anything like a complete account of such extraordinary animal features could not be undertaken here; nor would it be desirable, for our chief objective is the exposition of principles that are applicable to all animals. However, some peculiar adaptations will be given brief attention for they show how certain fundamental properties of protoplasm have been exaggerated and exploited to constitute organs that have peculiar properties.

The Gas Bladder of Fishes. If one opens the cœlom of a perch or other common teleost fish, a long, fairly thick-walled, membranous sac will be found along the dorsal wall of the cavity. In life it is filled with gas, usually chiefly oxygen, and serves as an organ of buoyancy. The gas is secreted from the blood by a small gland in the wall of the gas bladder; thus the hæmoglobin of the fish blood serves to carry oxygen not only for the respiration of the tissue cells but also for the filling of the gas bladder. Since the gas in the bladder is nearly pure oxygen, it is clear that its walls are impermeable to this gas, else it would diffuse back into the blood stream, the oxygen concentration in the bladder being higher than that of the blood. It appears that the amount of gas in the bladder varies with the weight of the fish and with its depth in the water. If a weight is attached to a fish the animal soon becomes accustomed to it and adds more gas to the bladder contents to compensate for the extra weight. Now if the weight be suddenly removed, the gas in the bladder is in excess of requirement and the fish comes rapidly to the surface and really has quite a struggle to remain under water until the excess gas has been released and the buoyancy returned to normal. In some varieties of fish the gas bladder has no tubular outlet and excess gas is returned to the blood by a diffusion mechanism. In others the bladder is connected to the pharynx by a small tube somewhat like that of the dipnoids (p. 170) and excess gas is released through this tube.

Electric Organs. Certain fishes are capable of discharging an electric shock amounting in extreme cases to two or three hundred volts, well over twice the voltage of an ordinary house current. The most common electric fishes are an African catfish, a South American eel, and a skate (elasmobranch) occurring in the coastal waters of the Gulf of Mexico and the Atlantic Ocean north as far as Cape Cod.

The electric organs consist essentially of great numbers of sheets of tissue superimposed to form electrical piles. All the sheets receive a branch from the same nerve fibre, and each sheet represents a greatly modified muscle. We know already (p. 234) that a stimulus is accompanied by a discharge of electricity; this is especially marked in the contraction of a muscle. Thus the contraction of any ordinary muscle, for example in the human arm, is accompanied by an electrical discharge of minute voltage and recovery from contraction includes the restoration of the original electrical charge on the boundaries of the muscle cells. The electrical organs of fishes are devices that take advantage of the electrical character of muscle action and add together the electrical properties of many sheets of muscle-like tissue; so the voltage varies with the number of sheets that compose the organ and with the stage of fatigue. When the organ is in normal resting condition and the animal is stimulated the electrical charge on the numerous sheets is released simultaneously by the stimulation of the single nerve fibre that communicates with the organ; the voltage of the discharge is the combined voltages of the electrical elements in the organ.

Defense Mechanisms. The electrical discharge of fishes, described above, is an example of the startlingly effective defensive reactions of animals that have always excited interest and on occasion dismay. A recital of the many and extremely varied defenses that animals employ in warding off attacks of other animals would be out of place here, but some cases may be examined with profit because they illustrate another of the great variety of possibilities residing in protoplasm. One may consider defensive mechanisms as being either PASSIVE or ACTIVE. Passive defensive mechanisms include protective coloration, spiny coverings, power of escape by rapid locomotion, chemical properties of the organism or its integumentary glands, and a multitude of other characteristics that tend to prevent animals from falling victim to carnivorous enemies. One would hardly regard the common garden toad as possessing remarkable powers of self defense, yet its integumentary glands are an example of a passive defense device; they secrete substances that are distinctly poisonous; the toad is rarely bothered by carnivorous animals.

The electric organs of fishes described in a previous paragraph are active defense organs. As in the case of all weapons, active defensive mechanisms may also be employed on offense by the animal. All are familiar with the stings of insects. The stinging apparatus of the common honey bee is a quite complicated affair, consisting of a pair of sense organs that select the place for insertion of the sting, a hollow shaft or sheath that directs the barbs, and a barbed dart that is driven outward by suitably placed muscles. At the base of the sheath mechanism are glands which secrete a poison that is injected through the sheath into the site of the sting. Insect bites are usually not the result of active defense but are feeding acts. They involve the piercing of the skin by modified mouth parts. The insertion of the mouth parts may be accompanied by the expulsion of the contents of mouth glands, as in the case of the bite of the mosquito.

In addition to the familiar stings and bites insects have other additional weapons of active defense. In the more southerly sections of the United States one may occasionally pick up fairly large dark beetles, with yellow ventral surfaces. They are to be handled with caution for this particular type has in the rear end of the body two small glands that squirt a vile-smelling liquid when the animal is disturbed. A related form has a refinement of this type of weapon. When the discharged liquid comes in contact with air it explodes with a small report and becomes a smoke-like vapor, behind which the beetle escapes. Beetles that have this sort of defense mechanism are known as bombardier beetles. It is said that there are twenty-five different species of bombardiers in the United States.

The cephalopod molluscs (p. 112) also employ screens as a means of confusing their enemies. The squid has a small gland with a sac or reservoir attached to the intestine near the anus. When disturbed the inky contents of this reservoir are expelled into the surrounding water, effectively masking the retreat of the animal.

The poisonous snakes have fangs that are pierced by canals much in the manner of a hypodermic needle. In the tissue at the bases of the fangs are poison glands and sacs containing the poison. When the snake has its mouth closed these fangs are folded backward into the roof of the mouth; when it strikes the act of opening the jaws pushes the fangs upright and pressure is brought to bear upon the poison sacs, which eject their contents along the canal in the fang into the body of the victim.

It would be possible to devote a great deal of space to descriptions of defense mechanisms, but sufficient has been said to show the general nature of passive and active defenses among animals. A moment's consideration of the defensive equipment of the human body will bring one to the conclusion that it is relatively poorly fitted with mechanisms for either passive or active defense. There is in most human races very little protective coloration; the exoskeleton is almost non-existent and very defective as a protection against carnivorous enemies; the integument does not contain poison glands. Powers of escape and of combat are inferior as compared with many other animals.

Luminescence in Animals. The visible light produced by animals is known to be associated with an oxidative reaction in which at least two substances that resemble proteins or protein products are concerned. One of these, called PHOTOGENIN, is the source of light and is not used up as light is emitted; the other substance, PHOTOPHELEIN, is destroyed in the reaction and consequently is being constantly replaced by the metabolism of the animal. The organs that emit light differ greatly in structure, but all are essentially glands. In the common firefly the organ is single; in some deep sea fishes light-emitting organs occur in numbers and may be associated with condensing lenses that converge the light into beams. The reaction between the substances concerned in light emission appears to be initiated by nerve impulses as in glands in general; hence it is probable that the intermittent flashing of the common firefly indicates a periodic nerve stimulus that sets in action the peculiar oxidative metabolic process. The mechanism is highly efficient, for light is emitted without heat, a characteristic that Man, in constructing lighting devices, has striven for without success.

Sound-producing Apparatus. The mammalian larynx with its vocal cords and the bird syrinx with its vibratory pessulus have already been described (pp. 171 and 349). All other sound-producing mechanisms are constructed on similar principles, namely, the vibration of a membrane over a column or container of air, except in the case of the whine produced by the rapid movement of the wings of certain insects. The insects are the only invertebrates that have organs specialized to produce sounds.

On the wing covers of male katydids are peculiar areas of thin wing membrane. The characteristic call of this insect is emitted by the rubbing together of these two areas, the air under the covers serving as a sound box. In the cricket each wing cover is provided with a device resembling a file and another resembling a scraper. When the chirp is emitted the wing covers are elevated at an angle and rubbed together, the scrapers and files being in such position as to cause the wing covers to vibrate. The whining or buzzing noises produced by flies, mosquitoes, bees and wasps, and other flying insects, result from the rapid beating of the wings against the air. In bees and wasps the sound may be produced while the animal is moving about on foot, but the flies and mosquitoes emit a buzz or whine only when in flight.

The Class Insecta As an Example of Divergence within a Related Group. Insects, because of their tremendous number of varieties, illustrate more than any other group the principle of divergence in adaptation. So numerous are the forms and so complex are the life histories, that the study of insects, Entomology, constitutes a highly technical special branch of Biology. The economic importance of insects lends special interest to their study.

The class Insecta is distinguished from other Arthropoda by the following characters: The body is divided into three portions, head, thorax, and abdomen (Fig. 60). There are three pairs of walking legs always present and always attached to the three segments that compose the thorax. The breathing apparatus consists of a set of fine tubules, the tracheæ, which ramify throughout the tissues and open to the air through apertures, termed spiracles, along the lateral walls of the thorax and abdomen (p. 168). Wings are not always present; when present there are either one or two pairs, always attached to the most posterior, or to the middle and posterior segments of the thorax. Insects are often confused with spiders, the class Arachnida, which have four pairs of walking legs, never have wings, and usually breathe by means of book lungs (p. 167).

Insect Types. The number of species of insects is far greater than that of all other animals taken together. Various authorities recognize nineteen different orders of insects, the order characters being wing differences, differences in mouth parts, and differences in number of stages in their life cycles, that is, in METAMORPHOSIS. According to the number of stages in their development, insects are divided into two groups, insects of INCOMPLETE METAMORPHOSIS, and

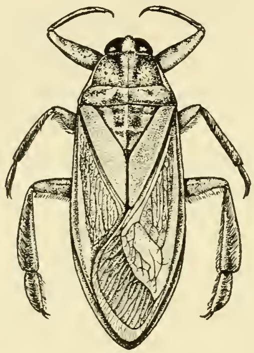

FIG. 213.

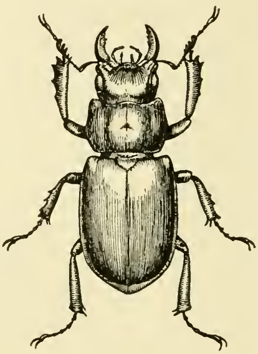

FIG. 214.

FIGS. 213 and 214.—A common bug and a common beetle, showing the difference in the position of the wings and wing covers when at rest.

insects of COMPLETE METAMORPHOSIS. Insects of incomplete metamorphosis pass through three stages in development, namely, EGG, NYMPH, and ADULT. Insects of complete metamorphosis pass through four stages, EGG, LARVA, PUPA, and ADULT. In insects of incomplete metamorphosis, the nymph and adult, and in insects of complete metamorphosis the larva and usually the adult, feed. Nymphs, larvæ, and adults are therefore the stages that may be economically important because of damage to crops, trees, and other property of value.

Uninformed observers frequently regard any insect as a bug, but bugs are in fact only one order of insects. The bugs, order Hemiptera (Fig. 213), are insects of incomplete metamorphosis having two pairs of wings and equipped with sucking mouth parts. The squash bug, the electric light bug, and lice, may be mentioned as examples of this order. Bugs are most frequently confused with the beetles, order Coleoptera, but the two are easily distinguished. The anterior pair of wings in the bugs fold over each other in a criss-cross pattern when the insect is at rest, while in the beetles the modified anterior wings, termed elytra, rest with their inner margins forming a straight line down the middle of the dorsal surface. The insect frequently miscalled the June bug, is in reality the May beetle.

Beetles, Coleoptera, are insects of complete metamorphosis (Fig. 214). The number of known species is very great; it is probable that there are more varieties of beetles still unknown than there are known. The larva and adult may both be injurious. Common examples of beetles are numerous; we call attention to a few, the weevils, fireflies, stag beetles, and lawn beetles.

Butterflies and moths are frequently confused. Both are members of the order Lepidoptera but are rather easily distinguishable. Moths always have antennæ shaped somewhat like feathers (Fig. 215), while those of butterflies are smooth with a knob or spindle-shaped enlargement on the end. Lepidoptera are insects of complete metamorphosis; in most cases the larvæ are the damaging feeding stage. Some adult Lepidoptera live only to reproduce and do not feed. The coloration of the wings is often arranged in a definite pattern that imitates some other object, as a leaf or a bit of bark, or mimics some other organism. Protective coloration is so complete in some that an observer must look closely to distinguish between the insect and its background. Protective coloration is perhaps most interesting among insects and particularly among moths and butterflies, but is not confined to this group of animals. In fact, all animals exhibit this structural adaptation to a greater or lesser extent.

Members of the order Hymenoptera and of the order Diptera

(Fig. 216) are also frequently confused. The Hymenoptera include the bees, wasps, and ants, while the Diptera are the flies, gnats,

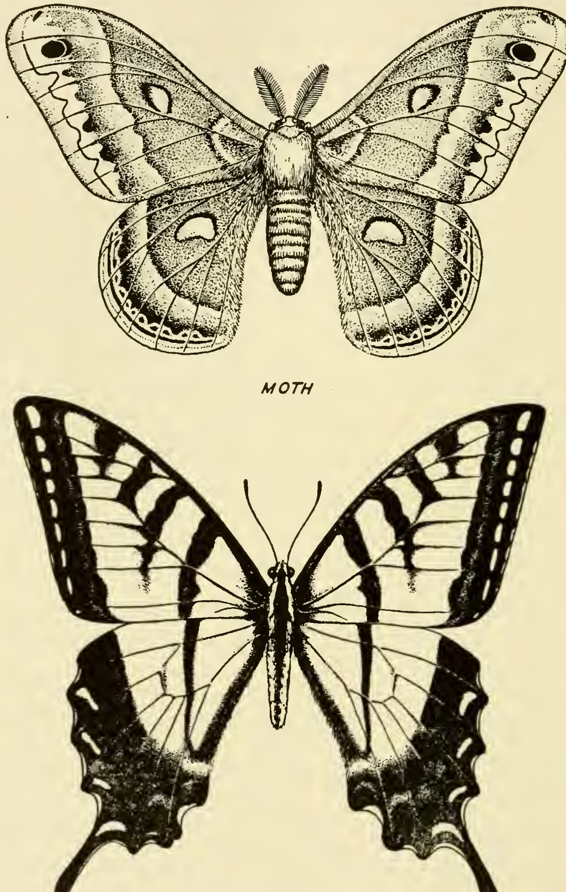

Fig. 215.—Compare the antennæ of the moth and butterfly.

midges, and mosquitoes. The distinction between the two orders is sharp; bees, wasps, and ants (when the last named have wings) have two pairs of wings, while the Diptera have but a single pair.

Insects, particularly Diptera, are of considerable importance in the transmission of disease, flies by the mechanical conveyance of infected materials and mosquitoes by the inoculation of the host with the micro-organisms of disease. It is not our purpose here to discuss the life cycles of insects in reference to their importance to public health. However, the mosquito has played such an important rôle in the spread of disease that an understanding of its life history is properly a part of general information.

All Diptera, including the mosquitoes, are insects of complete metamorphosis. The eggs of the mosquito (Fig. 217) are laid in

FIG. 216.—Common honey bee and common house fly.

boat-shaped bunches in water or moist places. The eggs hatch in a few days, the time required varying with the variety of mosquito and with the temperature. The larvæ are aquatic and are harmless to other animals. They live in water but are air breathers; next to the last abdominal segment is equipped with a slender breathing tube. They hang head downward in the water with this tube extruded at the surface. The larvæ grow rapidly and, after moulting, change into pupæ. The pupæ of the mosquito, unlike the pupal stage of any other insect, are active. They, too, have breathing tubes but these are on the thorax and are two in number. After a short pupal stage the skin splits and the adult emerges, using the cast pupal case as a raft. As soon as its wings harden the adult flies away. The mouth parts of the adult are adapted for piercing. The salivary excretions contain a substance which prevents the clotting

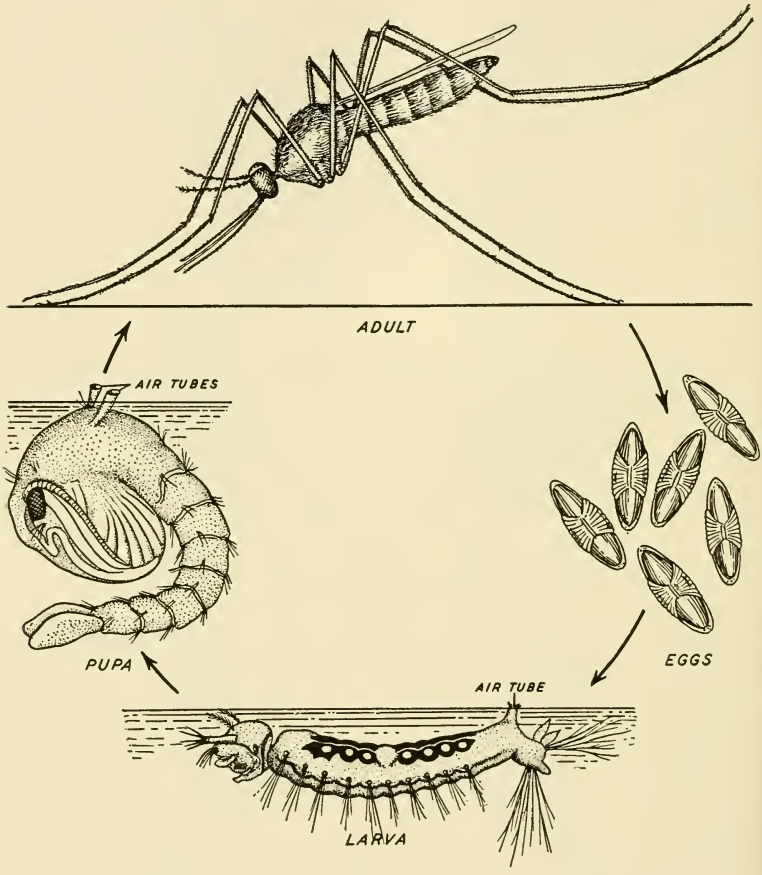

FIG. 217.—Diagram of the life history of a mosquito.

of the host's blood and thus permits the fine mouth tube to extract blood from the puncture. The malarial parasite, Plasmodium, which was discussed in detail earlier (p. 75) is harbored in the salivary glands of the Anopheles mosquito and the yellow fever micro-organism (a filterable virus) in the glands of the Ædes mosquito. These micro-organisms are injected into the host with the products of the glands. Not all mosquitoes that are capable of harboring these Protozoa are infected. Anopheles and Ædes mosquitoes abound in some localities that are free from malaria and yellow fever. A high degree of success in eradicating these diseases has been attained in certain regions, notably in the Panama Canal Zone, by the screening of infected persons, and the elimination of mosquitoes by draining stagnant waters and the free use of oil. A surface film of oil on the breeding places shuts the larvæ and pupæ off from air.

The amazing diversity of type among insects accounts for their almost universal presence, and their ability to live under the most unexpected circumstances. One form passes its larval stage in petroleum pools; another is able to bore its way through the lead housings of electrical conduits in order to get at the insulation. The drug store beetle lives on herbs and drugs that would cause the death of other animals. While chance mutations are responsible for the diversity of type, the adaption of certain species to a new food supply must be regarded as primarily a non-genetic functional adaptation, but the ability of the insects to adapt themselves to new and different foods is to be regarded as a genetic character.

Inheritable Functional Characters. Inheritable species characters that are functional adaptations include all the diverse species characteristics which enable the organism to utilize the sources of food and energy in its environment to provide for perpetuation of the species, and to seek surroundings suitable for its continued existence. Species functional adaptations are always associated with corresponding structural adaptations. These are particularly extensive in the life cycles of parasitic animals. Obligatory parasites are in many cases so sharply adapted to the tissues of certain hosts that they are unable to subsist on any other source of food. The hook worm, a member of the phylum Nemathelminthes, exists in its adult stage in the human intestine only. Such strictly limited adaptations are frequently associated with degenerative structural changes. The tapeworm, one of the phylum Platyhelminthes, does

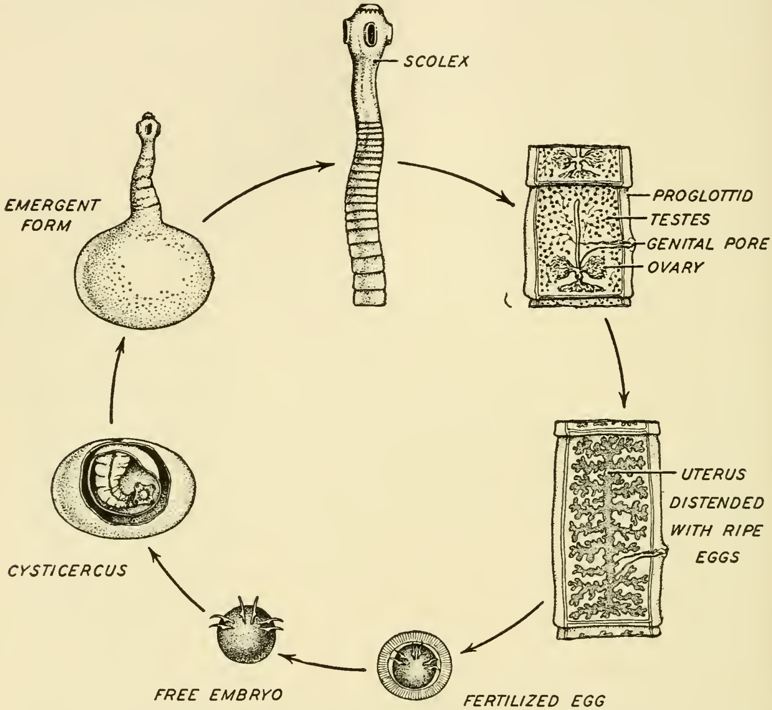

Fig. 218.—Diagrammatic representation of the life cycle of the human tape worm, *Tænia solium*. (Partly after Kühn: *Grundriss der allgemeinen Zoologie,* published by Georg Theime, Leipzig.)

not possess a functional digestive canal, absorbing its food already digested from the food in the intestine of the host.

The Tapeworm as an Example of Limited Habitat. The human tapeworm, *Tænia solium* (Fig. 218) is one of the class Cestoda of the phylum Platyhelminthes. In its adult stage it is found only in the human intestine. The adult body consists of a modified head termed the scolex, equipped with hooks by which it is attached to the intestinal wall. Posterior to the scolex the animal consists of a chain of portions, each very much like the next, called PROGLOTTIDS. The number of proglottids in a mature worm may be several hundred. A mature proglottid consists essentially of reproductive organs and developing embryos. Both ovaries and testes are found in the same proglottid and the egg is fertilized by sperms from the testes of the same section. Proglottids distended with fertilized eggs break off and are passed with the fæces. If the food supply of swine is in some way contaminated by fæcal material containing tapeworm proglottids, the larval worms infest the muscles of the animal and there form cysts. Within a cyst the larva becomes a sac-shaped structure in which is the inverted head of the new individual. If the meat of an infected swine is eaten without having been heated sufficiently to kill these BLADDER-WORMS, or CYSTICERCUS as they are called, the larva develops into a mature worm in the human intestine. The life cycle of this parasite requires one principal and one intermediate host, the human body and the swine. Other parasitic worms have more complicated life histories, in some cases involving more than one intermediate host.

The body of the adult tapeworm shows the structural degenerations that accompany its parasitic source of food and its protected habitat, for digestive organs are completely lacking and the nervous mechanism is degenerate. Still more extreme are the degenerative characters of an arthropod, Xenocœloma, that parasitizes a marine annelid, Polycirrus. After this small shrimp-like animal has established itself in the body wall of the annelid, practically its entire body is absorbed by the host, except for the ovaries and testes and the genital ducts. These remain functional and constitute the whole of the adult parasite. Even the muscles that control the exit of the genital products from the ducts of the parasite are derived from host tissue, not from the parasite. The ability of a parasite to control the metabolism and growth of its host to suit the purposes of the parasite is also shown by the protective galls that are formed about some types of insect larvæ which infest plants. That the action of the insect is specific is shown by the fact that on the same tree several types of galls may occur, each peculiar to some sort of insect larva. A skilled entomologist may distinguish the type of insect larva merely by observing the type of gall enclosing it.

Individual Modifications That Are Adaptive. Individual structural adaptations, as distinct from those inherited as species characters, are modifications induced by the conditions of a particular environment; they represent, as it were, the attempt of the body of each individual animal to adjust. Such adaptations include the widest variety of structural changes from the normal and usual shape, compensatory enlargement of muscles in one limb when the other is injured or removed, the encasement of foreign bodies by scar tissue, and similar individual characters. There is no evidence that such changes, imposed on the animal body from without, are passed on to future generations, regardless of whether or not the modifications enable the animal to cope more successfully with its surroundings. Individual modifications that are adaptive are the solutions of individual, not of species difficulties; each generation must solve such problems anew when, or if they are encountered.

The Nature of Response to Environment. Individual functional adaptations represent the constant changes in the protoplasmic reaction system brought on by the constantly occurring environmental changes. A fairly clear picture of the relation between the animal and its environment may be obtained by comparing the organism to a flowing stream.

The streaming motion of the water is evidence of kinetic energy. The path the water follows depends on the nature of the ground; obstacles deflect it here, slopes encourage a more rapid flow there, the force of the stream erodes away the bank at another place. So the direction of the flow and the changes in direction, the features that distinguish a river, are the result of the reaction between the stream and its environment. It is not possible to conceive of a river without its banks and bed; it is likewise impossible to consider the organism independent of its environment. As the nature of the terrain determines the direction and flow of the stream, so the environment of the organism, in part at least, determines the trend taken as the energy derived from nutrition forms and maintains the organism.

Functional adaptations may be referred to changes in the chemical and physical reactions within the protoplasm. Let us assume a cell that is in equilibrium with all its surroundings, so that there is a constant inflow of foods and oxygen and a constant outflow of wastes. Assume also that under such ideal conditions the rate of metabolic reactions is identical in all regions of the cell and that the surface membrane is identical with respect to electrical and permeability properties over the entire boundary. Now suppose a new factor is introduced into the environment; for example, the temperature is raised. The first effect must be at the cell boundary, so that electrical and permeability characteristics change in accord with the rise in temperature. But a change in the cell boundary also involves changes in the internal regions of the cell, a re-distribution of various substances and an alteration in the rate of metabolism. So, because of a change in the environment, the whole mechanism of life in the protoplasm is shifted, as when the collapse of a small portion of a stream bank causes the stream to shift position. If, in the case we have been considering, the nature of the environmental change is minor, or a substance or condition that the protoplasm may overcome or remove as waste, the cell returns to its original condition, as the river washes away and disposes of small cave-ins of its bank. If, however, the change is great, or a substance of such nature that the energy of metabolism cannot alter or otherwise dispose of it, either the life of the protoplasm becomes permanently altered, that is, adapted to the change, or it may become disorganized and die, as the stream may alter its course or be obliterated. The environment of every organism is constantly changing; day and night, for example, are constantly succeeding each other. The organism is therefore constantly changing in accord with the environmental changes. These modifications imposed on the organisms by its surroundings are superimposed on alterations in the organism with age and other conditions. Not only is the individual constantly changing; it is also changing in its ability to change. Moreover, ability to adapt is not identical in all organisms. Ability is itself a species character. So our attempt to group adaptations as species adaptations and individual adaptations is subject to this modification.

Trembley's Experiment with Hydra. From a great wealth of examples of individual functional adaptations, a few may be selected to illustrate their nature and range. Even the most simple forms are often able to solve difficult problems. One of the most striking cases was first brought to notice over one hundred and fifty years ago by the experiments of a French priest, Trembley, on hydra. The objectives of his extended investigations of hydra do not concern us here, but in the course of his experiments he attempted to find if the ectoderm and endoderm are interchangeable, whether if their positions were reversed, the characters of the two layers would change, ectoderm become endoderm and *vice versa.*

He first cut off the tentacles and then by means of fine instruments turned the animals inside out. When he returned later to examine the animals, he found the ectoderm on the outside and the endoderm on the inside. He suspected that they had righted themselves, and subsequent observations showed that to be the case. Next he repeated his operation of turning the hydra inside out, but this time he impaled them on bristles, so that the animals were suspended as sacks might be suspended on rods run through them. On returning he again found the ectoderm outside and the endoderm inside. Being unable to determine how a sac-like structure could have its inner and outer surfaces reversed while suspended in this fashion, he concluded that a transformation of the two layers had taken place. Another investigator repeated his experiments a century later. Trembley had been deceived. By inverting its upper end into the central cavity the hydra had found the bristle on which

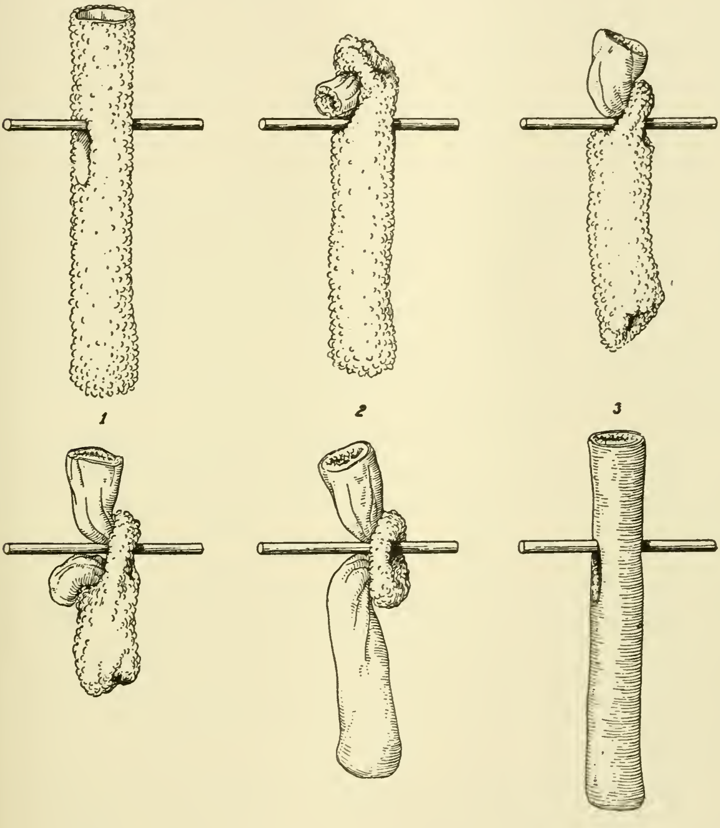

FIG. 219.—Diagrams showing the righting behavior of a hydra that has been turned inside out.

it was impaled, and then literally crept through the hole in its side. The lower portion presently did the same thing in a similar way, so that the animal was now righted, although still impaled on the bristle (Fig. 219). It is unthinkable that ever before in all preceding time the genus Hydra had ever been impaled in this fashion; its response under these wholly unique and exceptionally severe circumstances constitutes a most extraordinary demonstration of the ability of protoplasm to solve new situations as they are encountered. Such behavior also furnishes food for thought for the scientist in his attempts to interpret the reactions of protoplasm in terms of physical and chemical phenomena.

The hydra does not accomplish this solution by moving directly toward the only possible successful method but by a series of more or less random trials. Similarly, in finding a path around an obstacle a protozoon also makes a number of unsuccessful attempts. This so-called "trial and error" method (Fig. 19) is characteristic of the attempts of all animals to reduce the difficulties they encounter. A moment's thought will call to mind that the reader himself frequently solves difficulties by trial and error.

Behavior. Among the more complex animals the nervous system together with the muscles and other effectors, that is to say, receptor-transmittor-effector systems, are the mechanisms of emergency and temporary adjustment to the environment. The behavior of an animal is the sum of its responses to stimuli. Attention has been largely centred on motor responses and the whole subject of animal behavior deals almost exclusively with muscle contractions that transport the animal from place to place or cause the change in position of a part of the body in response to some environmental condition.

Animal behavior exhibits two different aspects, namely, responses that are reflex, automatic, independent of experience, regular in occurrence, and always of the same sort when the stimuli are identical, commonly called INSTINCTS; the second type of response is variable and associated with real or imaginary experience. It is in some way associated with, and controlled by that as yet undefined property of the brain known as the mind. Controlled behavior as exhibited by

Man and other advanced animals is commonly called INTELLIGENCE. Its very nature presupposes an internal self control involving ability to utilize past experience with environmental conditions, and an ability to exercise imagination, that is, to assemble hypothetical or imaginary environmental situations and to imagine their solution in advance of their actual occurrence. Just how these functions of the central nervous system are derived from the metabolic processes of the protoplasm of the human brain is wholly unknown. Instincts reach their greatest complexity in the insects, while controlled behavior, intelligence, is commonly assumed to reach its acme in the human behavior; by some the assumption is made that intelligence is exclusively a property of Man. At least one modern school of philosophy holds that instincts and intelligence represent the two possible functions of the nervous system, of equal order of complexity, and that evolution has resulted in their parallel development in insects and in Man. Fascinating as the discussion of the possible relation between instinct and intelligence may be, further speculation is out of place here.

Not all reflex acts are instinctive. It will be recalled that a reflex act is the result of a stimulus which passes more or less directly from an incoming sensory path to an outgoing motor path, without the necessity of involving the brain or other correlating nerve centre (p. 222). Repetition or training often succeeds in converting an act that at first requires the correlating effort of the brain into one that becomes a reflex. Reflexes acquired in this fashion are known as CONDITIONED REFLEXES. In recent years it has developed that very many human acts are conditioned reflexes, and that only a very few are instinctive. The training which results in the establishment of human conditioned reflexes begins very early in life and soon becomes so firmly established that heretofore they have been thought to be instinctive reflexes, that is to say, independent of previous training.

The nature of the external stimuli that induce more or less immediate response by animals permits their division into several groups: Light, Gravity, Electricity, Contact, Temperature, and Chemicals. Frequently more than one of these act together and the response on the part of the animal is the sum of their influences. Responses to such stimuli that are reflex and in a manner forced are spoken of as TROPISMS. The term is also used to refer to the orientations that occur when an animal is attempting a trial-and-error solution. If a planarian is exposed to a bright light it moves away from the lighted area; such an act is described as a NEGATIVE PHOTOTROPISM. The roots of a plant respond to gravity by growing downward, a response known as POSITIVE GRAVIOTROPISM. Thus a response is given in terms of the nature of the stimulus, gravity in the latter case, and the effect, for example, positive.

There is no uniformity among animals in response to these external factors; some are positive and some negative to light; most of the lower forms when placed in an electric field go toward the anode, but some behave in the opposite fashion. It is not profitable here to attempt to review the nature of the tropisms in the various animal groups; a basic principle that determines whether or not an animal within a given group is positive or negative to these stimuli, has not yet appeared. The major facts concerning the nature of the receptor organs have already been given (p. 223).

Certain characteristics of the tropisms reveal their basis in the energy-transforming processes of metabolism. For example, if the siphon of a long-neck clam is exposed to a beam of light, it is withdrawn with considerable promptness. It has been found that the response is elicited either by long exposure to light of low intensity or by brief exposure to a bright light. Furthermore, if the intensity in candle-power is multiplied by the time, the product is always a constant figure, which means that there is an accurate and quantitative relation between the time and intensity required to produce the response. This in turn means that the amount of energy required is always the same. The same law has been found to apply to the response of animals in general and in the light receptor organs is undoubtedly to be referred to the presence of some chemical that is sensitive to light and which requires a certain amount of energy in order to undergo its reaction. Just how the chemical transformation of a light-sensitive substance in the receptor organ actuates the nerve is not known.

Phototropism. An example of phototropic response was given above to show it is dependent on light-sensitive chemicals in the light receptors. PHOTOTROPISM, or response to light, includes HELIOTROPISM, or response to sunlight. Heliotropism is most strikingly shown in the growth of plants; all are familiar with the fact that plants in a partially shaded area bend toward the sunlight. So far as known, there is no special receptor organ in the plant; this behavior must be attributed to a general property of plant protoplasm, an influence of light on plant growth. Among all phyla of the animal kingdom are representatives that respond to light by some type of immediate contractile effort, not by growth.

Graviotropism. All animal forms in a way respond to gravity, for all exhibit righting reactions and either move or stand in more or less definite positions or balance with respect to gravity. The human balancing mechanism has already been described (p. 232). Another type of response to gravity is shown by some animals. For example, paramœcium always tends to move upward, responding negatively to gravity. If certain fresh water planaria are placed in water that has an abundant supply of oxygen they are indifferent to gravity; but when the oxygen supply decreases they become negative to gravity and persist in creeping upward. This is of course an adaptation, associated with the fact that oxygen dissolves in the water at the zone of contact between the water and the air, and tends to bring the animals into a region of oxygen supply.

Galvanotropism. It is usually outside the ordinary experience of animals to enter into electrical fields that are of appreciable strength. Biologists have made much of the responses of animals to electricity when treated experimentally, but their results only indirectly aid in the understanding of the normal and usual behavior of animals.

In the first chapter (p. 25) it was shown that colloidal particles bear electrical charges. If such a suspension of fine particles in water is connected with the poles of a battery, positively charged particles will move toward the negative pole and negatively charged particles toward the positive pole. This is quite understandable, since unlike charges attract and like charges repel. Similarly, if bacteria are placed in an electric field they behave as do colloidal particles, migrating toward the pole that bears the charge opposite to their own. But this comparatively simple explanation cannot be extended to the behavior of larger animals when exposed to electricity, without becoming involved in some complicated assumptions. Small animals such as insects, worms, frog tadpoles, and small fish do respond to an electric current; some types move toward the positive pole but the majority move toward the negative. Large animals, Man included, appear to be indifferent so far as definite orientation in an electric current is concerned.

Stereotropism. This term is applied to a type of response in which the animal seeks to place itself in contact with surfaces. It is highly characteristic of the behavior of burrowing worms such as the sandworm, Nereis (p. 140) and the earthworm. If earthworms are placed in containers with square corners they presently arrange themselves so that as much as possible of the body surface is in contact with the sides and floor of the container. It is probable that this reaction is of considerable importance in other phenomena of animal behavior, for example in the bunching together of animals for mutual protection (p. 384).

Thermotropism. All animals, whether warm- or cold-blooded (homoiothermal or poikilothermal) are affected by temperature and either seek out or accumulate in environments in which the temperature is best suited for their metabolic processes. But homoiothermal animals, having mechanisms that render them more or less independent of the temperature of the surroundings, have a greater latitude of movement. Because of this fact and of his ability to control his immediate environmental temperature to some extent, Man is well distributed over a wide range of temperature and climatic conditions.

Chemotropism. Responses to chemicals are perhaps the most common and continuous of all tropisms and constitute a most important part of animal behavior, from the lowest to the highest free-living animals. To provide more effectively for the reception of chemical stimuli the receptor organs of taste and smell (p. 224) occur in a variety of types. Responses are both positive and negative. If one walks over the mud flats along the seashore at low tide one may find many small snails, for example *Nasa obsoleta*, in depressions and along the trickling streams that follow the receding water. If a clam is crushed and some of its fluids washed into one of these streams, very soon the snails farther down become agitated and turn with surprising speed and promptness and move up stream toward the source of the clam juices. Bees may be conditioned experimentally to respond positively to certain odors and doubtless their visits to flowers are in part responses of the same sort. On the other hand, the fact is well known that all animals, including Man, avoid environments which contain a concentration of offensive or injurious chemicals.

A special type of chemotropism is the positive response of plants, particularly the roots of plants, to water. This fact is so commonly observed that it requires no especial illustrations here. Again, we do not have at hand a physico-chemical explanation of the mechanism which results in the very distinct positive growth of roots toward water in the soil. This response is often spoken of as HYDROTROPISM.

Other Responses and Behavior. In addition to these more or less general tropisms, animals that are equipped with sound-producing devices are also responsive to vibrations of corresponding frequencies. Then, too, reflexes set up by the sense of sight or light reception, by odors, and other stimuli produce a wide variety of responses. For example, certain fish swim upstream when placed in a water current. If the fish is placed in a stoppered bottle of water, in which there are no currents, and the bottle towed behind a boat, the fish similarly heads in the direction of motion of the boat, showing that this orientation is due to some reflex set up by the sense of sight. It is also true that the sight of food by acting through nerve reflexes will cause activity in the digestive glands of mammals.

The total behavior of an animal is the sum of such reflexes, tropistic responses and conditioned reflexes, plus other factors that are as yet unknown or difficult to evaluate. It has not yet been possible to account in a wholly satisfactory manner for the homing instinct exhibited by some mammals, birds, some insects and a few molluscs. The homing pigeon has been exploited as a means of communication and methods of training have been worked out in much detail, yet the nature of this instinct in the bird remains unknown. From time immemorial the homing ability of the cat has been the subject of anecdote and facetious adage; its powers are indeed remarkable, but perhaps not so extraordinary as many anecdotes would indicate. Rather carefully controlled experiments and observations by a skilled and reliable observer show that the homing ability of different cats varies. It was found that when a female with young was carried several miles from the kittens, hoodwinked and covered in a manner to prevent any visual recognition of location, the cat returned in a direct path within a few hours, crossing a deep ravine and many railroad tracks, climbing a four-hundred-foot rise, and traversing a maze of city streets. The same cat, completely anæsthetized with chloroform and carried to another point before release, returned in seventy hours. A mollusc, Chiton (p. 111) has been observed to retire daily to the same crevice during storms over a period of nine months, although other appropriate crevices were nearer to its location. The term "bee line" is descriptive of the fact that bees orient themselves with great rapidity and return directly toward the hive. Whatever the essential nature of such reactions may be, they illustrate a most remarkable sensitivity of the organism to its environment.

In Man, behavior is complicated by the ability of the brain to predetermine a response, to exercise will power and imagination. Thus the human behavior pattern is most intricate and as yet only partially studied. Individually the behavior of a human appears to be unique among animals and is only partially predictable. But human populations behave as a whole as do populations of other types of animal life. In both human and other animal population movements one notes the effects of food supply or lack of food, the instinct for perpetuation of the species and for physical protection or escape from impending disaster.

Animal Communities. From our daily experience we know that certain types of animals are to be found only in certain localities and that no single type is completely isolated from other animals. The study of the relation of the animal to its habitat and to other animals in its environment has for many years been known under the broad term of NATURE STUDY. During the first quarter of the current century, however, the method of study has been enlarged to include not only observation and survey of the occurrence and distribution of animals, but experimentation and exact physical and chemical study of the characters of the habitat that determine its fauna. Thus ECOLOGY has come to take a prominent place in the science of Biology.

We may begin with the most conspicuous of all environmental factors, namely, temperature, and consider that the average yearly temperatures of regions beginning with the Equator and ending with the Poles constitute a temperature gradient, with its high point at the Equator and its low point at the Poles. Along this gradient it is possible to mark off broad regions that include definite types of animal communities, the tropical group, the sub-tropical, the temperate, and so on.

Within these zones on this temperature gradient it is also possible to mark off areas, the fauna of which is determined by other factors. Thus aquatic fauna may be set off from land fauna, and marine fauna may be set off from fresh water fauna. The analysis of local groupings may be carried on much farther. Thus two fresh water lakes within a few miles of each other, having the same yearly temperatures, may possess quite distinct fauna. Examination will show that a number of quite local differences may be responsible for the differences in animal communities in the two lakes; for example, the floor of one may be stony and sandy, that of the other, muddy. Or the feeding streams of the first lake may flow through territory that contains one type of substance in excess, for example salts, while the waters pouring into the second lake may contain little of such substances. Then, too, the plant life of such lakes may be different, due to one or more of the conditions that have been suggested or will suggest themselves. Without exception all animal communities are superimposed on plant communities, for as has been emphasized, directly or indirectly all animals depend on plants for their source of materials and energy for vital processes.

If the fauna of a single lake is examined it will be found possible to separate the forms that occur into a number of local communities within the lake boundaries. Thus some types, for example, amphibian and insect larvæ, small crustaceans and small fish, will be found near the shore, while large fish and large crustaceans, if present, will in general be found in the deeper waters. Still more strikingly the animal life of the ocean divides itself into shore forms, surface forms, and deep water forms.

Ecologists in the study of such animal communities and distributions recognize the limitations of the various groups within certain levels or regions as due to the interplay of various environmental factors that occur as gradients in intensity. Thus in passing from the edge of the water outward to deeper portions of the lake or ocean one finds distinct temperature gradients, pressure gradients, light gradients, and gradients in oxygen concentration. Animals as a result of their behavior to external stimuli therefore tend to such regions as are optimum for their life processes, provided, of course, that the regions contain a food supply.

Similar facts apply to animal life of land areas. Thus the slope from the valley level to the crest of a mountain range, or divide, may represent a number of gradients, of temperature, rainfall, salt content of the soil, and so on. If the slope is steep the gradients may be correspondingly steep and the changes in fauna quite abrupt as one proceeds from the valley level upward.

Within areas thus established by the major environmental factors of temperature, pressure, moisture, and other conditions are to be found rather definitely outlined small communities. Thus a pond, a swamp, a hill, or during the summer season at least, even a single tree has its local fauna. A survey of a tree discloses that a variety of animals find food and shelter there; small mammals, slugs, birds, tree frogs, adult and larval insects compose a close community. The single and all-important connecting link in such communities is the interdependence of all members for subsistence. Ecologists speak of this linkage as the food chain.

Any food chain begins with the metabolism of green plants; a moment's consideration will direct our attention to the fact that such a linkage is in reality a detailed expression of the relations of life forms imposed by the nitrogen cycle (p. 43). In a fresh water pond, for instance, algæ and other water plants are present. Upon them feed insects and insect larvæ, snails and amphibian larvæ. Decaying plants afford food for bacteria, which in turn are eaten by Protozoa. Hydra are present and feed upon Protozoa and small Arthropoda. Annelida and flatworms feed upon bits of plant material and injured insects and other small animals. Turtles and crustaceans feed upon snails; small fish devour insects and insect larvæ and worms, and themselves afford food for turtles and large fish. Parasitic animals, for example tape and round worms, and bacteria attack fish and other animals. The dead bodies of these larger animals in turn afford food material for saprophytic bacteria. So the cycle of food goes on. Any animal community may be analyzed in a similar way (Fig. 220).

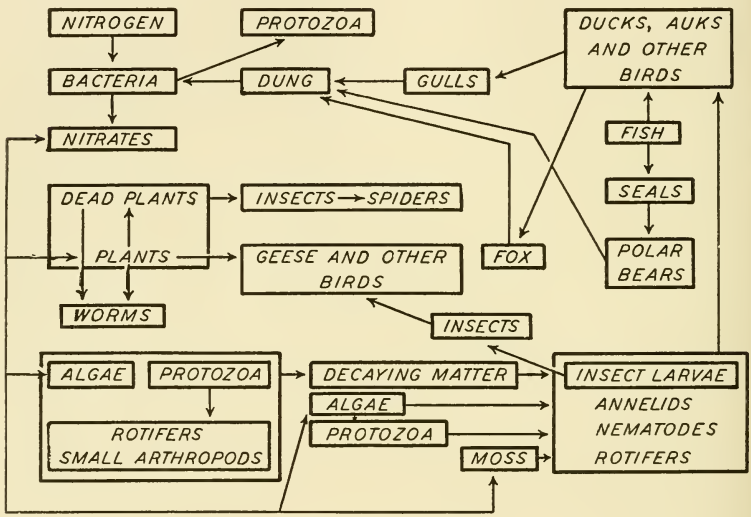

Fig. 220.—The food chain in an isolated community, the arctic Bear Island. Follow the arrows. (Adapted from Summerhayes and Elton: *Journal of Ecology.*)

The relative numbers of individuals in each of the various species of plant and animal life that make up communities regulate the food supply of the various types, that is, relative numbers establish a food balance. And the food supply in turn regulates to a considerable extent the number and size of individuals in the various species. Thus if the number of any one species is increased, the food balance is disturbed and may be restored or a new balance arrived at in several ways. The excess may die as a result of failure to find sufficient food, or migrations to establish new communities may occur singly or in groups, or the size of the individuals may be smaller than usual for that particular species. In a closed system, such as a land-locked pond, the migration of fish to new feeding grounds is impossible and the individuals may be quite small, due to excess number, or over-population. Game wardens recognize this relation between numbers and size and often remove the excess fish and transfer them to ponds or lakes which have been under-populated, so far as that species is concerned.

Even if undisturbed by Man, no animal community remains unchanged for any considerable period of time. Climatic changes occur, for instance, dry or wet seasons, that may be only of brief duration, but in effect disturb the plant life upon which the animals depend, or reduce or increase numbers of various animal species that make up the community. Other and less sharply defined influences are constantly affecting the life of the community, invasions of different species from without, erosions or other changes in the soil, accumulation of soil by decay of plant and animal life, and so on. Thus animal communities change, species disappearing or migrating, to be replaced by other types or to reappear again. A given locality may therefore at one time contain a preponderance of one type of animal and at another time contain a preponderance of another type. An example on the broadest possible scale is afforded by the known fact that in an earlier geological age enormous reptiles that have long been extinct occupied a prominent place among animals. On a small scale one may observe a succession of changes in an animal community within an aquarium. If dry hay is placed in water and seeded with a bit of mud taken from a pool, in a few days bacteria are present in large numbers, obtaining their subsistence from the decaying plant material. Presently small ciliate Protozoa appear and increase in numbers, living upon bacteria. Larger varieties of ciliates become prominent, feeding on smaller ciliates. Eventually, as the essential food decreases the community dies out. If an aquarium is set up containing the proper proportion of aquatic green plants and small animals, for example small fish, snails, planarian worms, hydra, or other aquatic animals, the community may become balanced so that the metabolism of the green plants present directly and indirectly provides just enough material and energy for the maintenance of the entire community. But a perfectly balanced community that persists without change probably does not exist in Nature.

Man himself, whether savage or civilized, is a member of a food chain. In the savage state the human body forms a link in a natural food chain, taking its share of the kills and itself falling victim to other animals as well as to disease and old age. Man in the civilized state arranges artificial food chains. In so doing he does not develop new principles but merely puts into wider execution the biological principles that govern all animal communities. Human food supply is at once diversified and stabilized by the introduction of long-distance food transportation, with the corresponding development of mechanical transport systems and the industrial efforts that such systems require. By selection in breeding and the application of the laws of heredity human foods are increased and improved. By suppression of species that have no value as human food, numbers and qualities are encouraged in domesticated plants and animals; pests and parasites that in Nature constitute links in the food chain are reduced or eradicated. Moreover, by technical methods recently developed, nitrogen is artificially fixed, that is, chemically combined into forms available for plant subsistence. So Man is able to dispense to some extent with nitrogen-fixing bacteria and thus to take a short cut to protein synthesis by green plants. Thus the human civilized community tends to include more and more of the habitable portion of the earth's surface and to establish therein food chains, that, while fundamentally grounded on the facts and relations of natural food chains, are artificially balanced. The food balance in civilized human communities is maintained only by special industrial effort. When such effort is restricted or extinguished, the human soon reverts to a place in a natural food chain. Here, then, is a direct and all-important relation between human industrial systems and the biological principles that govern animal communities and between human industrial life and the fundamental principles of transformation of energy and materials in living organisms. And history records for us how human communities respond to the food balance; both in savage and civilized countries migrations occur singly or in great numbers as a community becomes over-populated. There is no question that population obedience to the inexorable biological laws which govern animal communities in general constitutes the nucleus of the great military, economic, social, and governmental problems that always have, and apparently always will, face human civilizations.

But one may repeat that the biological principles which apply to animals generally are fundamentally responsible for civilization's vast industrial set-up. Nor is Man justified in assuming any especial credit for originality in his attempts to control and to provide a food supply by culturing and safeguarding animals and plants for human consumption. We are accustomed to regard this tremendous industry as something peculiarly human in origin and a cause for self congratulation on the part of civilization. Yet some varieties of ants herd a species of bug commonly known as plant lice, and care for them in order to obtain nutriment from the substances excreted by the bugs; other species of ants maintain slave ants to provide service for the handling of foods. Many varieties of insects store food with their eggs so that the young on hatching may have food immediately available. The fact that squirrels store foods for winter consumption, that bees store honey, and that dogs bury bones is often ascribed to human traits in these animals. On the contrary, these are characters that are exhibited by many animals, including Man. The behavior of lower animals in this respect is commonly regarded as instinctive; in Man it is assumed to be associated with intelligence; in both it represents a response to the necessities imposed by the food chain relation among living forms.

The exercise of intelligence, then, in the cultivation and handling of foods is a matter of ingenuity of method rather than of originality of principle. Associated with and as a consequence of intelligence is a certain restlessness that distinguishes human behavior in general. Other animals have solved their problems, or at least do not improve their solutions; the primitive method employed by the cat in catching mice continues to characterize cats and has never given rise to the development of a mouse trap. On the other hand, no human problem is ever permanently solved or static.

Social Life within the Species. The grouping together of animals of the same species represents, in the main, functional adaptations and serves various purposes. Such communities range from the seasonal and temporary aggregation of birds into flocks to include highly organized social communities. True social groups exhibiting cooperative effort and differences in duties do not occur among animals lower than the insects. Nevertheless, temporary aggregations of some of the simple Metazoa exhibit some interesting characteristics. Recent studies have shown that small aquatic animals are better able to resist poisons and temperature changes when in groups than when exposed singly. Moreover, individuals in such bunchings appear to conserve energy, for their rate of respiration is lower than when they are distributed singly. The reasons for these differences between the physiological characteristics of an individual when a member of a close group and when isolated are not yet clear. It is certain, however, that this tendency to form bunches characteristic of small crustaceans, worms, and other forms constitutes a protective action of considerable importance in the maintenance of life under unfavorable conditions.

Because of their intricate nature and the contrast with human society, the social lives of insects have always been of interest. Social organization among certain insects, particularly the bees and ants, is accompanied by anatomical differences between different members of the group, a society not only made up of individuals whose functions are different but also whose bodies are also different. A hive of honey bees consists of three structural types, workers, queen, and drones. The workers are by far the most numerous and active. Their mouth parts are specialized for collecting nectar and their legs for collecting and transporting pollen and working in wax. Workers are undeveloped females, essentially sexless. The queen is a fertile female, somewhat larger than the worker, but without the pollen and wax-working devices. Her function is entirely reproductive. The drones are the largest and are the males. They do nothing toward the maintenance of the life of the group, their function being solely the fertilization of the queen. After the nuptial flight the drones are disposed of by the workers and the queen remains quiet within the hive; she may continue to lay fertilized eggs for many years. Queens and drones are unable to provide food for themselves; they are examples of degenerative adaptive changes.

Complicated social lives of this sort and even more complex occur among the termites, ants, and wasps. Ants in particular collect slaves and guests of other species and in some cases are wholly dependent upon their slaves for food. Many very excellent and authoritative accounts of the social lives of bees, termites, wasps, and ants are available; to them the reader may refer for most interesting and informative reading.

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Chapter XI

THE HISTORY OF ANIMAL LIFE AND ITS INTERPRETATION

Fundamental Considerations. As the student of Biology becomes aware of the tremendous variety of living forms now existing in the world about him, so with the dawn of civilization there arose an awareness of the variety of life. Man has always, by fact or legend, attempted to account for his own existence and to trace his own history. Similarly, interest in the origins of all living forms is very old. In searching for materials with which to begin a study of the history of animals, it is obvious that living organisms, other than Man, do not leave written records; consequently, the history must be inferred from the forms as they exist now, from such skeletons and fossils as may be found, and from some certainties or regularities that may be observed to have occurred in all material things. Constant change is the constant fact which characterizes all things that the human mind may be aware of, changes that are not chaotic and haphazard but orderly and interrelated. This was recognized early in recorded human history and the idea that things at present are derived in an orderly fashion from things of the past dates back to the time of Greek civilization and no doubt still earlier. The doctrine of EVOLUTION is an interpretation of the history of matter which holds that these changes over periods of time are from the simple toward the complex, that earlier more primitive and more simple conditions have as the result of orderly change given rise to present complex conditions. Evolution as a broad concept comprehends Celestial Evolution, or the origins of the celestial bodies that preoccupy the attention of the astronomer; Terrestrial Evolution, or the origin of the Earth, which receives the attention of the geologist; Inorganic Evolution, or the evolution of the elements, which concerns the chemist and the physicist; Organic Evolution, or the origin and history of living forms, both plant and animal, a major doctrine for the guidance of the biologist.

Organic Evolution. No single field of thought has been so controversial and none has provoked more acrimonious debate than the subject of organic evolution. The reasons for the controversy are several. The facts of organic evolution are in apparent conflict with some religious beliefs and hence the concept meets with the opposition of powerful social and educational groups. Secondly, there is something acutely personal about the concept that Man has been derived from lower animals, something that is resented on the grounds of personal and racial pride. Thirdly, the opposition to the concept of evolution is strengthened by controversies between scientists. All competent biologists are agreed that the fact of organic evolution has been established by sound and far-reaching evidence, but there is no general agreement as to the method of evolution. This controversy as to the manner in which it has occurred has weakened the case for organic evolution in the minds of the uninformed and results in the withholding of confidence in the conclusions of the specialists. Then, too, perhaps because he in a way recognizes his relation to lower animals, the average human usually reserves to himself the right to an opinion on vital phenomena, notwithstanding the fact that in other technical fields he is willing to accept the decisions of specialists. Frequently, in the case of evolution as well as other sound biological principles, not only is the decision of the biologist rejected, but the evidence itself is denied.

The Mechanism of Evolution. While all who are competent agree that in the light of our present knowledge organic evolution is the historical background of living things, there are wide differences of opinion among biologists as to the method and manner by which evolution occurs. The whole concept of evolution as held today embraces the history of the development of the several views as to the mechanism of evolution. The Greeks expressed ideas that are unquestionably evolutionary interpretations of life but are curious mixtures of fact and fancy, observations of real, and descriptions of imaginary and fantastic beasts. The leaders of the early Christian church, particularly St. Augustine, drew their philosophy in part from Greek civilization and also expressed views that living forms arise by something like an evolutionary process. But in the sixteenth century a Spanish monk, Suarez, wrote pamphlets opposing the views of St. Augustine and advocating the doctrine of SPECIAL CREATION, namely, the thesis that all species have existed without change since their original simultaneous creation by supernatural effort. Suarez was not the first to advocate this doctrine, but his efforts gave it a strong impetus. In England, Milton's *Paradise Lost* had a similar and powerful effect. Thus after an interval of a thousand years the doctrine of special creation came to supplant the seeds of the doctrine of evolution in the mind of Western civilization. No further important progress in the development of the concept of evolution appeared until late in the eighteenth century, when Buffon, a Frenchman, wrote a natural history in which he showed with some clearness that the different forms of life were gradually produced. But Buffon interlarded his writings with comments to the effect that this could not be true, for he had been taught differently. In 1794 Erasmus Darwin, grandfather of Charles Darwin, published his book, *Zoönomia,* in which he suggested that acquired characters are inherited and that certain natural conditions operate to select the animals best fitted to survive. His work met with considerable antagonism and his views and those of Buffon made no immediate progress.

Lamarck. A complete doctrine of evolution first took form with the publication of the views of Lamarck in 1809, the year in which Charles Darwin was born. Lamarck expressed two principles as the basis of evolution: (1) Variations occur among plants and animals as a result of needs or of decrease in the usefulness of an organ; (2) these acquired characters are transmitted to succeeding generations. In a previous chapter (p. 339) the improbability of the inheritance of such modifications was shown; but this doctrine of use and disuse as an influence in heredity, this belief that the characters acquired by the adult in response to its contacts with the environment are transmitted to the offspring is in some quarters still vigorously debated.

Darwin. Lamarck's theory is based on two series of facts that are evident to everyone, namely, that variations occur, and secondly, that offspring resemble parents, in other words, the fact of inheritance. The feature of Lamarck's conception that is open to question is that variations which occur as a result of somatic changes in the organism (individual adaptations or acquired characters) become a part of inheritance. The next fully formed theory of evolution to appear is that of Charles Darwin in 1859. Darwin's theory is based on three sets of facts: (1) the occurrence of variations; (2) the fact of inheritance; (3) the fact of natural selection. The first two are of course involved in the formulation of Lamarck's theory. The third, natural selection, required further comment.

The meaning of this term will be made clear by illustrations. In breeding stock or fowls an artificial selection is practiced by the breeder; those animals which exhibit the desired character are thus artificially selected for mating and the others disposed of. A selective and eliminating principle also operates under natural conditions. Herbert Spencer has called this principle the "survival of the fittest." Thus if a mutation (p. 341) occurs which unfits the animal for its environment, it and its progeny are soon stamped out. If, on the other hand, the mutation renders the organism better fitted to cope with its surroundings, those individuals having this character soon assume dominance. For example, we may assume the sharp vision of the gull to be derived by evolution. By natural selection sharpness of vision has been developed and is maintained, for if gulls are hatched in which the acuity of vision is less than that required for the prompt discernment of prey, such individuals are at great disadvantage in the competition for food. Thus unfit individuals may be eliminated and a stock of genetic characters including sharpness of vision becomes the species character of the race.

Natural selection also operates in other ways to determine the character of the animals found in various areas. It acts to determine the coloration of animals. Where the background is sandy as on shore lines and in deserts, animals have a tawny color. In forests and among brush striped animals are found. In polar regions animals with white coats prevail. It seems hardly necessary to explain in detail how these inconspicuous colors make for safety of the species, and how variations that increase visibility are eliminated. Kipling's fable of the origin of stripes on the zebra and the spots on the leopard illustrates the usefulness of the color pattern. Mimicry, sexual selection, and the complicated life cycles of parasites are also regarded as further examples of natural selection and the operation of the law of the survival of the fittest.

Darwin's theory of the mechanism of evolution is distinctly different from that of Lamarck. The difference becomes clear if we cite an illustration, for example the webbed feet of certain aquatic birds. According to Lamarck's interpretation, the webbing between the toes is developed in response to a need, an adaptation imposed directly by the circumstances in which the bird finds itself. Darwin assumed the occurrence of variations without definitely explaining their origin. Some birds with webbing which appeared as a type of variation were better fitted for their environment and this inheritable variation (or mutation, in modern terms), then became the preponderant character of the race because of the elimination of those without webbing by the operation of the law of the survival of the fittest.

Weismann. Theories of the origin of inheritable variations, which both Lamarck and Darwin agreed are the basis of evolution, are chiefly associated with the names of August Weismann and Hugo de Vries. The theory of Weismann (1904) focuses attention on the germ cells as the source of all inheritable variations. Weismann's experimental work in which he showed that a mutilation carried on through many generations did not become inheritable, led him to the conclusion that the somatic cells of the body do not affect the inheritable characters that are transmitted through the germ cells. His evidence went far to refute the Lamarckian doctrine of the inheritance of acquired characters and to direct attention to germinal changes, occurring independent of any somatic influence, as the source of variations that are inheritable and hence responsible for evolutionary changes. The evidently complex nature of germ plasm involved Weismann in a series of correspondingly complex assumptions concerning the make-up of germinal material. This aspect of his theory does not concern us here. The essential feature of his doctrine is that the germ plasm forms a direct path from one generation to the next, that germ cells do not arise from somatic cells but only from germinal material, and that evolution is brought about by germinal variations completely independent of somatic modifications.

De Vries. Hugo de Vries in 1901 published his theory of mutations. Whereas Darwin's theory holds that small variations are the basis of evolution, De Vries by experimental work demonstrated that wide differences between parent and offspring sometimes occur. These mutations, as they are now called, are more frequent than is apparent to the casual observer. Records show that a considerable number have occurred among domesticated animals, for example, hornlessness in cattle and the peculiar conformation of Merino sheep. In laboratory animals mutations have occurred with considerable frequency. In Drosophila, a small fruit fly much used in experimental genetics, several hundred different mutants have appeared in the score of years that these animals have been bred in the laboratory. According to De Vries, species have not arisen by gradual selection but by jumps through sudden transformations.

Comparison of the Chief Theories of the Mechanism of Evolution. The main features of these four theories may now be set down, in order that they may be better compared:

Lamarck's Theory:

(1) Variations occur on the principle of use and disuse.
(2) Variations are inherited directly and improve with future generations.

Darwin's Theory:

(1) Variations occur; no attempt is made to explain their occurrence.
(2) Variations are either perpetuated or extinguished by natural selection.

Weismann's Theory:

(1) Germinal material is continuous from one generation to the next and not derived from soma.
(2) There is no inheritance of acquired characters, no effect of use and disuse; only germinal variations can be inherited and the occurrence of germinal variations is independent of the environment.
(3) Variations arise as a result of new combinations in the germ cells. Weismann recognized the possibilities of an almost limitless number of permutations and combinations when the germ cells of two parents become associated in the act of fertilization of the egg and regarded these possibilities as sufficient to account for germinal variations.
(4) The principle of natural selection by elimination of the unfit operates to determine which germinal characters shall persist.

De Vries' Theory:

(1) The formation of new species is due to sudden mutations, that is, the appearance of profound changes and differences between parent and offspring.
(2) Natural selection operates to retain or eliminate such mutations.

Modern Views. The vast accumulation of data on inheritance that have resulted from the experimental testing of the theories of

Weismann and of De Vries has deeply influenced modern views of the nature of the evolutionary process. Many have come to look upon the fact of mutations, germinal in character, as the whole source of evolutionary change and of the origin of species. All experimental efforts to show that characters acquired by the individual animal as a result of his experience or of his environment are transmitted to the offspring have either failed completely, or are open to quite different interpretations. Mutations are constantly occurring in various varieties of plants and animals and consequently their occurrence is given great weight as a possible source of new species. Moreover, the nature of the process of synapsis in the germ cells suggests that new combinations of genes are constantly being effected. The possibility of hybridization is also taken into account. Experimentally it has been possible to induce cross fertilizations between different genera, the resulting offspring being different from either parent. Occasionally such crossings are known to occur in Nature. But in pursuing this interpretation, that recombinations of genes and of mutations within the gene are responsible for evolution, great difficulties are encountered. For example, observed mutations are usually, but not invariably, Mendelian recessives, and represent alterations of already existing genes. Recessive characters are not apt to evolve, for they are usually heterozygotic in the following generations, unless, fortuitously, back crosses occur. Moreover, the appearance of new genes is exceptional, if it occurs at all. Other, and equally important, objections to the gene theory of evolution have been advanced. Consequently, this interpretation fails to satisfy some biologists. On the other hand, some geneticists are so thoroughly convinced that heredity can be accounted for only on the basis of the gene theory, that when the doctrine of evolution conflicts with the theory of the gene, they advocate that the whole concept of evolution should be thrown overboard.

While it has been impossible to show by experimental methods that acquired characters are inherited in the Lamarckian sense, still some biologists hold, and rightly so, that the experience of any one man, or for that matter the period of observation embracing the whole history of human intelligence, constitutes only an exceedingly minute fraction of the whole time during which evolution has been in progress. They further point out that Man cannot repeat this natural sequence of geological and climatic change and that therefore the most reliable evidence for evolution must be drawn by inference from paleontological and anatomical comparisons. This leads them to a Lamarckian interpretation of evolution.

Orthogenesis. Still another aspect of the problem of the nature of evolution concerns us, namely, that of ORTHOGENESIS, or of definitely directed evolution. This aspect of evolution was first presented in 1898 by Eimer. Briefly stated, this interpretation points out that the evolution of modern forms has followed a perfectly determined direction, complex forms arising in an orderly sequence as a complex adult arises in the development of an individual from the egg. In its first form Eimer adopted a Lamarckian interpretation of orthogenesis. The theory is capable of being easily converted into a vitalistic interpretation by assuming that the directive influence is a supernatural power.

Limitations of the Theories. One must distinguish sharply between the theories of the mechanism of evolution and the facts that constitute the record of evolution. The theories represent possible interpretations of the mechanism in the light of the facts of evolution. The facts are not open to question; they may be examined by anyone who has the interest to do so. The record is clear. The direction and pace of change from the simple toward the complex are obvious when the evidence is examined. Intellectual honesty forces an acceptance of the fact that evolution has occurred, as it forces one to conclude that the present status of national life in any country is derived from the history of the nation. The theories concerning the mechanism of evolution are at present but suggestions which provoke thought and stimulate investigation. But the theories are of themselves indecisive. It has come to be recognized more and more that a final explanation rests upon a more complete understanding of the whole nature of the physical and chemical processes that underlie vital phenomena. Science attains progress by adopting the mechanistic point of view as a working hypothesis. To be consistent in his science the biologist must also take the view that the stupendous pattern of evolution constitutes orderly changes in the expression of the energy transformations in protoplasm over an unbelievably long period of time. We do not yet know exactly how these transformations take place in the most simple type of cell carrying on its most simple vital characteristic. Consequently as modern biologists concern themselves more and more with rigorous examinations of the physical and chemical activities of protoplasm, the controversies over the probable method of evolution recede more and more into the background. Evolution is taken as an established fact which makes rational and unifies the facts of anatomy, of embryology, and of many other aspects of the organism.

The Evidence from Paleontology. The evidence that present-day complex plants and animals, including Man, have evolved in long past ages from more simple and more primitive forms, has accumulated from a variety of sources.

Life has existed on the earth for millions of years. During this time many types of animals and plants that are not to be found today have appeared, lived through periods of perhaps hundreds of thousands of years, and then have become extinct. The study of the records of plant and animal life in the form of fossils, consisting of flinty replacements of their bodies, of footprints, of imprints of their forms in rocks, and of shells and actual skeletons, constitutes the fascinating subject of PALEONTOLOGY. PALEOZOOLOGY deals with extinct animals; PALEOBOTANY with extinct plants. The facts that have been revealed by such studies have aided greatly in arranging present-day animals and plants in their proper taxonomic relationships.

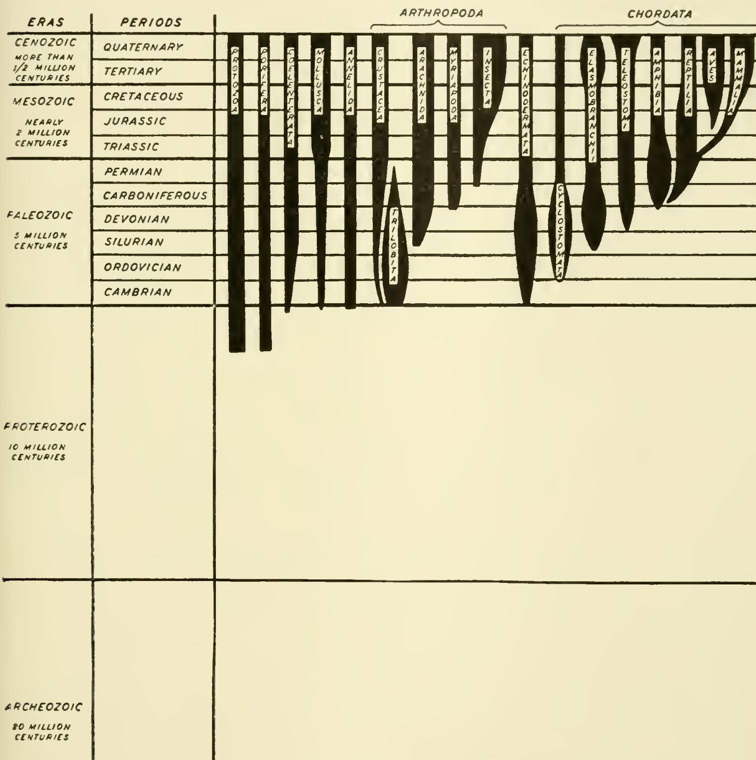

FIG. 221.—Table of the geological eras and representative animal types.

Representatives of all existing orders of animals are found among fossils, and in addition a considerable number of other orders that have become extinct. Thus our present-day forms represent only a portion of the number of types that have appeared. For convenience the geologists have divided the lapse of time since the earth assumed something like its present form into five eras (Fig. 221). There is some disagreement as to the period of time covered by these eras but that does not concern us here. It is sufficient to say that millions of years have passed since life first appeared on the earth. The accompanying table (Fig. 221) summarizes this distribution of animal life in time. It will be noted that the remains of Man are confined to the most recent era. The period marked by the presence of Man on the earth is therefore very short as compared with the time preceding his appearance. If we in turn compare the period of recorded history of Man, that is, the length of time since the human intelligence has been sufficiently developed to make observations and keep records, with the whole period of Man and again with the vast time that has preceded his appearance, it becomes clear to us why so little of the process of evolution has come under direct observation, why so few changes have been observed, and why our conclusions concerning the origin of any given form must be drawn by inference from fossil remains and by comparison with other forms. The most fruitful field of investigation of many of the concepts of Biology is by experiments which duplicate the processes of life under controlled conditions. But it is obvious that the effect of the long periods of the earth's history on living things cannot be repeated by Man under controlled conditions. It is the task of the paleontologist to read the record of Nature's great experiment; all these records point to a conclusion that is inescapable to a rational mind, namely, that the animals of the past are the ancestors of the animals of the present, and that the animals of the present have been evolved by descent with change.

The records of the life of bygone periods are incomplete; probably very many varieties of plants and animals have existed of which no traces have been found. Soft-bodied animals as they decay disappear; it is only when such bodies are accidentally embedded in mud under circumstances that leave their imprint in the resulting rock layers that any record is left. Violent upheavals of the earth's surface have occurred, accompanied by the subjecting of muds and slimes to terrific pressure and heat, which have destroyed any record of animal or plant life that such deposits may have contained. Others are buried by upheavals in inaccessible places. It is safe to say that of the total number of forms many have not been preserved, and of those preserved, only a small number have been discovered up to the present. Discoveries of fossil remains that are significant contain a large element of chance; it is after all surprising that so many different types have been found. To illustrate: the passenger pigeon less than a century ago covered North America in untold millions. It is now extinct; some museums exhibit mounted specimens. Just where would one go to look for preserved remains of this species whose habitat and general characters are known? In view of this, it is quite understandable that the records of forms which existed millions of years ago are incomplete, that here and there are gaps in the sequence of animal groups.

While the specialist regards the record as incomplete, a surprising amount of information concerning the life of the past has been collected and analyzed. It is extremely probable that the reconstructions of prehistoric scenes that form museum exhibits are highly accurate, for even fragments of animals yield a great deal of information to the trained observer who has a working knowledge of biological principles. To illustrate: The presence of animal life in any epoch presupposes the presence of plants, since animals are utterly dependent on plants, as has been shown in previous pages. A footprint indicates, in addition to other characters, whether or not the animal was a swimmer, a wader, or a land form. Fossil teeth indicate, in addition to the probable size and animal group of the owner, whether or not the animal was a flesh eater and something of the type of food. The finding of a single bone may be important in completing a record, for it is possible to reconstruct the entire animal from a single bone. Thus a leg bone indicates the probable size of other bones, for parts of a skeleton always have a proportionate relation to each other. In some forms this ratio between the relative sizes of bones has been worked out with mathematical accuracy. Similarly, knowing the proportions of the skeleton it is possible to establish the size and proportions of the entire animal. Knowing the size and anatomical characters of the animals, their food supply, and the animals and plants that occur in fossil form in the same layer of rock and in the same region, it is possible to visualize rather clearly a community of living forms that have been extinct for a period of time, the duration of which we can only faintly comprehend.

Moreover, in spite of the incompleteness of the record, its reliability is not open to question, for the preservation of forms that have been discovered has occurred at random and they constitute a fair sample of the variety of types that have existed. Furthermore, the presence of gaps in the record does not in any way invalidate the positive evidence afforded by evolutionary series of animals which are fairly complete. Since evolution has evidently occurred in some groups, it becomes a demonstrated fact. Then, too, experience has been that as time passes new discoveries are made which fill missing portions and complete the picture of evolution within the various groups.

An extensive account of the evidence for evolution contained in the fossil remains of animals cannot be given here; it will be sufficient to illustrate with a general statement and by means of a few examples of forms whose origin in time is fairly clearly understood (Fig. 219). The earliest indications of animal life reveal a considerable proportion of the great phyla already represented, the

Protozoa, Porifera, Cœlenterata, Annelida, Molluscoidea, Mollusca, Echinodermata, and Arthropoda of the early eras having left remains of types that with rare exceptions differ in important respects from modern types. Later records show successive appearance of more complex representatives of these phyla and the rise of new types, consummated by the appearance of the Vertebrata, and, in still more recent times, the class Mammalia. While the order of origin of many invertebrate phyla is lost in the far-distant past, it is inferred from the order of origin of the more complex animals in these phyla that the simplest animals were first to appear.

Fossil remains of the shell-forming Protozoa, the Foramenifera and Radiolaria, abound in certain limestone formations. In fact, some limestones are composed of countless billions of these tiny shells. All Foramenifera are marine animals; the occurrence of their fossils in any region indicates that that region was at some time a part of the ocean bed. Fossil Porifera are also common in some rock formations; having spicules of lime or of silica, they are preserved in numbers. The Cœlenterata are represented by fossil corals; soft-bodied cœlenterates have left only imprints in the rocks. Worms such as Annelida have left their tubular burrows. Of the Echinodermata the most interesting fossils are those of the class Crinoidea, once the most numerous of the phylum but now represented by comparatively few types. The Molluscoidea are chiefly represented by the shells of the members of the Brachiopoda. The most common type of fossils ordinarily met with are those of Mollusca. Many common limestones are made up almost exclusively of the calcareous shells of these animals. One has only to examine samples of crushed limestone to find numerous varieties more or less perfectly preserved. Fossil remains of Arthropoda are rather common. Imprints of insects have been found in which the wing spread was more than two feet. It rather staggers one's imagination to attempt to interpret what life must have been like when forms so outside our daily experience existed.

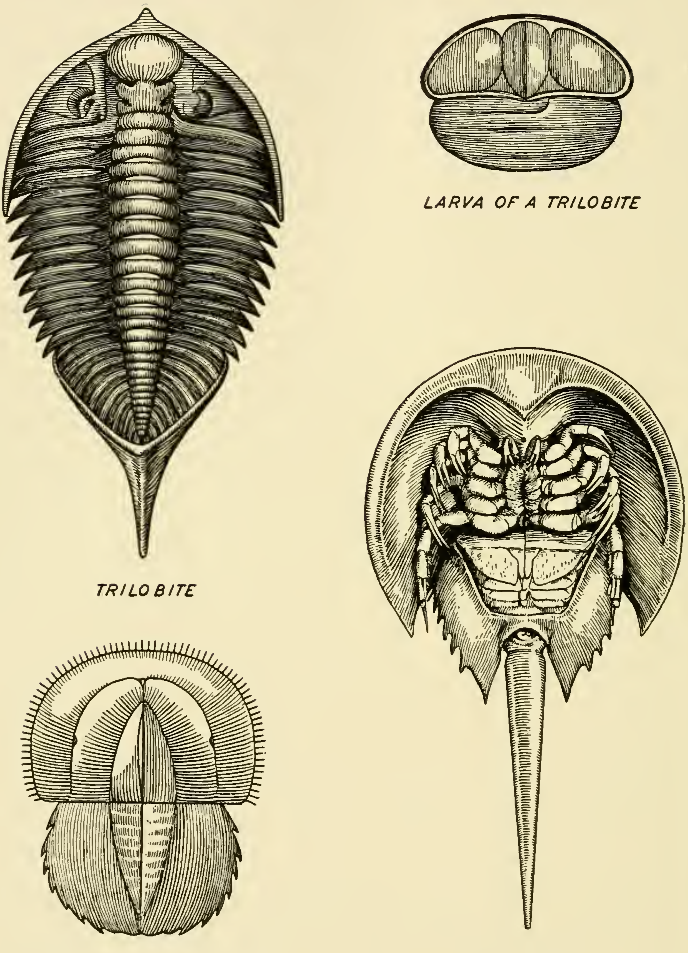

FIG. 222.—A modern king crab, its larva, and an extinct trilobite and its larva. (Partly after Lucas: *Animals of the Past,* published by McClure, Phillips, and Company.)

The trilobites are the most common of fossil Arthropoda. None of this group exists today. There were numerous sorts of trilobites. One must have been concerned in the origin of the king crab, for the immature modern king crab resembles a trilobite in many respects (Fig. 222).

Fossil fishes are not rare. Their study has thrown a great deal of light upon the origin, distribution, and relationship of modern fishes. An ancient order of Amphibia, the Stegocephala, were the first of the air-breathing animals. Unlike modern Amphibia, the bodies of some of these forms were scaly. But of all fossil forms the most bizarre, the most gigantic, and the most diverse in form and habitat were the reptiles. Today their remains make the most imposing of museum exhibits. Some were adapted to a marine habitat, some were waders and swamp forms, and some had the power of flight. They composed three orders: The Ichthyosauria, aquatic forms; the Dinosauria, enormous animals that lived in swamps or near water; and the Pterosauria, whose fore limbs were modified for flight; one type had a wing spread of twenty feet.

Ancestry of Birds. The developmental processes and many of the adult characters of birds and reptiles show distinct resemblances. On these grounds alone the conclusion is justified that modern birds represent a modification of a reptilian-like form. What amounts to confirmation of this conclusion is found in the fossil records. The latter portion of the Mesozoic Era was the period of dominance of the reptilian group. It was during this period that the Pterosauria, or Pterodactylia, flying reptiles, flourished. The wings of these forms, modified from the vertebrate fore limb, contained a long fourth digit, the first three digits remaining distinct (Fig. 223). In some modern birds the first three digits develop during embryonic life, but subsequently are obscured. Furthermore, in this era are found the remains of the first bird, Archæopteryx (Fig. 224). While distinctly a bird, this form also had many reptilian characters not found in modern birds. The tail was long and the vertebræ were not fused together to form the long sacrum of the modern bird. Not only did Archæopteryx have teeth, but the teeth were reptilian-like. Here, then, is a form that constitutes a link between these two groups of modern vertebrates. Obviously,

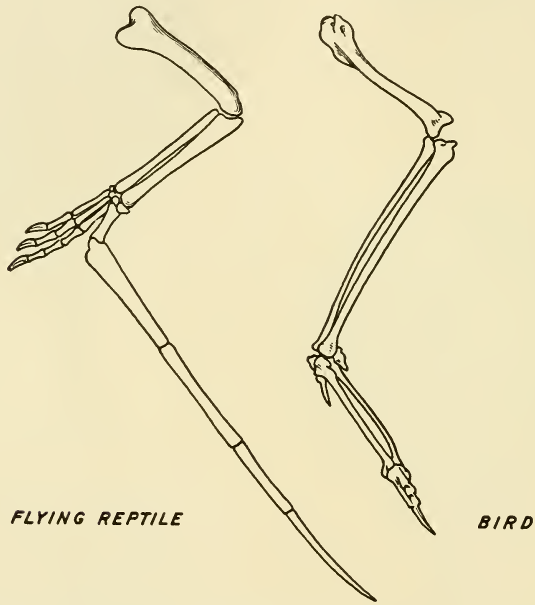

FIG. 223.—The wing bones of a pterodactyl (extinct flying reptile) and the wing bones of a modern bird. (After Lucas: *Animals before Man in North America,* published by D. Appleton and Company.)

our present-day birds are not derived from modern reptiles, but from reptilian-like ancestors at a time far back in the history of life on the earth.

Ancestry of Man. A somewhat similar path of origin of the human race has been traced. After the close of the Mesozoic Era, well into the Tertiary Era, appear fossils of animals resembling the anthropoid apes. In the next period, the Pliocene, a variety of primate fossils is found, including ape-like forms and one, *Pithecanthropus erectus,* which was either a man-like ape or an ape-like

Fig. 224.—Archæopteryx, an extinct primitive bird. The original fossil is in a Berlin museum. (After Vialleton: *Éléments de Morphologie des Vertébrés,* published by C. Doin et Cie, Paris. Original figure by Zittel.)

man, usually regarded as the latter. In the next era, the Quaternary, are found the remains of a number of primitive human types, one of which, the Neanderthal, has characters which classify it as a distinct human species, *Homo neanderthaler*. It is not regarded as the ancestor of modern Man, *Homo sapiens,* but as a parallel branch of the group, which has become extinct. Certainly it is clear that at this time there were many primate forms, some distinctly apes and others resembling Man, descended from some ancestral forms as parallel derivatives. So modern Man is in no way the descendant of apes or monkeys; rather Man, apes, and monkeys are distantly related modern representatives of a common ancient primate ancestor which appeared early in the Tertiary Era.

The two examples given illustrate a general principle that has been obscure to the uninformed, namely, that in giving rise to modern forms of animals and plants, ancient types have disappeared in the process, as a parent paramœcium disappears when it divides into two daughter animals. In other words, evolution has occurred by a modification of the stock, not by throwing off of different types with a preservation of the original in its primitive form.

Evolution of the Horse. It has been possible to trace with considerable accuracy the changes which have taken place in many forms. One of the clearest cases is the history of the modern horse (Fig. 225). In the early Tertiary Era are found the remains of a small animal with distinctly horse-like characters but with five digits on the fore feet and four on the hind feet. The middle digits in both fore and hind feet are distinctly larger than the others and the outer digits on the fore, and the inner digits on the hind feet are reduced to rudiments. The rocks of succeeding geological periods contain skeletons of larger animals of this type, with the middle digits still more emphasized and the other digits still more reduced. These differences in the feet are accompanied by similar transitional changes in other skeletal characters. It has thus been possible to trace the origin of the modern horse almost step by step to this early Eocene animal, Eohippus.

In summary, three principles are the essential derivatives of the evidence for organic evolution that has been preserved by the surface of the earth as it has undergone geological changes. (1) The oldest rocks contain the most simple forms and do not contain the remains of more complex animals found in other rocks of more recent date. (2) New forms that are found in later periods are present together with the nearest related forms of older periods.

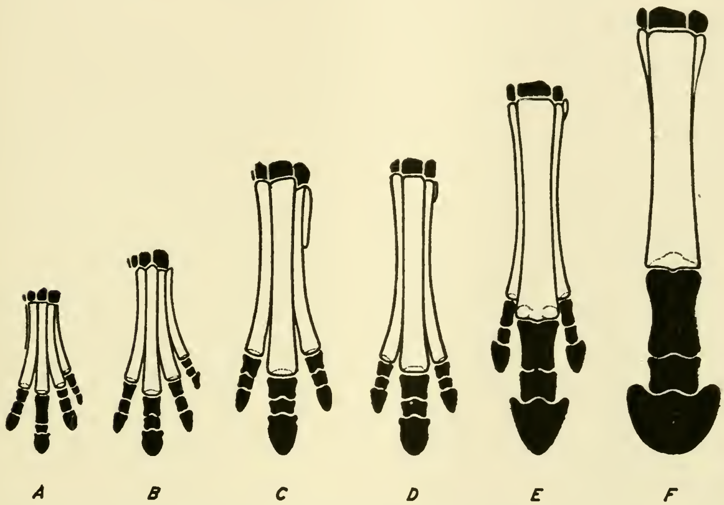

Fig. 225.—Stages in the evolution of the foot of the modern horse. A, B, C, and D were North American forms. E migrated to Asia. F is the modern type. (After Kühn: *Grundriss der allgemeinen Zoologie,* published by Georg Theime, Leipzig.)

(3) The sequence in time in which the various phyla, classes, and other groups appear is exactly the sequence that appears when present-day animals are arranged in order of increasing complexity. From the paleontological facts at hand our appreciation of the capacity of living matter to give rise to varieties of animal forms is greatly enlarged. Moreover, there is no reason to believe that all possible types of animals have appeared, that modern types taken together with those that are extinct represent all that protoplasm is capable of developing. In other words, there is no reason to sup-

pose that the evolutionary process has been halted. Furthermore, the fact that so many groups have become extinct and that as the centuries of the present age go by some modern animals have become extinct, shows clearly that we are not justified in assuming that any modern animals, including Man, are exempt from the possibility of extinction.

Evidence from Comparative Anatomy. Of the wide variety of facts of adult anatomy that can be interpreted only on the basis of an evolutionary series, only a few are listed here.

The basic body plan of many lower animals, which consists essentially of a tube-within-a-tube arrangement, as in Nemathelminthes, Annelida, and Arthropoda, is also the basic plan of higher animals, including Man.

Metamerism, or segmentation, is an architectural feature that is common to several phyla, most sharply defined in the adults of the lower forms and in the embryos of the higher forms. The various types of animals which exhibit this basic character also exhibit wide divergencies and alterations that can be explained rationally only on the interpretation that these divergencies and alterations in themselves represent the evolution of the metameric plan within the particular groups.

Unity of Plan within a Group: For example, all members of the class Insecta contain the same number of segments; moreover, all members of the class show three body divisions, head, thorax, and abdomen. All members of the sub-phylum Vertebrata (except cyclostomes) have four appendages and only four. And so on; the list might be extended almost indefinitely.

Vestigial and Rudimentary Structures: The original digits of the ancestor of the horse, Eohippus, are found as the splint bones of the modern horse. The human vermiform appendix is a vestige of the end of the long cæcum found in other mammals lower in the scale. The muscles of the human scalp and of the human ear are present in a reduced form and are usually not within the control of the will, whereas in mammals of lower type these muscles are well developed and under control. More than one hundred such vestiges in the human body have been listed. In snakes the pectoral and pelvic girdles and rudimentary appendages are present in the skeleton but do not appear externally. Not a single group of higher animals lacks rudimentary structures that are found functional in lower forms.

Comparisons of Organs and Organ Systems: Chapters VI and VII are very extensively devoted to a resumé of the comparison of the various organ systems and may be re-examined with profit, for such comparisons bring to light clear evidence for evolution as exhibited throughout the animal kingdom.

Continuous and Divergent Series: The nature of the evidence permits its division into two categories: CONTINUOUS SERIES and DIVERGENT SERIES. An example of a continuous serial evolution is shown by the vertebrate heart (Figs. 118-122). In the lower vertebrates this structure is essentially a tube, inserted directly into the blood system as a propelling organ. In the Amphibia, with the air-breathing character appearing, there is a partial division of the propelling organ into two separate systems, one concerned with distributing the blood throughout the body and the other with its aeration. The two are not completely separated, however, for the heart of the amphibian has but a single ventricle in which it is possible for some mingling of the blood of the two systems to occur. In some of the Reptilia the separation of the blood streams is not quite complete, the septum between the two ventricles being perforated. But in other reptiles and in Aves and Mammalia that portion of the heart which propels the blood to the lungs and that portion which propels it throughout the body are completely separated. The steps have been continuous from a single organ of propulsion inserted directly into the system to two separate organs in parallel, one concerned in the aeration of the blood and the other in its general distribution after aeration.

The digestive systems of vertebrates may be taken as an example of a divergent series (Fig. 226). The digestive systems of all vertebrates are composed of the same essential parts, pharynx, œsophagus,

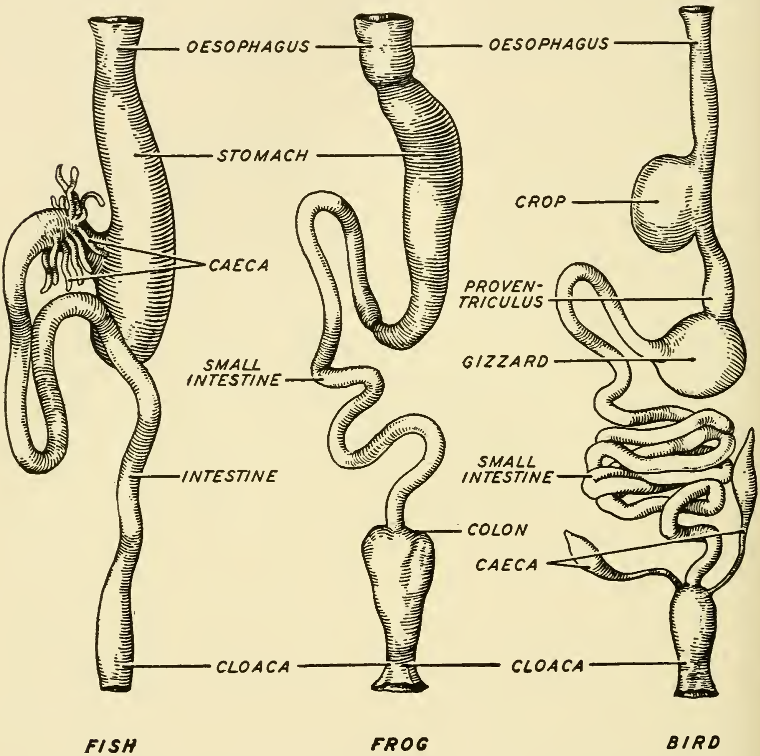

Fig. 226.—The digestive canals of a fish, a frog, and a bird. Partly diagrammatic. For a mammalian digestive system, see Fig. 107. (Partly after Wiedersheim.)

stomach, small intestine, large intestine, with two main glands, liver and pancreas. But in each type of vertebrate one or more of these parts is distinctly modified as adaptations to the particular type of food or life habit. Thus in ruminants, for example cattle, the stomach consists of four parts or chambers; in rodents, for example the rabbit the pouch at the junction of the small and large intestine, the cæcum, is nearly as long as the large intestine itself. In higher fishes there are a number of small pouches (intestinal cæca) around the small intestine; in the lower fishes, for example the shark, the vestige of the typhlosole of the Annelida is found modified as a spiral valve. One may regard the digestive system of a member of any vertebrate group as representing an alteration of a basic plan common to all vertebrates, the basic plan being in itself evidence of a common ancestry of vertebrates.

Evidence from Embryology. It is apparent to any observer that the developing embryo of animals high in the scale passes through stages and develops structures that are reminiscent of lower forms. Many years ago Müller expressed this as a biogenetic law, namely, that the development of the individual repeats the history of the race; Haeckel vigorously propounded and enlarged the doctrine, sometimes expressed by the high sounding phrase that "The Ontogeny repeats the Phylogeny." The limitations of this concept have been discussed elsewhere; the conclusion was reached that at no time is an embryo of one of the higher animals identical with the adult of a lower form and that the law of biogenesis must be restricted to mean that in a general way the processes of development of higher animals repeat the processes of development of animals lower in the scale. The nature of some of the evidence for this law is indicated in the paragraphs which follow.

From time to time in previous chapters various facts of development have been mentioned and discussed as historical in their significance. It is necessary here only to list some of the high lights that illumine the origin of the peculiar structures that appear in development:

(1) An early stage of development of all Metazoa consists of a single-layered hollow sphere of cells or some modification of such a structure, termed the blastula. Its geometrical shape is reminiscent

of the shape of colonies of certain Protozoa, for example, volvox (p. 89).

(2) The gastrula of Metazoa consists of a two-layered sac, or some modification thereof, the inner layer destined to become the digestive system and its attendant structures, the outer to become parts of the integument and the entire nervous system. The adult cœlenterate, hydra, is constructed on a similar plan, the inner layer being essentially digestive in function, and the outer layer containing cells specialized to receive and transmit stimuli.

(3) In all Metazoa the third germ layer, the mesoderm, gives rise to essentially the same types of adult structures, namely, circulatory, supporting, muscular, excretory (usually), and reproductive systems.

(4) The developmental stages of some phyla are very similar. For example, Mollusca, Annelida, some Molluscoidea, and Gephyrean worms pass through a stage in which the larvæ are free-swimming forms that closely resemble each other, known as trochophore larvæ (Fig. 76).

(5) The embryos of higher animals pass through a condition in which the character of segmentation is very distinct, although as development proceeds it becomes obscured to a considerable extent.

(6) Within a phylum, the basic organization of the various organ systems develops in much the same way, regardless of wide or narrow divergencies between adult types within the group. For example, the steps in the formation of the digestive system are very similar throughout the sub-phylum Vertebrata.

Specific examples of evolutionary records in the embryo are literally innumerable; in the embryo of cattle the formation of teeth which disappear before birth; the pre-natal hair coat in the human embryo; the neuropore that forms as the neural tube closes in the vertebrate embryo, which is identical in position with the neuropore of adult Amphioxus (lower chordate, p. 115) that permanently connects the neural canal of the adult with the surrounding water; the formation in mammalian embryos of the same basic structures, pharyngeal pouches, from which the gills arise in the fishes, and so on. The list is already extensive and is being added to from time to time as the significance of structures in the embryo becomes apparent. These embryonic vestiges, disappearing as they do before birth, admit of only one rational explanation, namely, that their significance is historical, that they constitute remnants of ancient ancestral inheritance.

Evidence from Parasitism. By comparing the anatomy and the development of parasitic animals with free-living forms that are similar, strong evidence of descent with change comes to light. But the changes have been retrogressive rather than progressive, for parasites of all sorts show either embryonic or adult vestiges of structures and organ systems that are well developed and functional in closely related free-living animals. The trend of degenerative changes that have accompanied the transition from free-living to parasitic life is illustrated by the three classes of Platyhelminthes, Turbellaria (free-living), Trematoda (parasitic), and Cestoda (parasitic). The Trematoda (example, the liver fluke), while resembling the Turbellaria (example, Planaria) in many ways, lack eyes and show other reductions in the nervous system. On the other hand, the reproductive organs of the Trematoda are the more conspicuous and active. The Cestoda (example, the tapeworm) not only lack eyes but also an alimentary tract. Moreover, the nervous system of the cestode is even less well developed than that of the Trematoda. On the other hand, the gonads of cestodes are still more conspicuous; mature proglottids of the tapeworm, for instance, consist almost entirely of ovaries and testes and are packed with fertilized eggs. In a previous chapter (p. 365) attention was directed to an extreme case of degeneracy in a parasite, *Xenocœloma brumpti*, a small arthropod that parasitizes a marine annelid, Polycirrus. The adult form of this parasite, if it may be called adult, consists of ovaries, testes, and genital ducts. The existence of an adult animal that consists solely of one organ system, namely, the reproductive, derived from a free-swimming larva not greatly different from that of other arthropods of its type, can be explained only on the assumption that as the animal acquired the parasitic habit, degeneration of adult structures, other than the reproductive system, occurred. In other words, the animal as it exists today is a product of descent with change, the changes in this case being degenerative.

The presence in parasitic organisms of vestiges of structures that are functional in related free-living forms is to be regarded as an expression of the history of the parasites, not different in principle from the significance of the vestigial structures found in animals in general.

Evidence from the Distribution of Animals. The distribution of animals is dependent on several conditions:

(1) *Barriers:* Long distances, wide bodies of water, mountainous regions, and sharp differences in climate serve to restrict the wanderings of animals, the degree of restriction depending more or less upon the effectiveness of locomotion of the animals. None of these except climate are absolute restrictions on the migrations of birds, because of their powers of flight. On the other hand, the mammals are slow to distribute themselves over land areas and are completely bound by wide water barriers because of their comparatively slow and ineffective method of locomotion.

(2) *Time:* The older the form, that is, the earlier its appearance among geological records, the wider its distribution. For example, the paddle fish, *Polyedon spatula* is found only in the Mississippi River and its tributaries. It belongs to one of the lower and more primitive groups of fishes. Extinct members of the group are found rather widely distributed, but its nearest living relative is a fish found only in the Yangtse River in China, the two forms being separated by half the circumference of the earth. The family Hypochilidæ of the spiders is represented by three living species;

one occurs in North Carolina, one in China and one in Tasmania. The wide separation of the living members of these groups is undoubtedly due to their great antiquity and to the obliteration of other intermediate representatives.

(3) *Food Supply:* Animals penetrate and persist in regions which provide adequate food and avoid regions that are sterile.

(4) *Number of Offspring:* Animals which reproduce rapidly and in large numbers distribute more widely than do those which reproduce less rapidly.

(5) *Climate:* Animals penetrate and persist in regions in which climatic conditions are favorable. Changes in climate bring about a corresponding withdrawal and redistribution.

These facts are in themselves simple and obvious. The addition of another fact is necessary to account for the present distribution of animals, namely, that modern forms are derived by evolution from ancestral forms. This fact becomes equally obvious when the present-day fauna of an area is compared with the fossil records of that region, for present-day animals native to a continent show distinct relationships to extinct forms found on the same continent. This is illustrated by the faunas of all the major land areas. In fact, the geological records which indicate the probable time of separation of the continents are in agreement with the fossil records of the animals that existed before and after the separation. The island of Madagascar affords an interesting illustration. This island is 250 miles off the east coast of Africa and geologists inform us that it has been separated from Africa since the Tertiary Era. Its modern animals do not include the large mammals of the mainland of Africa, but only those forms which existed on the mainland during the Tertiary, that is, when it was still connected with the continent, lemurs, insectivors, and a few other forms. Fossil remains of these are common to both Madagascar and to the mainland, but the modern types are peculiar to the island and show the evolutionary changes in an isolated group over a long period.

The island of Krakatoa between Java and Sumatra is now in the process of developing a fauna and doubtless will in time constitute an illustration of the effects of isolation and ensuing evolutionary changes. The island was partially sunk by a volcanic eruption in 1883, the area remaining above water being completely denuded of all life by hot lava and ashes. This catastrophe is used by Jules Verne as the climax adventure in one of his books. Three years later plant life was found on the island. Six years later a number of varieties of animals were found there, mostly insects. Twenty-five years later, in addition to insects, snails, lizards, and birds, were found. In 1920 there were more than 500 species of animals present, including bats and rats. These now constitute an isolated group; future additions will be casual. The hereditary possibilities of the group are contained in the germ plasm of these early arrivals, and their descendants may be expected to demonstrate descent with change from the original group, that is, evolution. In January, 1933, Krakatoa was again in mild volcanic eruption. Thus the isolated community of living forms is being subjected to the environmental changes that have been the common experience of life since its very beginnings. Such events have had profound influence in the distribution and survival of living organisms on all land areas.

Evidence from Histology and Physiology. The several tissues from various groups of animals present a uniformity of appearance under the microscope that is unmistakable. Thus the contractile tissues, striated muscles, of insects resemble the striated muscles of mammals; distinguishing between microscopic preparations of muscles from various mammals is very difficult except to a highly trained observer. In medico-legal cases the positive identification of blood as human blood is possible only by intricate chemical tests. Furthermore, certain cellular structures that appear in Protozoa as specializations appear with modifications throughout the entire animal series. The Sarcodina move by means of temporary extrusions of the cell substance, the pseudopodia; the white blood cells of Man move in the same fashion. Infusoria move by means of cilia; in Man the lining of the respiratory passages is made up of cells that have cilia on their exposed surfaces, which by constant beating maintain a flow of the overlying fluid. Mastigophora propel themselves through the water by the motions of flagella; the sperm cells of most animals have a similar mechanism of locomotion.

Histological preparations of various glands in vertebrates show striking resemblances in the nature and arrangement of the cells; liver tissue, for example, is easily distinguished, but the particular vertebrate from which the preparation was made cannot so easily be identified from the material. Not only do such tissues appear similar in preparations, but their products have the same physiological action throughout the vertebrate series. Therapeutic preparations from the thyroid, ovaries, pituitary, and other endocrine glands of lower vertebrates are effectively employed in the treatment of human patients. Moreover, the nearer the phylogenetic relationship the more nearly alike is the response of the blood to certain chemical tests. And in the phylogenetic series some Mollusca, the Annelida and all Vertebrata including Man utilize hæmoglobin as the chemical agent for the transfer of oxygen by the blood.

The foregoing pages have given merely the high lights of the various sources of evidence upon which the concept of evolution is based. It is not feasible to cite here more facts that are made rational by this interpretation; hundreds of volumes are required to cover the evidence now at hand. Familiarity with only that portion of the evidence cited convinces one that the facts show beyond a doubt the paths of origin of present-day living forms, although the exact direction of some paths is obscure in the great past. Moreover, no evidence is at hand which points to some conclusion other than the principle of evolution.

The Origin of Life. There is always an interest in the question of the origin of life. The problem is constantly being propounded to the biologist, for there are probably few rational minds that do not at some time or other ask themselves this question. But the present-day biologist, knowing that the facts are hidden in a very remote past and that the answer is still in the very remote future, is interested in the problem in only a mild way. A variety of suggestions have been advanced, which may be conveniently divided into several groups:

(1) *Special Creation:* All living things were at some time created from non-living materials by a supernatural power. Some would limit special creation to the origin of Man only, holding that other forms have arisen by the operation of natural laws.

(2) *Extra Terram:* Life arrived on the earth by transfer from interstellar space or from some other heavenly body. The suggestion begs the question; it cannot be proved nor disproved and is wholly speculative.

(3) *Spontaneous Generation:* Life arose from non-living materials by the chance association of the various ingredients that now compose living substance. A number of ingenious speculative theories have been proposed, each supported by a variety of facts. We will mention only the most commonly known facts here. In the first place, protoplasm in order to be alive need contain but twelve common elements which are found well distributed over the earth. Secondly, water, also universally present, forms the greatest proportion of protoplasm and many properties of protoplasm are also the properties of water. Thirdly, the salt content of protoplasm is similar to that of sea water. Fourth, the energy-releasing chemical reaction in protoplasm, oxidation, is also the most common chemical reaction in the non-living world. Fifth, so far as the problems have been investigated with success, protoplasm obeys the laws and principles of Physics and Chemistry that apply in the non-living world. According to the laws of probability, the

possibility of a chance association of the substances in protoplasm in the relation in which they now exist is not *zero*. Further than this no statement can be made that amounts to anything more valuable than a guess.

A second question is also frequently asked, namely: Is new life originating from the non-living now? So far as known, new living forms are not now arising *de novo*; the only known source of living material is other living material. Repeated attempts to demonstrate the spontaneous origin of life have been made. In fact, rumors of success appear with almost yearly frequency. None have stood the test of critical examination. There is no hope of immediate experimental production of the living protoplasm. The principles that have been discussed on previous pages here have been described rather than explained. Evolution and inheritance, reproduction and sex, development, growth, adaptation, contractility, irritability and transmission, behavior and all the extraordinary powers of the nervous system, are the end-products of reactions in the colloidal protoplasm. The various steps in these reactions are for the most part as yet unknown. It is unlikely that we shall be able to make something which we do not understand.

A third question follows from the first and second, namely: Are all living forms to be regarded as descendants of a single original organism, or has life originated in numerous primitive types from which are descended the multiplicity of present types? And like the first and second questions, the answer to this is also speculative. In the days when biologists were heavily involved in searching for facts having bearings on the validity of the theory of evolution, these questions were worked over, and shaped the interests and careers of the investigators. But now that the validity of the theory of evolution has been established, these questions become of less interest and importance; it is considered that any answer offered in the light of our present fund of knowledge must contain a deal of speculation. So no present-day biologist attempts a final answer.

Suggested Readings

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Chapter XII

THE SCIENCE OF BIOLOGY

Origins. The origins of the science of Biology, like the origins of all the sciences, extend far back into the dimness of the periods preceding the rise of Greek civilization. We now refer to Aristotle (384-322 B.C.) as one of the ancients who is the founder of systematic Zoology and of Natural History, but Aristotle himself referred to the ancients who preceded him by many centuries. Certainly the concept of evolution was expressed in the writings of Aristotle; his wide interests in classification of plants and animals, his extensive knowledge of animals and their life histories, his observations and conclusions concerning developmental processes, represent a height of development of interest in Biology that was not again attained for hundreds of years. Aristotle and the Greeks were then the source of biological knowledge throughout the Middle Ages, when the whole stream of human intellectual development diminished to a trickle. The stream was not entirely obliterated, however, for here and there appeared indications of a continuing current. Notable in preserving the continuity was Galen, who lived five hundred years after Aristotle. Galen was an anatomist and observer of some originality and his writings continued to be the authority in that field for twelve hundred years, a degree of permanence that no modern writer could conceivably attain. In the sciences, as in all fields of knowledge, progress was during this time almost arrested by the importance that was attached to the authority of the ancients. Galen's anatomical descriptions were expounded to students for centuries from platform or desk, without any demonstrations or accompanying dissections of the human body. It was not until the sixteenth century that the overthrow of the rule of authority in Biology was accomplished. The independence and originality of Vesalius (1514-1564) was the pre-eminent influence in this change. Vesalius, attempting to demonstrate human anatomy from the cadavora by following the descriptions of Galen, frequently found that the description and the facts shown by dissection were at variance. Finally he threw aside his Galen and taught directly from the specimen.

Biology in the Seventeenth Century. For this and other reasons the science of Biology began to gather impetus. The works of the British physician, William Harvey (1578-1667) mark the next great step in the development of the science, for Harvey added to the age-old method of observation a new method, that of experiment. Harvey's best known work is his demonstration that the blood traverses a continuous circuit, but he also made observations and experiments in other fields. His interests were wide and include descriptions of chick and mammalian embryos and speculations as to their origin, focusing attention upon the egg as the origin of all forms. Immediately following the time of Harvey occurred the invention and beginnings of development of the compound microscope. As is the case with all successful mechanical devices, the development of the microscope was not the work of one man but of a number of men; conspicuous among these were Grew and Hooke of England, Malpighi of Italy, and Leeuwenhoek and Schwammerdam of Holland. Even in its most primitive form this instrument opened great vistas for observation and for the revealing of a multitude of facts that in the absence of its powers would always remain unknown or in the realm of conjecture. The rise of modern Biology has accompanied and depended in no small measure on the development of the microscope. When Hooke, in 1665, first described the cellular appearance of tissues and Leeuwenhoek first discovered microscopic animals, spermatozoa, and other structures, they were unwittingly pioneering in the field of Cellular Biology.

Biology in the Eighteenth Century. The next great advance in the science dates from 1735, when Linnæus, a Swede, first published his *Systema Naturæ*, a work that brought order out of disorder in the attempts to arrange animals and plants according to various schemes of classification. The methodical mind of Linnæus established a rational basis for grouping plants and animals; his system is the basis of modern Taxonomy (p. 95). With this reasonable arrangement of plants and animals according to their structural similarities and dissimilarities as the basis for study, the conditions were established for the revival of the Greek concept of evolution, inactive since the days of John Milton and Suarez (p. 389). Linnæus himself regarded species as fixed and without the possibility of change, but the constant studies that his system of classification provoked of structural similarities in time could not fail to bring to recognition by others of the fact that such similarities represent actual relationships. Hence in the latter part of the eighteenth century Buffon, a Frenchman, and Erasmus Darwin, an Englishman, advanced their incomplete theories of evolution (p. 389) and in the first years of the nineteenth century the fully formed theory of Lamarck came forth. Charles Darwin's additions to the doctrine date from 1859, and the stimulus given by Darwin's great work still carries on.

The Cell Doctrine. Protoplasm. Meanwhile observers with the microscope had improved their instruments and had collected facts. In 1838 Schleiden, a Dutch botanist, and Schwann, a Dutch zoologist, together arrived at the important generalization that the cell is a structural feature common to all living objects and that it is the ultimate living unit. There followed a period of contention over the relative importance of the cell wall and the cell contents, until 1861, when the German, Max Schultze, in a masterly analysis of the facts then at hand promulgated the protoplasm doctrine and the essential basis of the modern cell theory. This stimulated an intensive study of the physical and chemical nature of protoplasm, but it was not until the final years of the nineteenth century that it was established, largely through the work of an American, E. B. Wilson, and a German, Fischer, that protoplasm is a colloid. Colloids had previously been described by the chemist, Graham, in 1861; it followed inevitably that the studies of the physical and chemical properties of protoplasm during the current century have become special phases of colloid chemistry. The cell doctrine has not gone unaltered since its first promulgation. The discovery that some living agents of disease are so minute as to be filterable (filterable viruses, p. 85) has led to questions as to whether or not the conventional definition of a cell is generally applicable to all living material. Moreover, the development of knowledge of the rôle played by the endocrine glands and their hormones (p. 203), and the knowledge of the regulation of form development by the relation of dominant and subordinate regions in the embryo and in regeneration have served to emphasize the fact that in Metazoa at least a cell is not an independent unit. What such cells do is controlled by other cells, either by means of transported chemical agents or by transmitted influences.

Division of Biology. The ever-increasing accumulation of facts and the ever-widening fields of interest during the latter half of the nineteenth century accelerated the break-up of the science of Biology into a great number of daughter sciences. Thus Pasteur, a Frenchman, Koch, a German, and Lister, an Englishman, in the latter part of the century, by experimental proof of the bacterial nature of many diseases, established the science of Bacteriology. Modern Embryology as a separate branch of Biology dates from a treatise on Comparative Embryology by Balfour, an Englishman, in 1880. Mendel, Weismann, De Vries, Bateson, and others whose names are associated with the development of the science of Genetics, realized their successes during the latter half of the century.

Physiology has its origins deep in the history of Biology, for Physiology has always been closely associated with, and in fact grew out of Medicine, which is an applied science of Biology. But even this old science in its modern form owes its origin in no small measure to the great French physiologist, Claude Bernard, whose active years extended into the latter half of the nineteenth century.

The Relation between Biology and Other Sciences. At the very beginning it was stated that a science consists of a body of interrelated principles which account for and rationalize a group of facts. But the science of Biology has ill-defined borders. On the one hand it is intimately related to the exact sciences, Physics and Chemistry, and on the other to the social sciences. Thus Biology stands as a group of principles that are integrated with many other fields of human interest, and are themselves derived in part from other sciences. Physics contributes the principles of mechanics and of the transformation and conservation of energy. In the absence of an understanding of these laws the life of a plant, the locomotion of an animal, or the expenditure of human effort become meaningless, or at least mystical performances. In the light of the laws of energy one may trace, as yet imperfectly it is true, to its ultimate source in the energy of sunlight, the effort expended by the reader in following these lines. Chemistry contributes the principles of the interaction of materials and these principles make the events that go on in protoplasm at least partially understandable. Geology affords the historical background of present-day life and Geography is an important set of facts that influence the distribution of life over the earth.

From the field of Biology extend paths which lead into the areas of the social sciences. The behavior of Man as an individual animal and in mass as animals in a community has its origins in the physical and chemical phenomena that are common to all living objects, for the human body is but one of an extremely numerous series of living forms. Human behavior includes much that is common to all animal behavior. It is coordinated and made more or less unique by the activity of the human mind, and the mind is conditioned in some way on energy transformations occurring in the human brain. We have seen how energy transformations in human protoplasm are as wholly dependent for a supply of energy on the photosynthetic reaction in the green plant as is the locomotion of the amœba, or any other exhibition of work done by a living object. Thus the science of human behavior in all its branches is grounded in biological principles.

Moreover, the biological principles that govern animal communities in general, their changes, migrations, and composition, apply to the relation between Man and his environment; food supply, preservation and perpetuation of the species, protection both by defense and offense, are characteristic of animals in general, Man included. Thus social organization, government, colonization, and many aspects of industrialism are outgrowths of biological factors in the life of Man and the science of Biology extends paths into these fields of human problems. The classic statement of Alexander Pope that the proper study of Mankind is Man has, therefore, very broad implications if considered in the light of present-day Science.

The Scientific Method. The present century has witnessed a tremendous growth and activity among all the sciences. This has impressed itself on the public and the phrase, "the scientific method," has come to be widely but sometimes very loosely used. There is a feeling that the "scientific method" is something new. It is worth while examining just what is meant by the term. Modern tools of science are new but the methods of thinking are old, perhaps as old as human intelligence. The logic of modern Science is also the logic of ancient Greece. Galileo used it in 1610 and arrived at the laws governing falling bodies.

As we have in recent years heard a great deal about the "scientific method," we have also heard much about "research" and witnessed a growth of this activity. There is nothing particularly new nor unique about research. In its essentials, research is merely the rigorous application of the human mind to fact finding and the rigid employment of the rules of logic in interpreting the significance of facts. All human progress in all past time and all that may be expected in the future arise from just these endeavors. Research that really contributes to knowledge and to welfare requires faithful application to sound principles, imagination, and utter honesty and open-mindedness. The fund of human knowledge has grown and will continue to grow by small accretions. The entire effort of a lifetime may be and most frequently is devoted to polishing one minute facet, to clarification of one small group of facts. In general, the investigator does not concern himself with an obscure animal primarily because his major interest is concentrated on that particular animal, but because the type of animal furnishes suitable material for the study of biological phenomena that are more or less generally applicable. A student of Protozoology, for instance, attempts to discover just what the lives of Protozoa reveal that has a bearing on the nature of life processes in general.

New truths of science are discovered when observations are fitted together to form a tentative explanation or hypothesis. The hypothesis or theory is thus first formulated by inductive reasoning from some facts at hand. Then the theory is tested by fitting with other facts and searches are instituted for still more facts. Often the facts do not fit the theory and the theory must be discarded or revised. Perhaps the greatest advance that ever has been made by scientists is the overthrow of the rule of authority that marked the long period of the Middle Ages. Science recognizes as of permanent value only the facts of the behavior of bodies in the environment, not what any person may have said about such facts. Sometimes the facts do not fit any theory that has been proposed and the solution of the problem then awaits the discovery of more facts or the development of a new theory. When a theory has been so fitted to the facts at hand that it is possible to predict or to describe in advance new facts from the theory, then it becomes a valid principle or law. On the basis of such laws it is possible to deduce events that may happen in the future, as the astronomer accurately predicts an eclipse of the sun, or to describe the characteristics of chemical elements as yet undiscovered, as the chemist has done, or to predict with accuracy the inheritable characters that will appear in the progeny of animals or plants, as is done by the geneticist. Thus science employs inductive logic in formulating theories and deductive logic in applying them. One of the attributes of the human mind is its constant striving to interpret the universe and all it contains in terms of laws, or regularities; it always has been so and no doubt always will be so. Hence the scientific attitude is not new; in fact, it is as old as human curiosity.

The task of the biological sciences is, in terms of the analogy of the Mexican jumping bean given at the beginning, the discovering of the causes of the motions of the bean, which, having been solved, involves the question of the causes of the motion of the insect larva within. In turn, the solution of the problem of the motion of the larva opens the question as to why the larval muscles contract. Thus the pursuit of a problem comes to involve more and more recondite studies. In the search for the ultimate WHY the scientist employs the most intimate facts of Nature. She is called upon to explain herself. Nothing is taken for granted, no facts are assumed *a priori*, and all theories are held tentatively, ready to be discarded if new facts invalidate them. It is so with such a well-established doctrine as evolution, for instance; the facts at hand can only be interpreted in the terms of this concept, but if in the future new facts appear that are not in alignment with this interpretation, evolution as a valid doctrine will be discarded.

In the search for answers to the constantly appearing series of questions and problems, sooner or later barriers are encountered; so Science is always engaged in a struggle at the barriers between what is known and what is knowable but as yet unknown. Thus all Science leads into indeterminism, as a line if extended leads into infinity. But the struggle at the barriers and the attempts to penetrate the unknown are not futile, for it has been human experience that immediate objectives and partial answers are attained by concerted and sustained attacks; new and illuminating principles are being disclosed and new methods and material welfare and enrichment of intellect are conferred on humanity.

The most striking example of recent success in the field of Biology has been the development of the Mendelian laws of heredity. This success is not total, however, for there are many facts of heredity and of cell behavior that have so far eluded analysis. So the present status of this great problem, as of all biological problems, is that of work unfinished. In fact, Biology as an exact science has only just begun, for the fact that the living substance, protoplasm, the physical basis of all vital phenomena, is a colloid was established less than four decades ago. Further progress depends upon the vigor and steadfastness with which the search for facts is continued and upon the fertility of human minds in their evaluation.

Biology Today. The present century has seen the development of Biology as an experimental science and an increasing tendency toward its becoming an exact or mathematical science. More and more it tends to draw closer to the exact sciences of Physics and Chemistry, as more and more it becomes evident that vital phenomena are but special cases of the operation of the principles of these sciences. Biology has come to make use of the tools and instruments of precision of Physics and Chemistry, to express its values as mathematical formulæ, and to think in terms of reactions and energy transformations. The descriptive branches, Anatomy, Taxonomy and their various subdivisions, are not obscured but are seen in their proper relation as descriptions of the necessary and indissociable medium in which the dynamics of life take place.

Experimental Technique. The technical methods employed by the modern experimental biologists are so diverse and so numerous that to describe any of them would be to omit others that are of equal or perhaps greater importance. In general, experiments are designed to test one single condition or effect, as Mendel studied the behavior of a single pair of allelomorphic genes. This requires that all other conditions be kept constant, or that the experiment be checked and controlled by a normal organism maintained under identical conditions except for the treatment required for the experiment. The experimental agent or condition is then varied in a known direction and to a known degree. For example, the geneticist mates plants or animals whose genetic make-ups are known but differ in one or more characters; the physiologist maintains all the conditions of his animal or plant at a constant level and then varies one condition, for example a gland is removed or the temperature of the environment changed. Thus the effects of a single factor or group of factors are isolated and studied by comparison with the control organisms. The effects are further compared with the behavior of non-living systems wherever this is possible. From the results certain hypotheses are advanced concerning the nature of the reaction in the organism. These hypotheses are then tested again and again by other types of experiments. If the hypothesis, or its subsequent modifications, has sufficient basis in fact that the results of experiments may be predicted with a high degree of accuracy, it is then known as a principle or law. A law merely expresses the probable basis for regularities that are observed in the life of the organism. From such efforts facts have been discovered that have revealed important principles of vital processes; the future will no doubt reveal much more. For human curiosity is insatiable and in laboratories of all civilized countries is a great army of students constantly testing, observing, and training their imaginations to project into the unknown.

Trends of Biology. Biology, like all Science, penetrates the unknown by a succession of advances on different fronts. A particular phase or problem may remain without marked progress for some time; then with a discovery that illuminates the problem more clearly, interest centers there and advances in our knowledge are soon registered. Meanwhile other problems have slowed down or become temporarily inactive, only to advance again later. Conspicuous among the contributions of the current century are: (*a*) The development and refinement of the Mendelian interpretation of heredity, with correspondingly rigorous study of the behavior of the chromosomes. (*b*) The development of the concept that the form of an animal results from a dominant-subordinate relationship of parts during embryonic development and in regeneration. (*c*) The transformation of more or less casual methods of Nature Study into a science, now known as Ecology, utilizing the methods of precision in study of the relation between the organism and its surroundings. (*d*) Increasingly rigorous examination of the physicochemical nature of protoplasm and its energy-transforming processes in development, irritability, contractility, secretion, and other phenomena that characterize life. (*e*) The development and study of the rôle played by vitamins. (*f*) The development of the study of the endocrine glands and the nature and action of hormones. No doubt these trends will determine the nature of progress in the immediate future.

Abstract and Applied Biology. One may divide the Biological Sciences into two lines of interest: (1) Studies that are pursued for the sole purpose of adding to the sum of human knowledge and thus gratifying Man's age-old instinct to project order into the world about him; one speaks of such interests as Abstract Biology; (2) The application of biological principles to human affairs, known as Applied Biology. However, there is no sharp nor well-defined line separating the two. For Applied Biology draws much of its technical and all of its theoretical methods and concepts from academic work, and Abstract Biology frequently looks to the Applied for fact and confirmation of theory and for new problems. In this treatment we have for the most part concerned ourselves with the abstract aspects of Animal Biology. We are therefore now in position to appreciate in a broad way some of the practical applications of the science.

Unlike Physics and Chemistry, the establishment of newly discovered principles of Animal Biology does not afford bases for spectacular inventions of mechanical devices and labor-saving tools and processes. Applied Biology can employ the principles of the science in a limited number of ways: (*a*) to increase human life span by improving health and preventing disease; (*b*) to increase the quantity and quality of food. While examples of the practical application of biological principles in both of these fields are abundant, the progress of Applied Biology until recent years has been relatively slow. In spite of the fact that our knowledge of the principles that actuate life processes is very incomplete, the world has at hand a tremendous storage of biological fact and known principles which have not yet been converted to practical use. This reservoir of theory and fact is constantly growing and is being constantly tapped by Applied Biology as it continues to increase in importance in human affairs.

In this discussion the history of the application of abstract principles to human welfare does not concern us; we purpose only to indicate the directions in which Abstract Biology has been of practical value and has influenced the daily life of civilized Man.

Medicine has both an academic, or abstract, and a practical value. The public is almost wholly interested in its practical applications, however, and does not commonly think of its indebtedness to the pursuit of knowledge for its own sake. A detailed statement of indebtedness, or even of a part thereof, would be out of place here, even if it could be given. It is sufficient to indicate the fields in which accomplishments in Abstract Biology have accompanied and contributed to accomplishment in the art of medicine.

Studies of metabolism in relation to growth and maintenance made upon small mammals resulted in the identification of the vitamins. The consequence is the control of deficiency diseases, pellagra, rickets, and so on, and the development of adequate rations not only for the maintenance of the human body but also for the benefit of domesticated animals. Work did not stop after the vitamins had been identified. Chemical analyses of foods, the chemical structure of the vitamins, and the search for other possible vitamins, continue. Activity increases rather than diminishes and other important results will no doubt be obtained.

Out of laboratory findings concerning the nature of bacterial life cycles has grown a science of Sanitation, which concerns itself with the eradication of disease-carrying insects, the purification of food and of water supplies, and the measures for control of epidemics. This science has made it possible for people to dwell in congested cities largely free from the devastating epidemics that scourged the cities of the past. Moreover, the nature of the metabolism of bacteria, what may be their chief source of food and how this food is chemically altered, has received attention. Hope may be expressed that such purely abstract work may in time reveal facts that will afford an opportunity for the control or elimination of pathogenic bacteria by attack on their food supply.

Studies of the life histories of all animals have included studies of the complicated life histories of parasitic animals. These studies have revealed the most vulnerable points in the life cycles of parasites and have brought about measures for their control. For example, knowledge that the infection of the human by hookworm takes place through the penetration of the skin of the feet by the larval forms makes it possible to prevent such infections by the destruction of the infected human excrement and compulsory wearing of shoes by inhabitants of infected areas. Similarly, the control of injurious insects is based upon their life histories, their feeding habits, and their sensitivity to various poisons. The biologist is interested in such life histories because they reveal relationships between various forms of animal life. Applied Science is interested because they reveal or suggest how control may be established.

The cell doctrine, the nature of protoplasm and of its response to drugs and chemicals and of its defenses against injurious factors in its environment, the nature of immunity, of contractility, of growth, of reproduction, and so on, are first the problems of the academic biologist. Practical applications of his findings are a part of the art of medicine. An illustration of the close interests of the two, but with widely different objectives, may be useful. The theory of anæsthesia, that is, the reversible decrease in irritability that results from exposure of the living organism to a wide variety of conditions, concerns the abstract biologist. His curiosity is stimulated by the problem of the nature of irritability and of the way in which various environmental conditions affect or extinguish it. The surgeon is interested in finding the perfect anæsthetic, the anæsthetic which will produce profound and sustained insensibility to injury or pain without danger and without injury or after effects. The close relation between these two interests in anæsthesia is so clear that it need not be discussed further.

It has been pointed out (p. 294) that in abnormal growths such as the various types of malignant and benign cancers or tumors, cells divide; in the benign type they undergo differentiation. The problems of why cells divide and what are the controlling chemical events in cell differentiation constitute most intriguing interests to the pure scientist. To the physician any solution of these problems would immediately suggest methods of control of such adventitious cell divisions as go on in cancerous tissue.

The Mendelian laws have become tools of great value in the breeding of domesticated plants and animals. Exceedingly important results have been secured in applying the principles of Genetics to securing disease-resistant and low temperature-resistant strains of plants. Similarly, breeding for high yield factors has increased the economic value of lands. It has been possible to know in advance what matings to make among domesticated animals in order to derive strains with desirable characters and to eliminate the undesirable.

Humanity in mass and individually is profoundly interested in its food supply. We have seen how animal food is ultimately derived from the metabolism of green plants and how it is dependent on their peculiar ability to utilize inorganic nitrates to form proteins (p. 43). In Nature the source of these nitrates is in the metabolism of certain nitrogen-fixing bacteria. A supplementary source of great importance in the development of modern agriculture is the deposits of animal and plant materials in certain regions, particularly the nitrate beds of Chile. Artificial methods of fixing the nitrogen of the air in forms available for plant nutrition have been developed and are assuming more and more importance in the world supply of fertilizers. Such methods make it possible to manufacture nitrates not only for fertilizers but also for the making of explosives wherever there may be a convenient source of power, for example, near a waterfall or near a coal-mining region. Increasingly, the artificial production of nitrates is dislocating world economic machinery with consequent effects on political and governmental systems. For a civilized country that has at its disposal an adequate supply of nitrates is independent of importations both in war and in peace.

Evidence is conspicuous on every side that the combined practical applications of Biology to human welfare are exerting a profound effect on civilization. Improvement of the amount and quality of human food, control of bacterial disease, more complete understanding of human physiology and the physiology of human reproduction and the physiology of childhood have combined to decrease human mortality among the young. With decrease of infant mortality there is an accumulation of more human adults with a corresponding effect on economic and industrial life. As a consequence of the increase in the number of adults there has begun to appear an increase in the diseases of later life; attention is now being focused on the control of the disorders of old age. Moreover, the building up and maintenance of the systems of disease control, of hospitals, of sanitary systems, of food raising and transportation, has brought into governmental and social machinery a tremendous factor that complicates the life of the civilized world.

It may seem unfair to claim all the accomplishments of Medicine, of Agriculture, and of Bio-chemistry, for Biology. However, by definition Biology is the science of life; by any path of reasoning one comes to the same conclusion, namely, that these accomplishments have been attained by the pursuit of knowledge of some characteristic of living organisms.

The growth of the science of Biology has not been without effect on philosophy and abstract thought in general. With concentration intensified on the physical and chemical nature of the processes that go on in protoplasm, has come a measure of success in explaining life in terms of natural laws. If, then, life is a manifestation of physical and chemical laws operating in a perfectly definite substance, the supernatural must be dispensed with so far as interpreting vital phenomena is concerned, must be pushed back and employed to explain the origin of these laws rather than their operation. Thus the successes of Biology have contributed to the growth of the doctrine of mechanism.

The development of the principle of evolution with its rational interpretation of the history of living organisms has similarly stimulated mechanistic philosophy and offered a profound insight into the materialistic basis of life as it exists today. Man is thus no longer to be set off as a special design of creation; his origins are not different in principle from the origins of other animals. Nor is Man the most recent and last effort of the evolutionary process; the human body in its present form is older than that of the modern horse, for example, and except for the brain is less highly specialized than that of several other mammals. The facts of evolution have brought about a sharp break from the belief that Man is the centre of all life, the last effort of creation, and its lord and controller; it is now recognized that Man falls into a regular and orderly place in the pattern of life and of evolutionary development. Unquestionably the recognition of the true place of Man has been one of the powerful influences in the growth of liberalism.

Whatever use is now or in the future made of the principles of Biology, whether they contribute to human welfare by reason of their value to applied science or to human thought because of their abstract value, the problems of Biology constitute a powerful challenge to the human mind. Not a day of a human life is spent without the individual's encountering, consciously or unconsciously, some as yet unsolved problem of vital phenomena, or some personal problem of human health, human behavior, human food, or human energy. The inquisitive nature of Man prompts him to undertake the solution of these problems and since time immemorial the more inquisitive minds have tended to accumulate into communities. The modern university is such a community. The function of such a group in human society always has been the acquisition and dissemination of knowledge, a function that never has been successfully divided, for every fact and every interpretation that a student encounters in any university curriculum are the products of someone's devotion to the search for truth. So university departments of Biology, however they may be administered or organized, have always and inescapably the two-fold function of investigating biological problems and of disseminating that knowledge already at hand. Devoted to this task is an army of scientists; all are human and therefore subject to the mistakes, prejudices, and flaws that characterize human effort in general. But their devotion to Science is an expression of an innate, personal adherence to a desire for knowing the truth. This interest cannot be successfully forced nor controlled by political pressure nor economic influence; scientists cannot be told to solve a certain problem within a certain time and in a certain way. Their work is like that of an artist, capable of great effort and accomplishment when the motivation is within the individual, but unsuccessful and sterile if it arises from external pressure.

Suggested Readings

(See also Readings for Advanced Students)

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GLOSSARY

Abdomen. The posterior portion of the main part of the animal body.

Acid. A chemical compound which contains one or more hydrogen ions that ionize in solution.

Accœlomate. The accœlomate animals are those which have no cœlom; for example, the Cœlenterata.

Acquired characters. Non-inheritable variations caused by the contact of the organism with its environment.

Acquired immunity. Immunity to disease, the result of having had the disease.

Adaptation. The characteristics of the organism which tend to fit it for the environment.

Adrenalin. The hormone produced by the medullary portion of the adrenal glands. It affects blood pressure, output of muscle sugar, plain muscle of the reproductive system, and has still other actions.

Agametic reproduction. The reproductive process that involves a bud, a fragment, or a spore.

Allelomorphic genes. Genes that are located in different chromosomes but influence the same inheritable character. Thus, the gene for blue eye color and the gene for brown eye color are allelomorphic genes.

Alternative characters. Differences in the same feature within the species. For example, blue and brown are alternative eye color characters in human inheritance.

Amino-acid. An organic compound containing COOH and NH_2; essential components of protein.

Amitosis. Direct cell division involving an unequal distribution of chromatin to the daughter cells.

Amnion. A membranous sac filled with amnionic fluid which surrounds the developing embryos of birds and mammals.

Amphimixis. As employed here the word refers to the fundamentally sexual process among Protozoa whereby two individuals interchange micronuclear materials.

Ampullæ. The bulbs at the extremities of the semicircular canals in vertebrates, in which are located the otoliths and the nerve endings that when stimulated record the sense of balance.

Amylase. A sugar-digesting enzyme in the vertebrate small intestine.

Anabolism. Metabolic processes that are constructive in nature.

Anaerobe. An organism that lives in the absence of atmospheric oxygen.

Anæsthesia. A reversible decrease in irritability.

Anaphase. An arbitrary stage in the process of mitotic cell division characterized by the migration of the chromosomes toward opposite centrosomes.

Anatomy. The science of structure.

Animal Biology. The principles of Biology as shown in the lives of animals.

Animal pole. If one considers the egg as a sphere the term animal pole refers to that pole of an egg most active in starting development; cleavage planes start at the animal pole. The animal hemisphere usually contains less yolk than does the more sluggish vegetal hemisphere.

Animal sociology. The relations of animal life within a geographical area.

Anther. The structure on the end of the stamen of the flower in which the microspores are produced.

Antheridium. That structure in the plant body which produces the sperms.

Antibody. Any substance produced by the host to neutralize poisons or to destroy invading bacteria.

Antitoxin. A substance produced by the host which neutralizes the poisons of invading pathogenic bacteria.

Archenteron. The primitive gut, formed in development when gastrulation takes place.

Archegonium. That structure in the plant body which contains the egg.

Artificial immunity. The immunity resulting when the body has been treated with vaccines or serums.

Aster. The form assumed by the centrosome and the rays appearing about it during mitotic division.

Astigmatism. A disorder of the eye involving defects in the symmetry of the lens.

Atom. The ultimate minute particle of a substance that cannot be further divided without changing the character of the material; for example, an atom of gold is composed of electrical bodies, protons and electrons.

ATRIUM. A receiving chamber of the heart.

ATTENUATED. When pathogenic bacteria are cultured under conditions that reduce their virulence, they are said to be attenuated.

AUTOCATALYSIS. A catalytic reaction wherein the products of the reaction increase the activity of the catalyst.

AUTOSOMES. Chromosomes not primarily concerned with the development of sex characters.

AXONE. The elongated portion of the nerve cell that conducts impulses away from the cell body.

BACK CROSS. A mating between parent and offspring.

BACTEREMIA. Disease in which the disease-producing bacteria are disseminated throughout the body of the host. See Septicemia.

BACTERIOLYSIN. A substance, produced by the host, that breaks down and destroys invading bacteria.

BASE. A chemical compound which when in solution releases an OH radical, or by reacting with water causes OH ions to form.

BERIBERI. A disease that involves the sloughing off of flesh and general systemic disturbances, due to the absence of Vitamin B from the diet.

BILATERAL SYMMETRY. The structure of the organism is such that if a vertical plane were passed through its mid-line dividing the animal into right and left halves, each half would be a mirror image of the other.

BILE. A secretion formed by the liver, composed of a number of substances that effect digestive processes.

BINARY FISSION. The process of reproduction in Protozoa whereby two daughter cells of equal size are produced by the division of the parent animal.

BIOGENETIC LAW. The individual in its life history repeats the history of the species.

BIOLOGY. The science that includes the principles which govern matter in the living state.

BLASTOCŒLE. The cavity within the blastula.

BLASTOPORE. The opening formed when the hollow blastula has been converted into a two-layered gastrula by the impressing of one hemisphere into the other.

BLASTULA. A stage in the development of Metazoa, in which the cells form a hollow sphere or some modification thereof.

Book lungs. The chief respiratory organ of the spider. They are essentially modified gills housed in chambers in the ventral body wall.

Botany. The science of plant life.

Breathing. The process of intake of a supply of oxygen from the environment and the expulsion of carbon dioxide by the animal body.

Bronchus. One of the tubes in vertebrates that lead from the trachea into the lungs.

Buffer. The term is employed by the chemist to include substances that release OH ions in the presence of an acid and H ions in the presence of an alkali, thus acting to neutralize both and to maintain a constant acid-alkali balance.

Cadaver. The body of a dead animal.

Calorimeter. A device employed to measure the heat produced by a reaction.

Cancer. An abnormal structure composed of cells occurring in animals. If the cells differentiate into a tissue it is known as a benign cancer or tumor; if there is no differentiation and the cells continue to divide it is known as a malignant cancer.

Carbohydrate. An organic substance containing carbon, and also hydrogen and oxygen in the same proportions as in water.

Cartilage bones. Bones that pass through a cartilage stage in their development; phylogenetically derived from the primitive cartilage endoskeleton.

Catabolism. Metabolic processes essentially destructive in nature.

Catalyst. A substance that causes chemical reactions to occur, or speeds up chemical reactions without being itself used up in the reaction.

Cell. A mass of protoplasm which constitutes the structural and functional unit of living organisms. It always contains a nucleus or nuclear material and is usually set off from other cells by a boundary membrane of some sort.

Cell wall. Non-living covering of the cell.

Cellulose. A complex carbohydrate formed by plant metabolism that commonly forms the cell walls of plant cells.

Cementum. A layer of substance that binds the tooth to its socket.

Centrosome. A small body just outside the nucleus of the cell. The first observable step in mitosis is its division and the migration of the two resulting centrosomes to opposite poles of the nucleus.

Centrosphere. Modified protoplasm in the vicinity of the centrosome.

Cephalization. The degree of organization obtained by the anterior or head end of the animal body.

Cephalothorax. In Crustacea the body is marked off into two main regions, the cephalothorax, consisting of the head and thorax, and the abdomen.

Chemical compound. A substance made up of molecules of the same sort.

Chemotherapy. Treatment of bacterial disease by means of chemical agents.

Chemotropism. Response to chemicals.

Chitin. A tough organic substance that forms the chief ingredient of exoskeletons of invertebrates, notably Arthropoda.

Chlorophyll. The green coloring matter in plants. It is a catalytic agent that in the presence of energy from sunlight causes carbon dioxide and water to unite to form carbohydrate.

Chloroplastid. A plastid containing chlorophyll.

Choanocyte. A type of cell occurring in members of the phylum Porifera. The cell is an elongated oval shape; on one end is a collar in the centre of which is a beating flagellum.

Chromatin. A substance characteristic of the nucleus of cells. It stains heavily with certain dyes and is known to be largely composed of nucleo-proteins. In this substance reside the inheritable characters.

Chromosome. A definite nuclear unit composed of chromatin. Within a species the chromosomes are always identical in number and shape.

Chyle. The food as it leaves the small intestine after digestion and absorption have occurred.

Chyme. The food as it leaves the stomach after stomach digestion.

Cilia. Motile protoplasmic fibres on the surfaces of some Protozoa and on the cells which form some epithelial linings in the Metazoa. In the Protozoa they constitute organs of locomotion. On metazoan epithelial cells their motion causes currents in the overlying liquids.

Cleavage. The early stage of development of the egg during which the first cell divisions occur.

Cloaca. A cavity of the posterior portion of the alimentary canal in fishes, Amphibia, reptiles and birds, that receives both the contents of the intestine and the excretory products of the kidney.

Cnidoblast. An ectodermal cell peculiar to the members of the phylum Cœlenterata. It contains a barb, the nematocyst, and has a sensitive structure, the cnidocil, which when stimulated causes a discharge of the nematocyst.

Cœlom. The body cavity of Metazoa. The cavity formed between the inner and outer sheets of mesoderm in the embryo.

Cœlomate. The cœlomate animals are those that have a cœlom, for example, the vertebrates.

Cohesion. The attraction for each other exerted by like molecules.

Colloid. A combination of two or more substances in which one or more are divided into particles greater than one molecule and suspended in another substance.

Commensalism. Two organisms intimately associated in such fashion that both obtain food from the same source.

Complementary genes. See Allelomorphic genes.

Complete metamorphosis. Describes insects which pass through four stages in their life history—eggs, larva, pupa and adult.

Conditioned reflex. A response which by repetition has been converted from a conscious act into a reflex.

Conjugant. Used to refer to a member of an associating pair in the process of interchange of micronuclear materials between Protozoa.

Contractility. The property of changing shape as shown by living organisms.

Corium. See Dermis.

Correlation. The unification of parts in the cell or in the organism to accomplish the life processes of the whole.

Cretin. A type of mentally and physically defective person. The defects are due to malfunction of the thyroid gland.

Cyclosis. The constant streaming of protoplasm within the cell; commonly observed in various Protozoa.

Cysticercus. A stage in the life history of the tapeworm in which the animal has the form of a bladder containing the inverted head; it develops in the muscles of swine.

Cytology. The science which treats of the minute structure of the cell.

Cytoplasm. Protoplasm outside the cell nucleus, exclusive of the protoplasm that forms the plasma membrane of the cell.

Defecation. The expulsion of undigested and indigestible material.

Dendrite. The elongated portion of the nerve cell, which conducts impulses toward the cell body.

De-nitrifying bacteria. Soil bacteria that in their metabolism liberate gaseous nitrogen from its soil compounds into the air.

Dentine. A bony structure just under the enamel and forming the bulk of the mammalian tooth and of the placoid scale.

Dermal bones. Bones derived directly from mesoderm without passing through a cartilage stage; phylogenetically derived from dermal scales.

Dermis. The inner layer of the integument of vertebrates.

Diaphragm. A muscular partition that in mammals separates the peritoneal cavity from the pleural cavities and is employed in the process of breathing.

Diastase. A starch-splitting enzyme.

Differentiation. The term is employed to include the processes whereby cells become structurally and functionally different as they assume special functions in the organism.

Digestion. The conversion of foods into physical and chemical states in which they are available for use in metabolism.

Di-hybrid. The progeny of a cross between two parents that differ in two pairs of alternative characters.

Diploblastic (Adjective). An animal that consists of two layers of cells and their derivatives.

Diploid number. The number of chromosomes characteristic of the nuclei of the tissue cells.

Dominant. A member of a pair of alternative characters is said to be dominant when the progeny of a cross between a parent having the character and one having its alternative all resemble the first-mentioned parent with respect to that particular character.

Ecology. The science which deals with the relation between the organism and its environment.

Ectoderm. The outer layer of cells in the early stages in the development of the Metazoa.

Ectoplasm. The protoplasm which forms the ectosarc.

Ectosarc. Living protoplasm forming the region just under the boundary (plasma membrane) of the cell; applied particularly to the Protozoa.

Effector. An organ that responds to an impulse. The chief effectors are muscles and glands.

Electrolyte. A substance that dissociates into ions when dissolved.

Electron. A component of an atom consisting of a negative electrical charge.

Element. A substance that consists of atoms all of the same sort.

Embryo. A new individual in the process of development.

Embryology. The science which treats of the processes of development of the organism from the egg to the adult.

Emulsification. The process of separation of fats into small droplets suspended in water.

Enamel. The hard surface layer of teeth and of placoid scales.

Endocrine glands. Glands that produce hormones and deliver their products by osmosis directly into the blood stream.

Endocrinology. The science of hormones and of the glands of internal secretion.

Endoderm. The inner layer of cells formed in the early stage of development of Metazoa.

Endolymph. The liquid that fills the membranous parts of the inner ear.

Endoplasm. That portion of the cytoplasm between the ectosarc and the nucleus of the cell.

Endosarc. That region of the cell between the ectosarc and the nucleus.

Endoskeleton. The internal supporting structure of an animal.

Energy. Power to do work.

Entomology. The science of insect life.

Enzyme. Organic substances that by catalytic action cause chemical actions to occur in the organism.

Epidermis. The outer layer of the vertebrate integument.

Epigenesis. A concept of embryonic development which holds that the process is one of up-building of adult structures by the constructive nature of embryonic metabolism.

Erepsin. An enzyme in the vertebrate small intestine that converts intermediate compounds derived from proteins into amino-acids.

Erythrocytes. Red blood cells.

Eugenics. The science of human inheritance.

Evolution. Organic evolution is a doctrine which holds that present-day organisms are the products of descent with change from earlier and more simple types.

Excretion. The elimination of wastes of metabolism by the organism.

Exocrine glands. Glands which deliver their secretion by means of ducts, either to the surface of the body or into some cavity that is indirectly connected with the surface, never into the blood.

Exoskeleton. The external hard structures of support and protection.

External fertilization. The meeting of egg and spermatozoon external to the female body.

Extra-cellular digestion. Digestion that occurs outside of cells or tissues.

Facultative anaerobe. An organism that may under certain conditions live in the absence of atmospheric oxygen and under other conditions live normally in its presence.

Fat. An organic substance derived from either plant or animal metabolism, made up chiefly of esters and often having the formula: $C_3H_5(CO_2C_nH_n)_3$. Not to be confused with mineral oils which are mixtures of hydro-carbons.

Fauna. The animal life of an area.

Fermentation. A reaction catalyzed by enzymes occurring in organic material.

Fertilization. The act of combination of two cells from individuals of opposite sexes; it results in the initiation of development of a new individual.

Fibrinogen. A substance in the blood that is converted to fibrin by the action of thrombin in the process of blood clotting.

Filterable virus. Bacteria so small as to be beyond the range of visibility of the most powerful microscope; so small that they pass through the pores of a porcelain filter. (There is substantial evidence that filterable viruses may be distinctly different in character from visible bacteria.)

Flagella. Long, rotating protoplasmic fibres that are the organs of locomotion of some types of Protozoa.

Food. Strictly speaking, any substance that provides either energy or materials which may be used in metabolism is a food.

Food balance. A condition in a community in which the holophytic nutrition of green plants and the holozooic nutrition of animals exactly balance, so that all plants and animals within the community have an adequate food supply.

Food chain. The sequence in which plants and animals depend on each other for food.

Fossil. The trace, imprint or replaced tissue of an extinct animal or plant. An actual skeleton or shell, for instance, is not a fossil.

Free martin. In cattle a female calf born co-twin with a male is almost always sterile and is called a free martin.

Functional adaptation. Physiological properties that are adaptive in nature.

Galvanotropism. Response to an electric current.

Gamete. A germ cell, either ovum or sperm.

Gametic reproduction. The reproductive process that involves germ cells.

Gametophyte. The stage in the life history of mosses, ferns and seed-bearing plants which produces gametes and reproduces by a sexual process.

Ganglion. An aggregation of nerve cells.

Gastrulation. The process of conversion of the blastula stage into the two-layer gastrula.

Gene. A system located in the chromosome that determines the development of an inheritable character.

Genotype. The genetic make-up of an individual. To express the genotype of the individual is to state the various genetic characters which that individual is capable of transmitting to its progeny.

Germ plasm. A general term applied to the reproductive cells, especially with reference to their properties in conveying inheritable characters.

Gizzard. A modified region of the gut tract particularly adapted to the abrasion of foods by the action of the wall muscles and the contained abrasives such as sand.

Glomerulus. Small bodies in the mesonephros and metanephros in which the essentials of the process of excretion occur.

Glycogen. A carbohydrate occurring in the liver and in muscle.

Gonad. The structure, either ovary or testis, in which the germ cells develop.

Graafian follicle. A structure in the mammalian ovary within which the egg matures.

Graviotropism. Response to gravity.

Green glands. The excretory glands of Crustacea.

Growth. Increase in size as a result of metabolism.

Hæmocyan. A green copper-containing substance occurring in the bloods of most Mollusca, Arthropoda, and some other invertebrates.

Hæmoglobin. The red agent in the blood of a few molluscs, annelids, and vertebrates that is responsible for the blood color. Its function is primarily the transfer of oxygen and carbon dioxide.

Hæmophilia. A state of the blood in which it does not clot in the normal manner.

Haploid number. The number of chromosomes characteristic of the mature germ cell; one-half the diploid number.

HELIOTROPISM. Response to sunlight.

HERMAPHRODITE. An individual equipped with the reproductive organs of both sexes.

HETEROGAMY. The character of producing germ cells that may be distinguished as eggs and sperms.

HETEROSPORY. The character in flowering plants of producing two different types of spores by the sporophyte generation, one type to develop into the male gametophyte, the other into the female gametophyte.

HETEROZYGOUS. An individual is said to be heterozygous when it carries in its genetic make-up the possibility of transmitting either of two alternative characters.

HIBERNATION. The winter period of quiescence characteristic of the life cycles of many animals.

HISTOLOGY. The science that deals with the cellular structure of tissue.

HOLOPHYTIC NUTRITION. The essentially constructive metabolism of green plants involving the synthesis of carbohydrates and of proteins from simple inorganic substances.

HOLOZOOIC NUTRITION. The essentially destructive metabolism of animals whereby they utilize the carbohydrates derived from plant metabolism as their source of energy and plant proteins, or proteins derived indirectly from plants, in constructing their own proteins.

HOMOIOTHERMAL (Adjective). An animal whose body temperature is independent of that of the environment.

HOMOLOGOUS. Structures are said to be homologous if they are derived from the same embryological origins.

HOMOLOGOUS CHROMOSOMES. Chromosomes bearing the same or alternative characters.

HOMOZYGOUS. An individual is said to be homozygous when its genetic composition carries only one type of gene for any given character.

HORMONE. A chemical agent in the circulatory fluid, particularly in vertebrates, that influences the metabolism of the body in a particular way. Hormones diffuse readily through membranes and are not easily destroyed by heat. In general they are produced by special glands of internal secretion.

HUMAN BIOLOGY. The principles of Biology that are concerned with human life.

HYDRANTH. An organ that is the terminal of a branch in the Hydrozoa. Hydranths are of two sorts, feeding and reproductive.

Hydrolysis. A chemical reaction in which water is one of the reacting substances.

Hydrostatic pressure. The pressure exhibited by a column of liquid because of gravity.

Hydrotropism. Response to water.

Hypertonic. A solution containing such a concentration of solutes that its osmotic pressure is greater than that of its surroundings.

Hypostome. The structure in the feeding hydranth of Hydrozoa in which the mouth is located.

Hypotonic. A solution that because of its salt content has an osmotic pressure less than that of its surroundings.

Immunity. A state of the body that does not permit disease to develop as a result of bacterial invasions.

Inbreeding. Mating of individuals that are closely related.

Incomplete metamorphosis. Describes insects which pass through three stages in their life history—egg, nymph, and adult.

Individual adaptations. Adaptive characters that are peculiar to an individual animal.

Instinct. Responses that are reflex, automatic, independent of experience, and regular in occurrence.

Insulin. A preparation derived from the islet tissue of the pancreas that has to do with the regulation of the sugar content of the blood.

Intelligence. Response that is variable, associated with experience, and controlled by imagination.

Internal fertilization. Fertilization occurring in the female body.

Interstitial cells. Usually refers to the endocrine tissue in the ovary and testis that is the site of production of a hormone which influences the development of the secondary sex characters and perhaps the primary as well.

Intra-cellular digestion. The digestion of foods within the cell.

Ion. An atom or a combination of atoms that when dissolved bears electrical charges.

Irritability. The property of responding to some influence arising outside the cell.

Isogamy. Some plants produce germ cells that cannot be distinguished as eggs and sperm; they are known as isogamous plants.

Isolecithal (Adjective). Eggs with a relatively small quantity of yolk evenly distributed throughout the cell.

Isotonic. A solution the osmotic pressure of which is exactly equal to that of its surroundings.

Kinetic energy. Energy in action.

Lacteals. Fine vessels of the lymphatic system that occur in great profusion in the walls of the intestine.

Leucocytes. White blood cells.

Life. A collective word used to include all the phenomena that are characteristic of matter in the living state.

Lipase. Fat-splitting enzymes.

Macronucleus. The larger member of two nuclei that occur in some types of Protozoa.

Macrospore. A cell developed in the base of a flower which subsequently develops into the egg-producing gametophyte generation.

Malpighian tubules. Fine tubules that constitute the excretory organs and empty into the intestine of insects.

Mechanism. The doctrine that regards life processes as manifestations of physical and chemical principles.

Mediastinum. The partition separating the right and left pleural cavities in mammals; it is traversed by the trachea, the œsophagus, main blood channels, and nerves.

Membrane. A partition between two substances. Living membranes are of three types: non-cellular basement membranes that separate layers of cells; the cell boundary; membranes composed of cell layers, for example, the lining of the intestine.

Membrane bones. See Dermal bones.

Mesoderm. The intermediate layer of cells that develops between the endoderm and the ectoderm.

Mesolecithal (Adjective). Eggs that are intermediate between isolecithal and teleolecithal as regards quantity and distribution of yolk.

Mesonephros. The excretory organ of most fishes and all Amphibia. It also develops in the embryos of mammals but does not function in some embryos. It becomes converted into important parts of the male reproductive system of the mammal.

Metabolism. A collective word used to include all the chemical activities of living protoplasm.

Metagenesis. A life cycle that includes sexual and asexual generations in regularly occurring sequence.

Metamerism. A type of animal structure which is characterized by the subdivision of the body into ring-like compartments or metameres, each resembling adjacent compartments.

Metamorphosis. The transformation of larval forms in the development of animals.

Metanephros. The kidney of reptiles, birds, and mammals.

Metaphase. An arbitrary stage in the process of mitotic cell division characterized by the longitudinal splitting of each chromosome aligned on the equatorial plate of the mitotic spindle.

Metaphyta. Plants consisting of many cells in which specialization of structure and of function is well defined.

Metazoa. Animals consisting of more than one cell in which the cells show appreciable specialization of function and of structure.

Micronucleus. The smaller member of two nuclei that are found in some types of Protozoa.

Microspore. Spores of flowering plants that develop into the sperm-producing gametophyte generations. Commonly known as pollen.

Mimicry. The imitation by the organism of some other living form or of some inanimate object.

Mitochondria. Rod-like structures occurring in the cell cytoplasm.

Mitosis. The usual process of cell division, involving an equal division and distribution of the chromosomes to daughter cells.

Molecule. A combination of atoms that forms a complete and more or less stable chemical unit.

Monoblastic. An animal consisting of a single layer of cells or its derivatives would be described as monoblastic. No adult monoblastic Metazoa occur. The blastula stage of the embryo might be described as monoblastic.

Mono-hybrid. The progeny of two individuals who differ in a single alternative character.

Myopia. Near-sightedness.

Nares. Air passages of the nose.

Natural selection. The effect of environmental conditions serves to eliminate living forms which are not fitted to survive and thus acts to select the fittest for survival.

Nematocyst. A barbed coiled fibre in the cnidoblast cell of the Cœlenterata. When discharged together with a poison it serves as a defensive weapon, but more especially serves in the capture of food by the tentacles.

Nephridia. The excretory tubules of Annelida.

Neural crest. Two ribbons of ectodermal cells on either side the primitive neural tube of the vertebrate embryo; some of these cells become the ganglion cells of the dorsal roots of the spinal nerves; others form the cells of the sympathetic system; still others are concerned in the formation of certain endocrine glands.

Neuroid transmission. The transmission of impulses by tissues other than nerves.

Neurology. The science that deals with the nervous system of animals.

Neuromotorium. A small body in the protozoon, Diplodinium, which appears to be a regulating centre in its coordination mechanism.

Neuron. The nerve cell.

Nitrogen-fixing bacteria. A type of bacteria that in their metabolic processes combine the nitrogen from the air with elements in the soil, for example, potassium, to form inorganic nitrogen compounds. Nitrogen-fixing bacteria commonly inhabit nodules on the roots of plants, especially clovers, beans, *etc.*

Notochord. An axis of the chordate body consisting of a rod of cells in the body wall dorsal to the cœlom.

Nuclear membrane. A thin membrane surrounding the cell nucleus.

Nucleo-proteins. Proteins characteristic of the cell nucleus. They are complex molecules containing nucleic acid and appear to be essential to life, since all cells contain them.

Nucleus. A more or less spherical body of specialized protoplasm that occurs in all cells and without which a cell cannot exist.

Nutrition. The process of obtaining and utilizing foods.

Obligatory anaerobe. An organism that cannot live in the presence of atmospheric oxygen.

Ontogeny. The process of development of a new individual.

Oogenesis. The process of conversion of the primordial female germ cell into a mature ovum.

Oogonia. An early stage in the maturation of the egg, during which the germ cells increase in number by ordinary mitotic divisions.

Organ. A special part that performs a particular function. For example, the human stomach is an organ concerned in digestion; the flagellum of a mastigophoron is its organ of locomotion.

Organ of Corti. The structure in the inner ear which bears the nerve endings that receive sound vibrations.

Organ system. An assembly of organs which performs a general function; for example, the teeth, salivary glands, œsophagus, stomach, liver, pancreas, small intestine, large intestine, and rectum, are the chief organs that compose the human digestive system.

Organelle. A diminutive of organ; applied particularly to the organs of Protozoa and to cell organs.

Organic evolution. The doctrine which holds that present-day plants and animals have evolved from earlier forms by descent with change.

Orthogenesis. The doctrine which holds that organic evolution is emergent, in that it has followed a definitely directed path that proceeds always from the simple toward the complex.

Osculum. An aperture in the body of Porifera out of which the water passes.

Osmosis. The passage of molecules or ions through a membrane.

Osmotic pressure. The pressure developed by a solution against a membrane impermeable to the molecules of the solute.

Otolith. Dense concretions in the ampullæ of the semicircular canals; when dislocated by gravity they stimulate the nerve endings which record the sense of balance.

Ovary. The organ that produces ova.

Oviparous (Adjective). Egg-laying forms.

Ovum. A cell, capable of developing into an adult, produced by a female or by female gonad.

Parasite. An organism which inhabits and obtains its subsistence directly from the tissues of another living organism. Parasites may be external or internal, and occasional or obligatory.

Parthenogenesis. The development of an egg without having been fertilized by a spermatozoon.

Pasteurize. To sterilize partially by heating to a temperature just above the maximum that bacteria can endure. First developed by Pasteur.

Pathogenic (Adjective). Refers to a parasite that causes disease in its host.

Pepsin. A proteolytic enzyme occurring in the gastric juice.

Peptone. A second intermediate product in the digestion of proteins; formed from proteoses.

Pericardial cavity. A cavity, usually derived from the cœlom, which contains the heart.

Perilymph. The liquid surrounding the membranous parts of the inner ear.

Periosteum. A layer of connective tissue that closely invests the bones.

Peristalsis. The rhythmic contractions of plain muscle; occurs as the motions of the digestive canal in Man.

Peritoneal cavity. That portion of the cœlom which contains the viscera.

Permeability. The property of a layer or partition that determines its penetrability.

Pessulus. The vibratory member in the voice-producing apparatus of the bird.

Phagocyte. A white blood cell capable of ingesting foreign particles and bacteria.

Phagocytosis. The process of engulfing foreign particles or bacteria by certain white blood cells.

Phenotype. The external appearance of an individual with respect to one or more inheritable characters.

Photogenin. A substance which is the source of luminescence in luminescent animals.

Photophelein. A substance that reacts with photogenin in producing luminescence in animals.

Photosynthesis. A metabolic process occurring in green plants whereby carbohydrates are constructed by the catalytic action of chlorophyll on water and carbon dioxide in the presence of sunlight.

Phototropism. Response to light.

Phylogenetic (Adjective). The history of an organism as traceable through lower forms.

Physiology. The science of function.

Pistil. The central shaft in a flower, usually made up of more than one tube fused together and ending outward in a more or less flattened stigma.

Placenta. A structure composed of fœtal membranes and a region of the wall of the uterus of mammals. It is the organ of nutrition, the means of excretion, and the organ for interchange of oxygen and carbon dioxide during the uterine life of the young of mammals.

Planula. A flattened plate of cells, an early stage in the development of members of the phylum Cœlenterata.

Plasma. The liquid portion of the blood.

Plasma membrane. Living protoplasm specialized to form the boundary of the cell.

Plastid. A dense mass of protoplasm occurring in the cell cytoplasm. There may be several sorts of plastids in the same cell.

Pleural cavity. A cavity containing the lung.

Plica. A transverse fold in the mammalian intestine.

Poikilothermal (Adjective). An animal whose body temperature varies with that of the environment.

Pollen. The microspores produced in the anthers of the flower. They are the spores which when transferred to the stigma develop into the sperm-producing gametophyte generation.

Polocyte. A non-functional cell produced during the maturation of the ovum. When the primary oocyte divides, one of the two daughter cells is the first polocyte. When the secondary oocyte divides, one of the products is the second polocyte.

Polyhybrid. The progeny of a cross between two parents that differ in many pairs of alternative characters.

Potential energy. Energy in a state of suspended activity.

Preformation. A concept of embryonic development which holds that the process is one of unfolding of structures already present in the germ.

Presbyopia. Far-sightedness.

Primary oocyte. An early stage in oogenesis during which the nuclear phenomena of synapsis occur.

Primary spermatocyte. An early stage in spermatogenesis during which the nuclear phenomena of synapsis occur.

Primordium. A structure in an embryo destined to develop into a specific organ or part of the adult.

Proboscis. A snout that may consist of mouth parts as in some insects, or of other head parts, for example, the trunk of the elephant.

Proglottid. A segment of the tapeworm containing the reproductive and excretory organs and identical with adjoining segments.

Pronephros. The primitive excretory organ of vertebrates.

Prophase. An arbitrary stage in the process of mitotic cell division characterized by the formation of a spireme of chromatin, the disappearance of the nuclear membrane, and the formation of the mitotic spindle.

Protein. A complex organic molecule characterized by containing $COOH$ and NH_2 radicals.

Proteolytic enzyme. An enzyme that digests proteins.

Proteose. An intermediate product, the first step in the digestion of proteins.

Prothallus. The small heart-shaped sexual generation or gametophyte in the life cycle of ferns.

Prothrombin. An enzyme contained in the blood platelets concerned in the formation of a blood clot.

Proton. A component of an atom consisting of a positive electrical charge.

Protophyta. Plants consisting of single cells or of simple associations of cells that show no tissue specializations.

Protoplasm. A definitely organized colloidal substance consisting of at least 70 per cent water, about 15 per cent proteins, also fats, carbohydrates, and inorganic substances, which is the physical basis of life.

Protozoa. Whole animals composed of single cells or of colonies of unspecialized cells.

Pseudocœle. A type of body cavity that appears secondarily in such forms as the Platyhelminthes.

Pseudopodia. Temporary extrusions of the body of such forms as Amœba, which serve as organs of locomotion.

Pulp cavity. The cavity in the centre of the tooth and of the placoid scale.

Radial symmetry. The structure of the organism is such that all parts are symmetrically arranged with reference to an axis.

Radical. A group of atoms that forms a part of a molecule and may be replaced by a single atom, or which acts as a unit in reactions. For example, in H_2SO_4 the SO_4 is a radical that is replaceable by some single atoms and in reactions forms the negative ion of metallic salts.

Ramus. A connecting nerve fibre.

Recapitulation. See Biogenetic law.

Receptacle. The structure in the base of a flower which contains the egg.

Receptor. An organ for the reception of stimuli.

Recessive. A member of a pair of alternative characters is said to be recessive when the progeny of a cross between a parent having the character and one having its alternative all resemble the alternative contributed by the second-mentioned parent.

Reductional division. That division during maturation of the germ cells in which the number of chromosomes is reduced from the diploid to the haploid in the daughter cells.

Reflex act. A response to an outside stimulus that is effected without the passage of the impulse through the brain.

Regeneration. The restoration of a part that has been lost.

Rejuvenescence. The restoration of a young condition.

Rennin. An enzyme that curdles milk.

Respiration. The cell process of oxygen intake, oxidation in the protoplasm, and carbon dioxide elimination from the cell. In complex animals, breathing and the transportation of oxygen and carbon dioxide by the blood are added processes.

Respiratory quotient. The ratio between the carbon dioxide given off and the oxygen taken in during respiration.

Rickets. A metabolic disturbance characterized in the young of mammals by under-development of bone and due to the absence of Vitamin D from the diet.

Salt. A compound formed when the hydrogen atoms of an acid are replaced by some other type of atom.

Sap vacuole. A cavity often present in plant cells, filled with cell sap.

Saprophytic metabolism. The metabolism of parasitic plants and of plants that subsist upon dead organic matter.

Saprozooic metabolism. The metabolism of parasitic animals and of animals that subsist on dead organic matter.

Scolex. The head region of the tapeworm.

Sebaceous glands. Oil glands in the integument of vertebrates.

Secondary spermatocyte. A stage in spermatogenesis that results when the primary spermatocyte divides, reducing the number of chromosomes to one-half the diploid number.

Segregation. The separation of a character in pure form after it has been associated in a previous generation with its alternative character.

Self bred. Fertilization occurring by means of the union of egg and sperm from the same individual.

Seminiferous tubules. Tubules in the testes of vertebrates that are the site of origin of the spermatozoa.

Semi-permeable. A membrane is said to be semi-permeable if it allows the passage of small molecules such as water and holds back large molecules.

Senescence. The process of becoming old.

Septa. A partition; used to refer to the partitions that separate the segments in annelids and to homologous partitions in the muscles of higher animals.

Septicemia. Disease in which the disease-producing bacteria are disseminated throughout the body of the host. See Bacteremia.

Serum. (*a*) The liquid portion of the blood after the removal of the blood corpuscles and the clotting agents.
(*b*) The serum as described in (*a*), containing antibodies for immunization or treatment of bacterial disease.

Serum therapy. Treatment of disease by means of blood serums containing antibodies.

Sinus venosus. The first chamber that the blood enters in the heart of fishes and Amphibia.

Soma. A general term applied to all tissues exclusive of the germ cell.

Somatic mesoderm. The outer sheet of mesoderm that in the embryo immediately underlies the ectoderm and forms the outer lining of the cœlom.

Somatic number. The number of chromosomes characteristic of the nuclei of the tissue cells.

Sori. Crescentic shaped organs containing spores, located on the under side of fern leaves.

Special creation. The doctrine which holds that animals and plants were created simultaneously by the creative effort of some supernatural power.

Species adaptations. Adaptive characters that are common to all members of a species, inherited.

Sperm. A cell produced by a male or by a male gonad which combines with a cell from the female and initiates the development of a new individual.

Spermary. A sac-like protrusion on the body wall of hydra in which the spermatozoa are developed.

Spermatid. A stage in spermatogenesis resulting when the secondary spermatocyte divides. Spermatids have the haploid number of chromosomes.

Spermatogenesis. The process of conversion of primordial male germ cells into mature spermatozoa.

Spermatogonia. Male germs cells in their primary condition while undergoing multiplication by ordinary mitosis.

Spermatozoon. The male germ cell of animals.

Spherical symmetry. The structure of the organism is such that all parts are symmetrically placed with reference to a point.

Spiracle. (*a*) An aperture in the body wall of insects and some spiders that leads into the respiratory tubules.

(*b*) A modified anterior visceral cleft in the elasmobranch fishes.

Spiral valve. A winding shelf within the small intestine of elasmobranch fishes, for example, the shark.

Splanchnic mesoderm. The inner sheet of mesoderm that in the embryo adheres closely to the endoderm and forms the inner wall of the cœlom.

Spongin. An organic substance which forms the chief ingredient in the supporting framework of some sponges, for example, the common bath sponge.

Sporangium. The structure on the spore-bearing generation of plants in which the spores are produced.

Spore. A single cell capable of developing into an adult without being fertilized. Among animals only the Protozoa form true spores. Spores are usually enclosed in a protecting case; when at rest their life processes go on very slowly.

Sporophyte. The stage in the life cycle of mosses, ferns, and seed-bearing plants which produces spores and reproduces only a sexual generation solely by the development of spores.

Stamen. A highly modified leaf that in the flower bears the organs which produce microspores.

Stereotropism. Response to contact.

Stimulus. Any agent or condition that causes living matter to respond.

Stratum germinativum. A layer of cells forming the inner and growing portion of the epidermis.

Structural adaptations. Anatomical characters that are adaptive in nature.

Sudiferous glands. The sweat glands.

Symbiosis. The term in its original meaning broadly includes the living together of two organisms. Its meaning tends to be confined to those cases in which the two organisms are intimately associated and do not harm each other.

Synapse. The structure that forms the contact between axone and dendrite.

Synapsis. Refers to the behavior of members of chromosome pairs during their period of contact in the maturation of the germ cells. In synapsis the members of each pair are conjoined and interchange of allelomorphic genes may occur.

Synaptic mates. Refers to the pairs of chromosomes, carrying the same or alternative characters, that conjoin during synapsis.

Syrinx. The voice-producing apparatus of the bird.

Taxonomy. The science of classification.

Teleolecithal (Adjective). Eggs containing a relatively large quantity of yolk and polarized so that the greater quantity of yolk is in the vegetal hemisphere.

Telophase. An arbitrary stage in the process of mitotic cell division characterized by the re-formation of the nuclear membrane and the reorganization of the nucleus of the daughter cells.

Thermotropism. Response to heat.

Thorax. The forward portion of the main part of the animal body.

Thrombin. An enzyme in the blood formed by prothrombin and concerned in the conversion of fibrinogen to fibrin.

Tissue. An association of cells and intercellular substance in a metazoon or a metaphyte. The cells in a tissue are usually of the same sort.

Toxemia. Disease in which the disease-producing bacteria are confined to some organ or tissue and produce their effects on the host by reason of the poisonous nature of the substances formed in their metabolism; these poisons are absorbed by the host circulation and affect all other regions of the host body.

Toxin. A product of bacterial metabolism poisonous to its host.

Trachea. The tube in air-breathing vertebrates that leads air from the larynx toward the lungs.

Tracheæ. The fine tubules in insects and some spiders that plumb the air to the tissues and constitute the essentials of a respiratory tract.

Transmittor. As used here this term refers to tissues that conduct impulses.

Trihybrid. The progeny of a cross between two parents that differ in three pairs of alternative characters.

Triploblastic (Adjective). An animal that consists of three primary cell layers and their derivatives.

Tropism. Response that is forced by the nature of the stimulus.

Trypsin. A proteose-digesting enzyme of the small intestine.

Typhlosole. The longitudinal fold of tissue in the stomach-intestine of annelids.

Umbilical cord. A long cord that serves as the conduit containing the blood vessels which maintain connection between the mammalian embryo and the maternal uterine wall.

UNDULATING MEMBRANE. A delicate membrane associated with the gullet in some of the Protozoa.

VACCINE. An immunizing preparation consisting either of a culture of weakened live bacteria or of killed bacteria.

VALENCE. The number of bonds by which an atom attaches to other atoms in forming molecules.

VARIATION. Differences between members of the same species. Variations that are inheritable are now referred to as mutations; non-inheritable variations produced by the effect of the environment are referred to as acquired characters or modifications.

VEGETAL POLE. Refers to that pole of an egg which is characterized by being the region least active in development. The vegetal hemisphere usually contains more yolk than the more active animal hemisphere.

VESTIGIAL ORGANS. Organs, either in the embryo or adult, without apparent use and homologous with functional organs in lower forms.

VILLI. Small folds of tissue.

VISCERA. The large interior organs of the animal body.

VITALISM. The doctrine that regards life as due to some supernatural activating principle.

VITAMINS. Substances occurring in small quantities in the food supply necessary for continued maintenance of life.

VIVIPAROUS (Adjective). Forms that give birth to well-developed young.

ZOOLOGY. The science of animal life.

ZYGOTE. A fertilized ovum.

INDEX

Pages with accompanying illustrations and diagrams are indicated by italics.