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THE ELEMENTARY PRINCIPLES OF GENERAL BIOLOGY

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THE ELEMENTARY PRINCIPLES OF GENERAL BIOLOGY

BY

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New York
THE MACMILLAN COMPANY
1920

Set up and electrotyped. Published January, 1914.

Norwood Press
J. S. Cushing Co. — Berwick & Smith Co.
Norwood, Mass., U.S.A.

"Before the great problems [of Biology], the cleft between Zoölogy and Botany fades away, for the same problems are common to the twin sciences. When the zoölogist becomes a student not of the dead but of the living, of the vital processes of the cell rather than of the dry bones of the body, he becomes once more a physiologist and the gulf between these two disciplines disappears. When he becomes a physiologist, he becomes, *ipso facto*, a student of chemistry and physics."

D'Arcy Thompson, — "Magnalia Naturæ."

PREFACE

In this book I have endeavored to present in an elementary way some of the fundamental generalizations that are the product of modern research in biology. The artificial division between the study of plants and that of animals is one that is becoming increasingly difficult to maintain, inasmuch as some biological principles are best illustrated by phenomena in the plant world, others by those of the animal world. I have tried, therefore, to utilize both aspects of the subject and to draw my illustrative material impartially from both kingdoms.

The practice that insists upon the student getting his knowledge of natural science at first hand needs nowadays no justification. The laboratory method of study has shown itself to be not only the best means of acquiring a concrete and accurate knowledge of the science studied but also a primary prerequisite for those habits of thought that are essential to what has come to be known as the "scientific method." Nevertheless in Biology the field is so broad and so varied that the student is very likely to lose sight of the fundamental principles that underlie all living nature. Moreover, these principles do not grow out of the laboratory work so obviously nor are they so easily demonstrated by experiment as is the case with such sciences as chemistry and physics. This book is accordingly planned to supply a background for a laboratory course in Biology and to supplement the facts acquired in such a course, the exact nature of which will depend upon the convictions or preliminary training of the individual instructor.

On the other hand, it is believed that the general reader also will find here a simple statement of the fundamentals of General Biology, a subject that is becoming increasingly important in our everyday life.

In covering so much ground I have been compelled to condense many subjects to paragraphs that might well have deserved whole chapters to themselves. The wide-awake teacher, I think, will have no difficulty in amplifying those portions that he esteems most important or in which he is most interested. I am conscious, too, of the fact that many generalizations have been stated in a much less cautious way than would have been the case if condensation had not seemed so essential a feature. But, apart from this, I think that it is preferable, pedagogically, that a student should get a few clean-cut fundamental ideas which perhaps require subsequent qualification than that he should have vague notions in which exceptions to rules figure as largely as the rules themselves. For instance, it is best that he should acquire the fact that the division of chromosomes in mitosis is equal and that in consequence the number of chromosomes in an individual or a species is constant, leaving any consideration of the accessory chromosome, important as it may be, to a time when the former concept shall have taken firm root.

A chapter on Animal Behavior was projected but was abandoned when it was found that its inclusion would have increased the size of the volume unduly. For the same reason no apology need be offered for the constant reference by name without comment to the various groups of animals and plants. The first-hand knowledge of the types in the laboratory will have supplied the descriptive details for which there is no room in the present work, although text-figures have been freely used to illustrate the forms mentioned.

In such a book as the present one, little can be claimed for originality except the manner of presenting the subject. I have sought counsel and criticism in those fields in which my personal knowledge is least dependable, and I hope that such errors as may have crept in will not be significant ones. I am particularly indebted to Professor George T. Moore, Director of the Missouri Botanical Gardens, who read the whole book in manuscript, and to Professor Walter E. Garrey, who read the proof of the first four chapters. Acknowledgments are also due to the following for the use of clichés or permission to copy figures: to Herr Gustav Fischer, Jena, for permission to use figures 7, 13, 34, 55, 60, and 82; to Messrs. Henry Holt and Co., for the use of figures 8, 22, 49, 92, 94, 100, 106, and 112; to Messrs. Ginn and Co., for the use of figures 31 and 103; to the American Book Co., for the use of figures 2, 52, 97, and 109; to Messrs. G. P. Putnam's Sons, for the use of figure 16; to Messrs. D. Appleton and Co., for the use of figures 19, 58, 62, 67, 70, 90, 93, 95, 96, and 113; to Messrs. Longmans, Green, and Co., for the use of figure 23; to Messrs. P. Blakiston's Son and Co., for the use of figure 64; to Professor C. B. Davenport and the Editors of the *Popular Science Monthly*, for the use of figure 71; to Professor Davenport and Messrs. John Wiley and Sons, for the use of figure 73; to the Columbia University Press, for the use of figure 110; to Professor John Schaffner, for permission to copy figure 66; to Professor C. C. Curtis, for the use of figures 51 and 107; to the Editors of the *American Review of Reviews*, for the use of figure 108; and to Sir E. Ray Lankester, for permission to copy figure 112. For photographs from which were made figures 85, 98, and 99 I am indebted to the kindness of Professor S. M. Coulter. All the other illustrations, with the exception of figures 6, 10, 24, 25, 37, 40, 42–44, 50, 54, 56, 57, 63, 74, 77, 88, 89, and 114, are from publications of The Macmillan Co.

J. F. A.

JANUARY, 1914.

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THE ELEMENTARY PRINCIPLES OF GENERAL BIOLOGY

GENERAL BIOLOGY

CHAPTER I

LIVING SUBSTANCE

Biology, the "science of life," includes in its broadest aspects the investigation of all that pertains to the structure and functions of living things. The observing and recording of the wonderful variety of Nature will always have a fascination not only for the poet, but for the scientist as well. But the latter is more especially concerned with the meaning, the analysis, or the explanation of natural phenomena. Philosophy tells us that science can never hope to get the ultimate explanation of anything which it observes. All that it can do is to reduce the complexities to simpler expression, to find the common denominator for things that seem at first glance unrelated, in the same way that the mathematician by processes of factoring reduces elaborate and complex algebraic expressions to simple statements of relation. And, just as in mathematics, the greater the number of variables we have to deal with, the more involved and difficult becomes our computation, so in physical and biological science the greater the number of unknown factors there may be, the greater becomes our difficulty in reducing them to fundamental principles. This is why biology is so strikingly an "inexact" science in comparison with physics or inorganic chemistry. Yet, it is not necessary even for the physicist or the chemist to know what is the ultimate nature of matter or force or electricity or atoms in order to study such things and formulate general laws based on such observation; nor is it necessary for the biologist to concern himself with the meaning or nature of life in order to find out what principles govern in the world of living things.

The study and comparison of the structures of plants and animals, of their methods of growth and reproduction, their relation to each other and the world about them, has revealed the fact that there is an underlying unity in nature that makes it possible for us to sum up our observations in general principles, incompletely understood, of course, but more or less applicable to all living things. The consideration of these general principles forms the basis for a General Biology in the sense in which it will be taken in the present work.

Although we shall not attempt to elucidate life in any philosophical sense, it is of interest, notwithstanding, to discover at the start just how much science can tell us of the nature of life, or of living things as a whole.

Living and Non-living. — If a biologist should ask the average layman whether he could tell the difference between something alive and something that is not, he would hardly be taken seriously. Yet, if such a layman should be pressed to define just what he meant by "being alive," he might be hard put. It might be assumed that some characteristic chemical compounds are to be found in living matter which are absent in non-living matter. But thousands of exact chemical analyses have been made of every sort of living thing and no element or compound has ever been found which is essentially different from what may exist in the non-living world. Long ago a distinction used to be made between "organic" and "inorganic" substances, — the former being the product of living "organisms." But such a distinction has broken down. It is possible to synthesize substances in the test tube, identical in chemical composition with those formed in Nature's laboratory, — the tissue of plant and animal. Indeed, the ability to artificially reproduce natural products in this way has proved of great value commercially, and artificially synthesized indigo, camphor, etc., now supplement in large measure Nature's meager store of such things.

Nor is it easier to discover any unique physical phenomena in living things. So far as we can observe, — and the more our observations are extended, the more is the conclusion confirmed, — living matter obeys the same physical laws that obtain in the rest of the universe. Again, living things grow: but so do crystals and clouds. They reproduce themselves, but, as we shall see later, this is but a discontinuous form of growth, and may be paralleled, perhaps, in other " inorganic " bodies.

Life and Death. — If we find it so difficult to point to any one thing as the touchstone of living matter contrasted with non-living matter, what shall we say of the difference between that which is alive and that which has been, but is no longer, — in other words between living matter and dead matter? A turtle may justly be called a dead turtle if we cut off its head, yet, if we cut out the heart of such a decapitated turtle and suspend it on hooks in a moist chamber, wet with a weak solution of common salt, such a heart will go on beating rhythmically for days. So long as it beats we are forced to consider the substance composing it as living matter.

We must make a distinction, then, between *general life and death*, which affects the whole organism and *elemental life and death*, which affects only the elements or tissues. This distinction is much more apparent in animals than in plants on account of the greater degree of specialization in the former. Ordinarily, decay and disintegration in the tissues promptly follow general death, but experimentally we may avoid this contingency if we exclude bacterial invasion,[1] and such a piece of tissue may be kept passively " alive " for a considerable interval of time, regaining its functions when replaced in a living organism. In this way sections

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[1] See Chapter IV.

of blood vessels and other organs have been cut out and later replaced in the same or other animals without injury. By keeping such a tissue at a trifle above freezing point the period of suspended vitality may be extended to weeks or months.[1] Recent experimenters have shown that not only may the pieces of excised tissue be kept passively alive, but that under proper conditions they will sprout and grow like so many plant cuttings. It is only necessary that they be surrounded by a nutritive medium drawn from the same animal from which they came, and that they be kept free from all bacteria.

If the turtle heart in the experiment described should after a while cease to beat, but later begin to do so again, we would of course say that, like the excised tissues just described, it was still alive during its period of inactivity, although our only knowledge of its being alive is derived from its subsequent beating. For, we say, our idea of life, however vague it may be, does not admit of discontinuity. Once alive, always alive, until dead.

The experimental physiologist is not so sure of that. Such a suspended heart muscle of the turtle will not beat except in the presence of salt (or some sodium compound). But in pure salt solution it stops beating. The pure salt acts as a poison. We might now consider the muscle dead, were it not

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[1] We find an analogous instance in Nature in the fact that many seeds will retain their vitality unimpaired for years, until proper conditions of warmth and moisture cause them to sprout and grow.

for the fact that if we add a little calcium chloride to the salt solution, the heart begins to beat again. The calcium has neutralized the ill effect of the sodium. If, then, contracting is any criterion of whether the heart is alive or not, its life would seem to depend upon the presence or absence of something wholly outside the living matter itself.

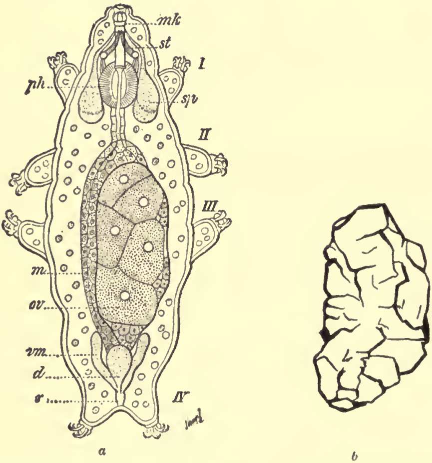

FIG. 1. — A tardigrade (*Macrobiotus*): *a*, in the creeping active condition; *b*, dried, in the state of apparent death.

Under perfectly natural conditions such a state of "ceasing to live" and then resuming life again is not uncommon. Some animals that live in shallow puddles exposed to the chance of drying up are capable of drying up also, and remaining in an apparently lifeless condition for long periods of time, blown about in the dust by the winds (fig. 1). Falling in a favorable spot where there is sufficient water, they "come to life again" and resume their activity as if it had never ceased. The excessively minute "germs" of bacteria keep the race in existence in this way.

In seeking an analogy to these phenomena a German scientist, Preyer, has compared the plant or animal to a clock, which goes through its characteristic movements so long as the energy in its mainspring lasts. It may be stopped and remain so until its pendulum is set swinging again, in which case it may be compared with a fertile seed. But if its mainspring be broken or if it run down, even though externally it be just the same in appearance, it no longer "goes." Some such a difference as this may exist, not to push the comparison too far, between an organism in which life is merely suspended and one that is dead.[1]

Our search, therefore, for the answer to the ancient

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[1] Waller has shown that in such forms of living substance as nerves, which do not contract or give any visible evidence of life or death, it is possible by galvanometric test to show that a "live" nerve deflects the needle, whereas a "dead" one does not; in other words that the electric response is a very delicate and accurate sign of life. By this means he claims to have been able to mark the "beginning of life" in an incubating hen's egg. A Hindu physiologist, Professor Bose, has claimed, on the basis of very careful experimental work, that this electrical sign of life is dependent upon the "molecular mobility" of the matter, and that it disappears when "molecular fixation" or strains ensue. Herein may be, possibly, the simple difference between living and dead matter.

conundrum, "What is life?" so long as we attempt to solve it by processes of analysis, leads us up a blind alley no matter what clue we follow. Yet, in spite of our difficulty in defining living matter, we recognize the existence of it as something real and not imaginary, and when we compare the innumerable kinds of living things from the standpoint of their physical and chemical composition, we find that they all have much in common; that life, whatever its metaphysical aspects, has also a material basis, a "life stuff" or living substance. This living substance has received various names, but that which is most commonly used is Protoplasm.[1] This is what Huxley called in enduring phrase "the physical basis of life."

Chemistry of Protoplasm. — In studying the physics and chemistry of protoplasm we find that it is exceedingly complex. But its complexity arises from the almost infinite combinations and permutations of a very limited series of chemical elements. Carbon, hydrogen, oxygen, nitrogen, — these we find in all protoplasm, and they constitute its bulk. Sulphur and phosphorus are also always present, but in very much smaller quantities, and usually chlorine, potassium, sodium, magnesium, calcium, and iron as well. Many other elements occur normally, though rarely, in the protoplasm of certain animals and plants. Iodine occurs in sea-

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[1] Bioplasm, a term used by many English authors, is perhaps preferable, but protoplasm is firmly established in the literature of biology

weeds and in the thyroid gland of certain animals. Zinc and manganese seem to be normal constituents of the tissues of some mollusks. In other words, protoplasm is not a definite chemical substance or compound, like quartz or salt or starch, but is sometimes one thing, sometimes another. Rather, it is a mixture of various things, all of them, however, of an infinite complexity of mutual relations, — " a mixture, but certainly no jumble." The word "protoplasm," then, is a sort of group name covering a multitude of different sorts of such chemical mixtures, as many as there are different manifestations of life phenomena.

It has been just said that the bulk of all kinds of protoplasm is made up of carbon, hydrogen, oxygen, and nitrogen. These exist in elaborate combinations, of which the carbon atom seems, as a rule, to form the heart or foundation. The older "organic chemistry," or the chemistry of organisms and their products, has become the " chemistry of the carbon compounds."

An exception must be made to the statement that the combinations of the four elements cited are always complex. One of the simplest of all compounds, water (H_2O), is a necessary constituent of living matter. The percentage of water in all protoplasm is high. Muscles are three fourths water, even bones, nearly one fourth, and in the jellyfishes of the open sea, that which is not water is but one per cent or less of the total bulk. With these facts in mind, one is inclined to think of living organisms as liquids that contain solid matter rather than as solids with a percentage of liquids. The large amount of water in protoplasm is a very important and significant feature of its make-up, since it affords a means for the transfusion of substances from one part of the animal or plant to another, and gives the organism a certain necessary plasticity as well.[1]

The combinations of carbon (C), oxygen (O), hydrogen (H), and nitrogen (N) that make up the bulk of protoplasm fall into three great groups or classes, the proteins or albumens, the carbohydrates (sugar and starches), and the fats. These three groups are much more easily described than defined.

The *Proteins* are found in all protoplasm and are indispensable to the processes of life. They constitute a large and diverse group differing widely one from another, but all sharing certain group charac-

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[1] Recent advances in physical chemistry have thrown much light on the physical and chemical processes of protoplasm. It has been discovered that, in great dilution, many chemical substances tend to dissociate into ions, as *e.g.* NaOH into Na and OH, each ion consisting, in the current explanation, of an atom or atomic group bearing a charge of negative or positive electricity. As a rule, it is only in this dissociated condition that atoms are active in combining with one another. It has been found by experiment that the effect of certain salts on protoplasm (for instance the poisonous action of the heavy metals) is in direct proportion to the ionization of the salts. It has been shown also that certain salts are absolutely essential to life processes, although the amount required may be very minute. A fresh-water crustacean, *Gammarus*, according to W. Ostwald, inevitably dies if placed in absolutely pure distilled water, but will live indefinitely if a trace of common salt (NaCl) be added. The amount necessary is only eight ten-thousandths of a gram (twelve thousandths of a grain, Troy) to a liter of water.

teristics. Among these are the invariable presence of nitrogen along with the carbon, hydrogen, and oxygen, and a very large and complex molecule, which is always lævo-rotatory, *i.e.* turns the rays of polarized light to the left, and contains sometimes thousands of atoms.[1] About half the weight is carbon and 15 per cent to 18 per cent nitrogen.

A giant protein molecule is not exactly a unit in itself, but is usually an aggregation of smaller atomic groups or other protein molecules weakly held together by the bond of "chemical affinity," just as a village of five hundred inhabitants may be thought of as made up not exactly of that many individuals, but of one hundred families composed in turn of an average of five persons each. The atomic groups may freely break away from the protein molecule or be added to it, and in this instability lies the great significance of the presence of the proteins in all living matter. (See chapter on Metabolism.) As examples of nearly pure protein may be mentioned lean meat fiber and white of egg (albumen).

J. Loeb and Pauli have called attention to the strong probability that the proteins in animal protoplasm are united with the ionized[2] inorganic salts to form "ion-protein compounds." This hypothesis accounts for many otherwise inexplicable phenomena, and explains the importance of even extremely minute quantities of certain salts in life processes.

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[1] An analysis of the blood pigment of the horse has yielded the following formula: $C_{712}H_{1130}N_{214}O_{245}Fe_1S_2$.

[2] See page 10.

The *Carbohydrates* (as also the Fats) lack the nitrogen characteristic of protein. They contain only carbon, hydrogen, and oxygen, the latter two always present in the proportion found in water, twice the number of hydrogen atoms as of oxygen. They are simpler in structure than the proteins, but like them may be combined into molecular aggregates of higher degrees of complexity. The simple sugars or *monosaccharids,* of which dextrose or glucose is the most familiar, have the formula $C_6H_{12}O_6$. By combining two molecules of a monosaccharid with the loss of a molecule of water[1] a disaccharid may be formed, of which the most familiar example is cane sugar (sucrose). Under the influence of yeast a monosaccharid will break up into carbon dioxide and alcohol, a process known as fermentation. By continuing the addition of monosaccharid molecules, one to another, each time with the loss of a molecule of water, more complex sugars, the *polysaccharids,* are formed. These are the starches and dextrines, and, most familiar of all, cellulose and woody fiber. The carbohydrates in general are more abundant in plants than in animals, although one of them, *glycogen,* which is found abundantly in the liver and muscles of higher animals, is of very great importance in animal nutrition.

The *Fats* contain the same elements found in the carbohydrates, C, H, and O, but in different proportions and arrangements. In every case they are the result of the combination of an acid with

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[1] $C_6H_{12}O_6 + C_6H_{12}O_6 = C_{12}H_{22}O_{11} + H_2O$.

glycerine. The acids, with few exceptions, belong to the "fatty-acid" series. Three molecules of fatty acid, not necessarily of the same kind, combine with one of glycerine to form a fat. The cleavage and recombination of these two component parts of a fat (the fatty-acid element and the glycerine) is easily accomplished. When the fatty-acid portion combines with an alkali, it forms a soap. Fats are insoluble in water, but readily soluble in ether, benzine, etc., — a fact made use of in the cleaning of clothing. They may be shaken up in alkaline water until the particles become very finely divided and remain in suspension, forming an *emulsion*. The most familiar example of such an emulsion is milk.

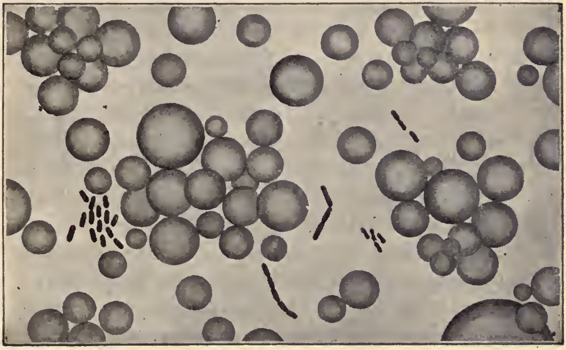

FIG. 2. — Milk under the microscope, showing the nature of an emulsion. The spheres are fat globules, the dark rods lactic-acid-forming bacteria. (From "Elements of Biology," copyright, 1907, by George William Hunter. — Permission of the American Book Co., publishers.)

Physical Structure of Protoplasm. — Proteins are not soluble in water in the usual sense, that is, they do not make a clear solution as do sugar and salt. They do absorb a great quantity of water, however, and swell up enormously. In the presence of large amounts of water they may become very finely divided and form permanent aqueous *suspensions*, which differ from true solutions in that they will not diffuse through vegetable parchment or animal membranes. Such substances are usually known as "colloids," in contrast to "crystalloids" or substances which do diffuse through such membranes. Another characteristic of colloids is their property of coagulating or "setting," a familiar example of which may be observed in the hardening of the white of an egg in the process of boiling. Such coagulation may be produced by heat, electric currents, dehydration, and chemical reagents. Certain classes of colloids, like the egg albumen, are unalterable when once coagulated, and are known as irreversible. Others may be brought back to the fluid state any number of times. Such substances, of which gelatin is an example, are called reversible. The essential difference between "solutions" of colloids and of crystalloids consists in the fact that the particles of the former are larger and are enveloped in a film of water, whereas true solution involves the separation of the crystalloid into its molecules or even into its ions, in which condition the particles obey the law of gases and the solution exerts pressure (osmotic pressure) in all directions. The colloidal nature of the proteins, therefore, is probably to be attributed to the great size of the molecules of which they are composed, aggregates which in fact are not true molecules but composites of other smaller aggregates. Chemists refer to this welding together of molecular aggregates as polymerization. As we shall see later, the process of animal digestion involves merely the breaking up of these aggregates into others of lesser degree, small enough to diffuse through the lining membranes of the alimentary canal.

Protoplasm, being composed largely of proteins, is thus colloidal in its physical make-up. But the examination of living protoplasm with the high powers of the microscope reveals a structure much more complex than may be found in a mere lump of non-living colloid. Living substance has a characteristic physical structure of its own, to explain which several theories have been advanced. According to one, the essential basis of protoplasmic structure is granular, and granules are certainly to be found in protoplasm. Others find fibrils like detached threads, others see a skein or reticulum in the meshes of which more watery substances are held. The view first advocated by Bütschli is, however, the one most commonly held by biologists. According to this theory, protoplasm has the structure of a foam in which the denser parts surround the lighter as the film of water does the air in soap bubbles. Perhaps a more accurate object of comparison would be a fine emulsion. In an emulsion, instead of a gas and liquid (as in soapsuds), we have two liquids of different densities and qualities, forming what is known as a *diphasic system*. According to Bütschli protoplasm is such an emulsion, composed on the one hand of substances insoluble in water which are highly viscous or sticky, and on the other hand of a watery medium supporting the various-sized particles of the former.

Owing to the fact that the refractive indices of the different components of protoplasm are nearly the same, it is very difficult to see its structure in the unaltered living state. Biologists have recourse, therefore, to "fixing" or coagulating the protoplasm with various poisons and dyeing it with aniline or other colors. Under such circumstances protoplasm appears to have a skein or net structure. But this has been interpreted as being merely the appearance of particles caught and held by surface tension — the films of the bubbles, so to speak, which when set and viewed in connection with those of adjacent bubbles appear to form a continuous layer or thread. This view is justified by the fact that artificial emulsions, subjected to the same processes of fixation and staining employed in the study of protoplasm, show a strikingly similar appearance to that of living substance. More recent investigations, involving the dissection of living protoplasm under the highest powers of the microscope, seem to point to the conclusion that Bütschli's conception may require certain modification. The physical "phases" in which protoplasm consists appear to be all colloidal, differing only in the amount of water which they absorb, an amount which may be rapidly altered under varying circumstances.

Organization of Protoplasm. — Not only is protoplasm, chemically considered, a mixture of a great variety of substances, but this aggregate of materials composing a given mass of living matter in one kind of animal or plant differs from that of another. Moreover, the same mass of protoplasm is constantly changing with regard to the substances composing it, thus making impossible anything like a fixed and definite picture of its *exact* composition. But it is also true that it is not so much the substances composing it, as the relations, both physical and chemical, that these bear to one another that determines the character of the protoplasm. A comparison may make this clearer. A watch is a delicately constructed and complicated mechanism of many parts which by their action in moving the hands in certain fixed relations of time and space enables us thereby to tell the time of day. It is possible for any one to take such an instrument apart and make a little pile of the wheels, screws, and springs, but when he has done so, the mass of metal and jewels that he holds in his hand is no longer a watch and cannot be made to serve its original purpose. The very apparent reason is that the inherent quality of a watch, by virtue of which it *is* a watch, that is, a timekeeper, is involved not only in the parts composing it, but in their relations to each other as well, and such a mechanism will run correctly only when every part is in its proper place and adjusted carefully to every other part with reference to the joint action of the whole.

It is so with protoplasm. However we may define life it is certainly true that the property of protoplasm, by virtue of which it is "living matter," is bound up in the interrelations of the various parts composing it. And just as a machine must be properly assembled, to use a technical phrase, so protoplasm does not exist as living substance except it be organized. Destroy or fundamentally alter this organization and, although we may get the same chemical analysis of the material and the same weight of substance, it is no longer alive. But it must be noted that the comparison with the watch cannot be pushed too far, for, unlike a rigid mechanism, protoplasm is extremely plastic and capable of adjusting itself to very wide ranges of structural alteration without ceasing to be alive. Indeed the living organism is constantly so adjusting itself in response to external conditions, — a phenomenon which many hold to be the fundamental and characteristic fact of life itself.

The Cell. — The difference between an oak leaf and a waxen image of one is not alone a difference in the chemical substances composing the two. Should we cut a thin slice from the wax leaf and examine it under a microscope we could distinguish nothing to mar its homogeneity. Should we do the same with the leaf itself we would find at once that the leaf bears to its waxen counterfeit the same relation that a mosaic figure does to a photograph. Instead of being homogeneous in structure it is composed of innumerable little units, — the aggregate of which makes up the mass of the leaf.

These structural units of organization of protoplasm are called *cells*. The word owes its derivation to the fact that the discoverer of the first cells described found, in examining a thin slice of cork, that the cork was made up of little boxes like the cells of the honeycomb. Similar observations were made later on a great variety of tissues until it was established that all plants and animals are composed of cells as structural units in much the same way that a house is built of individual bricks or stones.

FIG. 3. — Section of a leaf, showing its cellular composition: *a*, a breathing pore or stoma; *b*, upper layer of "palisade cells" which contain most of the chlorophyll; *c*, epidermal cell. (Bailey.)

Of course the shapes and structures of these units vary greatly in accordance with the kinds of tissues in which they are found or the activities they reveal, but there are certain structures that are common to all cells, and they may be considered fundâmental in cell organization. Postponing for a moment the consideration of the outer limit of the cell or cell-wall, we find that all cells agree in having the protoplasm composing them differentiated into two parts, — a more or less central one, — the *nucleus*, often rounded in outline and somewhat dense in consistency, which is surrounded by a less dense area, —

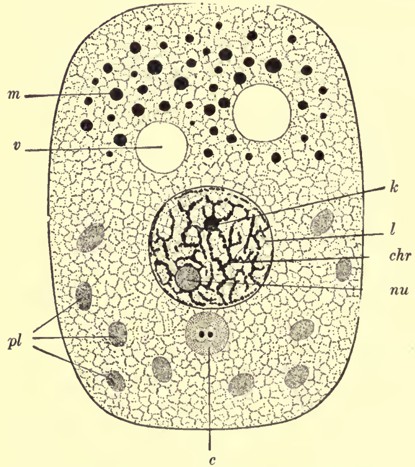

FIG. 4. — Diagram of a composite cell. *M*, metaplasmic bodies; *v*, vacuoles; *pl*, plastids (chloroplasts); *c*, attraction sphere inclosing a double centrosome; *nu*, true nucleolus; *chr*, chromatin network; *l*, linin network; *k*, karyosome or chromatin nucleolus. Vacuoles are especially characteristic of plant cells. The chloroplasts are found only in plant cells. They are capable of independent growth and reproduction. It is these that give the green color to leaves. — (From Wilson.)

the *cytoplasm.* Nucleus plus cytoplasm together make up the cell.

Bounding the cytoplasm there may be a definite, often thickened *cell-wall.* This is especially characteristic of plant tissues, in which the cell-wall becomes very thick and rigid through the deposit of various carbohydrates (pectin, cellulose). It is the latter (or its derivative, lignin) that gives its characteristic rigidity and hardness to wood. In animals, on the other hand, in only one rather obscure group [1] does cellulose occur, and it is the exception rather than the rule for the cell-wall to attain any considerable thickness or prominence. In many animal cells there is no cell-wall at all, — the viscosity and surface tension of the mass of protoplasm holding it together.

The nucleus and cytoplasm are found by delicate tests to be chemically different, the former combining more readily with basic and the latter with acid substances. The cytoplasm often contains vacuoles filled with a watery fluid or with different sorts of non-living substances, such as crystals of silica (that give the knife-edge to certain kinds of grass), chlorophyll bodies (that give the green color to plant leaves), starch grains (as in the potato), yolk granules (such as make up the bulk of the yellow of a hen's egg), and various other substances. Such substances, being non-living material, manufactured by the cell, are called *metaplasm* in contradistinction to the living protoplasm.

In the cytoplasm is also found the *centrosome,*

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[1] The Ascidians or "Sea Squirts."

a structure that appears only at certain periods of the cell's activity and is either invisible or nonexistent throughout the greater part of cell life. (See under Cell Division, Chapter IV.)

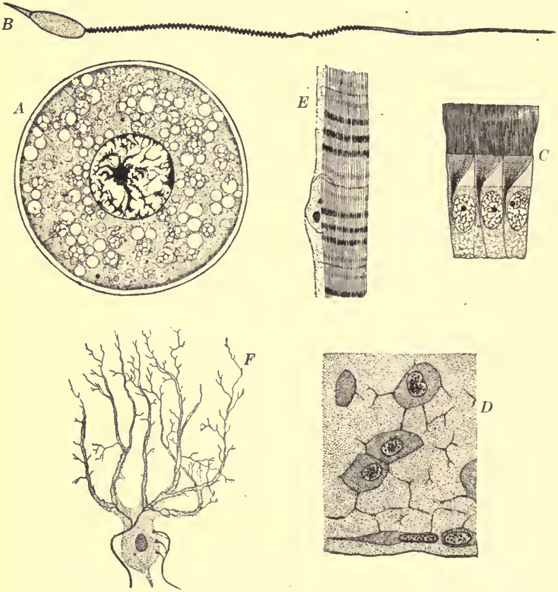

FIG. 5. — Various kinds of cells: *A*, female germ-cell, ovum of the cat; *B*, male germ-cell, spermatozoon of a snake, *Coluber; C*, ciliated epithelium from the digestive tract of a mollusk, *Cyclas; D*, cartilage of a squid; *E*, striated muscle fiber from an insect larva, *Corydalis cornutus; F*, a nerve cell from the cerebellum of man. — (Dahlgren and Kepner.)

The nucleus (sometimes called karyoplasm in contrast to cytoplasm), owing to the fact that it has about the same refractive index as the cytoplasm, is usually almost or quite invisible in living cells, and must be fixed and stained before it can be easily seen. Its outline is always sharply distinct from the adjacent cytoplasm, and often a limiting membrane seems to be present, though the presence of the latter in all living cells is not definitely established.

Within the nucleus the protoplasm is further differentiated into two substances, — one that stains very readily with most dyes, and for that reason is called *chromatin*, and another (the linin) that stains with great difficulty, and looks like a sort of network or scaffolding supporting the chromatin. Both chromatin and linin are surrounded by a watery transparent fluid sometimes termed *hyaloplasm.* In many cells, especially egg-cells of animals, a *nucleolus* is prominent, — a rounded aggregation of chromatin material which is found to be chemically different from the true chromatin, but the nature and function of which has never been clearly understood.

The nucleus owes its acid nature to the chromatin, which is largely made up of some form of *nucleic acid*, a complex substance having a characteristic percentage of phosphorus. When fixed and stained, the chromatin usually appears in the form of granules of either large or minute dimensions, sometimes arranged in the form of a skein or network, with "knots" at the intersections. Only in cells that are in process of reproduction is there any definiteness of form, shape, or number to the chromatin aggregates.

Usually we find only one nucleus in a cell, but sometimes many nuclei occur, scattered through the cytoplasm. In plants the cell-wall is an important part of the cell, since it affords the necessary rigidity and strength to the plant, functioning in this way much as the skeleton does in animals. But we find that the presence or absence of a cell-wall is conditioned largely if not entirely by such a demand. In tissues where there are strains and stresses to be borne, cell-walls develop in response to such stimuli, but where they are not necessary they do not appear, or only partially develop. Such tissues, however, are found to have as many nuclei as if they were cut up by cell-walls into individual cells. They consist, as it were, of a mass of cells "run together," and for that reason are called cœnocytes or syncytia (singular, syncytium). The presence of the nucleus

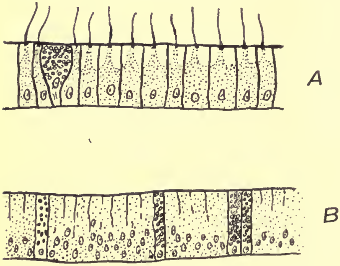

FIG. 6. — Sections of the outer epithelium (skin) of a creeping Ctenophore (*Cœloplana*): *A*, a ciliated region in which the cells are provided with locomotor organs in the form of vibratile cilia, a gland-cell at the left; *B*, a non-ciliated region of the same epithelium; the cell-walls are barely indicated (except in the gland cells); nuclei are, however, abundant.

seems to be necessary to the cytoplasm in order for it to properly carry out its functions, for we find that a fragment of a cell, provided it has a bit of nuclear matter included, will continue to live, whereas a bit of cytoplasm without a nucleus soon disintegrates and dies. The nucleus, in other words, is essential for the life of the cell, and, accordingly, since the presence or absence of a cell-wall is not a determining character, we may consider the essential features of a cell to be a mass of protoplasm dominated by a nucleus. The cell is thus a dynamic or functional unit rather than a static or structural one. On this account the term *energid* has been used in place of the less accurate word "cell."

CHAPTER II

PRIMARY FUNCTIONS OF THE ORGANISM

We have seen that protoplasm, although it may be resolved into a mixture of various complex chemical substances with a more or less definite physical structure, does not exist as protoplasm *per se*, but is always organized in certain definite relations, one part to another and to the environment of the whole. The unit of this organization is the cell.

The individual organism usually consists of many cells linked together in a complex whole, but the individual may also subsist in a single cell. In the latter case we speak of the individual as a Protozoan (or Protophyte, if a plant), and in the former as a Metazoan (Metaphyte, if a plant). As a rule the one-celled organisms (sometimes spoken of collectively as Protista) are simpler both in structure and in function than those of many cells. Such, however, is not always the case. The most complex of the Protozoa is as specialized in organization and functions, if not more so, than the simplest of the Metazoa. It would probably be more accurate to speak of the Protozoa as *non-cellular* rather than one-celled, since the differences between the two groups are qualitative rather than quantitative, *i.e.* are not based on the number of cells present. So from another point of view we may consider the protozoan individual to be comparable to the metazoan individual, with the difference that for purposes of utility the body of the latter is subdivided into a great number of dynamic centers (cells), whereas that of the former is not so divided.

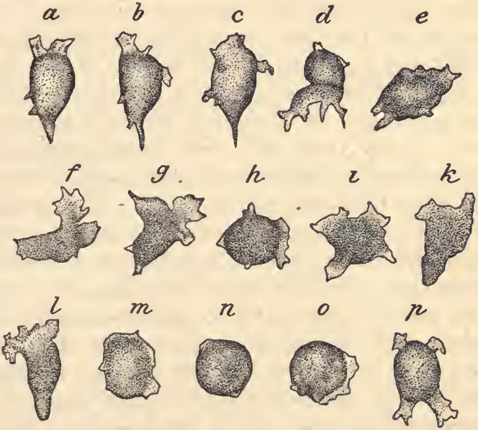

FIG. 7. — A white blood corpuscle (leucocyte) of the frog sketched at frequent intervals; from *a* to *m* the temperature was gradually raised, then lowered (*n* to *p*). — (From Hertwig, after Engelmann.)

In the metazoan body, however, some of the cells live a relatively free and independent existence, and we will begin our study of the phenomena of cell specialization with such a cell.

In the blood stream of most animals are to be found free cells, " corpuscles," floating in the liquid plasma. In vertebrates the majority of these cells are of definite shape and are the carriers of the characteristic red pigment of blood. Such corpuscles are also found in a few worms and other lower organisms. In addition to these there occurs in nearly all metazoans in which there is any blood or body-fluid another sort of free cell, leucocytes or amœbocytes, distinguished from the former by the lack of red pigment and especially by the absence of any definite shape or bodily outline. If we examine the blood of an earthworm or a crayfish with a microscope, we may study these cells with comparative ease. If the plasma containing such cells be kept slightly warm, these leucocytes will be found to change form continually. Short processes flow out from the cell-body in different directions, and the rest of the protoplasm appears to flow or be pulled along after them. In this way the cell is able to progress slowly over the slide of the microscope or over the walls of the blood-vessels in which it normally occurs. In other words the cell possesses the function of *locomotion.* The lobelike processes (called *pseudopodia* or " false feet ") are protruded at any part of the cell-body or on several parts at the same time. This function of locomotion is therefore *unlocalized*. The surface of the cell appears to be somewhat sticky (viscous) and retains a hold on solid objects. When the cell is creeping, a pseudopodium sticks in this way to something solid, the protoplasm then contracts, and the rest of the cell is pulled along with a flowing movement. The actual basis for these creeping movements is thus the *contractility* of the protoplasm constituting the cell.

In the course of these creeping or "amœboid" movements the leucocyte may encounter a bit of worn-out tissue or a vagrant bacterium. It then throws out pseudopodia on both sides of the object, which flow around it, meet beyond, and thus swallow into the body of the cell the bacterium or tissue-fragment, together with a little drop of the fluid in which both are floating. (The bacterium has been *ingested.*) While inside the cell-body of the leucocyte, certain changes are induced in such a particle by products secreted by the leucocyte that tend to dissolve or *digest* it. That part which cannot be so digested is removed by the reversal of the process employed in swallowing it, *i.e.* the leucocyte creeps on and leaves it behind, — it is

FIG. 8. — Phagocytes (leucocytes) from the cœlomic fluid of the earthworm: *A*, agglomeration of phagocytes surrounding a foreign body; *B*, single leucocyte, with vacuoles. — (From Sedgwick and Wilson, after Metchnikoff.)

egested. The digested material is later built up into the substance of the cell protoplasm by the process of *assimilation.* These three functions, — ingestion, digestion, and egestion, — like that of locomotion, are not localized, but may take place at any part of the body.

If bacteria[1] be introduced into the body of an animal at any point, the leucocytes will soon be found gathered in great numbers at the same point. It has been shown that this gathering is due to a mechanical, *i.e.* not purposive, " attraction " exerted on the cells by the chemical substances produced and excreted by the bacteria. In other words, the gathering of the former is a *response* to an altered condition of the medium in which they exist. In the same way the cells will move from a cool region to one of greater warmth, and on a culture-slide, through which runs a weak current of electricity, may be caused to gather at the negative pole. A dead leucocyte will not respond to any of these "stimuli." The response is therefore a function of living matter and is spoken of as a result of its *irritability.* Irritability has been defined as " the capacity of living substance of reacting to changes of environment by changes in the equilibrium of its matter and its energy."

All of the above phenomena may be observed also in *Amœba proteus*, a free-living cell found in slime and stagnant water. *Amœba* is an independent organism, whereas the leucocyte is one cell out of a

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[1] *e.g.* pus-forming *staphylococci.*

myriad composing an organism. Both, however, exhibit these primitive functions inherent in living matter. At certain times *Amœba* secretes about itself a tough protecting membrane or cyst which is the product of protoplasmic activity. Within this cyst the living substance tides over unfavorable periods, reproducing later in a characteristic way to be described in another connection. Under favorable circumstances *Amœba* has been observed to divide in two half-cells by a simple constriction and severance of the cell. This process is preceded by a division of the nucleus, so that each "daughter

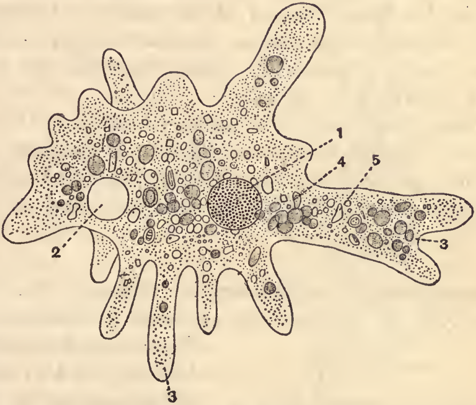

FIG. 9. — *Amœba proteus* (much enlarged): *1*, nucleus; *2*, contractile vacuole; *3*, pseudopodia; *4*, food vacuoles; *5*, grains of sand. — (From Shipley and McBride, after Gruber.)

cell " resulting from such a cleavage has half the nuclear material of the original parent cell. In this way the number of individuals is greatly increased, and the continuity of existence of the race of *Amœbæ* insured. Such a function of *reproduction* also accounts for the great number of leucocytes within the blood stream of an animal. Although the details of the process are not known it is probable that they are essentially similar to what has just been described for *Amœba.*

These, then, seem to be primary functions of living matter: contractility, assimilation, irritability, secretion, and reproduction. Of nutrition and the phenomena concerned with it we shall have more to say in the next chapter.

Specialization in Locomotor Organs. — In but few cells do we find the elementary functions of living matter so evenly balanced and so little specialized as in the leucocyte and *Amœba.* The common form of *Amœba* just described is called *Amœba proteus* because of the fact that it constantly changes its shape, the production of pseudopodia being unlocalized, as we have seen. In another species of *Amœba, Amœba angulata,* there has been

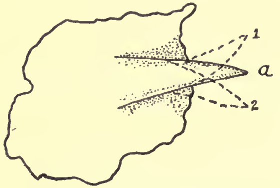

Fig. 10. — *Amœba angulata* (semi-diagrammatic), showing the antenna-like pseudopodium, *a*, which vibrates back and forth in the positions marked *1* and *2*. — (After Jennings.)

described a more or less permanent pseudopodium which extends from one edge of the cell-body freely into the water "and waves back and forth, serving as a sort of feeler or antenna."[1] In yet another form, *Mastigamœba*, there is a permanent lash or flagellum projecting from one portion of the body, the rest of the creature retaining "amœboid" movements. In the group of Protozoa called "*Flagellata*," the amœboid habit is not found, but the animal moves very swiftly by the lashing of one or more permanent whiplike flagella. In these three types we see three different grades of special-

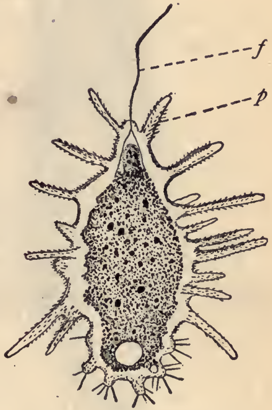

FIG. 11. — *Mastigamœba aspera:* *f*, flagellum; *p*, pseudopodium. — (From Calkins, after Schultze.)

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[1] In the comparisons that follow, the reader must not understand that one type has been transformed into another in any way whatever. The different steps have been arranged side by side much as one might form an exhibit of different models of the telephone or the phonograph from the first crude type to the modern improved machine. In one sense, though not in a material or genetic sense, the perfected phonograph has been derived from the earlier model. In the case of specialization of cells, however, as we shall see from the consideration of *differentiation in development* there is often a very direct genetic relationship between cells of a specialized type and those of the most generalized types.

ization, in each one of which, compared with *Amœba proteus*, there has been brought about a very much greater efficiency in movement through a concentration of effort and the localization of the organ of locomotion.

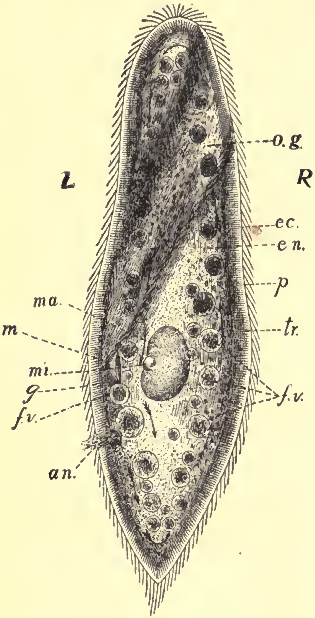

FIG. 12. — *Paramecium* viewed from the oral surface: *L*, left side; *R*, right side; *an*, excretory area ("anus"); *ec*, ectosarc; *f.v.*, food vacuoles; *g*, gullet; *m*, mouth; *ma*, macronucleus; *mi*, micronucleus; *o.g.*, oral groove; *p*, cuticle; *tr.*, trichocyst layer. — (From Jennings.)

In another group of the Protozoa, not only the function of movement, but also that of ingestion has become more or less specialized. In the Ciliates, of which *Paramecium* is a typical though not the most generalized example, the animal swims rapidly by means of bristle-like cilia developed all over the cell-body. These are practically all alike, and consequently the movements of the animal are very uniform and circumscribed. The cilia along the oral groove are somewhat heavier and are employed to force food particles into the so-called gullet to a point where they are ingested. Thus, in comparison with *Amœba*, localization is found not only in the function of locomotion, but also in that of ingestion.

In a relative of *Paramecium*, *Stylonychia* (see fig. 13), the cilia are themselves differentiated in various regions of the body for different functions.

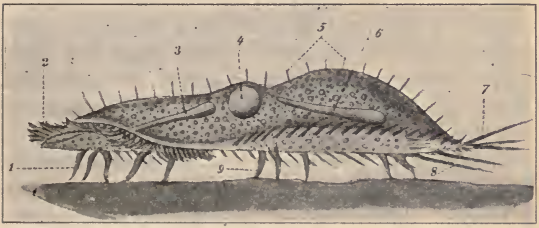

Fig. 13. — *Stylonychia* creeping on its oral ("lower") surface viewed from the left side: *1*, anterior cirri; *2*, adoral zone of membranelles; *3*, anterior branch of the pulsating vacuole (*4*); *5*, dorsal cilia; *6*, posterior branch; *7*, caudal cirri; *8*, posterior cirri; *9*, ventral cirri. — (From Lang, after Bütschli and Schewiakoff.)

Although those on the upper side have almost disappeared, yet *Stylonychia* is more active and has a greater variety of movement than *Paramecium*. This is due to the fact that the cilia on the lower side of the cell-body are fused together in places to form stout, elastic, hooklike "cirri," shaped and inserted in such a variety of ways as to enable *Stylonychia* to crawl and jump. Rows of ordinary cilia enable it to swim. In addition to these forms of cilia, there occurs in the oral groove a series of platelike membranes, formed by the fusion of many cilia, that beat with the motion of a fan and drive the food down the gullet with force and precision. This function is further subserved by undulating membranes (see fig. 13) likewise formed of fused cilia. Each of these types of locomotor organs has a special function to perform. In some way there has come about a *division of labor* among the cilia in different parts of the body, one group of cilia performing one function, another group another; and in proportion to the extension of this division of labor there has arisen a corresponding *efficiency of action* of each part. Along with this physiological specialization of function there has developed the corresponding modification of structure which we have called *differentiation.* Physiological specialization and morphological differentiation are thus two connected consequences that result from a division of labor among the parts of an organism. The fundamental function involved in the examples just described is, however, in each case the contractility of the protoplasm. It is in the method or the physical basis of utilizing this function that efficiency is attained; just as the same amount of current from the same wire will produce a brighter light in a tungsten filament than in a carbon incandescent lamp.

The limits of the specialization of contractile organs are apparently soon reached. In some Protista, however, there has been a differentiation of contractile substance within the cell-body, a localization of the function of contractility to certain regions of the cell.

In *Vorticella,* a ciliate protozoan that is usually rooted plantlike to a fixed base, the long stalk which the cell-body develops (see fig. 14) is very contractile, extending the vorticella-bell to a considerable distance and then suddenly pulling it back. During this movement the stem coils and uncoils like a spring, owing to the presence in it of a very contractile fiber of differentiated protoplasm. The stem contains little else than this contractile fiber (myoneme, of authors), and we may say that the sole function of the stem, aside from that of supporting the "bell," is to withdraw it out of danger or extend it into an area of greater food supply. In return for this the bell eats and digests and reacts for both. Here is a division of labor that has proceeded so far that a different kind of protoplasmic substance has

FIG. 14. — *Vorticella: a,* extended; *b,* contracted; *c,* the stalk more highly magnified, showing the contractile fiber which is not seen in *a* and *b.*

been segregated from the rest, and in this area, one primary function of living substance has been emphasized to the practical exclusion of the others.

If a cell-wall should form across the base of the vorticella-bell, and if both cells should then remain together, we should be justified in speaking of the contractile member of this two-celled organism as a muscle-cell. We know of no instance of such a development in *Vorticella* or any other protozoan, but in the Metazoa the segregation of the contractile function of protoplasm into a special area and the differentiation of this area into contractile muscle-cells is almost universal. Such a cell is in turn differentiated with respect to the nature of the con-

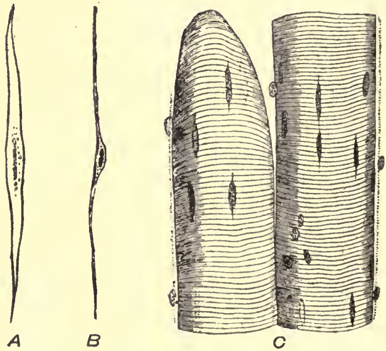

FIG. 15. — Types of muscle-cells: *A* and *B*, smooth muscle-cells; *C*, two fragments of cross-striated muscle fibers (cells); at the left above, the end of a fiber. Note the numerous nuclei. — (Verworn.)

traction which it is of advantage to the organism to have produced. In the vertebrates the tissues that carry out slow, rhythmic contractions, such as those of the intestinal walls, are made up of small, narrow, spindle-shaped cells (fig. 15) with a single nucleus and a delicate longitudinal striation. The skeletal muscles and those throughout the animal series in which rapid or " voluntary " movement is produced are very highly differentiated (fig. 15 *c*). In the specialization of their substance along the line of contractility they have lost the function of food-taking, and to a great degree, though not entirely, that of conduction and general irritability.

Specialization in Conducting Organs. — A particular kind of irritability, however, has come into play in connection with another sort of cells called nerves. Nerve-cells represent another line of specialization. Here the function of specific irritability and conduction has been developed, until, in compensation, the functions of contractility and nutrition have entirely disappeared.

An experiment of Professor J. Loeb's demonstrates in an interesting way the performance of the same function by a highly specialized tissue and by a less specialized one. One of the group of degenerate animals called Tunicates is provided with two siphons (fig. 16) or passages, through one of which the water passes into the saclike body and through the other of which it flows out. Midway between the two is situated the nervous system, consisting of a single large " ganglion " or nerve-knot, from which ramify nerves in all directions. In *Ciona*, a member of this group, if one of these siphons is touched with a needle, both of them contract almost simultaneously. If, however, the ganglion be snipped out with a pair of scissors and one of the siphons be touched with a needle, the one stimulated will contract at once, but only after a considerable interval does the other siphon likewise contract. There has been a conduction of the stimulus in both cases. In the first instance the nervous system afforded so perfect a means of conduction that the contraction of both siphons occurred almost together. In the second experiment, however, the only path of conduction lay through the intervening muscle fibers, specialized along the line of contractility but not that of conduction. Hence the conduction was very imperfectly and slowly carried out.

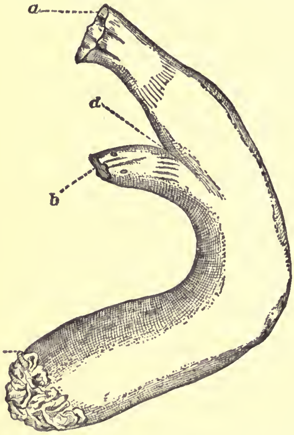

FIG. 16. — *Ciona intestinalis*, a Tunicate : *a* and *b*, the two siphons ; *c*, foot ; *d*, location of the ganglion. — (From Loeb.)

Secretion. — The majority of cells retain in greater or less degree the primary function of protoplasm called secretion. By virtue of its chemical and physical organization living matter not only builds non-living food substance into itself to form new protoplasm (nutrition), but it reverses the process and forms from its living substance non-living products or secretions. Certain types of cells are specialized in this direction to a great degree, and we speak of them as *secretory or gland cells.* But many animal cells and nearly all plant cells secrete a denser substance about themselves, the cell-wall, and further, a *cement substance* which binds the cells together into a unified mass. Cellular secretions are thus of two sorts, " permanent " secretions that remain in place after being formed, and secretions which, when elaborated, are passed out of the cell-body to other parts of the organism. In plant tissues the cell-wall is usually greatly thickened and strengthened by the secretion of *cellulose,* a derivative of which gives wood its hard quality. In animal tissues the cell-wall is not usually so thickened, but a similar result is obtained by the development of intercellular substances. These give the *connective tissues* their characteristic structure and qualities. In the latter the cells are specialized in the production of secretions until the functions of contractility, irritability, and conduction have almost if not entirely disappeared, and the intercellular substance is produced in such quantities as to outbulk many times the living cells themselves. According to the nature of this intercellular substance the connective tissue is described as white fibrous tissue, yellow elastic tissue, cartilage, bone, etc. Strikingly dissimilar as these types of tissue are, they not only are examples of the same sort of protoplasmic activity, but all of them in development have been shown to be derived from an original, much more generalized type of primitive connective tissue cell.

In the other phase of secretory activity mentioned, the production of secretions which are freely transported to other parts of the organism, we have a very easily apprehended example of the division of labor between the parts.

Specialization in Digestion. — *Amœba*, when it has ingested a particle of food-substance, *digests* it by dissolving it so that it can be assimilated into the protoplasm. It does so by means of minute quantities of a substance which it secretes that acts chemically upon the food. (See Chapter III.) This process of digestion, like that of ingestion, may take place in all parts of the cell-body, *i.e.* it is not localized. In the complex structures composing the body of a higher animal it is obvious that it would be impossible for food to come in contact with every part of the body so that each cell could attend to its own function of digestion. Accordingly, we find that the principle of the physiological division of labor comes into play in very simple and otherwise quite generalized forms (such as *Hydra*). The secretion of digestive fluids and the function of alimentation in general becomes restricted first to a layer of cells (in *Hydra*) and then to localized regions of this layer (digestive portion of the alimentary canal), the specific secretions for different kinds of food eventually being segregated in higher animals in different areas of the canal (stomach, duodenum, etc.). Such an adaptation makes for much greater efficiency. However, in some parasitic worms, such as the tapeworm, which lies in the alimentary canal of its host and, so to speak, does not have to exert itself to get or digest food, the localized apparatus for alimentation has disappeared, and the digested food supplied by the host is absorbed directly through the body-wall of the worm.

FIG. 17. — Transverse section of *Hydra*, showing the cœlenteric cavity and the two layers of the body wall. — (Shipley and McBride.)

In connection with the specific character of the secretions of gland cells has arisen the necessity for the production of large quantities of the secretion at one time in a limited space. The natural extension of the secreting area is ordinarily quickly limited by the need for concentrating the secretion at a certain point. In consequence the secretory surface is increased by folding and by sinking below the surface of the cell-layer (epithelium) of which it is a part, so that a maximum amount of secreting surface is produced in a minimum of space. In this way is developed a *gland* (see fig. 18), the common channel for the substance secreted being the *duct*.

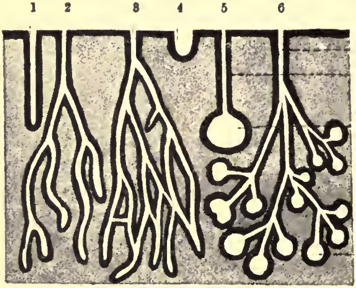

Fig. 18. — Diagram of the formation of glands by the sinking in of a secretory area of the epithelium: *1*, simple tubular gland; *2* and *3*, branched tubular glands; *4* and *5*, simple alveolar glands; *6*, branched alveolar gland. — (Hertwig.)

All organisms possess the power of reproducing themselves, otherwise the species of which they are members would become extinct. In the higher plants and animals this, like the other properties of living matter, has become the special function of a certain class of cells, the so-called germ-cells. In these cells as in other classes we can trace the gradual increase of efficiency and certainly of action of the function through a division of labor.

Summary. — We have seen that the organism, whether simple or complex, may be looked upon as a machine that does certain things; in other words, " works." The nature of the work that the protoplasmic machine does sets it off from all others as something unique and (at present at least) inimitable. No machine that man has ever made reproduces itself, repairs itself, or automatically adjusts itself to changing external conditions. These primary functions, however, are carried out with varying degrees of perfection by different sorts of organisms. As a rule the organisms of comparatively complex structure perform these functions as a unit more efficiently than those of a lower grade of organization. This is due to the fact, as we have seen, that the functions are performed by various parts of the whole organism particularly adapted for the purpose. Physiological specialization and structural differentiation come into play side by side as the result of a division of labor. An organism in which this phenomenon has been extensively developed is spoken of as *specialized.* One, such as *Amœba,* in which there is little or no specialization, is called *generalized.* As a rule this is the criterion by which we estimate the position of a plant or animal in the scale of life.

A "low" form is a generalized one, a "higher" form is one that is specialized. This "criterion of perfection" confronts the student of nature at every turn, but the *method* by which such a condition comes about is the great central problem of biology as yet unsolved. Specialization affects particularly the cells, since it is these that are structurally differentiated. In proportion, however, to the degree of their specialization they lose their own independent self-sufficient identity and become merged with others into aggregates of cells of similar function. These aggregates we have already referred to as *tissues*.

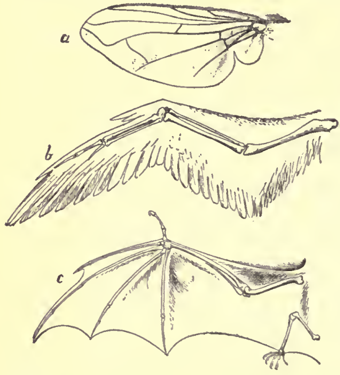

Fig. 19. — Diagrams of wings, showing homology and analogy: *a*, wing of a fly; *b*, wing of a bird; *c*, wing of a bat. *c* is the homologue of *b*, *a* is an analogue. — (Jordan and Kellogg.)

Again, for the better carrying out of the various functions of the whole organism, different tissues are combined into *organs*. The stomach, which not only digests food, but also kneads it and breaks it up, is made up, in addition to secretory tissue, of muscular and connective tissues as well. Again, organs of allied and connected functions are combined into *systems*, some of which, like the nervous and circulatory systems, pervade the whole organism.

It is of great interest and value to compare animals and plants with respect to the degree of specialization of their parts; for such a comparison often reveals relationships. In making such comparisons it is sometimes found that organs carrying out the same function, such as the wing of a bird and that of a butterfly, are of a very diverse origin and structure. On the other hand, the wing of a bird and the foreleg of a dog, in spite of the apparently very different functions which each performs, have each the same origin relative to the rest of the body and the same general internal structure. Such a similarity we call *homology*, and we speak of the two parts as *homologous*, whereas the similarity of function between the wing of a bird and of a butterfly we speak of as *analogy*, and the parts as *analogous*.

CHAPTER III

METABOLISM

Oxidation. — It is known that oxygen exists in two forms, ordinary atmospheric oxygen and ozone, the molecule of the former consisting of two atoms (written O_2), and that of the other of three (O_3). During thunderstorms ozone is often formed from oxygen by condensation, through the action of electricity. Both gases are chemically active in combining with other elements or compounds, a process known as oxidation. The activity of ozone, however, is much greater than that of ordinary oxygen. It gives up its extra atom of O with facility, and is, therefore, spoken of as less stable than the latter. But the resulting product of oxidation by either oxygen or ozone is exactly the same. The only difference between the two must be the way in which the atoms of O are combined to form the molecule. In oxidation there is an evolution of heat, which is the release of the intrinsic energy of combination in the oxygen or ozone molecule. Measurements have shown that in the oxidation of finely divided platinum by ozone, some 72,400 calories[1] more of heat per gram is evolved than in the corresponding oxidation by ordinary oxygen. This figure must represent the additional amount of

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[1] A calorie is the measure of heat required to raise one cubic centimeter of water one degree.

energy locked up in the ozone molecule in comparison with the oxygen molecule. When we speak of this energy as being locked up or "latent," we have exhausted our knowledge of it. We know that it is there, holding the atoms together by what we call "chemical affinity," and that, when the atoms are released from their bonds, this energy becomes evident to our senses; that is, it becomes kinetic, and assumes various forms, such as heat, light, electricity, or motion.

Two points of great significance must be noted in the illustration just given; first, the fact that the more complex substance (O_3) has latent a great deal more of the energy of combination than the simpler one (O_2); and secondly, that the former breaks down or gives up its latent energy more readily than the latter. Few atomic combinations are as simple as oxygen and ozone and at the same time are so readily disrupted; indeed, among the more complex substances it is a general rule that the greater the complexity of the molecule, the greater the amount of its potential energy and the greater its instability.

The storing up of the potential energy of "chemical affinity" is well illustrated by a so-called endothermic compound such as acetylene, — C_2H_2:

Heat of combustion of C_2 = 2 × 96,980 cal. = 193,960 cal.
Heat of combustion of H_2 = 2 × 34,960 cal. = 69,920 cal.
Total 263,880 cal.

Heat of combustion of C_2H_2 (acetylene) . = 310,600 cal.
Difference . = 46,720 cal.

That is, the energy that binds together the hydrogen and carbon in the form of acetylene is nearly one sixth greater than the sum total of the intrinsic energy, measured by the heat evolved in combustion, of the same amount of either element taken separately.[1]

Conservation of Energy. — In the above example the potential energy is released as heat, but it is conceivable, on the basis of other experiments, that this energy, released by the breaking down of acetylene, might be employed at once in building up some other chemical compound, and thus be nonevident to us except from its end-result. At any rate the decomposition and recombination (analysis and synthesis) of any chemical compound may be repeated indefinitely, the same amount of energy being released or absorbed at each change. All the forms of energy known to us may be transformed one into another in this way. Gravitation acting on the molecules of water in a brook may be caused to drive a waterwheel. The wheel, by its motion, in addition to producing heat by friction, may also run a dynamo,

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[1] The above figures refer to the heat of combustion of one gram each of carbon, hydrogen, and acetylene. If equivalent amounts of substance be taken the difference is even more striking. The molecular weight of acetylene is 26 and every gram of acetylene contains twenty-four twenty-sixths of a gram of carbon (mol. wt. of C = 12) and two twenty-sixths of a gram of hydrogen (H = 1); twenty-four twenty-sixths of 193,960 cal. is 179,040 cal. and two twenty-sixths of 69,960 cal. is 5,378 cal.; the sum of these is 184,418 cal. or 126,182 cal. less than the heat of combustion of one gram of acetylene.

the electricity generated by which affords us light, heat, and such chemical analyses and syntheses as are involved in cooking. In all these transformations of one kind of energy into another, though much is wasted in manipulation, none is lost; in other words all can be accounted for. This conception, that the sum of energy in the universe is constant and merely changes its form from one kind to another, is one of the great generalizations of natural science, and is known as the " Law of the Conservation of Energy."

Chemistry teaches us also that the more complex " organic " compounds are built up of relatively few *kinds* of atoms; but these are combined and recombined into groups of higher and higher orders, an absorption of energy taking place with every combination, until a huge aggregate results, the potential energy of which is enormous. Thus, a molecule of a simple sugar, dextrose ($C_6H_{12}O_6$), may be combined with another molecule of a similar sugar to form a new sugar of a higher order, cane-sugar or sucrose ($C_{12}H_{22}O_{11}$).[1] In this reaction a molecule of water is subtracted. More molecules may be added to the combination over and over again, like keys on a keyring, if the molecule of water is each time removed. With every such combination there is an addition to the amount of potential energy accumulated in the molecule, and of course this energy must be supplied from without. Usually its source is the heat of the alcohol or gas flame which

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[1] $C_6H_{12}O_6 + C_6H_{12}O_6 = C_{12}H_{22}O_{11} + H_2O$.

the chemist supplies. Furthermore, if a compound sugar, like the cane-sugar just described, should be broken up, it would not resolve itself into its ultimate components (atoms) at once, but the line of cleavage would occur first at the point where the two larger groups had joined. In other words, the affinity of the two simple sugars for one another is much weaker than the affinities of their constituent atoms for each other. In general, the simplest compounds, such as CO_2, H_2O, NH_3, etc., are bound together by very strong chemical affinity and require much force to disrupt them, whereas the chemical affinity binding together very complex organic substances is usually so weak that these molecules often appear to disintegrate spontaneously, for which reason they are spoken of as unstable. These facts, as we shall see, have an important bearing on the utilization of food substances by plants and animals.

Chemical Synthesis in the Organism. — Green plants not only require the normal conditions of heat and moisture demanded by all living things, but they require sunlight as well, else they grow pale and sickly. This is true even of those plants, like ferns, that thrive best in the shade. The position and attitude of every leaf on a tree is adjusted to receive the maximum amount of sunshine. If we inclose a leaf in a glass tube filled with CO_2, and then expose it to the sunshine, after several hours we will find by tests that a large part or all of the CO_2 has disappeared and has been replaced by an equal volume of oxygen. The total volume of the gas has not been altered, but we find that the carbon has disappeared from the tube. And since this change will not take place in the dark, even if the other conditions be similar, we conclude that the sunlight has supplied the necessary energy. What, then, has become of the carbon?

Green plants always have a certain amount of food material stored up in the leaves, usually in the form of starch. The presence of starch may be easily detected by testing with a solution of iodine, which colors it a bright blue. If we keep such a plant in the dark for a while, it will exhaust this store of starch, as may be shown by the leaves giving a negative test with the iodine.[1] If, however, we pin a strip of cork across part of a leaf from which the starch has been exhausted, and expose the

FIG. 20. — Experiment showing the function of sunlight in the synthesis of starch in the green leaf. A slice of cork is fastened over the leaf and the rest of the leaf exposed to the sunlight. The figure to the right shows the result when the cork is removed and the leaf dipped in solution of iodine. — (Bailey and Coleman.)

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[1] In such an experiment the chlorophyll must be dissolved out in hot alcohol before the iodine is applied, in order that its green color may not mask the starch reaction.

partially covered leaf to the sunshine for a while, we find, when we treat it with iodine, that, whereas the strip covered by cork gives a negative test as before, the rest of the leaf which was exposed to the sunshine turns a deep blue with the iodine. This demonstrates that starch has been actually formed in that part of the leaf which has received the sun's rays. This conclusion we can confirm with the microscope, for the starch granules may be found in the chlorophyll bodies of the cells after such exposure to sunlight.

Out of the water absorbed by the plant, and the CO_2 always present in the air, in the presence of chlorophyll and the sunshine, the plant can synthesize starch,[1] which may be conveyed (in the form of sugar) to other parts of the plant-body to be stored up as reserve food or utilized at once as a source of energy for the vital processes of the plant. The CO_2 in the air is the source of the bulk of the carbon compounds in the substance of the plant. This is shown by the fact that most plants grown in an atmosphere free from CO_2 die (of starvation) even if the soil in which they are rooted be richly supplied with carbon compounds. Conversely, they will thrive in a substratum free from carbon compounds if they have access to ordinary air.

Although starch is the first *evident* product of this process (photosynthesis), yet it is probably

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[1] $6\ CO_2 + 6\ H_2O = \underset{\text{glucose}}{(C_6H_{12}O_6)} + 6\ O_2 \ \dots\ (C_6H_{12}O_6)_n\ (-\ n\ H_2O = \underset{\text{starch}}{(C_6H_{10}O_5)_n}.$

only the end-product of a long series of changes. The carbohydrate food in many plants is more often in the form of a dilute solution of sugar, which, of course, is much less easily demonstrated than the solid starch.

Production of Fats and Proteins. — We know of no other food than the starch that is synthesized from such simple chemical compounds,[1] and it has been shown that the fats and proteins are produced from the starches as a foundation. The spontaneous production of fatty oils in seeds containing starch has been directly observed, and, since the fats contain no elements not also found in the carbohydrates, such transformation involves no more than a rearrangement of these elements in the molecule. It is known that water and CO_2 are produced as the result of such a change, although we have still much to learn of the intermediate steps in the process.

The explanation of the origin of the proteins is much more difficult, for proteins possess, in addition to the carbon, hydrogen, and oxygen of starch, a high percentage of nitrogen, as well as sulphur, and often phosphorus. These latter elements are obtained from the soil in the form of nitrates (or nitrites), sulphates, and phosphates, and are absorbed through the roots of the plant in solution. The nitrates (sodium or potassium) probably enter into union with the carbohydrate radicle to produce some simple amino-acid such as asparagin ($C_4H_8N_2O_3$). By a succession of syntheses involving

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[1] Other organisms recently discovered can apparently utilize carbon monoxide (coal gas), while still others may use methane (marsh gas) as their only source of carbon.

> the condensation of these amino-acids, other radicles or "albuminous nuclei" are welded on, combined, and recombined with the carbohydrate base, or with each other, each time with the disappearance of the potential energy of chemical affinity, until the huge, complex, unwieldy, protein molecule results, and becomes a part of the mixture we call protoplasm. This process has been shown to take place in the green leaves, although it goes on in the dark.

To summarize: The plant in its myriads of cell-laboratories is constantly carrying on a variety of chemical syntheses. First, the carbon element of the CO_2 derived from the air, and the H_2O absorbed from the soil, are combined in the green leaves to form carbohydrates, such as sugars and starch. These molecules may be welded together to form more complex carbohydrates, such as dextrine, cellulose, or wood fiber, or they may be combined and recombined with other elementary compounds containing nitrogen and sulphur until the complex and unstable albuminous or protein molecule results. Each step involves the change of kinetic energy into potential energy, and all this energy is derived in the first instance from sunlight. This building-up process from simple to complex is called *Anabolism*, and, as a consequence of this process, the plant is endowed with an immense reserve of potential energy.

Dissimilation. — But the plant is all the while *living*, — developing new buds and leaves, maturing its fruit, secreting characteristic products, even moving, although its movements may not always be evident. Says Huxley, referring to the constant streaming and circulation of the protoplasm in the cell: "The wonderful noonday silence of a tropical forest is after all due only to the dullness of our hearing; and could our ears catch the murmur of these tiny maelstroms as they whirl in the innumerable myriads of living cells which constitute each tree we should be stunned as with the roar of a great city."

All these phenomena, as we know, are but manifestations of energy. What is its source? From careful experiment we have learned that it is not only the breaking down of the circulating food substances, but may be the disintegration of the protoplasm itself. Made up of complex aggregations of matter held together by the power of chemical affinity, the protoplasm is a storehouse of potential energy that may be translated into kinetic energy by the disintegration of the unstable compounds composing it. In proportion, then, as the plant does work of any sort, it draws on its own substances for the energy requisite. Here we have the direct reverse of the building-up process just described. The circulating food substances or the living tissue itself is constantly breaking down and as constantly being renewed. This continuous flux and flow is called *Metabolism*, the tearing down process, *Katabolism*.

Metabolism in Animals.—The whole animal world is dependent upon the plant world for its existence, since even the flesh-eaters depend ultimately upon the plant-eaters for food. For animals, unlike plants, are quite unable to utilize, directly, the energy of the sun's rays, and combine into sugars and starches the water and CO_2 with which they are surrounded. Nor can they, like plants, utilize the nitrogen as it exists in simple combination. Nitrogen is an essential element of protein, and protein an essential of protoplasm, and without it the animal cannot repair the wastes of katabolism. But this nitrogen must be furnished to the animal already combined in proteins.

The metabolism of animals therefore begins at a higher level than that of plants. Plants take in and assimilate gases and liquids of very simple composition, whereas animals require liquid or solid food already organized as fats, carbohydrates, or proteins. The latter kind of nutrition is sometimes referred to as *Holozoic*, the former, which is characteristic of all green (chlorophyll-bearing) plants, as *Holophytic.*

Some groups of plants, however, show decided exceptions to such a rule. The bacteria and the fungi, for instance, lack chlorophyll and cannot manufacture starch, but must depend on other organisms, either plant or animal, for their food supply. Such plants are called *parasitic* when they feed on living tissue, or *saprophytic* when they subsist on dead and decaying tissue. Even some of the higher plants, such as the dodder, a relative of the morning glory, have abandoned the independent manufacture of their own food materials and live as parasites on other plants.

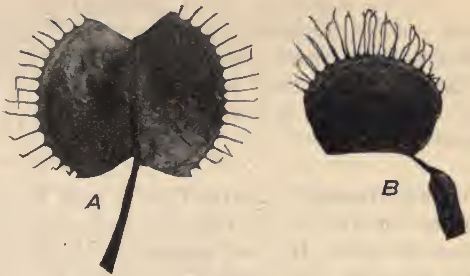

FIG. 21. — Leaf of the Venus' fly-trap: *A*, open; *B*, closed. Note the three sensitive hairs on each leaflet of *A*.

Some plants, indeed, might be called, if not holozoic, at least "amphizoic," since they have developed means of catching and killing living animal prey. Of such are the familiar "Venus' Fly Trap" (*Dionœa*), or the "Pitcher plant" (*Nepenthes*),

FIG. 22. — Two leaves of the sundew (*Drosera rotundifolia*); the one to the right in the expanded condition, that to the left shortly after the capture of an insect; the tentacles of the right half are bent over to bring the glandular tips in contact with the prey. Magnified 2½ times. — (From Barnes, after Kerner.)

etc. In the ingenious traps possessed by such plants unwary insects are caught and killed; digestive fluids there secreted dissolve the tissues of the prey, and they are absorbed precisely as they would be in the stomach of a carnivorous animal.

Foods in General. — In the light of what has just been said, it will be seen that we must modify our notions of foods. It is not enough to classify foods as the scientific cook books do, — merely as carbohydrates, fats, and proteins. Since the sole purpose of taking food is, as we have seen, the accumulation of a store of energy, we might define a food to be anything that contains potential energy. The CO_2 and H_2O are foods to a green plant only when combined with the energy of sunlight. They are better called food-materials. A welsh rarebit, the food value of which is very high, which I may eat with impunity, may be "the other man's poison." But a stick of hickory that supplies the wood-boring beetle larva all the nourishment it requires, is to me useless because, for my purposes, the large amount of energy locked up in it is not available. If, however, I reduce the stick to sawdust and boil it with sulphuric acid, thereby converting it into glucose, it becomes a very good food. We must, therefore, modify our previous definition by designating as a food anything that contains *available* potential energy.

Fate of the Foods in the Higher Animals. — In animals the fats and carbohydrates yield a ready source of energy in the form of heat. Whether they are always directly oxidized in the animal body without ever having become part of the tissue itself is perhaps questionable, but this seems to be true of the carbohydrates if not of the fats. The liver functions in an important way in the carbohydrate metabolism of Vertebrates. The digested sugar is transformed into another carbohydrate called *glycogen* (" animal starch "), and stored up in the liver, and later in the muscles, in the form of granules. The glycogen is dissolved and given back to the blood stream as the body requires it between meals, or is oxidized in place, to release the energy involved in muscular work.

Similarly, the fats are stored up in the different parts of the body or in special organs (the fat-body of the frog, *e.g.*) to be drawn on as need arises. If neither fats nor carbohydrates are available, the proteins in the blood stream or even those of the tissue itself may be broken down to supply the necessary energy. Hence, the fats and carbohydrates are often spoken of as the " protein-sparing " substances.

In the digestive tract of the higher animals the fats are split into their components, glycerine and fatty acid, through the action of the enzyme, lipase.[1] Being absorbed in this form they are recombined in the epithelial cells or within the capillaries and circulate as

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[1] See page 83.

fats in the blood, or are laid down in various parts of the body, unchanged. The carbohydrates are all split into simple sugars (*e.g.* glucose) before being absorbed, and possibly circulate in the blood loosely combined with the serum-proteid base in the same way that oxygen combines with hæmoglobin.

The proteins follow a more complicated path, although our knowledge of them is confined almost wholly to what we know of the metabolism of warm-blooded animals. Using the digestive fluids of the alimentary canal, we can split up protein (a strip of lean meat, for example) into smaller and smaller bodies until we reach the amino-acids, which are the units out of which the proteid molecule is built up. These are absorbed through the blood-vessels of the alimentary canal and are apparently split further into *urea*, $CO(NH_2)_2$, on the one hand, and on the other hand a residue which is then resynthesized into complex albumens that circulate in the blood stream or are built up into the protoplasm of the tissues. Although an absolute essential for the maintenance of life, nitrogen is not accumulated in the body; the greater the amount of nitrogenous food ingested, the greater the amount of urea eventually excreted, — a condition known as nitrogenous equilibrium.

Rôle of Oxygen in Metabolism. — It is a matter of familiar experience that all animals require an abundant supply of oxygen in order to live. The air-breathing vertebrates are especially sensitive to the lack of this element, and if deprived of a supply of oxygen soon succumb with characteristic symptoms of asphyxiation. If we boil water and thus drive out the air dissolved in it, fishes and other aquatic animals soon die. But plants are no less dependent upon a supply of oxygen. If a transparent cell of plant tissue, in which the protoplasm is in active streaming movement, be so mounted that the surrounding air can be replaced by pure hydrogen, the streaming will cease entirely until oxygen is again supplied (the hydrogen is itself inert toward protoplasm). Plants likewise cease to grow in the absence of oxygen. The presence of this element thus appears to be an absolute necessity for life as it exists on the earth to-day.

But an important exception to this statement must be noted. A number of the lower plant forms have been found to thrive in an absence of oxygen and indeed to refuse to grow in its presence. Such forms, which include numbers of the bacteria, are called *anaërobic.* Some bacteria are able to adapt themselves to either the presence or the absence of oxygen; others can thrive only in the absence of it. The former are termed facultative anaërobes, the latter obligate anaërobes. Among the latter are numbered some of the most dreaded disease-producing or pathogenic organisms. And in this connection their anaërobic habit is of much significance. The germ of tetanus (lockjaw), for example, is very widely distributed, and the only reason that the disease is not much more frequent than it is, is that the spores of the active agent cannot develop in the presence of oxygen, and hence only those wounds that are deep and that close over, thus excluding the air, are likely to afford sites for the development of the poison-producing bacteria.

Combustion and Respiration. — Since oxygen is so significant in organic life, it is important to find out what rôle it plays in metabolism. It was among the earlier discoveries of modern chemistry that when anything is burned, the combustion involves a using-up of oxygen (oxidation) and will not take place in the absence of oxygen. When wood is burned, the carbon in it unites with the oxygen to form CO_2, and the hydrogen to form H_2O or water. It is easy to observe that in plants as well as in oxygen-breathing animals not only is O taken in, but CO_2 is expelled. This interchange is known as respiration, and it was an obvious step to compare it with ordinary combustion, particularly as the production of the bodily heat of the higher animals is unquestionably dependent upon oxidations. From this standpoint, the foods which the organism takes into itself were supposed to be oxidized with an evolution of energy, in the same way that the fuel burnt under an engine boiler generates steam to drive the wheels of the engine.

In the burning of fuel the oxygen supplied by the draft combines directly with the fuel, but it is not difficult to show that the CO_2-production of an animal or plant bears no direct relation at all to the intake of oxygen. A frog in an atmosphere of hydrogen will continue to evolve CO_2 without any possible supply of gaseous oxygen. The CO_2 in such a case must have been evolved as a by-product of changes taking place in the tissue substance itself.[1]

These reactions, taking place constantly in the tissues, are obviously of a very different sort from the exchange of gases (breathing) to be observed in higher plants and animals. They constitute the true respiratory process. But the term *respiration*

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[1] Chemists have discovered, indeed, that dry oxygen, at low temperatures, is the greatest retarding agent in combustion. We are familiar with the fact that iron rusts much more quickly if wet than if dry, and if kept perfectly dry, will not rust at all. The rusting is an oxidation or slow combustion resulting from the combination of the metal with oxygen to form iron oxide. In this case the reactions are perhaps as follows (Matthews):

$$\begin{array}{lll} \text{I.} & Fe + 2\,H_2O & = Fe(OH)_2 + \mathit{2H} \\ \text{II.} & 4\,H + O_2 & = 2\,H_2O, \text{ or} \\ & 2\,H + O_2 & = H_2O_2 \\ & H_2O_2 + Fe & = \mathit{FeO} + H_2O. \end{array}$$

In the first equation the iron combines with the water to form ferrous hydrate and hydrogen. The latter would immediately reduce the former to metallic iron again if there were not oxygen present with which it can combine to form hydrogen peroxide, which, giving up its extra atom of O, forms ferric oxide, or iron rust, and water. The oxygen acts thus not as a direct combining agent with the iron, but rather as a sort of depolarizer to take off the nascent hydrogen, and the oxidation of the iron is effected by the hydrogen peroxide.

It is supposed that in animal and plant tissues much the same sort of thing takes place, but with infinitely more complicated reactions. The essential point, however, is that the oxygen does not combine directly with the carbon element of the protoplasm to form CO_2, but, where water enters into reactions with the substances composing the tissues, it acts as a sort of depolarizer to combine with the hydrogen liberated. The CO_2 probably arises *independently* as a by-product in the shifting and rearrangement of various components of the substances making up protoplasm. "It is a sort of receipt for a given amount of energy released by chemical decomposition."

is so firmly associated with the external phenomena just mentioned that its use in connection with the oxidations and reductions taking place in tissues is apt to be misleading. For this reason the term *Energesis* has been proposed for tissue respiration. Since the function of the process is to release the necessary energy required in the life of the organism, this word is very appropriate and deserves wider use.

Poisons. — So long as katabolism is compensated by an approximately equal anabolism, the life process proceeds normally. If the destruction of protoplasm, however, occurs too rapidly for the constructive changes to keep up with it, then abnormal conditions arise which soon result in the death of the tissue or of the organism. Thus, although oxidations are absolutely essential for life, excessive oxidation soon destroys the protoplasm, and certain oxidizing substances, such as potassium permanganate, are *poisons* on this account. Other substances, such as the salts of the heavy metals, mercury, silver, etc., destroy the life of the protoplasm by entering into permanent combination with substances composing it. Other more complex substances act as poisons by substituting themselves for essential parts of the protoplasm. Thus many of the proteins elaborated by plants, such as strychnine, morphine, caffeine, etc., are deadly poisons to the tissues of higher animals. The actions of these substances are, however, very diverse. Indeed, the animal organism constantly forms such protein-like or nitrogenous compounds as by-products of normal metabolism, and these, unless removed by excretion, poison and eventually kill the organism that produces them.

Another group of substances, called anæsthetics, of which chloroform and ether are the most familiar, depress the activities of protoplasm and, if not counteracted, kill it. The action of such substances is still a matter of debate, but since all of them are fat solvents, it has been supposed that their poisonous action may be exerted on the fatty components of protoplasm. The poisonous action of these substances is of a different character from the depressant action mentioned. If the action of the anæsthetic is not too violent or too prolonged, the protoplasm will later recover its activities and resume its functions as before. It has been shown that, whereas the action of poisons (including such substances as ether and chloroform in poisonous doses) greatly increases the permeability of the cell membrane, the merely anæsthetic effect is accompanied by a temporary decrease of permeability.

Antiseptics. — Nearly all the disease and physical suffering that man is subject to is the result of the activity of microörganisms that find lodgment within the body, and, rapidly multiplying, produce poisons that affect the whole system. We combat these by the use of such poisons as have been mentioned above, — chemicals that either inhibit the growth of the organisms or destroy them. Especially useful are bichloride of mercury, alcohol, and phenol (carbolic acid).

The Cycle of the Elements in Organic Nature. — The ultimate source of the carbohydrates and fats in plants and, hence, secondarily in animals, is, as we have seen, the carbon existing as CO_2 in the atmosphere. There is reason to suppose that in geologic time past, owing probably to great volcanic activity then, the amount of CO_2 in the atmosphere was much greater than it is at present.[1] At any rate the proportion of CO_2 in the air nowadays is surprisingly small, — not more than .05 per cent, of which the carbon itself, the part utilized by the plant, constitutes but a little more than one fifth. The botanists have calculated that the cellulose in a single dried tree trunk weighing 11,000 lbs., represents a carbon moiety of 5500 lbs., and that to secure this amount of carbon such a tree must have drained more than 16,125,000 cubic yards of air of its CO_2. Meteorologists calculate that, although the atmospheric envelope of the earth may extend (in a very tenuous state) several hundred miles above the surface, yet seven eighths of it by weight lies under a height of 10.2 miles from the ground. Allowing for the diffusion of its constituents, we may estimate, for the sake of the argument, that the surface vegetation can draw tribute of CO_2 from a height of ten

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[1] Geologists have even ascribed the initiation of the glacial epochs to the decrease of CO_2 in the atmosphere, consequent in part upon the great development of plant life in preceding epochs. See Chamberlain and Salisbury, *Geology*, III, p. 424.

miles. The surface of the state of Oregon is given as 94,560 square miles, that is to say, 945,600 cubic miles of air cover that densely wooded state. On the basis of the calculation made in the last paragraph this would allow but 338.1 trees of the sort mentioned to a cubic mile, or 3381 to a square mile of surface, or one tree to every 918 square yards, — a number which is probably exceeded many times in any one generation.

Of course, both plants and animals "breathe out" quantities of CO_2 in respiration as described in the previous section, yet such amounts must be far inadequate to make good the loss to the atmosphere through plant growth.

Since we have seen that the carbon compounds in the soil cannot be utilized by the plants to build up carbohydrates, it is evident that the air must be constantly supplied with quantities of CO_2 from some source. Before we follow this farther, let us consider for a moment the nitrogen balance sheet.

The plant draws from the soil all the requisites for its protein, and, hence, for the bulk of its protoplasm. The rapidity with which a crop, say of wheat, can exhaust the available and necessary mineral food in the soil has been frequently and strikingly demonstrated in America, where the originally rich virgin soils have been repeatedly "robbed" and then abandoned for other unworked fields. Only recently, when the supply of free land is reaching its end, has pressure been brought to bear on the agriculturist to replace by fertilizers what his crops have drawn out of the soil.

It is obvious that the materials thus removed depend largely upon the kind of plant that is growing, each kind drawing out certain things for its own particular needs. Yet there are some mineral compounds that are demanded by all plants, the absence of which interferes with or prevents normal growth. These, as has been noted already, are the metal salts of phosphoric, nitric, and sulphuric acids, usually potassium phosphate, potassium nitrate, and calcium and magnesium sulphates. It is possible to make a solution[1] of a mixture of these salts in which plants will thrive. The absence of any of the above-mentioned elements in such a solution induces marked disturbances in the normal growth of the plant.

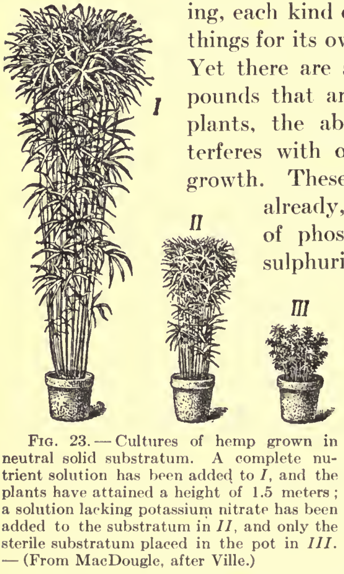

Fig. 23. — Cultures of hemp grown in neutral solid substratum. A complete nutrient solution has been added to *I*, and the plants have attained a height of 1.5 meters; a solution lacking potassium nitrate has been added to the substratum in *II*, and only the sterile substratum placed in the pot in *III*. — (From MacDougle, after Ville.)

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[1] The following solution, devised by Schimper, has been much used in experimental work: calcium nitrate, 6 gm.; potassium nitrate, 15 gm.; magnesium nitrate, 15 gm.; potassium phosphate, 15 gm.; sodium nitrate, 1.5 gm.; distilled water, 600 cc., to which is added a trace of ferric chloride

The amount of nitrogen taken from the soil, annually, by an average crop in Alsace was estimated at approximately 46 lbs. to the acre. Less than half this amount is returned directly to the soil (mostly as volatile ammonia). Moreover, every inch of rain falling on the land and draining through it causes an additional loss of something like 2½ lbs. of nitrogen to the acre. There must be an excess of nitrogen, therefore, in the soil over and above what the plant life demands. Here again, as was the case with the carbon, the demand would seem to greatly exceed the supply.

Since man first began to develop the art of agriculture, he has practiced various methods of replenishing the soil from which his crops have taken their foods. Especially has he used various sorts of manures, which contain nitrates and phosphates. Modern man has added to these fertilizers various mineral substances which he quarries from the earth, such as phosphate of lime and " potash " (potassium phosphates and sulphates). The so-called " basic slag," a residue from metal smelting, which contains 12–20 per cent of phosphoric acid, is nowadays finely ground and largely used to replenish the supply of phosphates. The weathering of the rocks also slowly adds to the soil the soluble components needed by organic life, and of course this was their original source. But whatever man can return to the soil is obviously insignificant compared with what Nature's crops remove. The huge stores of nitrogen and carbon constantly built up into plant and animal tissue must be, somehow, as constantly restored.

Destruction of Organisms. — Each year sees a prodigious crop of annual plants — "weeds" — in every vacant lot. Of course a large part of their bulk is water, yet even if dried out, the accumulations of a few years, if preserved, would so cover the ground as to make it impossible for other plants to struggle up from the soil to the light. The reproductive capacity of nearly all animals is astonishing, and the struggle for existence entails the destruction of hosts of individuals every year. Yet we do not find the surface of the earth cluttered with dead animals. Indeed we rarely see one at all, or, if we do, it is only the whitening bones which the rains are slowly washing away. What, then, becomes of them? The answer is at every hand. Wood is more resistant than animal tissue, and we can everywhere observe

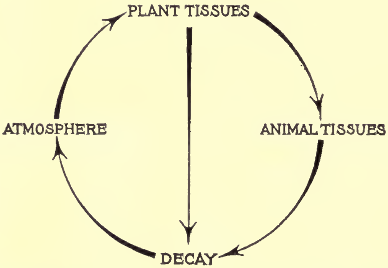

FIG. 24. — Diagram of the carbon cycle in organic and inorganic nature.

the phenomenon of its slowly rotting away. With animal remains the process is much more rapid. In the end, however, the myriads of animal and plant individuals, after their brief existence on the earth, dissolve back again into the elements from which they were built up. " Dust to dust " is a very real and constantly recurring cycle. The complex substances composing living tissue by successive cleavages become resolved into H_2O, CO_2, NH_3, and similar compounds. Were this not so, the material to build the organic world would soon be exhausted, and the earth would be so covered with the remains of animals and plants, accumulating during long periods of time, that life would be impossible. In very hot, dry climates, as in deserts, animal remains actually do dry up and " mummify," without decaying. In the presence of moisture, however, dissolution begins as soon as life is extinct.

Putrefactive Organisms. — This process of dissolution, which is merely the cleavage of the protoplasmic compounds into their simpler components, doubtless would go on automatically, at least to a certain point, but the process is hastened and carried to a final conclusion by the assistance of various kinds of bacteria and molds, known as the *putrefactive organisms.* In the light of what has just been said these obscure and unpleasant atoms of life are one of the most important agents in the economy of nature. They are the wreckers, tearing down that Nature may build herself anew. Through their action, carbohydrates and fats are reduced to CO_2 and H_2O, and proteins are dissolved, by a long chain of reactions, among other things into NH_3 and CO_2. The urea excreted by animals goes the same way. By this means the rotation of the elements through organic and inorganic nature is hastened and facilitated. The ammonia in the soil is taken in hand by another group of bacteria, the nitrite bacteria, which oxidize it to nitrous acid (HNO_2). This combines with potassium or ammonia in the soil to form potassium or ammonium nitrite. Another group then further oxidizes the nitrite into nitrate,[1] and makes it available for plant food. There is a similar cycle for the sulphur and phosphorus, but these elements, although absolutely essential for organic life, are but a small fraction of the bulk

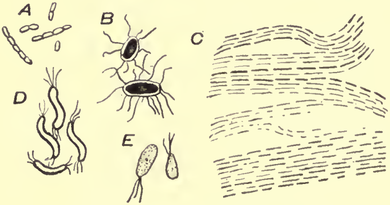

FIG. 25. — Putrefactive bacteria of various sorts: *A*, *Bacillus urea*, the agent that ferments urea into ammonium carbonate and water and eventually into carbon dioxide and ammonia; *B*, *Bacillus subtilis*, a putrefactive organism commonly found in hay infusions; *C*, the same in the inactive zoöglœa condition; *D*, *Spirilla*, *sp.*, from hay infusion; *E*, *Bacterium* "*termo*," from fermenting infusion of peas.

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[1] I. $2\,NH_3 + 3\,O_2 = 2\,HNO_2 + 2\,H_2O$.
II. $2\,HNO_2 + O_2 = 2\,HNO_3$

of the carbon, hydrogen, and nitrogen in living things, and in consequence there is little danger of the supply ever becoming exhausted. The purpose of phosphate fertilization is to supply the demands of the nitrogen-fixing bacteria (*Azotobacter*), rather than the green plants themselves, and thus to aid the process of nitrogen fixation (see below).

Denitrification. — The circle, nevertheless, is not so ideal as it might seem, for there exists another group of bacteria in the soil whose special activity it is to reduce nitrates again to gaseous nitrogen, which escapes to the atmosphere and is added to the inert quantity that plants are unable to " fix " or utilize. This means a constant loss of available nitrogen, a constant deficit, so to speak, in the annual balance sheet, and when the facts first became known, considerable doubt was expressed as to the future habitability of the earth when the available nitrogen should have been reduced too far. Fortunately for our peace of mind, there have been discovered yet other kinds of bacteria and molds that are capable of fixing, that is, combining with the nitrogen of the soil. These seem to be everywhere present in soils and make up for the loss due to the denitrifying bacteria.

It has been known for many centuries that it improves the land to grow crops of peas, beans, or their relatives, and plow them under as " green manure." The ancient Romans and the Chinese and Japanese carried out such practices without knowing any reason for the improvement. It has been known for a long time, too, that the rootlets of leguminous plants (*i.e.* peas, beans, alfalfa, etc.) are beset with little nodules or tubercles, which were supposed to be pathological growths of the nature of galls. Comparatively recently it has been demonstrated that these tubercles harbor minute bacteria endowed with the property of fixing atmospheric nitrogen, and that this is the chief reason for the value of such plants as fertilizers. We discover, therefore, that

Fig. 26. — Tubercles on roots of clover. — (Osterhout.)

life not only goes on *upon* the earth but *in* the earth as well, and that the soil, far from being the lifeless mass of rocks and dirt we are accustomed to consider it, is pulsing with life in every granule, harboring a multitude of different organisms that live in darkness and for the most part without oxygen, but whose activities are so vital for the more familiar life above the ground that one could not exist without the other.

Nature of the Energy Transformed. — *Movement.* — The latent energy of chemical affinity may be transformed into all the other forms of energy known. The movements of an animal are primarily brought about by the contractility of its protoplasm, which is almost always differentiated (except in Protozoa) as muscular tissue.

Intracellular circulation has been previously mentioned. This is a form of motion probably universal in animals and plants. The simplest form of motion, after this, is that described in the previous chapter in connection with the movements of leucocytes, and known as amœboid, because it is the characteristic and only form of locomotion possessed by *Amœba.* A similar mode of unlocalized movement is also found in many pigment cells and in the primitive connective tissue cells of the developing embryo.

The majority of the Protozoa move by means of special organs of locomotion, differentiated either as *cilia,* covering all or parts of the cell-body, or as *flagella*, inserted at the end or side of the cell. It is supposed that both cilia and flagella are hollow extensions of the cuticle, which by a sudden contraction on one side produce a resultant movement like that of a fishing pole when a fly is cast. Fixed ciliated cells are also found as components of many tissues in Metazoa, as in the nasal passages of vertebrates. By the force of the beating cilia currents of liquid are urged along over the surface of the epithelium.

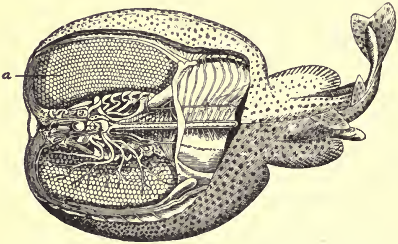

Fig. 27. — The electric ray (*Torpedo*); the skin partially cut away so that the electric organ, *a*, is visible; it consists of numerous polygonal columns of modified muscular tissue. — (From Verworn, after Ranvier.)

The most highly developed tissue of locomotion is, of course, striated muscle. When a muscle contracts, it shortens and thickens without changing its bulk. Movement is communicated through its fixed tendons to whatever bones or other structures it may be attached. When a muscle has made a number of contractions, it shows a marked increase in acidity. This is due to the appearance of sarcolactic acid, which can be shown to be a product of the breaking down of substances in the muscle fiber.

Heat. — During contraction the muscle also develops heat, and it has been estimated that the amount of energy liberated as heat is five times that utilized as mechanical energy, *i.e.* "work" in the ordinary sense. This is shown by the "warming up" that physical exercise brings. The contracting muscle liberates still a third form of energy, namely, electricity, which may be measured by a capillary electrometer.

Electricity. — Both heat and electricity as accompaniments of muscular activity are, in a sense, waste products and represent a certain necessary loss. On the other hand, heat is a transformation of energy very necessary to the organism, not only in the higher animals, where a definite bodily temperature must be kept up, but in all animals and plants as well, since it is only in the presence of a certain amount of heat that the necessary oxidations and reductions involved in metabolism can take place. We are all familiar with the rise of temperature produced by fermenting yeast. In both animals and plants the evolution of heat is usually brought about by the cleavage of a carbohydrate.

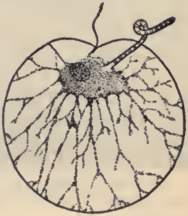

FIG. 28. — *Noctiluca,* a phosphorescent marine *Protozoan;* magnified 30 diameters. — (From Weysse after Cienkowski.)

Static electricity is probably always developed by both animals and plants, as a universal concomitant of vital activity, but in some forms, such as the electric eel and electric ray (Torpedo), an arrangement of muscle fibers, in the structure of a galvanic pile, permits of the accumulation of a charge, so that such an animal can give a severe shock.

FIG. 29. — Phosphorescence in *Noctiluca*. A portion of the body is represented, with numerous scintillating dots. — (From Calkins, after Quatrefages.)

Light. — The energy transformations of metabolism also occasionally take the form of light. This is often called phosphorescence, owing to the fact that the light usually resembles the glow of phosphorus. As a matter of fact it has nothing to do with phosphorus, which in its free and luminous state is an active poison to all living protoplasm. Phosphorescence is a special characteristic of many minute organisms of the sea and of the bacteria that develop in decaying wood and fish. Some of the more complex animals are provided with special light-giving organs that flash in the dark like torches. Certain insects show a remarkable development in this direction. The most familiar example is that of the firefly, which has light-giving organs at the base of the abdomen. In the depths of the sea many of the fishes that inhabit those abysses have similar light-producing spots distributed over the body in characteristic ways. One of the species even develops such an organ at the end of a filament like a pendent incandescent lamp.

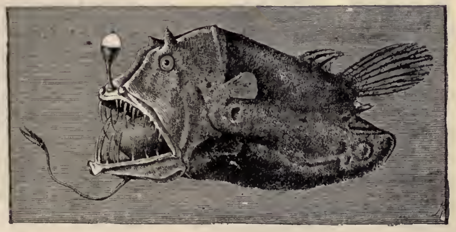

FIG. 30. — Lantern fish (*Linophryne lucifer*). The phosphorescent bulb doubtless functions as a lure to entice other fishes within reach of the jaws. The body is distended with a large fish that has been swallowed. — (After Collet.)

It has been found that the efficiency of the firefly's light is practically 100 per cent, that is, none of the energy is lost as heat; whereas in an ordinary incandescent lamp but 3½ per cent is utilized as light, and in an arc but 15 per cent, the rest of the energy being wasted as heat. In the insects mentioned above, the glow is produced by the oxidation of some specially secreted substance, probably fatty in nature, and the flashes of the firefly correspond with the intervals of taking in air through the respiratory tubes.

In addition to the foregoing forms of energy protoplasm utilizes its latent energy to produce the characteristic products that have already been described. These include, besides the food reserves, such as fat, starch granules, egg-yolk, etc., minute quantities of other substances (zymogens and hormones) which enable the cell to accomplish its multitudinous reactions with the minimum expenditure of energy.

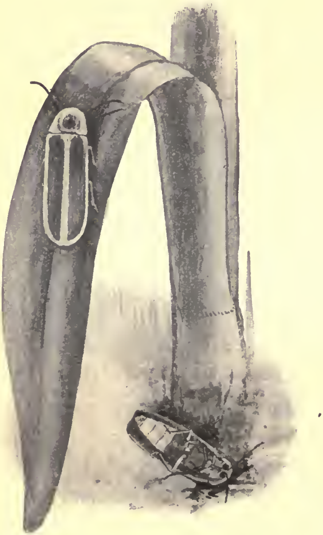

FIG. 31. — The firefly; the one on the ground shows the phosphorescent organs (the three white segments of the abdomen). — (From Linville and Kelly.)

Enzymes and Enzymotic Reactions. — If starch be taken into the mouth or placed in a test tube with saliva, it is acted upon by the saliva and its molecules are split into their sugar elements, in which form they may be absorbed through the lining wall of the digestive tube. The chemist can also boil the starch in any strong acid and produce the same change. In this case, however, a strong reagent and a high degree of heat are necessary. The mildly alkaline saliva at ordinary temperature thus seems to be able to accomplish the same result with a minute fraction of the expenditure necessary in the second experiment.

The prompt and effective action of the saliva is due to the presence therein of a minute quantity of a substance called *ptyalin*, one of a large group of somewhat similar substances which we call enzymes. A similar enzyme, called *pepsin*, splits up proteins in the stomach; another, *lipase*, splits fats, in various parts of the body; another clots blood, and so on. None of these enzymes has been isolated in a pure state, and we know little of their composition, although it has been surmised that they are allied to the proteins. They are certainly not alive in the usual sense of the word, for they may be precipitated without injury with absolute alcohol and other reagents. They are, however, destroyed by boiling and do not " work " well below a certain minimum temperature. Most of them need a special environment (*e.g.* hydrochloric acid for pepsin) to work best, and each of them is specific in its action; that is, affects only one kind of substance. The most remarkable thing about them, however, is that although a minute quantity will produce a relatively enormous effect, the enzyme does not appear to be used up at all, and the process may go on indefinitely, provided the products of its action are removed as soon as formed. Some of these enzymes are reversible, splitting and synthesizing the same substance, as conditions differ. In these processes, enzymes seem to follow the same " law of mass action " as well as the equations of reaction-velocity in relation to temperature that have been worked out in inorganic chemistry.

Within the cell, through the aid of enzymes there present, analysis and synthesis may take place side by side, and by a series of such changes, oxidation following reduction in continuous sequence, the most complex molecules may be built up, the energy of one disruptive process being utilized to combine the components into a molecule of a higher order. Oxidizing enzymes or " oxidases " seem to be present in all protoplasm, and owing to their presence the necessary oxidations take place in the organism very rapidly at a comparatively low temperature. The seat of these oxidations, and hence of the oxidative enzymes, appears to be in the nucleus.

A distinction was formerly made between the so-called " unorganized ferments," such as pepsin, and the " organized ferments," such as the active principle of yeast, which was supposed to require the presence of a living cell in order to work. It has been found possible, however, to crush all life out of the yeast cells and, by filtering the extract, to get a solution which is as active a fermentative agent as living yeast. The distinction between the two sorts of enzymes then falls to the ground. The only difference seems to be that some enzymes work within the cell and others without. The idea that the action of enzymes is physical and mechanical is strengthened by the fact that finely divided platinum (platinum black) will produce catalytic effects similar to those produced by oxidizing enzymes.

The most wonderful feature of all, perhaps, is the fact that the protoplasm makes its own enzymes, since they are, of course, the secreted products of the activity of the living substance, developed in just the places and apparently at just the time when needed.

Since the action of enzymes is mechanical, the question has often arisen, — How is it controlled? Why, for example, does not the stomach digest itself? We hardly know enough about enzymes to answer such a question in detail, but we have learned that many enzymes when produced are incapable of performing their offices until supplemented by another element, usually produced in a different region. The pancreatic secretion has no power to digest proteins until it has been "activated" by the secretion of the lining wall of the intestine, a secretion induced by the flow of acid liquid from the stomach. The action is due to the presence of a complementary body, *enterokinase,* which apparently combines with the *zymogen* (or enzyme-former), called *trypsinogen,* to form *trypsin,* the proteid-cleaving enzyme of the pancreatic secretion. Similarly it has been discovered that the muscles cannot reduce the glycogen which is necessary as a source of their activity, without the presence of an activating substance, also formed in the pancreas and transported to the muscles in the blood. It seems likely that the majority of enzymes are thus compounded of a zymogen, secreted in the cells in the form of granules, and an activator with which it must unite before becoming capable of its specific action. In the stomach of warm-blooded animals the activator of the pepsin is hydrochloric acid, which is only excreted under the stimulus of the presence of food. But there seems to be also an *antipepsin* formed, which neutralizes the enzyme and prevents self-digestion.

Internal Secretions and Hormones. — The cells and tissues of an organism, either singly or grouped in glands, produce a variety of secretions, such as starch, cellulose, egg-yolk, silica crystals, lime, mucus, zymogen granules, etc. These products are usually visible, and, being often extruded from the cells in which they are formed, they are spoken of as *external secretions*. By means of experiment it has been demonstrated that in addition to the external secretion of certain organs there is also an external secretion, so called, which, instead of collecting in ducts and being thus transported away from its source of origin, passes directly into the blood stream. Many " ductless " glands, such as the thyroid, have a large blood supply, which takes up such an internal secretion, but other glands, such as the pancreas, in addition to the evident external secretion (the "pancreatic juice," with its various digestive enzymes), have been shown by experiment to develop important internal secretions as well. Thus it has been found that total extirpation of the pancreas produces the unexpected result of inaugurating glycosuria (diabetes), — a condition in which the kidneys constantly eliminate sugar from the blood. If, however, only a small portion of pancreatic tissue be left, no diabetes or only a very mild form results. It is evident that the existence of this sort of diabetes is dependent upon the absence of pancreatic tissue. Even when the pancreas has been removed, if a small part be grafted in where the blood can come in contact with it, no diabetes follows, a result that indicates not only that the ordinary intestinal secretion has nothing to do with it, but also that it is necessary for the blood to flow in contact with the pancreatic tissue. For this and other reasons, it has been concluded that the pancreas supplies to the circulating blood an important internal secretion, which, in some way at present unknown, controls the utilization of sugar in the animal organism, and in the absence of which this sugar passes out of the body unchanged.

The adrenals, ductless glands attached to the kidneys, have been shown, in much the same way, to produce a substance, the presence of which in the blood rapidly increases the blood pressure and produces a strong contraction of the peripheral blood-vessels. This substance has recently been isolated from the extract of the gland, and is found to be a white, crystalline, somewhat bitter powder, to which the name adrenalin has been given. Practical use of this substance has been made in surgery. By its application small hemorrhages may be entirely done away with, particularly in delicate operations on the nose and eye. There has been synthesized recently a substance similar to adrenalin, if not identical with it, which produces the same effect.

Another ductless gland, the thyroid, by its secretion, influences the normal phenomena of differentiative growth in the higher animals. When the thyroid is diseased, the whole system is affected. In extreme cases degenerative conditions known as " cretinism " and myxedema result. If the gland be extirpated in a very young animal, death inevitably follows, but if small pieces be introduced elsewhere in the body by grafting, or especially if an extract of the gland be fed, the evil results disappear, or are greatly mitigated. The extract has been shown to owe its efficacy to the presence therein of a chemical compound (thyroiodin) containing a high percentage of iodine. Another somewhat similar ductless gland, the thymus, is also found in the throat. If tadpoles be fed thyroid, their metamorphosis is greatly hastened, and they turn into tiny frogs before they have had time to grow to normal size. On the other hand, if fed thymus, differentiation is inhibited and growth accelerated, with the result that they grow into large tadpoles, but do not metamorphose at all.

The flow of half-digested food into the intestine mixed with hydrochloric acid (chyme) that is poured stimulates the cells of the lining membrane of the latter to produce a substance called secretin, which, passing into the blood, is carried to the pancreas. Here it stimulates the excretion of pancreatic juice, which flows out into the intestine, apparently in direct response to the inflow of food, but really in response to another sort of stimulus. A chemical excitant like secretin, or thyroiodin, or the other products just described, has been called a *hormone*, and it is likely that the number and importance of such substances will be greatly increased by further investigation. They are the products of protoplasmic activity, like the zymogens, but, unlike them, they are not destroyed by boiling, even in hydrochloric acid.

CHAPTER IV

GROWTH

In all normal plants and animals, anabolism nearly always tends to exceed katabolism, with a consequent increase in the bulk of the living substance. When this increase in volume is permanent, we call it *growth*. Such changes are to be distinguished from temporary changes in size or form due to the rapid imbibition of water or the evolution of gases. They are also to be distinguished from differentiating changes such as occur in development. The latter may or may not be accompanied by the increase in mass called growth. In plants, growth is a phenomenon which generally continues as long as the organism lives. In animals, it is a special feature of the earlier period of the organism's life, and then usually comes to an end. At that time a balance of metabolism is struck, after which the energies of the organism are directed, not toward increase in size, but toward reproduction. For this reason the period of greatest growth is coincident with immaturity. The enormous disproportion in the amount of growth in the earliest stages of existence is illustrated by some calculations of Professor Hertwig. He estimates the volume of the human ovum at .004 cubic millimeter, whereas that of the child at birth is from three million to four million cubic millimeters, an increase of one billion times. Yet from the first year to the twentieth the ratio of increase is figured at only one to sixteen.

Since the organism is composed of cells, it is obvious that to accomplish this growth the cells themselves must increase either in size or in number. It was early discovered that both these changes take place, and that the latter seems to be consequent upon the former. We have seen that the nucleus " dominates " the rest of the cell, as it were, and that without the presence of a small portion of nuclear matter the normal changes of metabolism in the cytoplasm cannot go on. This influence of the nucleus appears to have rather narrow limits, and if the cell gets to be too large, portions of it may get out of the range of the nuclear influence. Sometimes this is avoided by the fragmenting of the nucleus, the parts being distributed about the cell; but this occurs in only a few kinds of cells. Normally, when the bulk of the cell has increased by growth to the natural limit, the nucleus divides into two halves that move apart and divide the original cell between them, thus making two new cells, separated by a newly formed cell-wall. Occasionally the cell-wall does not form, in which case we have a *syncytium* resulting. When the two daughter-cells have grown to the size of the original mother-cell, the process is repeated, and so on, the number of cells in a given tissue increasing with the growth of the tissue, but the average size of the cells themselves remaining nearly constant.

Since the cell gets its food by absorption, it is also of advantage to divide in this way in order to increase the absorptive surface; for whereas solids vary as the cubes of a dimension, surfaces vary only as the squares of a dimension. To use a concrete illustration, the combined surface of two halves of an orange cut in two in the middle is greater than that of the original orange by just the added areas of each cut surface, the cubic content remaining the same.

Mitosis. — The direct cell division just described, in which the nucleus simply cuts in two and the two halves move apart while the cytoplasm cleaves between them to form two new cells, is sometimes observed, but is by no means the usual method. It will be remembered that the content of a cell is normally very heterogeneous, so that a division plane passed through the middle would result in producing two dissimilar halves, and if this were repeated a number of times, the various elements of nucleus and cytoplasm being segregated each time, the resulting cells would soon lose all real resemblance to one another, and the tissue which they compose would lose its homogeneous character. We know that this does not happen. Instead of this direct method of division we find that another sort of cell cleavage usually takes place, to which the name of *mitosis*[1] has been given. This process is an extremely complicated one, and it will be more

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[1] The direct cell division just described is called *amitosis*.

readily understood if we preface its description by a simple illustration. Suppose that we have a small box full of marbles of different kinds and sizes, some glass, some agate, some porcelain, etc. By pushing down a dividing partition exactly in the middle we could divide the box into two halves, the cubic content of each of which would be the same. It will be seen that only by the rarest accident would the various marbles be so distributed through the box before we divided it that the actual contents of each half space would be identical, and then only if there were no odd marbles in the original box. Suppose, however, that to begin with we should exactly divide each and every marble in two and put one half on one side of the partition and the other half on the other side. The result would be that the two halves of the divided box would be not only equal in size, which they were before, but also identical in contents. If we could endow box and contents with the power of growth, we see that when both should have doubled in size, we would have two boxes of marbles each similar to the original box.

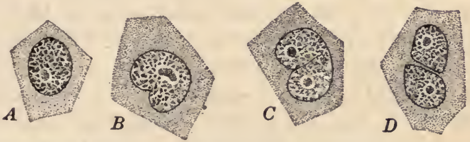

Fig. 32. — Four stages in the direct (amitotic) division of the follicle cells of the cricket's egg. — (From Dahlgren and Kepner.)

Something like this takes place in the process of indirect cell division, at least so far as the nucleus is concerned.

The greater part of cell life is passed in the so-called "resting stage," in which the chromatin substance is scattered through the nucleus apparently in the form of granules. When a cell is preparing to divide, these granules begin to aggregate and fuse together (or at least appear to do so, though it is claimed by some that each granule retains its individuality). By such an aggregation the chromatin assumes the form of a tangled thread or skein.[1] This later segments into a number of separate bodies to which the name *chromosome* is given. The number of such chromosomes, which varies from one or two to a hundred or more in each cell, is normally always constant in any one species. Sometimes they even reveal individuality in relative size and shape. At the same time that these nuclear changes are taking place there may be observed in the cytoplasm a tiny dot surrounded by a mass of radiations. This structure is appropriately termed the *aster* and the central body the *centrosome.* This appears to develop about a central granule, the *centriole.* The centrosome divides and the two halves move apart about the nucleus, each apparently carrying a portion of the aster with it, until they have placed themselves on opposite sides of the nucleus. They are connected with each other by the rays of the divided aster so as to produce what, from its appear-

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[1] Whence the name *mitosis,* from *μίτος.*

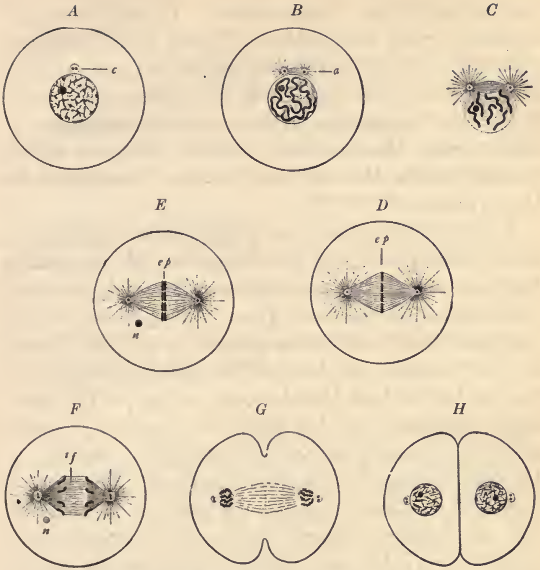

Fig. 33. — Diagrams illustrating mitotic cell division: *A*, resting cell; *B*, prophase showing spireme and nucleolus within the nucleus and the formation of spindle and asters (*a*); *C*, later prophase showing disintegration of nuclear membrane and breaking up of spireme into chromosomes; *D*, end of prophases, showing complete spindle and asters with chromosomes in the equatorial plate (*ep*); *E*, metaphase — each chromosome splits in two; *F*, anaphase — the chromosomes move toward the asters; *if*, interzonal fibers; *G*, telophase — showing reconstruction of nuclei; *H*, later telophase, showing division of the cell into two. — (From Hegner, after Wilson.)

ance, is called a *spindle.* The nuclear membrane having broken down in the meantime, these rays penetrate the nuclear area and appear to fasten themselves to the chromosomes. Through the pull exerted by the contraction of these fibers the chromosomes are swung into an equatorial plane. Not all the fibers radiating from the centrosomes go to make up the spindle proper; other radiations at the sides — the so-called mantle fibers — attach themselves to the cell-wall or lose themselves in the cytoplasm.

The next step consists in a longitudinal splitting of each chromosome and the shortening of the spindle fibers attached to each side so that the two half chromosomes separate. That this splitting of the chromosomes is only accompanied by and not caused by the fastening on them of the spindle fibers is evidenced by the fact that in many instances the chromatin aggregate in the skein or "spireme" stage splits precociously before the spindle has formed or the spindle fibers have become attached. The divided chromosomes move toward the poles of the spindle (or are dragged toward them), and in the interval between may be seen fibrils of the spindle in the midst of which a row of granules often appears, foreshadowing the formation of the new cell-wall. When the chromosomes have moved to each pole of the spindle, the reverse of the preparatory changes previously described begins to take place, and the individual chromosomes fuse together into a spireme which eventually breaks up into a mass of granules characteristic of the original "resting stage."

The stages involved in mitotic cell division may be made clearer by a diagrammatic summary.

Nucleus	Cytoplasm
1. Formation of spireme.	Appearance of centrosome and aster.
2. Segregation of chromosomes.	Division of centrosome and aster.
3. Breaking down of membrane.	Moving apart of centrosomes to opposite poles; attachment of spindle fibers to chromosomes.
4. Formation of equatorial plate.	
5. Splitting of chromosomes.	
6. Separation of daughter chromosomes.	Contraction of spindle fibers.
7. Re-formation of spireme.	Disappearance of astral rays and centrosomes.
8. Disintegration of spireme into granules of resting stage.	Formation of new cell-wall.

Stages 1–4 are sometimes called "prophases," stage 5 "metaphase," and stages 6–8 "anaphases."

Such is the orderly series of changes undergone in all cells that divide indirectly. The synchrony of movements in nucleus and cytoplasm is not always just the same as indicated above, but the modifications are not fundamental, usually consisting in a hastening or a delaying of changes on either one side or the other, and the end-result is always the same.

Abnormal Mitosis. — Under certain conditions, such as the division of an egg-cell fertilized by more than one sperm, or in degenerative growths as in cancer and tumors, often three or more centrosomes and spindles appear, and as a consequence the chromosomes are laid hold of on all sides, "multipolar" spindles being formed. These phenomena indicate that the spindle is a complicated piece of mechanism, which like all machines may "go wrong."

Nature of the Centrosome. — The centrosome, from the leading part it appears to play in cell division, has been the object of very careful research. It has been held by some that it is a permanent organ of the cell, but this seems not to be the case. Not only is it normally absent in many dividing cells, but there is no question but that it is formed anew in succeeding cell divisions, most often in the cytoplasm. Centrosomes, moreover, have been caused to develop by chemical reagents in enucleated fragments of unfertilized eggs after the true egg centrosome and spindle has developed in another part of the same egg.

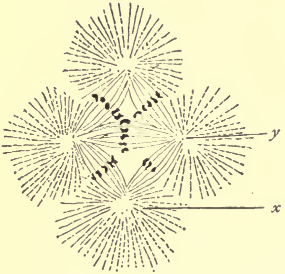

FIG. 34. — Abnormal mitoses. Four-poled spindle in a developing sea-urchin's egg after poisoning with quinine. The spindle x-y lacks its share of the chromosomes. — (Hertwig.)

The mechanical basis of the mitotic spindle has been difficult to get at, because practically the only means of studying cell structure is by killing, fixing, hardening, sectioning, and staining cells and tissues, and it is sometimes hard to decide whether all that we observe existed in the living cell or are artifacts produced by our manipulations. The spindle is the physical expression of forces operating within the cell, but whether as cause or as effect is not easy to say, and there have not been wanting theorists who interpreted the phenomena from either point of view. Comparisons have been instituted between the spindle and the lines of force depicted when a horseshoe magnet is held under a layer of iron filings, and the claim has been made that the spindle we see is but the arrangement of the particles of protoplasm in accordance with lines of a force, itself as invisible as magnetism. On the other hand, dividing cells have been dissected in the living condition, and it has been amply demonstrated that the spindle and the asters are real and tangible things, and that the separation of the chromosomes is accompanied by the contraction of these threads. It has even been suggested that the spindle fibers are the result of chemical changes in the semiliquid cytoplasm analogous to the formation of the ropy fibrin in the clotting of the fluid plasma of the blood.

Cell multiplication is to be looked upon, not as an end in itself, but as a readjustment of the physicochemical relation of two sorts of protoplasm contained in nucleus and cytoplasm, following an increase in substance. Considering the tissue as a whole, this growth is a continuous process; from the standpoint of the cells as physiological units it is discontinuous. But the discontinuity is thus only apparent, not real. Indeed there is always retained, not only a physiological, but also a certain physical continuity between the cells.

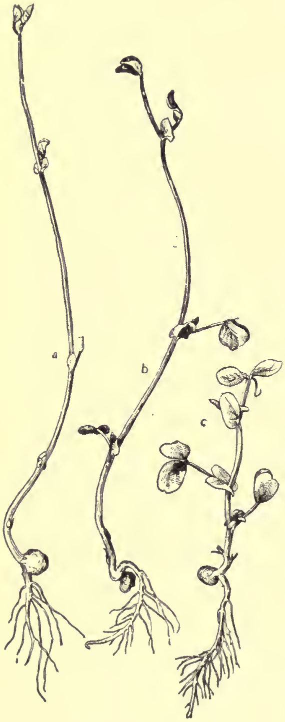

Fig. 35.—Peas grown 6 days in darkness (*a*), in about ⅛ light (*b*), and open in greenhouse (*c*). (From Duggar's Plant Physiology.)

Influence of External Conditions on Growth

Light.—One of the factors of most significance in the normal growth of animals and plants is that of light. It makes a great difference, however, whether this light is diffuse or whether it is the direct sunlight. Sunlight completely inhibits the growth of many Protista and lower plants (bacteria, molds, etc.) and destroys the organisms. For this reason sunlight is one of the most effective sterilizing agents known. The majority of animals and plants, however, require an abundance of light for normal growth and development. Seedlings grown in the dark and those grown in diffuse light present a striking contrast. The former are "spindling," weak and pale, and always much larger than those grown in the light. Even diffuse light thus seems to have a retarding effect on growth as such, although necessary for the normal development of the plant. The difference in size between plants grown in the dark and those grown in the light is perhaps due to the loss of water that takes place in the light, with a consequent concentration of protoplasm. This idea is supported by the fact that aquatic plants and animals grow faster in the light than in the dark, owing doubtless to the fact that such a loss of water does not occur.

The white light of the sun may be broken up into the components of the spectrum, and it has been discovered that the various-colored rays of the spectrum have very different effects upon growth. The actinic (ultra-violet) rays are the most active, and it is probably their presence that makes direct sunlight so destructive to living matter. The action of the other rays varies, but in some plants there is a progressive inhibition of growth from the red end of the spectrum to the other.

Temperature. — Various different organisms are to be found thriving in all extremes of heat and cold between 0° C. and a very little below the boiling point. In general, however, growth is accelerated both in plants and animals by a *slight* increase of the

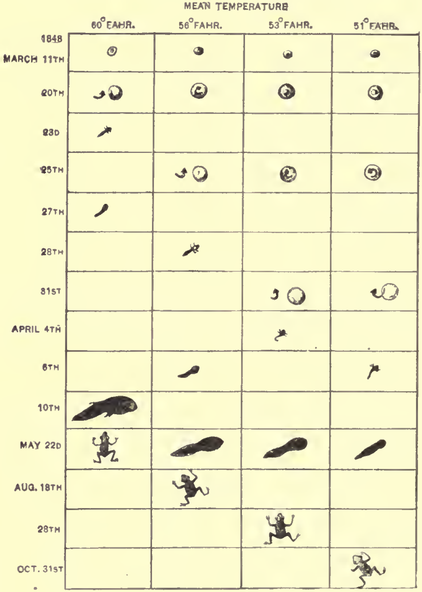

Fig. 36. — Chart showing the correlation between the stage of development of the frog on successive days and the temperature at which it has developed. — (From Davenport, after Higgenbottam.)

normal temperature. This is well illustrated by the accompanying chart (fig. 36).

Effect of Chemical Agents. — Since growth can take place only at the expense of food substances which are elaborated into protoplasm, it is, of course, obvious that the chemical nature of the available food supply will have a marked influence upon the growth of both plants and animals. Careful experiments seem to show that growth is advanced most in the presence of abundant nitrogenous compounds, next in the presence of fats, and least in that of carbohydrates. Growth may also be greatly accelerated by various chemical stimuli. Thus it has been found that many poisons, deadly to the organism when in any considerable concentration, yet stimulate growth when in extreme dilution. Mercuric chloride, strychnine, cocaine, ether, and many other poisons act in this way.

CHAPTER V

TISSUE-DIFFERENTIATION FOR SPECIFIC FUNCTIONS

I. Differentiation in Animals

In the Protista cellular differentiation is identical with differentiation of the organism. It would be the same, so far as *Paramecium* is concerned, if each cilium were a tiny vibratile cell instead of being, as most biologists believe, a minute portion of the one cell composing the body of the animal. We then might speak of these locomotor organs as the "ciliary system." In the many-celled animals and plants the organism also acts as a unit, and the differentiation of cells for the better performance of specific functions such as we have traced in the previous chapter is carried out apparently with reference only to the needs of the whole. The structure of the higher animals is so complex and the various systems so specialized that, in studying them, this point is often lost sight of.

Alimentary System. — The taking in of food is the most necessary function of living things, and only those forms, like the tapeworm, which have become absolved from the responsibility of seeking food on their own account are without a special apparatus for seizing, storing, and reducing foods. In practically all animals there is a central tubular cavity into which the food is taken to be dissolved or digested by the secretions elaborated for this purpose. In the simplest of the Metazoa (*Cœlenterata* and "flatworms") this sac has but one external opening through which all the food is taken in and from which all the non-utilizable parts are ejected (fig. 37). In

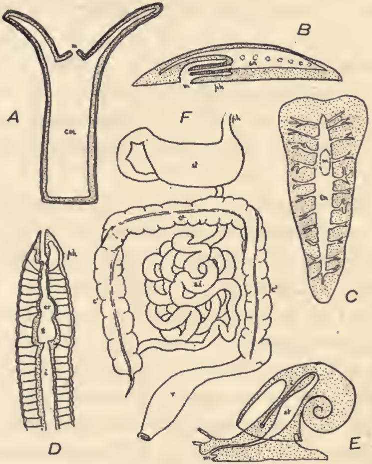

Fig. 37. — Diagrams of various types of digestive systems: *A*, *Hydra* in which there is no distinction between body cavity and digestive cavity; *B*, a longitudinal section and *C*, a horizontal section of a (polyclad) flatworm in which there is no body cavity; and but one opening to the many-branched digestive cavity; *D*, anterior end of earthworm; *E*, section of snail; *F*, alimentary canal of human being; *m*, mouth; *ph*, pharynx; *en*, enteron or digestive cavity; *st*, stomach; *cr*, crop; *g*, gizzard; *i*, intestine; *s.i.*, small intestine; *c*, colon; *r*, rectum.

other animals the tube is open at each end and the food passes slowly from mouth to vent. A few forms, such as the snails, have both openings close together. Some animals, such as the pigeon, or the deer, are compelled to seek their food in danger of attack and have developed the habit of taking in a quantity of food to be stored in a crop or similar sac to be digested at leisure in safer surroundings. Probably the stomach, which is found in one form or another in most animals, functions primarily as a storage chamber.

The differentiation of the alimentary canal is usually specially related to the habits of the animals. Thus, meat eaters require far less bulk to obtain the same amount of food substance than do vegetable eaters, and we find the alimentary canal in the latter much larger and longer. In the cat the alimentary canal is but three times the body-length, whereas in a sheep it may be as much as twenty-eight times as long. In order to increase the absorptive surface and hasten the taking up of large quantities of digested food the inner surface of the alimentary canal is often thrown into folds and wrinkles which greatly increase the superficial area without increasing the size of the tube. Thus in the earthworm there is developed the so-called *typhlosole*, which is a fold of the dorsal wall of the intestine that hangs pendent within the cavity of the tube. In many fishes the same end is attained through the development of the *spiral valve*, which is a fold of the inner lining of the intestine developed in the form of a screw and largely increasing the absorptive surface. In mammals the whole inner surface of the intestine is lined with innumerable finger-shaped processes called *villi* that project into the intestinal cavity and enormously increase the absorptive area.

Sensory Organs. — Since food must usually be captured before being eaten, we find that in the great majority of animals (the "higher" ones particularly) all the sense organs available, whether of seeing or touching, smelling or tasting, are concentrated in close proximity to the mouth. This specialization of organs in one portion of the body has brought about a sharp differentiation of that part from the rest of the body, a *cephalization* or " head-specialization." Sensory organs in the beginning were probably diffusely scattered over the body as they are now in the simplest types, and the concentration of this system in one locality, *i.e.* the head, has made necessary a means of communication between such centers and more remote parts. Thus we find a system of *nerves* connecting the sensory centers with other parts of the body, particularly the muscles, and affording paths for stimulating " impulses " which result in coördinating movements and thus unifying action.

Concentrations of nervous elements into centers of this sort are termed *ganglia* (singular, ganglion). The ganglia are larger and more complex in the region where the majority of sensory impulses arise, that is, the head, and in higher forms of animal life these

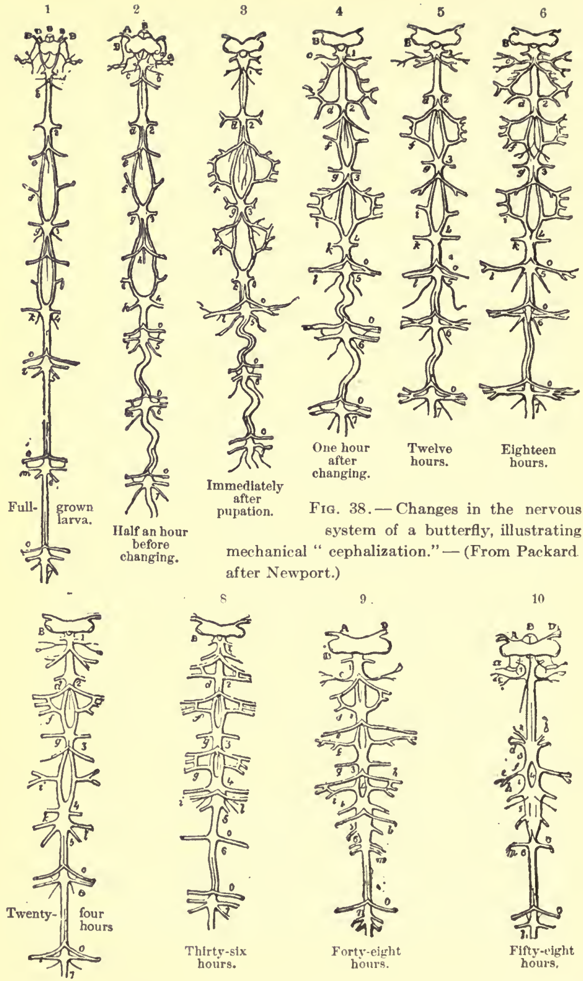

Fig. 38. — Changes in the nervous system of a butterfly, illustrating mechanical "cephalization." — (From Packard after Newport.)

Full-grown larva.

Half an hour before changing.

Immediately after pupation.

One hour after changing.

Twelve hours.

Eighteen hours.

Twenty-four hours

Thirty-six hours.

Forty-eight hours.

Fifty-eight hours.

nervous centers reach a large size and a very high degree of complexity. They are then called the brain. But most animals are more or less elongate, and this central condensation of the nervous system is also distributed along the longitudinal axis. In vertebrates this forms the spinal cord, which is a thick-walled hollow tube. In invertebrates the central nervous system is solid and often double, or in the form of a ladder. In vertebrates the central nervous system and brain is constantly dorsal[1] to the alimentary tube; in invertebrates, with few exceptions, the central nervous system is ventral to the alimentary canal, although the brain is always dorsal. Accordingly the connections between the brain and the rest of the nerve cord in invertebrates have to go around

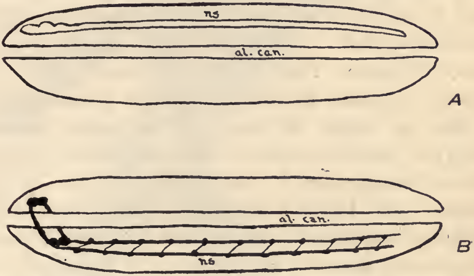

FIG. 39. — Diagrammatic comparison between the vertebrate type (*A*) and the invertebrate type (*B*), with respect to the relation of the nervous system to the alimentary canal.

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[1] "Dorsal" and "ventral" are here used in their ordinary though somewhat inaccurate meanings.

the alimentary canal in a sort of ring or collar. (See fig. 39.)

Skeletal Structures.—*Endoskeleton.*—In the Protozoa the cell-body is so small that it holds together, as a rule, of its own viscosity. Yet even here, in those groups in which the protoplasm is most foamy and watery, we find a skeleton or supporting framework developed which gives rigidity and form to the protoplasm itself. Sometimes, as in the sun-animalcules (*Heliozoa*), this skeleton attains great complexity. In some groups of Protozoa it is composed of silica, in others, of lime. In the corals, the soft "polyps" secrete so much skeleton that the animal portion becomes but a fraction of the whole. In the sponges the skeleton is made up of innumerable needles or spicules of lime or silica. In one group of sponges the skeleton is composed of a network of tough fibers of peculiar composition. When the protoplasmic portion of the sponge has been soaked out, this skeleton forms the "bath-sponge" of commerce.

In the larger animals the weight of the body would make it impossible for a constant form to be maintained were it not for the fact that there exists an internal framework or scaffolding to which the softer parts are attached. In the vertebrates this is usually made up of mineral elements, the bones, although in some of the lower fishes the skeleton is composed of cartilage (gristle) instead of bone. This bony framework may be divided into two systems, one underlying the central nervous system and hence constituting the longitudinal axis of the animal (axial skeleton), and the other giving support and rigidity to the limbs (appendicular skeleton). In addition, the brain and connected sense organs are surrounded and protected by an enveloping *skull*, to which is attached the bony framework of the jaws. The axial skeleton is divided into segments called vertebræ which provide the proper balance between flexibility

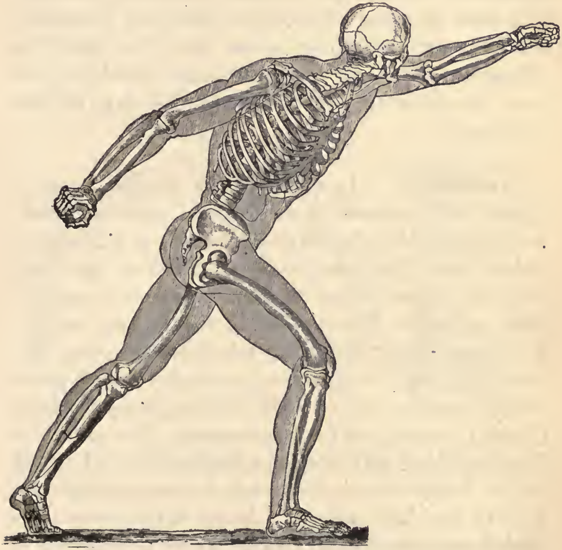

FIG. 40. — Endoskeleton of man. — (From Coleman.)

and rigidity. In development, this " backbone " is preceded by an unjointed rod of cartilage called the *notochord*, which is ultimately replaced by the vertebræ. The very lowest types, however, do not develop any other axial skeleton than the notochord. The great group of animals possessing this structure, either in the embryo or in the adult, is called the *Chordata*. Thus, all vertebrates are chordates, but some chordates are not vertebrates (*i.e.* have no true backbone).

Exoskeleton. — In many of the simpler forms of animal life, instead of an internal skeletal framework upon which the softer parts are suspended, there is developed a thick and hard external skeleton, which not only supports the internal organs, but protects them as well. Particularly in the insects and the Crustacea (crabs and their relatives) the outer skin secretes a very tough, hard substance called *chitin* which forms a sort of shell, jointed at appropriate places to permit of free movement. The animal is thus provided with a semipermanent suit of armor which, being non-elastic, must be shed periodically to permit of body growth. Many of the vertebrates that do not require an exoskeleton for the purpose of body support are provided with such skeletal structures for protection. Thus the scales of fishes and snakes are a sort of very flexible coat of mail, and the feathers of birds and thick hair of wild animals belong to the same category. In the turtles the development of protective armor has gone on to such an extent that the whole body is inclosed in a heavy bony box. In the mollusks (shellfish, snails, etc.) this sort of protective structure has taken a different line of development through the formation of a calcareous shell. This is often complex in its structure, and composed of several layers. It is usually developed to such an extent that the weight of mineral covering reduces the free movement of the animal to a minimum.

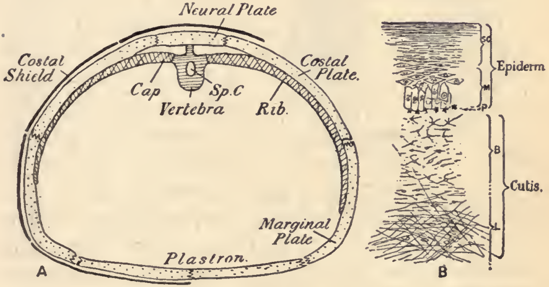

FIG. 41. — Diagrammatic transverse section through the shell of the tortoise. On the right side the bony shields have been removed. The endoskeleton is cross-lined, the exoskeleton is dotted. *Sp.C*, spinal chord; *Cap*, head of rib. — (From Gadow.)

Muscular System. — The tissues involved in locomotion and other movements act by their power of contraction. In order to bring about orderly movements they must be attached to rigid supports. In the vertebrates, these are the bones of the skeleton, to which the muscles are firmly attached. The bones themselves are covered with a tough skin of connective tissue, the periosteum. This is continuous with a dense inelastic tendon that spreads over and permeates the muscle bundles, forming the perimysium. Muscle and bone are thus most intimately bound together into a unit. In invertebrates with a chitinous exoskeleton the muscles are usually attached to the hard shell or to internal plates that arise from the shell. In forms like the worms, in which the whole body contracts strongly, the muscles are to be found in sheets, usually running in different directions, and exerting a reciprocal action on one another. In the very lowest and simplest forms they occur as isolated fibers. In such cases they represent the first step in the specialization of the contractile function common to all protoplasm.

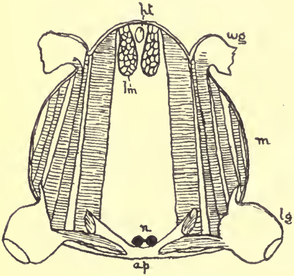

FIG. 42. — Diagrammatic cross-section through the thorax of an insect, showing the nature of the musculature and the manner of the insertion of the muscles to the exoskeleton: *ht*, heart; *n*, nerve cord; *wg*, root of wing; *lg*, root of leg; *ap*, apodeme or chitinous brace; *lm*, longitudinal muscles of the "back"; *m*, dorso-ventral muscles operating wings and legs. — (After Graber.)

Circulatory Systems. — In most of the lower animals, particularly those protected by a tough or a hard outer covering, the tissues of the interior are very soft and loosely held together. The organs are, as it were, awash in the body fluids. The alimentary canal occupies a relatively large part of the interior space, and, in consequence, the digested food is absorbed and passed on by diffusion to all parts of the body. Likewise the waste-products of metabolism find their way without difficulty to the special organs that provide for their elimination. In the larger animals, and particularly in those with relatively solid tissues, with a great development of muscles and an alimentary canal of small dimensions compared with the whole body cavity, it would be impossible for the digested food to find its way to the places where it is most needed, particularly to the skeletal muscles. Appropriate to the need for transporting such substances long distances from the alimentary canal and also of transporting the metabolic waste-products from the seat of their production to the excretory organs, there is a system of tubes, the circulatory system, which performs the same function carried out by a railroad system in a thickly settled community; that is, it transports substances from the region where they are produced to the region where they are utilized. The medium of transportation in the case of the organism is the blood. Thus, not only is the digested food carried from the intestine to the tissues which are to be fed, or to organs that serve as storehouses, but the oxygen taken in in respiration is supplied to all the tissues, the various hormones are transported from one place to another, and the waste products of katabolism are drained off to the excretory organs by the same route. Such a system in its most elementary form may be found in the insects. Here it consists of a simple dorsal tube open at both ends, which by its alternate contractions and expansions keeps the body fluids "stirred up" and provides for an indefinite circulation of substances. In the sides of the tube are mouthlike apertures provided with valves, called ostia. Through these the body fluids can enter when the tube expands, but, owing to the valves, they can leave only through the open ends. The necessity for a complicated set of blood tubes in these animals is obviated by the develop-

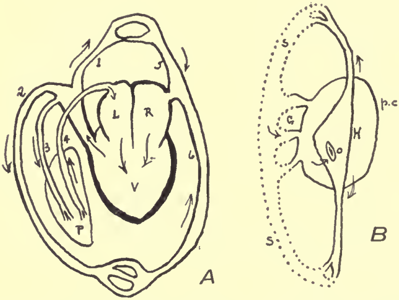

Fig. 43. — Diagrams of the circulation of the frog (*A*) and of the lobster (*B*), the former illustrating a closed system, the second, an "open" system: *L*, left auricle; *R*, right auricle; *V*, ventricle; *1*, arterial branch to the head; *2*, arterial branch to the rest of the body; *3*, arterial branch to the lung (*P*); *4*, pulmonary vein returning aerated blood from the lung to the left auricle; *5* and *6*, venous trunks returning blood from the head and body to the right auricle; *H*, heart sending out arterial blood both to the anterior and to the posterior part of the body; *s*, sinuses, in which the blood accumulates to be returned through the gills (*G*) to the pericardial chamber (*p.c.*), whence it finds its way to the interior of the heart through the ostia (*o*).

ment of a remarkable system of air-tubes, the trachea, which open to the exterior and, permeating the insect body in every direction, permit a direct supply of atmospheric oxygen to get to all the tissues.

The lobster presents a next higher step in differentiation and specialization. Instead of the elongate dorsal tube there is a boxlike heart, likewise provided with ostia, but opening also into a number of blood tubes (arteries) that carry the blood away from the heart. These arteries divide and subdivide until finally they empty their contents into the open spaces between the muscles and other organs, called sinuses. From these spaces the blood seeps back and, after traversing the gills, reënters the heart through the ostia. Thus a circuit is completed, definite through part of its extent and indefinite through the rest. In vertebrates the blood not only leaves the heart by way of arteries, but is returned to it by another system of tubes called veins, the two systems being connected by much finer vessels called capillaries. Thus the entire circuit is completed within definite channels. Such a system is called a " closed " system in contrast to the " open " system of the lobster.

Excretory Organs. — The waste-products mentioned above are not only of no use to the organism, but, on the other hand, in most cases, are active poisons, whose ill effects are evident if they be ever so slightly concentrated. It is of the highest importance to the animal that these substances be eliminated as soon after their formation as possible. Even in the least differentiated of the Protozoa special

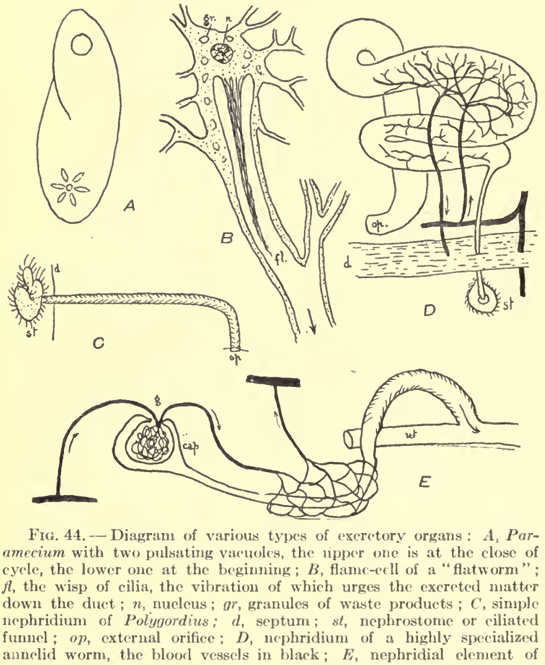

Fig. 44. — Diagram of various types of excretory organs: *A*, *Paramecium* with two pulsating vacuoles, the upper one is at the close of cycle, the lower one at the beginning; *B*, flame-cell of a "flatworm"; *fl*, the wisp of cilia, the vibration of which urges the excreted matter down the duct; *n*, nucleus; *gr*, granules of waste products; *C*, simple nephridium of *Polygordius;* *d*, septum; *st*, nephrostome or ciliated funnel; *op*, external orifice; *D*, nephridium of a highly specialized annelid worm, the blood vessels in black; *E*, nephridial element of vertebrate kidney; *g*, glomerulus; *cap*, capsule of urinary tubule ciliated in its lower portion, blood-vessels in black.

structures are found which provide for such elimination. In such organisms there is usually a spot on the outer margin of the cell-body toward which the dissolved " waste-products " concentrate. These form a gradually enlarging bubble which finally ruptures and squeezes its contents out through the cell-wall to the exterior. In most Protozoa this excretory function is definitely localized, and the formation and extrusion of the excreted drop of fluid follows a regular rhythm. Such an organ is called a " contractile vacuole." With the enlargement of the body and the multiplication of the cellular units composing it, it becomes impossible for such excreta to find their way to any particular spot, or even to diffuse through the tissues with sufficient rapidity to prevent the ill effects mentioned above (" intoxication "). Definite channels are found in most Metazoa through which these products pass. In the tapeworm and its allies these tubes are very delicate and permeate the body in all directions, opening to the exterior in pores. Each tube is thought to be the differentiation of a single cell and each terminates (or rather, more accurately, originates) in a so-called " flame-cell." This cell has a wisp of cilia projecting into the cavity of the tube, by the flickering movement of which, suggestive of a candle flame, the absorbed fluids are urged down the tube and ultimately to the exterior.

In the great group of the Annelids, of which the earthworm is the most familiar example, the body is composed of a great number of segments arranged like a row of pill-boxes strung on a tube, the tube being the alimentary canal. Each segment, although a component part of a single organism, has a certain structural individuality of its own, and is separated from its neighbors on either side by a partition wall, the septum. The inclosed space, the " body-cavity," is filled with a watery fluid and is lined with a network of blood-vessels through whose walls the circulating waste-products transfuse into this fluid. In each segment there is found an open-mouthed, trumpet-shaped tube, fringed with strong cilia, which passes through the septum into the cavity of the segment just behind, and after a more or less convoluted course opens directly through the body-wall of that segment to the exterior. The action of the cilia creates a current in the fluid which passes down the tube, and drains off to the exterior the liquid contents of the body-cavity, laden with wastes. Such an excretory apparatus is of very widespread occurrence in various groups of animals and is called a *nephridium* (plural, nephridia).

Such a nephridium is found only in the most simply organized annelids. In the higher annelids we find the mechanism much improved by the elimination of unnecessary steps and the securing of greater economy of energy and increased efficiency. Thus in the earthworm, branches of the blood-vessels surround portions of the nephridial tube, and the major portion of the excreted substances transfuse directly through the walls of the blood-vessels into the cavity of the nephridium, instead of transfusing first into the body-cavity The ciliated funnel in such a case may become almost (though not entirely) functionless. This is much the same improvement that would be effected in the transport of grain to ships if, instead of unloading the sacks of wheat from the cars to the dock and then again to the ship, an arrangement were made whereby the grain could be poured directly from the cars into the hold.

In the vertebrates a comparable relation of blood system and excretory tubules is found. Instead of being distributed throughout the body, these tubules are concentrated into a single organ, the kidney; the blood-vessels supplying the kidney develop tiny knots of capillaries called glomeruli (Latin, *glomerulus*, " little ball "), which afford a very large surface in a small space and thus permit the diffusion of the maximum of waste substances in a minimum of time. In the higher vertebrates there is no trace of the openings of these tubules into the body-cavity. In lower forms, however, such as the frog, they may be observed on the surface of the kidney although they are functionless.

II. Differentiation in Plants

Plants differ strikingly from animals in the emphasis which evolution has laid upon various functions common to both. Animals are, for the most part, actively moving creatures, seeking food in various places, and consequently endowed with elaborate systems of differentiated protoplasm in the form of muscles and sense-organs. In plants, on the other hand, the assimilative (" vegetative ") function is predominant, and the manifold differentiations which we find are nearly all in the line of structures for elaborating, taking up, and storing foods, and of supporting the plant-body (omitting, of course, all consideration of the reproductive function, which will be discussed in a later chapter).

Accordingly, we find little trace of nervous system or muscular system. Yet some plants, like the Mimosa or sensitive plant, react to stimuli with a definiteness that is comparable to a nervous reflex in animals. The leaf of the "Venus' flytrap," when an unwary insect touches it, springs shut with such suddenness and vigor as to catch the prey and hold it fast. This action is brought about by three sensitive spines which may therefore be held to be analogous to animal sense-organs. A number of plants have the habit of folding their leaves at night, in "sleep," the stimulation being the change from daylight to darkness. Moreover stimuli are transmitted (usually slowly, to be sure) from one portion of the plant to another. Plant tissues may be anesthetized, and when stimulated, they show "fatigue." We may conclude, therefore, that although the basis of the mechanism may be entirely different from that of animals, yet, in so far as the plant tissue is differentiated sufficiently to receive stimuli from without and transmit them to other parts of the plant-body, there to bring about an appropriate response, it may be asserted that plants possess a rudimentary nervous system. They differ from most animals in lacking any sort of a coördinating or central nervous system; that is, the impulse is conveyed directly from a more or less diffusely sensitive area to the tissue which reacts.

Plant Movement. — We ordinarily think of plants as rooted fast in the ground. Nevertheless, apart from the lower forms, mostly unicellular, which move as do many Protozoa by means of the lashing of flagella, a little observation will show that most plants execute movements differing in intensity from the sharp folding of the leaflets of the sensitive plant to the gradual circling of the sunflower head as it follows the sun from east to west during the day, or the twisting of the climbing tendril. No such specialized tissue as muscle is to be found in plants, but all such movements are to be attributed to changes in the water content of masses of spongy tissue, such that when the cells are full of water, the resistance of the walls, or *turgor* of the tissue, makes it stiff and erect, whereas the withdrawal of the water from the tissues causes the leaves or other parts to become flaccid or droop. A difference in the amount of turgor on opposite sides of the stem will thus cause the stem to bend to one side or the other according to which side is under the greater tension. Sudden movements are brought about by rapid alterations in the turgor in localized areas under the influence of external stimuli.

Supporting Structures. — In animals, as we have seen, the skeleton consists of a framework, either external or internal, to which the softer tissues are attached or by which they are inclosed. This skeleton, whether of chitin, or bone, or merely of connective tissue, owes its rigidity to the deposit among the living cells of a non-living intercellular substance; the cells themselves have very thin walls. In plants, on the other hand, we find that the intercellular substance is laid down in the form of dense cell-walls of the cells themselves, and that nearly the whole tissue of the stem or root is in one sense skeleton. This intercellular substance is a complex carbohydrate called cellulose, or a derivative of cellulose, lignin, and although it forms the cell-walls it is, of course, not living substance itself, any more than the plates of lime in bone. Not all the cells are uniformly developed in this manner. In most plant tissues there has arisen a differentiation of the supporting or "mechanical" tissue which frequently occurs in bundles or strands of fibers, constituting a sort of internal skeleton. Hemp and flax are abundantly supplied with these fibers, which provide us with linen, hempen cord, etc. On the outside of roots and stems, particularly of the larger plants (trees), the cell-walls become enormously thickened, with an accompanying diminution of the protoplasmic substance, to form bark or cork. The cork is impervious to water and may be compared with a secreted exoskeleton, like chitin, which protects the softer living portion beneath. In trees the whole central part of the stem is composed of solid supporting tissue (wood), the living portion of

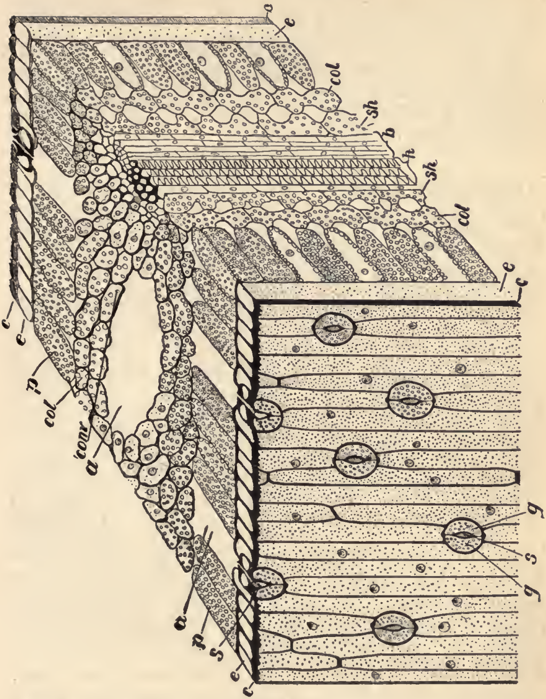

FIG. 45. — Stereogram of the leaf of an *Iris:* *e*, epidermis; *c*, cuticle; *p*, palisade cells filled with chlorophyll-bodies; *col*, collecting cells; *conv*, conveying cells which assist in the transfer of the synthesized sugars from their place of origin to the veins; *sh*, conducting sheath of vein; *h*, wood of vein; *b*, bast or woody fibrous portion of vein; *a*, air-space; *s*, stoma; *g*, guard cells. — (Osterhout.)

the trunk being confined to the comparatively narrow layer between this and the bark.

In the leaves the skeleton assumes the form of branching " ribs " or " veins." In some groups, *e.g.* the grasses, these are single and unbranched; in others they form a network.

Circulatory System. — In plants, as in animals, in those species which are of such a size that substances do not diffuse readily through their tissues, there is a system of tubes which permit the circulation of liquids from one place to another. The movement of the circulating liquids is due to mechanical agencies external to the protoplasm. There is, of course, nothing corresponding to a heart. The tubes, which are of various sorts and positions, often occur in bundles. They are formed by the coalescence of cells, end to end, and the subsequent dying out of the living contents. The prime factor in causing the ascent of water in the plant tissue is the " transpiration " or evaporation of water from the leaves. Just how this operates is still a complicated and unsolved problem. A result of such movements of liquid is the transportation of food substances to various portions of the plant-body.

Alimentary System. — Algæ derive their food from the surrounding medium, and their tissues are correspondingly soft and permeable. There is for this reason no localized area for the alimentary processes. In land plants, on the other hand, there is a twofold source of food, the soil and the air. The plant can take in food from the soil only in solution, and such dissolved substances can transfuse only through very thin cell-walls. Accordingly the roots of such plants are covered with delicate threadlike processes called root-hairs, each of which is composed of a single thin-walled cell and is, indeed, merely an extension of a cell of the skin of the rootlet itself. These root-hairs are quite short-lived and are to be found therefore only in the youngest root-branches. The organs for taking in food from the air are the green leaves. The upper and lower surfaces of the leaf are usually made up of rather stiff cells, forming a cuticle, in which are found numerous mouthlike openings between the cells, called stomata, that lead to air-spaces within the leaf. The body of the leaf is made up of numerous irregular or elongate cells, loosely packed together, and crowded with green chloroplasts or chlorophyll bodies, the means whereby the carbon dioxide of the air is fixed and converted into carbohydrate (see Chapter II).

The substances taken in through the roots, and the sugars and starches formed in the leaves, are distributed throughout the plant-body by means of the circulatory system mentioned above. In lower plants with relatively undifferentiated tissues such a distribution of substances must take place by direct transfusion through the cell-walls themselves. As in animals, however, food is not taken in continuously in higher plants, at least not in the leaves. The formation of sugar depends upon sunlight, and ceases, of course, at night. During the day the sugar is usually converted into starch and stored up in the leaves as such. During the night, however, this excess is converted again into sugar and carried away to nourish the plant elsewhere. As in animals, various parts of the plant may serve as storehouses. Accumulations of food are usually found in seeds, where their presence is of manifest advantage to the developing plant. Under the influence of certain fungi the underground stems of certain plants (*e.g.* the potato) thicken up and accumulate starch. Such accumulations of "reserve" food may not always be starch. They may be sugar (sugar beet) or fat (cotton seed).

Some plants, including the whole group of fungi (molds, etc.), draw their food supply from other plants or animals. As they get their food at second-hand, already elaborated, they lack or have lost the special structures by means of which other plants manufacture their own food.

CHAPTER VI

ONTOGENESIS

There is no reason, *à priori*, why the individual plant or animal, barring accident, should not live forever. We can conceive of a perfectly balanced metabolism in which the up-building or tissue-repairing process would exactly balance the disruptive or tearing-down process. As a matter of fact we know of no form, even among the simplest, of which this is true. In all, katabolism after a certain time tends to exceed anabolism. In spite of Nature's wonderful recuperative powers, the living organism, like a machine, tends to wear out, and after a brief period is fit only for the scrap-heap.

Competition, the "struggle for existence," is severe among different species, and a species that is able to replace frequently its worn-out members with vigorous new individuals would maintain its level of efficiency, so to speak, at the highest point. Moreover, where numbers count so heavily, the species that might be able to replace each worn-out veteran with a hundred or a thousand new recruits, would have a corresponding advantage over one that could not do so.

Whether or not some such conditions as these may have been the cause, they indicate, at any rate, an advantage to the species of the phenomenon of reproduction, — the replacement of individuals by others from the same stock. Each individual passes through a cycle of birth, youth, maturity, senility, and dissolution, but before the final stages are reached, it normally produces other individuals to take its place.

Biogenesis. — This phenomenon clearly implies a continual stream of life, in which individual succeeds individual like waves on the ocean. The physical connection of the individual with its ancestry is thus obvious. An aphorism of a century ago expresses it, — "*Omne vivum ex vivo*," "all life from [pre-existing] life." But a contrary view was also held until very recent times, viz. that living organisms may arise from non-living matter. This conception, which has been called spontaneous generation or abiogenesis, arose from incomplete or misinterpreted observation. Thus it is a matter of everyday observation that maggots develop in rotting meat. Whence do they come, if not from the meat itself? A generation less well trained in the methods of exact research found no difficulty in accepting just such an hypothesis, but an ingenious Italian, Redi, showed that if the meat be covered with gauze so as to keep out the blow-flies, no maggots ever develop, since these are produced, not from the meat, but only from the eggs which the fly lays on the meat. In brief, it has been conclusively shown, in every instance, that no living forms are to be found to-day, except such as have arisen from preëxisting individuals of the same species.[1]

Individuals give rise to other individuals either by simply cutting in two to form two half-organisms, each of which reorganizes its tissue so as to complete itself to the specific type, or by budding off a small portion of itself, which grows and differentiates to a form similar to its parent, or, finally, by budding off a single cell, which grows and differentiates into an individual like its parent.

Reproduction as a Growth Process. — It was pointed out in a previous chapter that, in most cases, cell division is a consequence of cell growth or "cumulative integration" and, in fact, may be considered as a phase of the growth phenomenon, discontinuous instead of continuous. The result is to increase the mass of a tissue without differentiation, and without the alteration of the size-relations of its components, the cells. In the case of free-living one-celled organisms, cell division results from the same cause, — with the difference that the newly formed cell units are free individuals instead of elements of a mass. This is, however, a distinction without any real difference. On the other hand, certain unicellular organisms, after fission, remain

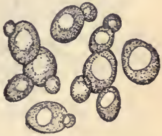

FIG. 46. — Yeast plants, illustrating simple budding. — (Bailey.)

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[1] Or in rare cases as mutants from closely related species. See next chapter.

attached to one another in chains or masses. Such a mass might justly be called a tissue, except that it is convenient to restrict the use of that term to a cell-mass which, in turn, is a part of a still more highly organized complex. In certain Algæ this connection of cells with one another is transitory and indefinite. In some forms, however, the connection is permanent, and the mass consists of a definite number of cells. In such a case we speak of the cell group as a *colony*. The combination of individuals in a colony is not only found in the *Protista*, but in many of the higher groups as well, particularly in such forms as are fixed to one spot (sea squirts, cœlenterates, sponges, and most plants).

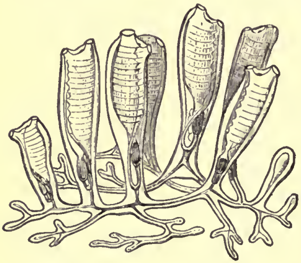

FIG. 47. — Budding in an animal (*Clavelina*). The individual organisms develop from an outgrowth of the body-wall analogous to a plant rootstalk. Natural size. — (Herdman.)

Fission in Metazoa. — Not only in the Protista, but in metazoa also, are found examples of reproduction by fission. In *Ctenodrilus*, one of the lower Annelids, the worm cuts in two by transverse fission much as an elongated protozoan. The separate portions of the original body then become transformed into complete individuals by a shifting and readjustment of the original tissues, some of which become modified to wholly different uses to what they served before.

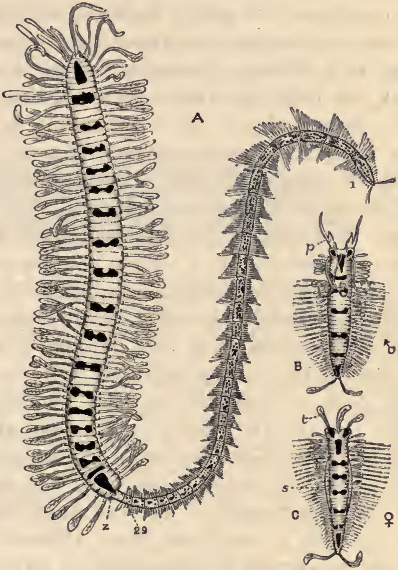

Fig. 48. — Vegetative reproduction (terminal budding) in an Annelid worm, *Myrianida: A*, an asexual individual which has produced by budding from a zone (*z*) a chain of twenty-nine zooids, the oldest being labelled *1*, the youngest *29; B*, a ripe male zooid; *C*, a ripe female zooid. — (Malaquin.)

In Myrianida, another worm of the same class, the divisions follow each other so rapidly that one individual is not budded off before another constriction becomes visible, and the result is a chain of individuals in various stages of differentiation.

It is evident that if, instead of separating from the parent organism, the newly formed " sub-individuals " remain attached, we would have a resultant organism of a different character, compounded, so to speak, of individual units held together by a sort of common bond. It is supposed by some that the segmental structure more or less evident in nearly all the animal kingdom came about originally through some such suppressed fission. Just as we have seen that whereas the stress of growth and the necessity for maintaining a certain relation between nucleus and cytoplasm results usually in the cleavage of the cell, but on the other hand results sometimes in the suppression of this cleavage through a distribution of the nuclear substance to form multinucleate cells or syncytia, so also conditions of existence that in the beginning brought about a cleavage of the whole organism (schizogeny) also may have made it advantageous for the separate parts to remain together. We can trace different degrees in such a condition, from *Ctenodrilus*, in which the separation is immediate, or *Myrianida*, in which it is temporarily retarded, to the tapeworm, in which the segments are permanently attached together to form a " segmented body." In the tape-worm, however, the segments at the posterior end may drop off without losing such vital functions as they are endowed with, and the number of segments in the body apparently has no influence on or relation to the individuality of the organism. In the higher animals this primitive segmentation has become overshadowed by the unity of the whole, so that no segment could be sacrificed without destroying the individual. This type of bodily structure is called metameric segmentation, and is the fundamental plan in nearly all the animal phyla,[1] from the generalized Annelids, in which the segments bear to the body somewhat the same relation that the individual cars do to a vestibuled train, to the higher vertebrates, in which the segmental feature is plainly evident only in the developmental stages.

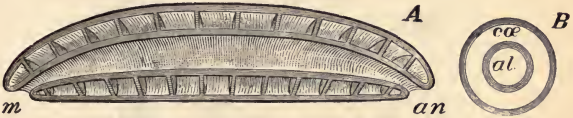

FIG. 49. — Diagram of metameric segmentation (as of the earthworm): *A*, longitudinal section of the body showing the alimentary canal and cœlom divided by septa; *B*, cross-section; *coe*, cœlom; *al*, alimentary canal; *m*, mouth; *an*, anus. — (From Sedgwick and Wilson.)

Fission in Lower Plants. — In the important group of the Bacteria, multiplication takes place exclusively by fission. In the spherical type (*Coccus*) the planes of division may be repeatedly

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[1] The exceptions are the higher Mollusca, Flatworms, Cœlenterates, and Sponges.

transverse, producing strings or chains of cells (*Streptococci*), or they may be alternatingly in two vertical planes, producing groups of four, or, finally, the planes of division may occur in the three dimensions of space, producing groups of eight (*Sarcina*) in a cubical aggregate.

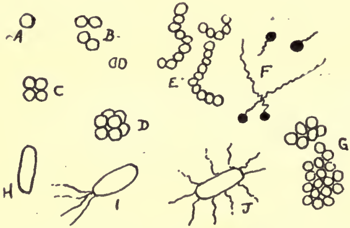

FIG. 50. — Types of Bacteria, illustrating various modes of fission: *A*, simple *coccus* form; *B*, *diplococcus* (fission in one plane only, the pair separating as formed; *E*, chain form (*streptococcus*), the fission all in one plane, but the cells remaining together; *C*, division in fours (tetrads) in one plane; *D*, division in three planes to produce cubes or bale-like masses (*sarcina*); *G*, division planes at random, to produce masses (*staphylococcus*); *F*, flagellated *cocci* (nitrogen-fixing bacteria of the soil); *H*, rod-form (*bacillus*); *I*, *bacillus* with flagella at one end (putrefactive bacteria); *J*, with flagella all over the cell body (typhoid *bacillus*).

Budding. — From reproduction by fission of the parent body, to reproduction by cutting off of a small portion of the body, is a short step. In the latter case the individual identity of the parent organism is unaffected, and the part budded off develops into the specific type by individual growth and differentiation. Such a process of reproduction is known as gemmation or budding and is well-nigh universal in the plant kingdom as well as in those animal types that have a plantlike habit, such as the sponges, cœlenterates, and tunicates. Familiar examples are the "runners" of strawberries, the "shoots" of willows and other trees, the tubers of potatoes, etc. The most primitive condition in plants was doubtless that of a plant-body (*thallus*), dying or drying up in the middle, and leaving two

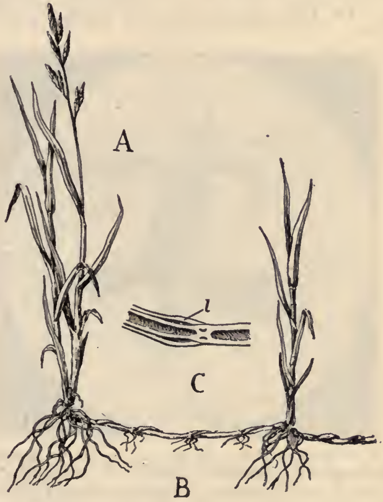

FIG. 51. — Habit of growth of a grass: *A*, aerial stem terminating in a branched inflorescence; *B*, underground stem or rhizome sending up a new shoot from one of the nodes; *C*, section through the node of a stem that has been placed horizontal, showing the sheathing leaf base, *l*, and the beginning of the upward curvature of the stem. — (From Curtis.)

or more vigorous extremities to pursue an individual existence. The development of runners and shoots is a special modification of the same process.

In the animal realm, one of the simplest examples of budding is found in the common fresh-water Hydra. In this form, the interstitial cells at a certain point begin to increase in numbers, and form a knoblike protrusion on the side of the hydra-body. By a shifting and rearrangement of the cells composing this lump, a cavity forms, in direct communication with the inner cavity of the Hydra. This bud grows until it attains a considerable size, when the cells at the extremity begin to differentiate into ten-

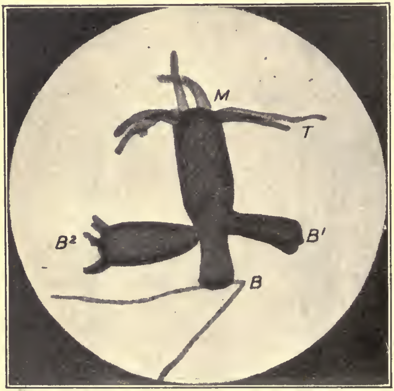

FIG. 52. — Budding *Hydra*, as seen under the low power of a compound microscope: *B*, attached end; B^1, B^2, buds; *M*, mouth; *T*, tentacles. — (From Hunter's Elements of Biology: American Book Co.)

tacles, a mouth opens, and the bud becomes in all respects an individual Hydra, able to carry on all the functions of life. The process is completed by a severing of the connection between bud and parent.

Permanent Budding. — In the majority of the marine relatives of the Hydra the buds formed in this way do not separate from the parent stem, but remain attached, forming colonies of many individuals. Such a condition of *persistent* budding is characteristic of plants, but occurs as well in many Protozoa. In some instances the buds run together in such a fashion that it is impossible to discriminate one individual from another. In *Syllis* we have a highly organized worm that divides and subdivides, like the branches of a tree, while individual heads develop here and there.

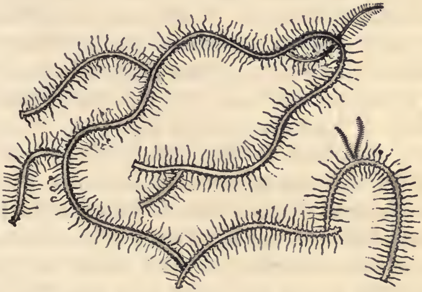

FIG. 53. — Portion of *Syllis ramosa*, an annelid worm in which the collateral buds branch repeatedly. — (M'Intosh.)

Spore-formation. — In many types of Protista a modification of reproduction by fission is found, which is especially advantageous in certain conditions of existence. After repeated divisions of individuals in a free state, the organism may surround itself with a thick wall, forming a *cyst* within which the protoplasm fragments into a multitude of minute particles called *spores*, each of which has the potentiality of developing into an individual like that which formed the cyst. In this way a species may tide over a critical period, as of drouth, in such an encysted condition. When favorable conditions again intervene (perhaps after several years), the multitude of emerging spores insure the immediate existence of a large number of individuals, and thus reduce the chances of extermination for the race In the bacteria, under certain conditions, the protoplasm of the tiny cell condenses into one or more spores, which, on account of their minute size, may be blown about in the dust, and thus afford the most effective means for the dispersal of the species. Propagation by spores is, indeed, a feature of development throughout the plant kingdom.

Plants are adapted in large measure to what we call a "vegetative" existence; that is, with the exception of the Protophyta, most of which are motile, they are fixed in the place where they sprout and cannot seek food elsewhere if it fails, or avoid extremes of climate by migrating. This disadvantage is compensated by the production of spores, which are frequently developed in enormous number and, being scattered by various agencies far and wide, bring about an extensive distribution of the species.

The method of propagation just outlined, whether by spores or by buds, by simple or multiple fission, is termed vegetative or asexual reproduction. We may define it as the cutting off from an organism of a single mass of protoplasm (of one or many cells) which independently differentiates into an organism resembling its parent. The greatest diversity in vegetative reproduction is to be observed in the various groups of animals and plants, but in every case it can be explained as a special form of the growth process.

Sexual Reproduction

In nearly all forms of organic life, reproduction is complicated by an accompanying phenomenon, the meaning of which is not at all clear. In the bacteria and a few other Protista vegetative reproduction is the only sort known. In all others we find that, either accompanying the vegetative reproduction, or alternating with it, there occurs the production of certain reproductive cells (germ-cells) to which the name *gamete* is given. Two of these gametes fuse together, either completely or partially, and from the fused cell (called the zygote) a new individual develops, or, more accurately, the zygote transforms by growth and differentiation into a new individual. When the two cells fuse completely into one, in the formation of the zygote, the process is termed *hologamy*. When the fusion involves only the nucleus, it is called *karyogamy.* It is doubtful, however, if pure karyogamy ever takes place. The total fusion of gametes, in turn, may be of various degrees of specialization, either between similar cells (isogamy) or between cells of different sizes (anisogamy), leading to the differentiation of sexually specialized cells (oögamy).

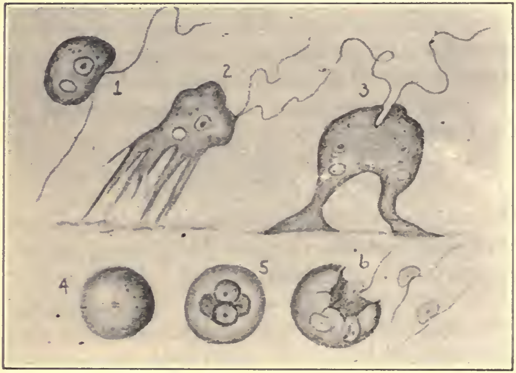

FIG. 54. — *Bodo lens: 1*, normal "monad"; *2*, same in the semi-amœboid condition preparatory to conjugation; *3*, two individuals in the process of coalescence; *4*, the resultant zygote; *5*, a zygote whose protoplasmic contents have divided into spores; *6*, young monads escaping from the sporocyst. — (After Kent.)

Total Conjugation. *Isogamy.* — Even in the "lowest" of the Protista, the generalized condition in which two similar adults conjugate to produce a zygote is very rare. In such a case, the entire organism functions as a gamete. One of the most primitive examples is *Bodo lens.* In this species, two free-swimming individuals (see fig. 54) come to a temporary resting position with one flagellum touching solid matter. They then sway toward each other, meet, and fuse into one. Their flagella disappear, and a thick covering or cyst is secreted about the fused mass. After a period of rest, the contained protoplasm fragments into a number of spores, or into individuals like the parents, which escape from the cyst as typical "monads" of a smaller size. Other *Bodos* show a certain difference in size between individuals of the same culture. Conjugation occurs apparently at random between these dissimilar individuals and between similar ones.

It is perhaps more usual for the fully developed microörganism, instead of fusing directly with another similar individual, to fragment into a number of minute, active, individuals called microgametes, which conjugate with one another. The latter procedure must be of advantage to the species, since on account of the much larger number of new individuals produced at one time, the race is not so likely to be exterminated.

One of the most primitive examples is *Stephanosphæra*, which consists of a colony of eight flagellate individuals (fig. 55) arranged in a plate within a gelatinous sphere of which they form the equator. In reproduction, each cell of the colony divides into sixteen or thirty-two smaller individuals (gametes), all of the same size, which break out of the gelatinous sphere, swim away, and conjugate, two by two, to form a zygote. Each zygote divides into four free individuals, each of which secretes a gelatinous sphere and by successive divisions gives rise to a new eight-celled colony.

Anisogamy. — A further advantage would accrue to the species that developed microgametes, in comparison with one that did not, in that the larger number of individuals so produced would be more active on account of their smaller size, and therefore,

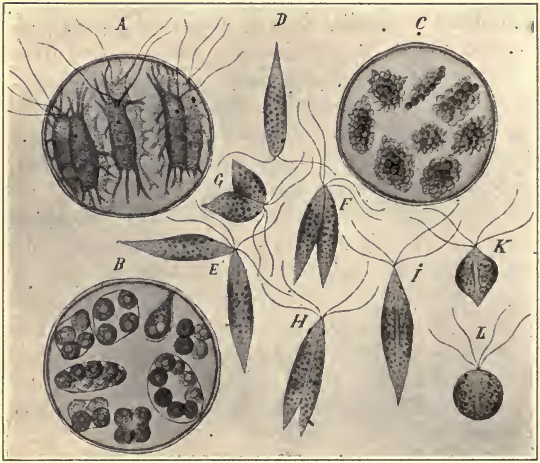

FIG. 55. — *Stephanosphæra*, a colonial flagellate which reproduces by isogamy: *A*, a mature 8-celled colony in equatorial view; *B*, a colony whose individuals by repeated divisions have formed daughter-colonies within the mother colony; *C*, a colony, whose individuals by repeated divisions have formed flagellated individuals that function as gametes; *D*, single gamete on a larger scale; *G* to *L*, stages in the process of conjugation. — (From Hertwig.)

because of their greater number, would have more chances for meeting and conjugating with one another, assuming, as is probably the case, that their meeting is purely accidental. But this sort of a specialization would also have its drawback, arising from the fact that the reduction in size of the microgamete also involves a reduction in the amount of reserve food material stored within the cell. The latter is an important consideration in tiding the zygote over the critical period of encystment, and on this account it is evident that in such a form as the *Bodo* just described the zygote arising from the accidental fusion of a larger gamete (megagamete) with a microgamete would stand a better chance of surviving and perpetuating the race than the zygote formed of two fused microgametes. As a matter of fact, we find that in the great majority of existing forms *zygosis* [1] occurs between dissimilar gametes, — a condition we have called anisogamy. The distinction is very likely more than that of mere size, and probably involves subtle differences in protoplasmic organization, but our conclusions in that regard are wholly inferential. Even in isogamy, the two conjugating gametes may be physiologically different; that is, the morphological difference may develop secondarily.

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[1] The partial or complete fusion of two gametes is more often referred to as "fertilization," but this word, which represents an archaic conception of development, is misleading. *Zygosis*, a word coined by Lankester to denote the fusion of the gametes to form the zygote, is preferable because it describes the phenomenon without interpreting it.

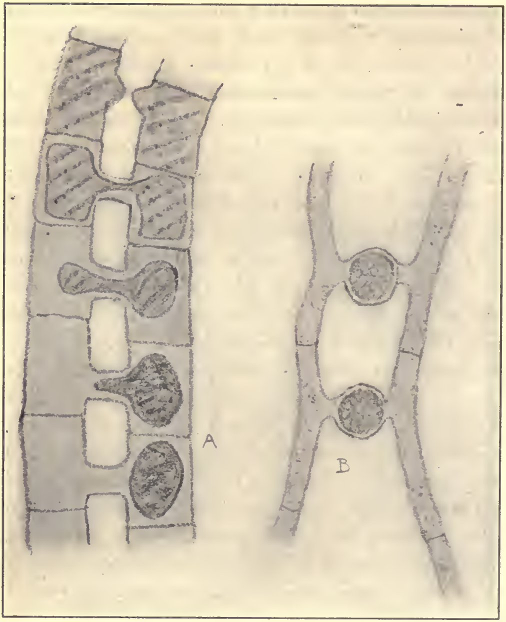

Fig. 56. — Conjugation of two strands of *Spirogyra*. The upper cells are just forming the conjugating tube. This has been established in the next couple of cells. In the next two pairs of cells the cell-protoplasm is passing over from one strand to the other. In the lowermost cell this process has been completed, and the cell-contents have fused into a zygote, which secretes a thick wall about itself and becomes a resting spore.

Fig. 57. — Conjugation of *Mougeotia*. In this form the cell-contents fuse midway between the two conjugating strands.

The difference between the gametes may be of varying degrees. In *Spirogyra,* in which the long filaments approximate one another, and the contents of the cell of the one strand flow out into those of the other, forming a chain of zygotes (fig. 56), the condition is almost that of isogamy, the only difference between the gametes being that of relative passivity and activity. If the protoplasm of both strands flowed out and fused midway, we would have an example of pure isogamy. Such a condition is found in some species of a relative of *Spirogyra*, *Mougeotia*.

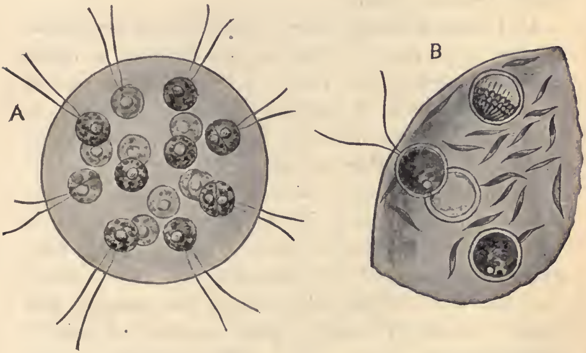

FIG. 58. — *Eudorina: A*, a mature colony (from nature); *B*, formation of the two kinds of reproductive cells.

Sexual Differentiation. — In *Eudorina* (fig. 58) we have a colony of sixteen to sixty-four flagellate cells, that, like *Stephanosphæra*, are imbedded in a gelatinous sphere which they secrete. There are, however, two kinds of these colonies from the standpoint of reproduction. In one kind, the cells divide into microgametes, in the other, megagametes[1] result from the taking up of reserve food by the individual cells of the colony. When two such differentiated colonies, in their aimless wanderings, bump into each other, they stick together, and the microgametes of one colony separate, penetrate the gelatinous envelope of the other, and fuse with the megagametes there. Each resultant zygote, after a resting period, divides into a sixteen- or thirty-two-cell colony.

In *Volvox*, a closely allied type, the differentiation of the two kinds of gametes has reached a much greater degree. The *Volvox* colony is composed of a great number of individual units (as many as 22,000), which are not only united by the gelatinous matrix in which they are immeshed, but by protoplasmic intercellular connections as well. In autumn, a score or more of these cells begin to grow by the accumulation of food reserves, until they exceed the size of an ordinary cell many times (see fig. 59). Other cells reverse the process and divide repeatedly, until a great number of minute microgametes result. The differentiation is not alone one of size. In proportion as the megagametes increase in bulk, they become immobile and lose the two flagella with which the other cells are provided; on the other hand, the cell-body of the microgametes is markedly attenuated, and their activity is correspondingly increased. The megagametes

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[1] *μέγας* = large; *μίκρος* = small.

do not begin to develop until the microgametes have matured and broken away from the colony, so that little or no opportunity is afforded for zygosis to occur between members of the same colony. The fusion of the passive megagamete and the active microgamete occurs within the colony of which

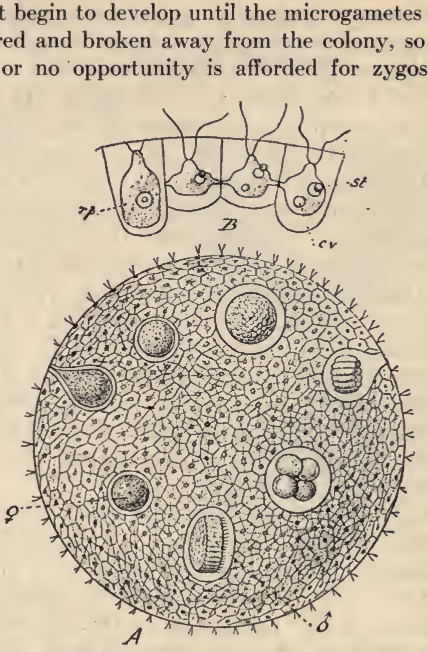

FIG. 59. — *Volvox globator*, a large colonial flagellate: *A*, a sexually ripe colony, showing microgametes (♂) and macrogametes (♀), in various stages of development; *B*, a portion of the edge of the colony highly magnified, showing three flagellate cells united by protoplasmic threads, and a single reproductive cell, *rp*; *st*, stigma or "eye-spot"; *cv*, contractile vacuole. — (From Bourne, after Kölliker.)

the former is a member, and the resulting zygote, becoming encysted, either develops directly into a "daughter-colony," or winters over in a cyst, to produce a new colony the next spring. In such a case, the multitude of the swimming cells composing the original colony perish. We see here a fundamental difference between a colony such as *Eudorina*, in which each member is capable of functioning as a gamete, and of reproducing the race, and *Volvox*, in which only a very few of the cells so function, and the great majority perish with each generation. This condition is an accompaniment to a form of specialization, in which certain cells of the organism become peculiarly adapted for the function of reproduction. When the specialization has gone on so far as is the case in *Volvox*, we usually speak of the large passive megagamete as an *egg*, and the tiny active microgamete as a *sperm*.

Those cells of the aggregate that exercise the reproductive function we speak of as *germ-cells*, in contrast to the *somatic cells*, which have lost this function. The differentiation has thus affected the character of the protoplasm in the two kinds of cells, one kind — the *germ-plasm*, in which the function of reproduction is especially developed, — is, from one point of view, immortal, whereas the *soma-plasm* dies with each generation and is renewed with each generation by growth from the germ-plasm.

Partial Conjugation

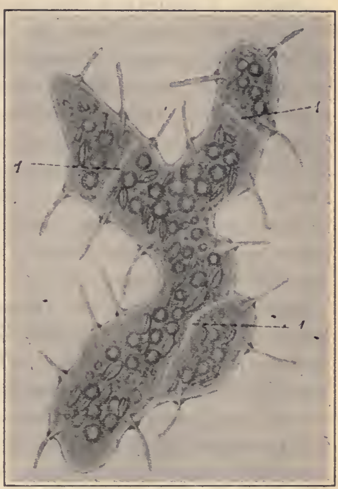

Fig. 60. — Plastogamy in a protozoan (*Trichosphærium*). In three places (marked with a *1*) the limiting boundary of the individuals is still intact. The form is multinucleate. — (From Lang, after Schaudinn.)

Cytoplasmic Conjugation (Plastogamy). — In certain cases (slime-molds, *Heliozoa, Rhizopoda*) two or more cells may come together, and the cytoplasm of the cells may fuse, while the nuclei retain their individuality. For this to occur, it appears necessary that the cytoplasm should be in a peculiarly labile and plastic condition, since instances have been observed and recorded of one *Amœba* swallowing another, and later egesting it with its individuality unimpaired, no such fusion having taken place. In many of the Flagellata (*cf. Bodo,* above) zygosis is preceded by an "amœboid" stage, which is undoubtedly correlated with a more viscid and plastic condition of the protoplasm. It is impossible that there should not be some interaction between the cytoplasm of two fusing individuals, even if the nuclei remain individually distinct.

Nuclear Conjugation (Karyogamy).—In the great majority of cases, however, both in plants and animals, the essential feature of zygosis appears to be the fusion of the nuclei of the two conjugating gametes. Just as it seems necessary for the cytoplasm to be in a peculiar physical (and doubtless also chemical) condition before plastogamy can take place, so also of the nucleus. But whereas the preliminary nuclear changes are perhaps more complicated and subtle than those of the cytoplasm, they are easier to observe.

In all the Metazoa and Metaphyta, specialization has progressed to the point of differentiation between somatic cells and germ-cells. The latter cells share with the former a common ancestry; that is to say, in any one individual they must have all descended from a single zygote. There is reason for believing, however, that the germ-plasm is differentiated from the soma-plasm at the beginning of individual development. It is therefore not a matter of indifference *which* cells become gametes. But since the individual itself must come to a point of *sexual maturity* before its gametes are able to continue the existence of the race by conjugating with other gametes, sexual maturity of the individual is coincident with the maturity of its gametes. In other words, in spite of the fact that the germ-plasm is a thing apart from the soma-plasm, its cells, like soma-cells, go through the stages of progressive specialization, characteristic of individual development (ontogeny). Of the physico-chemical changes involved in this specialization we have no inkling. The external and visible changes incident to its conclusion have been carefully studied, and to them is usually applied the term *maturation*. In animals, the process is practically the same, up to the final stage, in both sperm and ova. It may be roughly divided into three successive periods: a period of multiplication of individual pro-gametes (apparently without differentiation), followed by a period of growth, very much more extensive in the ovum than in the sperm, and lastly, a period of differentiation which is known as reduction. In many species the eggs are shed from the parental body at the conclusion of the second period. But before zygosis can occur, *reduction* must always take place. In this remarkable phenomenon the egg or sperm divides twice in rapid succession, by mitosis, — a mitosis, however, which differs markedly from all others known, in two particulars. In the first place, when the chromatin skein begins to condense and resolve itself into chromosomes, instead of the usual number of chromosomes there appear in the spindle of the maturing gamete but half as many as the normal number. These are often arranged in groups of four called tetrads. The elements of the

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[1] It is believed that the tetrad arises by a fusion of chromosomes in pairs (synapsis) and the subsequent splitting of the fused chromosomes,

tetrad behave as chromosomes in the subsequent stages of mitosis. Half of them are pulled to one pole of the spindle and half to the other, and the cell-wall that forms divides the maturing gamete (termed *spermatocyte*, in the male, or *oöcyte*, in the female) in two. The second peculiarity of the maturation mitoses arises from the fact that when these two daughter-cells (spermatocytes or oöcytes of the second order) divide again, they do so without the intervening " resting stage " which is elsewhere universal in indirect cell division. The chromatin units have already been segregated into two groups in the first division. They are immediately divided again into two groups, which separate in the two daughter-cells. Four daughter-cells thus result from the division of the first spermatocyte (or oöcyte), and, although the latter had, previously, twice the normal number of chromatin units, the number in each of the resulting four cells has been reduced to half the normal number on account of these two rapidly succeeding divisions. This reduction of the chromosomes is of much theoretical interest in connection with the subject of heredity. The process seems to be identical in both egg and sperm so far as the nucleus is concerned, but the difference in the behavior of the cytoplasm, in spermatocyte and oöcyte, is very marked. The two cleavages, in the case of the spermatocyte, result

longitudinally and transversely, to produce the four units of the tetrad. Accordingly, there are half as many tetrads but twice as many chromatin units as the normal number of chromosomes.

in the production of four cells of equal size, each of which metamorphoses into a sperm-cell characteristic of its species and capable of "fertilizing" an egg-cell. But in the oöcyte of the first order, whereas the cleavage of the nucleus is equal in each of the two daughter-cells formed, that of the cytoplasm is so unequal that one of the daughter-cells is but a fraction of the size of the other. In the second cleavage the same disparity is seen, so that, although as the result of the two successive cell divisions four cells result, one of these is very many times the bulk of the other three together. This larger cell is the one usually called the egg. The other three cells, which may be looked upon as abortive eggs, are called polar bodies because they usually remain attached for a time to the so-called animal pole of the egg-cell. They finally fall off and disintegrate. Like the sperm, the egg which has budded off its polar bodies has the reduced number (one half) of chromosomes.

NUCLEAR PHENOMENA OF ZYGOSIS IN ANIMALS

Conjugation. — The male gamete, or sperm, is, in most animals and in the lower aquatic plants, a highly specialized cell of minute size, equipped with one or more whiplike flagella that enable it to swim rapidly in a liquid medium. In the higher animals the shape of the sperm is often that of a miniature tadpole. The egg-cell, on the other hand, in most cases is spherical in form. It is enormously greater in volume than the sperm, its size depending upon the amount of reserve food-substance with which it is packed. In spite of the disparity in size of the two kinds of germ-cells, so far as the nucleus goes both cells are very much alike.

In animals, when a sperm-cell encounters an egg, it penetrates the outer surface and generally instigates some sort of a sudden change in the egg cytoplasm that prevents other sperms from entering. In some forms, however (*e.g.* birds), it seems to be the rule for a number of sperms to penetrate the egg. But only one of them functions in the process of zygosis. In most cases the tail is absorbed and the nucleus moves in toward the center of the egg-cell, while the egg-nucleus advances to meet it, impelled by some sort of " attraction " not yet understood. When the two nuclei, or " pronuclei " as they are called at this time, have met, they merge into one nucleus. The commingling of chromatin material is probably not a true fusion, inasmuch as the chromosomes into which the nucleus is resolved appear to maintain their individuality in subsequent cell divisions. From this fact it results that, since the pro-nucleus of each gamete, having undergone " reduction," has but half the number of chromosomes characteristic of the species, the nucleus of the zygote, composed as it is of the sum of two such pro-nuclei, has the normal number of chromosomes restored. In this way the chromosome number is maintained unchanged, from generation to generation. It must also be borne in mind that since every cell of the organism traces its origin

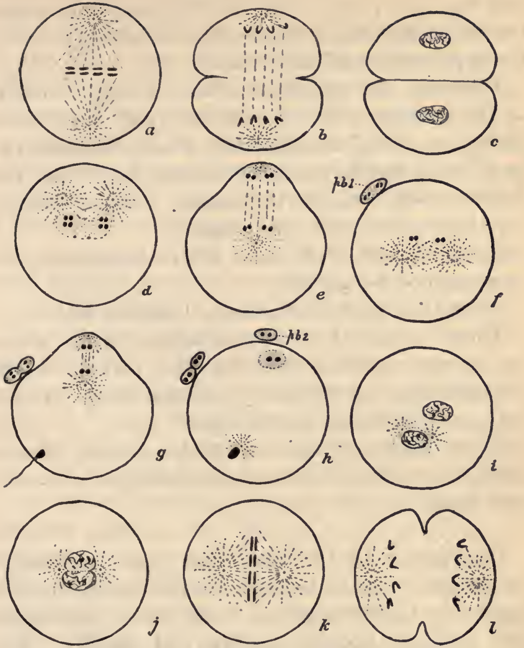

FIG. 61. — Diagrams illustrating the maturation, zygosis, and cleavage of an animal egg (somatic number of chromosomes, 4) · *a–c*, normal mitosis of oogonium; *d–e*, tetrads and formation of first polar body (*p. b 1*), in one of the cells of *c*; *f–h*, formation of second polar body, division of the first and entrance of sperm; *i–j*, fusion of egg and sperm nuclei, each with reduced number of chromosomes; *k–l*, first cleavage of zygote.

— its cell genealogy, so to speak — back to the unicellular zygote, and since the chromatin of the nucleus of the zygote is derived, half from one gamete and half from the other, every cell in the resultant organism shares this double nature, that is, half its chromatin is paternal, half maternal.

Following the formation of the cleavage nucleus, as the nucleus of the unicellular zygote is called, a series of rapidly accomplished transformations ensues, which molds the undifferentiated cell into the form characteristic of the species. These changes may be grouped into three stages:

First: A period of rapid cell multiplication unaccompanied by growth.

Second: A period of growth, together with —

Third: A period of differentiation, during which the tissues resulting from the first period become changed from a generalized condition to one involving specification or specialization.

These three periods cannot be sharply distinguished, one from another, particularly the second and third.

Cleavage. — In the first stage, just mentioned, the original zygote becomes subdivided again and again into a great number of cells, which, with each cell division, become smaller and smaller. The energy for these repeated mitoses is found in the reserve food material which is stored up in the egg-cell, even before its maturation. In such animals as have a very brief larval period, or in which the larva is self-supporting at a very early age, the amount of such reserve food, or "yolk," is much less than is required by a form which has a long period of development, as, for instance, a bird. In the latter case, the amount of reserve food is so great that it bulks far more than the protoplasm itself, and crowds the greater part of the living substance to one side of the cell. On the other hand some eggs contain so little food yolk that they are almost transparent, and what metaplasm there is is evenly distributed throughout the egg-cell. Such an egg is called isolecithal. In the eggs of many animals, even before cleavage begins, the protoplasm may be seen to be visibly differentiated in different regions which are destined to develop into various parts of the organism. There appears to be every gradation in the degree of such differentiation. In some cases there is apparently none at all. In others, different zones or strata may be seen. In many such eggs mutilation of certain parts of the egg-cell produces corresponding defects in the resultant organism, showing that the protoplasm was already specifically differentiated before cleavage.

The amount and distribution of the food-yolk is of the greatest influence in determining the nature of the cleavage process. In an isolecithal egg the first cleavage usually divides the egg-cell into two approximately equal daughter-cells, which, in turn, divide, each into two others of about the same size. This process is repeated in rapid succession until the original zygote has been halved, quartered, and then cut into 8, 16, 32, 64, 128 cells, etc., the process continuing until the first step in differentiation occurs. The result of such repeated cell division is a rounded mass of tiny cells that looks somewhat like a mulberry, and, for that reason, the stage is often called the *morula.* In very few species, however, is the process of cleavage so regular and symmetrical as just described. In many forms, not only are the cells of a different size, but the cleavages do not all occur in regular order, some coming on faster than others. In nearly all cases, however, the result of the continued cleavage is to produce a mass of cells that remain attached to one another in a single layer. Owing perhaps to the stress of surface tension acting on the cells and pulling them away from the center, the resultant is a hollow sphere. The stage just described is called the *blastula.* The closed cavity surrounded by the single layer of cells (blastomeres) is called the blastocœle.

In eggs in which there is a large amount of yolk, the cells resulting from cleavage are of very unequal size. Since the yolk is heavier than the protoplasm, it " settles " to one side of the zygote, and the blastomeres that arise on that side are therefore larger on account of the presence of the yolk, and, for the same reason, slower in forming than those of the opposite side. This reaches its extreme in eggs like those of birds, in which the protoplasm is crowded to a small disk-like spot at one side, and the mass of yolk is so great that the cleavage is not accomplished at all, but affects only this protoplasmic disk-like spot. Such an egg is termed *meroblastic* or partially cleaving, in contrast to *holoblastic* or totally cleaving, eggs.

Gastrulation. — Differentiation may be said to begin at about this point, although, as we have seen, the undivided zygote, in many cases, is regionally differentiated from the start. When the blastula stage has been reached (in a typical holoblastic egg), one side begins to pit in or "invaginate," as one might indent a soft rubber ball with his thumb. (See fig. 62.) This process continues in some species of animals until the invaginated cell-wall comes to lie against the inner side of the rest of the blastula wall, obliterating the blastocœle and forming a two-layered shell surrounding a newly formed central cavity. This cavity, unlike that of the blastula, opens to the exterior at the region of invagination. This stage is called the *gastrula*, the cavity is called the *archenteron*, and its opening to the exterior just

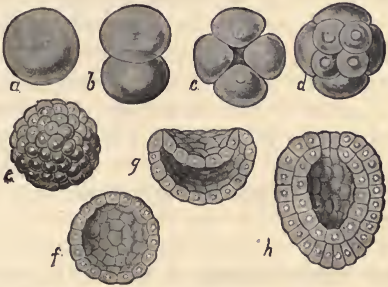

Fig. 62. — Cleavage and gastrulation in a holoblastic egg (the pond snail): *a*, undivided zygote; *b*, first cleavage; *c*, second cleavage; *d*, third cleavage; *e*, blastula; *f*, blastula in section; *g*, beginning of invagination, in section; *h*, completed gastrula, in section. — (From Jordan and Kellogg, after Rabl.)

mentioned, the *blastopore.* In many eggs the invaginating process stops before the blastocœle is obliterated, but the same relations of parts obtain. In eggs in which yolk is very abundant, such as those of the frog, the yolk-laden part of the zygote cleaves into much larger cells (macromeres) than the opposite region, — so large, in fact, that these cells bulk greater than the segmentation cavity of the blastula, and it is physically impossible for these cells to invaginate into such a cavity. The same result is reached, however, by a growth of the smaller upper-layer cells over the macromeres, so that the latter disappear within the former. The final result is essentially the same as that previously described, viz. a two-layered gastrula with a central cavity (archenteron), communicating with the exterior by a blastopore.

Further Differentiation. — In the higher vertebrates the process of gastrulation is greatly modified and obscured by the nature of the cleavage, but essentially the same change takes place in all animals, — the conversion of a single-layered blastula into a double-layered gastrula. The outer layer of the gastrula is called *ectoderm,* the inner layer, *endoderm.* There quickly develops between the two, as an outgrowth, mainly from the endoderm, a third layer or mass of cells known as the *mesoderm* or middle layer. From these three *germ-layers* there are subsequently differentiated all the tissues and organs of the animal body. From the ectoderm develops the outer integument, the sense organs, and the nervous system. From the endoderm develops the digestive portion of the alimentary canal. From the mesoderm develop all the other structures. Just as the unicellular zygote became differentiated into the blastula, and the latter into the gastrula, so the germ-layers, which are primarily sheets of apparently similar cells, differentiate into the most varied forms. This is accomplished ultimately by the differentiation of the cells themselves (histogenesis), as in the formation of muscle cells or nerve-cells, but such a change is preceded by a shaping of rudiments of organs by the differential growth of the germ-layers. Thus the ectoderm, in the vertebrates, forms first a shallow groove along the axis of the embryo, which becomes deeper by the more rapid growth of the sides, until the latter close over and meet above to form a tube, the anterior end of which, by a further complication of folds, flexures, and cell-growth becomes the embryonic brain. The cells composing such a structure are apparently all alike in appearance. Not until the organ is "blocked out" does histogenesis begin.

The tracing out of the relative times of appearance, the structure, and mutual relations of the various parts of the organism as they are transformed, one from another, as well as the dynamic factors that may control or alter these changes, constitutes the special science of embryology. The details of these later transformations vary greatly in different forms of life. All animals, however, begin development with the unicellular zygote, which, following cleavage, is changed into a blastula that, in turn, is transformed into a gastrula. Both blastula and gastrula stages, particularly the latter, may be very greatly modified by secondary conditions. It was recognized by one of the earliest embryologists that the younger stages of all animals resemble one another much more closely than do later ones. This generalization may be stated: development is from the general to the particular, from the relatively undifferentiated to the specialized (Von Baer's law). The whole series of transformations which an organism undergoes from zygote to individual dissolution is termed its *Ontogeny*.

Conjugation in the Protozoa. — The Protozoa, in spite of their apparent simplicity, are in most cases very highly specialized, and their specialization is nowhere so marked as in their methods of sexual reproduction. The majority of them reproduce rapidly under favorable circumstances by binary fission, or, in some cases, by the formation of spores. After a time, owing to influences which are imperfectly understood, this asexual reproduction slows down and comes to a standstill. It may be artificially stimulated (in the case of ciliates) by adding chemical substances to the medium, such as beef-extract, potassium phosphate, etc. On the other hand if each generation of the dividing ciliates is segregated in a few drops of culture fluid, asexual reproduction may go on apparently indefinitely. Experimenters have followed such a line beyond the

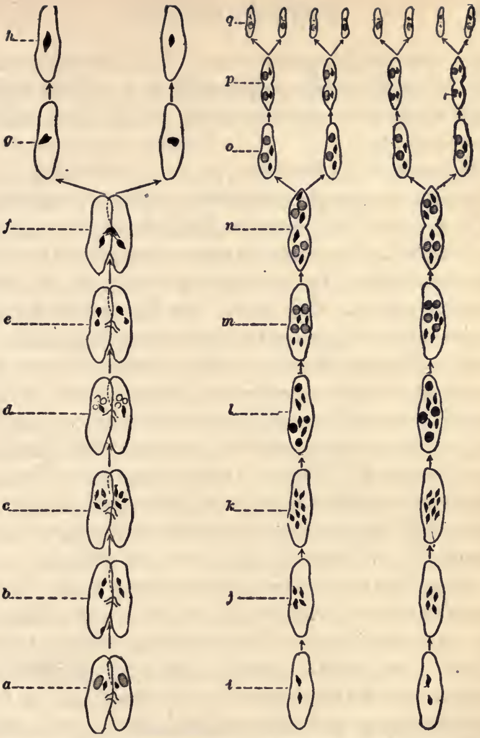

FIG. 63. — Conjugation and reproduction of *Paramecium*. The macronucleus has been omitted from all except *a*. After attachment the micronuclei of each conjugant divides twice (*b, c*); three of the resulting nuclei degenerate and the other divides again (*c, d*); one of the half-nuclei then passes over to the other cell and there fuses with the one left behind (*e, f*); the animals then separate; the zygotic nuclei then divide repeatedly (*i–m*), some of them transforming into macronuclei; the cells then reproduce by binary fission until the nuclei are distributed in the usual way; reproduction then takes place in the ordinary manner. — (From Hegner, after Calkins and Cull.)

three thousandth generation. Whatever the causes may be that induce conjugation in an ordinary culture, it seems to be evident that they are external to the organism.

In many of the Protozoa, as already described, conjugation is a complete mingling of the two organisms in a zygote. In others, conjugation is temporary, and there is an exchange of nuclear substance between the two cells. In the ciliate infusoria, of which *Paramecium* is the most familiar example, the macronucleus degenerates and the micronucleus of each conjugant divides twice. Three of the four resulting nuclei degenerate. The fourth divides again, one half passing into the other conjugating cell and there fusing with the alternate half that does not pass over. The two individuals then separate, and after a number of divisions of the new, compound nucleus, a rapid series of cell divisions results in the production of a great many new individuals.

Many of the Protozoa form spores under certain circumstances. This is especially characteristic of the parasitic forms. It is very interesting to discover that *Amœba proteus*, which is usually considered one of the simplest of all organisms, and the vital processes of which are frequently used to illustrate the functions of protoplasm at their lowest level of specialization, has a very complicated process of spore-formation. The nucleus of the *Amœba* divides repeatedly until about seventy small nuclei result. These then fuse, two by two (still within the same cell), and the fused nuclei redivide several times until two hundred or more result, each of which forms a "spore-mother cell," which, in turn, produces a number of spores. From each spore there develops a new *Amœba*.

Parthenogenesis. — We have seen that reproduction is a kind of discontinuous growth, and that while it is a usual accompaniment of zygosis in the higher forms, there is probably no fundamental connection between the two phenomena. Zygosis, whether partial or incomplete, may perhaps be looked upon as a sort of rejuvenescence of the organism which is the more necessary and occurs the more frequently in proportion to the degree of specialization of the organism. In the majority of the higher forms it is necessary with every individual generated. Some of the Metazoa, however, like the Protozoa, are able to produce successive generations for a long time without the stimulus of sexual conjugation. Such a phenomenon is known as *parthenogenesis* or *agamy*, and occurs as a normal incident of existence in many forms, particularly the insects.

In the plant-louse, or *Aphis*, the outline of the life history of a common species is something as follows: in the autumn the female lays a large so-called winter egg, which, like most eggs, has been "fertilized" by union with the sperm. In the following spring this egg hatches into a wingless female called the stem-mother, that forthwith begins to reproduce parthenogenetically a long series of generations like herself, precisely as a single *Paramecium* may populate a bowl of water. Should food fail, these females develop wings and fly to a more favorable locality, where they in turn start a series of agamic generations. This is kept up until fall, when, instead of the "parthenogenetic females" there are produced (still agamically) sexual forms, which mate. The female lays her winter egg, and this provision for the continuity of the species having been made, the whole season's progeny dies.

Natural parthenogenesis of this sort is strikingly illustrated in some of the minute gall-producing wasps. These insects lay their eggs in the tender tissue of a plant, which reacts by producing a tumor-like "gall," within which the egg develops and from which the perfect insect of the second generation later emerges. In many species of these insects, only one sex is known. It has been discovered, however, that in some forms the insect that emerges from a gall produced by one "species" is of the type of

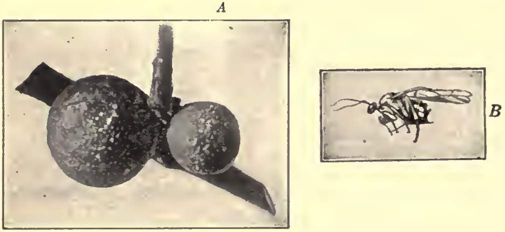

FIG. 64. — A gall-making wasp (*Holcaspis globulus*): *A*, galls on oak, natural size; *B*, the gall-maker, twice natural size. — (From Folsom's "Entomology," permission of P. Blakiston's Son & Co.)

another "species." One type is parthenogenetic, the other sexual, in regular seasonal alternation. Of some species, the male is unknown, and it may be that the female reproduces continuously by parthenogenesis. Development by zygosis seems to be only an occasional incident to the life history of such a race.

Artificial Parthenogenesis. — Although not many kinds of animals naturally develop agamically, yet those that do are by no means "lower types." On the contrary they are usually highly specialized, and the ability to develop in this way is an expression of their specialization. Such examples demonstrate that whatever may be the function of the sperm in zygosis, the egg of each species contains within itself alone the potentiality of developing into an individual, typical of the species of which it is a member. Such being the case, if development can be inaugurated in an egg that never normally develops by zygosis, by analyzing the agency that brings about such an effect, we may get a clue to the nature of the action of the sperm in producing the same result. Within the last few years a great deal of experimental work has been done, which, although perhaps it does not get very far in analyzing the phenomena, does serve to show the subtle complexity of the forces involved, and indicates the nature of the stimulus exerted.

It was found first that potassium chloride added to sea water in which were the matured eggs of a sea-worm, *Chætopterus*, induced the egg to undergo a rapid series of divisions, producing a cell-mass which roughly resembled a larva. This was, however, without cellular organization, and eventually went to pieces. Such cell development at random is suggestive of the condition we find in tumors and galls, — reproduction without organization.[1] In the case of *Chætopterus*, however, *differentiation* may take place even without cellular organization.

It was found that the eggs of other animals,[2] when ripe, can be induced to segment by a variety of means, — shaking, varying the osmotic pressure of the sea-water, acids, CO_2, etc., all being effective, though not always for the same species.

Continuing these experiments, a number of American investigators, among whom Professor Jacques Loeb is the most conspicuous, have succeeded in imitating, artificially, the processes of Nature, by inducing unfertilized eggs to develop normally by chemical and physical means. The methods employed have been complicated, and the data are as yet too incomplete to afford a basis for generalization, but such experiments show that probably all eggs contain within themselves all the potentialities for normal development, and that " fertilization " or zygosis is only an accompaniment to, not a necessity for, individual development.[3]

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[1] Mature eggs that are not fertilized quickly disintegrate (autolysis). The potassium prolonged the life of the protoplasm in the above experiment.

[2] The sea-urchin is a favorite form for experiment.

[3] In spite of the truth of this statement we must not lose sight of the profound significance of the phenomenon of zygosis from another standpoint. The mixture of germinal substance (*amphimixis*) that results

Like a wound clock (to vary Preyer's comparison), the egg is a mass of matter, of which the parts, although in unstable equilibrium, are at rest because of a sort of inertia. When an appropriate "stimulus" comes, whether that of the sperm or that of some chemical or physical agent, cell division begins to follow cell division in rapid succession. "Stimulus" is used, of course, in a very broad sense, since the changes induced in the egg-cytoplasm by the sperm or by external agents are fundamental in character and profoundly alter the chemical and physical nature of the protoplasm. Like chemical reactions in general, the rate of division is influenced by the temperature. A regular rhythm of O-production and CO_2-production has been demonstrated in cleaving eggs, which probably is an external indication of the growth of the chromatin from the cytoplasm (by oxidation), in the resting stage between one mitosis and the next.

Doubtless in both naturally parthenogenetic eggs and ordinary eggs much the same sort of specific stimulus is necessary to inaugurate development. The parthenogenetic individual, however, is able to supply that stimulus itself, whereas in the majority of animals it must be supplied from without.

Alternation of Generations in Animals. — In the worms that reproduce by fission, after a number of

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from the combination of two gametes of diverse origin must bring about a very different end-result from that which would be the fate of the egg if it were to develop by itself, *i.e.* it insures a bi-parental inheritance (see Chapter VII).

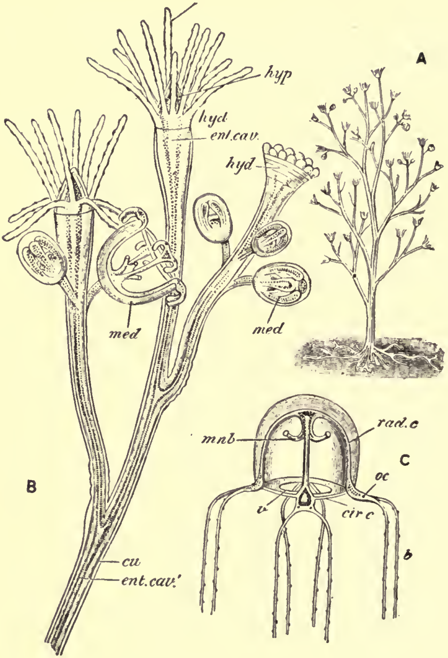

Fig. 65. — A colonial Hydroid (*Bougainvillea*) and its Hydromedusa: *A*, complete colony, natural size; *B*, a portion of the same, magnified, showing the branched stem bearing hydranths (*hyd.*) and medusæ (*med.*), one of the latter nearly mature, the others undeveloped: each hydranth has a circlet of tentacles (*t*) surrounding the mouth (*hyp.*), and contains an enteric cavity (*ent. cav.*) continuous with a narrow canal in the stem. The stem is covered with a cuticle (*cu.*); *C*, a medusa after liberation from the colony, showing the bell with tentacles (*t*); *oc*, eye-spots. — (From Parker, after Allman.)

individuals have been produced asexually, the latter generations produce eggs and sperm. The individuals developing from the zygosis of these gametes again reproduce asexually, and so on. It is the same with the majority of those forms that normally reproduce by budding. In a colonial hydroid, for example, the individuals of the colony (hydranths) come into existence by the process of budding from other hydranths of the colony, and the majority resemble their immediate progenitors. But some of the individuals thus budded off differ from the rest both in structure and function. Instead of remaining attached to the parent stem, they break away as free individuals, and their peculiarly differentiated structure enables them to live an active existence in the water. These are the hydromedusæ. In the second place these individuals, unlike the fixed members of the colony, produce eggs and sperm-cells that are released when mature and conjugate in the open sea. From the zygote thus formed there develops an individual that is unlike the free-swimming, sexual medusa, its immediate ancestor, but resembles the hydranth from which the medusa budded off. By repeated asexual reproduction this produces another hydroid colony. In some fresh-water hydras there has been described the development of sexual organs on buds still attached to the parent stem. If the habit of always developing them in such a fashion should become confirmed, it is easy to see how the condition found in the colonial hydroids may have come about. If some of the buds remained attached (as in the ordinary colony), while others separated from the parent stock, and if the function of reproduction should have become confined to these latter colonies, we would have the condition just described for the hydroid. Such a division of labor between the parts of the colony (*i.e.* the individuals), whereby one particularly specialized group of individuals reproduces sexually and the rest asexually, is known as *metagenesis* or alternation of generations, since the sexual individual resembles, not its immediate parent nor its descendant, but, so to speak, its grandparent or grandchildren. The asexual stage may, however, include more than one individual, particularly in those types that reproduce by fission or budding. Such an alternation of sexual and asexual generations occurs in widely separated groups of animals, probably having arisen independently in all of them.

Sexual Reproduction in Plants

In the simplest plants, as in the simplest animals, vegetative or asexual reproduction is the rule, with or without spore-formation. In the bacteria, and some green algæ, no other method is known. Of the lower plants that live in water, the spores are frequently provided with flagella and are motile. For this reason they are called *zoöspores.* The spores of land-plants are, however, non-motile, although in some groups they are so minute and light that they float in the air and are borne everywhere by the wind.

Although plants, in comparison with animals, are handicapped in their ability to move about over the surface of the earth and thus effect the maximum dispersal of the species, yet such a defect is compensated by this ability to produce spores in enormous quantities. But in all except the very simplest plants reproduction by germ-cells is also to be found. In the plant world, accordingly, we find an alternation of sexual and asexual generations. One plant (generation) produces gametes (whence it is called the gametophyte); the zygote arising from the fusion of two gametes develops into another plant (generation) which produces spores and is therefore called the *sporophyte*. The gametophyte generation in many groups is telescoped into the sporophyte, as it were, and its true relations can be made clear only in comparison with simpler types.

Liverworts and Mosses. — In the liverworts the plant-body (thallus) has the form of a green, leaflike structure, growing close to the ground, and sending down minute, feeding root-hairs into the earth from the lower surface. This is the gametophyte. Along the edges are developed spermaries (antheridia) and ovaries (archegonia), which produce the male and female gametes. The former are active, and, swimming about in the dew or rain, meet and fuse with the egg-cells. From the zygote thus formed there arises, by repeated cell divisions, a mass of cells *within the archegonium itself*, which becomes differentiated into a structure quite unlike the liverwort thallus. This is the sporophyte. It develops at the expense of the archegonial tissue and matures within itself great numbers of minute spores. When these sprout, they grow into a plant-body resembling the original "liverwort," — that is, the gametophyte.

Much the same sort of development is to be observed in the mosses. The sporophyte here grows into a long stalk (drawing upon the tissues of the gametophyte for its sustenance), at the end of which is borne the sporangium. From each of the multitude of tiny spores sprouts another gametophyte or moss-plant, and so the cycle is completed. The sporophyte of mosses, unlike that of liverworts, although mainly dependent upon the gametophyte tissue for its food supply, is, nevertheless, provided with some chlorophyll-tissue, and hence can manufacture some food of its own.

Ferns. — In the fern, the familiar leaflike plant is the sporophyte; the gametophyte is a tiny, heart-shaped thallus, somewhat like a very simple liverwort. The gametes of both sexes develop on the lower side of the thallus (prothallium). The sperm are motile and swim to the egg-cell in the dew or rain. The fertilized egg divides into a mass of cells within the antheridium, drawing its sustenance, as in the mosses, from the tissue of the gametophyte. However, it soon begins to develop a green, leaflike branch, that grows upward, and a root-stalk that grows into the earth. Thereupon it is independent of the gametophyte and grows to a much greater size, leaf after leaf being developed on the growing rootstalk. Eventually, sporangia are developed in enormous numbers on the under side of the leaves, usually in clusters (sori). The spores, falling on damp soil, sprout, and, cell division following cell division, a mass of cells results which soon takes the form of a tiny prothallium, — the gametophyte of another generation. In the more complex ferns two sorts of spores are formed, large ones called megaspores and smaller ones known as microspores. Both produce gametophytes upon germination, but the prothallium arising from a megaspore produces female gametes only, whereas one arising from a microspore produces male gametes only. We have here a sexual differentiation in the sporophyte or non-sexual phase.

Seed Plants. — We have traced a progressive emphasis which the course of evolution has laid on the sporophyte, compared with the gametophyte, generation. In the liverwort the gametophyte is the "plant" and the sporophyte a tiny parasite upon it. In the higher mosses the gametophyte is larger and the sporophyte, although still largely dependent upon it, is able to contribute some of its own food. In the ferns the sporophyte, although dependent upon the gametophyte in the beginning, soon shifts for itself and completely overshadows the latter. Finally, in the seed plants, the representatives of the plant world most familiar to us, the conditions are reversed, and we find that the sporophyte is the "plant," the gametophyte being a minute dependant upon it.

In the seed plants there always occur the two kinds of spores, — megaspores and microspores. The latter are more often known by the more familiar term *pollen*. In some species of plants both are borne on the same plant (monœcious type); in others, each is developed on a different plant (diœcious type).

The leaves which bear the microsporangia are called *stamens*, those that bear the megaspores, *carpels*. Both these forms of metamorphosed leaves are usually surrounded by other, highly modified, frequently colored leaves (petals, sepals), to form a *flower*. When the carpels grow together in a mass, as is frequently the case, we speak of it as the *pistil*.

The carpels bear sporangia, to which the name *ovule* has long been given, although it must not be forgotten that they are not "eggs," but are developed by the sporophyte, the asexual generation. The megaspore is never released from the sporangium, and the sexual generation begins its existence there. On the other hand, the microspores (pollen) are matured in great numbers in the sporangia of the stamens, and, when released, are carried by the wind, insects, and other agents to the sticky termination of the pistil (the stigma). When one sticks here, it begins to sprout and grow, much as moss-spore on damp ground. Since, in the flowering plant, however, the megaspores are *inside* the carpels and are never released, the pollen spores must grow down into the carpel to them. This it does in the form of a (relatively) long pollen-tube. The *pollen-tube* is the male gametophyte, and it grows directly through the tissues of the stigma and style, to the megasporangium, which it penetrates. One of its cells (or nuclei) is the male gamete.

The Germination of the Megaspore. — The first step in the development of the megaspore consists in the division of its single nucleus into two, which move apart into either end of the cell. Each nucleus then divides twice, so that there are produced two groups of four nuclei each, in either end of the spore-cell. The latter, meanwhile, grows rapidly at the expense of the surrounding tissues. Now, one nucleus from each group (the polar nuclei) leaves the others and moves toward the center of the cell, where the two meet and fuse. The cell now contains three nuclei at each end and one double one at the center. The latter forms the *endosperm*, a mass of food-storing cells that fills the embryo-sac. The three nuclei at the bottom of the cell (the antipodal nuclei) disintegrate. Sometimes they form cell-walls and even build tissue, but have no further fate. Of the other three nuclei at the distal end of the sac, one is the egg or gamete, the other two (known as synergids or " helping cells ") are sacrificed for the nourishment of the gamete, much as are the two polar bodies of the animal-egg.

The Germination of the Microspore.—Each of the microspores is functional. In germination the nucleus divides, forming two cells, a large one called

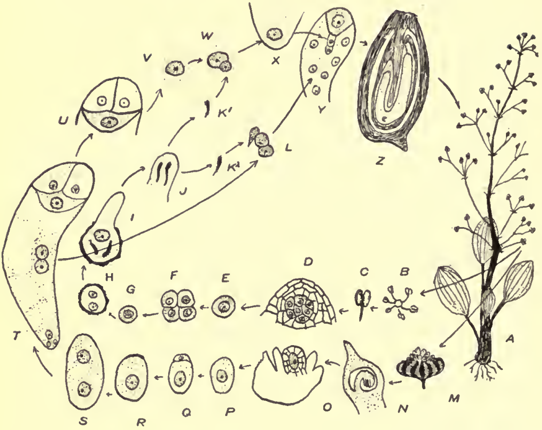

FIG. 66. — Diagrammatic Summary of the Life-cycle of a Seed Plant (*Alisma*). *A–G; A, M, N; X, Y, Z, A,* — the sporophyte phase; *H–X; P–X,* — the gametophyte phase. *A,* the mature plant whose flowers bear stamens (*B, C*) and pistils (*M*); *N*, a section through the megasporangium; *O–R*, the developing megaspore; *Q*, with the degenerating tapetal (nourishing) cell. There is but one megaspore in *Alisma* instead of the four that are found in most seed plants. *T*, the complete embryosac with the two endosperm nuclei in the middle, the three antipodal nuclei at the lower end, and the egg-nucleus with the two synergids at the other end; *V*, the egg-nucleus. *D*, the development of the pollen-mother-cells; *E*, one of the pollen-mother-cells that divides into *F*, a tetrad; *G*, a microspore (pollen grain); *H*, division of the microspore nucleus; *I*, beginning of the pollen-tube, with one tube-nucleus and the two gametic nuclei; *W*, fusion of male pronucleus with egg-pronucleus; *X*, the zygote (gametospore); *Y*, beginning of embryo formation; *Z*, the seed, containing the developed embryo which grows into *A*. In some forms the second male pronucleus K^2 fuses with the endosperm nuclei (*L*). (After Schaffner.)

the *tube-cell*, and a smaller one which divides again into two male gametes. The tube-cell, in its growth down the style, clears the way for the two gametes, and when it has entered the embryo-sac, it swells and ruptures, discharging the two gametes, one of which conjugates with the egg-cell, the other with the endosperm cell.

The zygote, formed by the fusion of these two gametes, develops into the embryo of the plant. Meanwhile, the endosperm cell also divides and forms a growing tissue that packs about the embryo. The food (oil, starch, etc.) contained in the endosperm nourishes the embryo plant until it is able to get its own food. Finally, the outer layers of the ovule secrete various kinds of hard protective coverings which form the seed-coats, and the young plant, thus wrapped up, is cast off as a *seed*. In this way, unfavorable seasons are tided over. In some cases the carpels themselves, or tissues adjacent, become soft and succulent, forming *fruits* that inclose the seed. When suitable conditions of temperature and moisture again intervene, the sporophyte within the seed resumes its growth at the expense of the stored-up food, and, bursting its seed-coats, grows out, takes root, and resumes the cycle. The embryo has a root, a stem, and one or two leaves called cotyledons. In those seed-plants with one cotyledon — the monocotyledons (palms, lilies, orchids, etc.) — the leaves are parallel-veined, there is a "pithy" stalk (like that of corn), and, usually, flower-parts arranged in "threes." In those with two cotyledons — the dicotyledons — the leaves are netted-veined, the stem has a hollow cylinder of wood, and the flowers are usually in "fives" or "fours."

In plants, as in animals, the number of chromosomes is constant for any one species. When the germ-tissue of the sporophyte develops the spores, the cells which are to become megaspores and microspores are found to have but half the number of chromosomes that occurs in other cells of the sporophyte. This reduction is accomplished, not by the formation of chromatin "tetrads," as in animals, but by a precocious splitting of the spireme thread in the mitosis which precedes the formation of the spore-mother cell. Four megaspores are formed, which are usually arranged in a linear row. Likewise, four microspores are formed, which are arranged in a spherical mass and called by the botanists "tetrads." These tetrads, composed each of four adherent pollen grains, are to be carefully distinguished from the chromatin figures in the spermatocytes and oöcytes of animals.

Parthenogenesis in Plants. — As in animals, so in some seed plants, development may take place without zygosis, a phenomenon that has been referred to previously as parthenogenesis.[1] Development occurs by the spontaneous cleavage of the egg-cell and the consequent formation of the embryonic

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[1] The authentic cases are *Thallictrum* (two species), *Alchemilla* (nearly all species), *Ficus hirta*, and *Antennaris alpina*. Also one pine, *Pinus pinaster*.

plant. In such cases there is no reduction of the number of chromosomes. There is evidence that the initiatory "stimulus" of development may be derived from contact of the egg with the surrounding endosperm. In the case of the fig (*Ficus*), the puncture made by a tiny wasp[1] (*Blastophaga*) is probably the cause of development.

Apogamy. — Very similar to true parthenogenesis, and much more common, is the production of a sporophyte by a gametophyte from other sources than the egg-cell, but still without fertilization. This is termed *apogamy*. Sometimes the embryo is produced by growth of gametophyte tissue (frequently in ferns), and this is to be classed as simple budding. In other cases, the embryo develops by the cleavage of the synergids, which are to be considered as abortive eggs. This is common in the orange, the dandelion, and many conifers. In a very similar way, among the ferns, prothallia (gametophytes) may be developed directly from the leaflike sporophyte, without the intervention of a spore. This is called *apospory*.

The Probable Evolution of the Plant World. — The simplest forms, both in animal and plant life, are aquatic, and life appears to have begun in the water. In an aqueous medium, free-swimming organisms can go in any direction, and the conjugation of gametes is effected with relative ease and certainty.

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[1] It is of interest to note that in the frog's egg, development may be induced by puncturing the unfertilized egg with a needle.

The advantage of asexual reproduction or spore-formation lies in the fact that species may thus tide over periods of unfavorable conditions, or, on the other hand, rapidly multiply the vegetative phase of the plant's life in favorable circumstances. In leaving the water for the land, the original aquatic traits were at first, in large measure, retained; that is, the gametophyte phase was most prominent, and the gametes were aquatic. This is a condition we find in the mosses and liverworts. In the ferns we still find the gametes to be motile, aquatic cells, but the difficulties and dangers of this mode of reproduction are compensated by a marked increase in the degree of specialization which the asexual or spore-forming phase has attained.[1]

Finally, in the seed plants we find the free-swimming germ-cells replaced by gametes that are throughout protected and inclosed by the tissues of the gametophyte, and the young sporophyte that results from their conjugation is protected and supplied with food. Division of labor has brought about an increasing efficiency from the standpoint of competition with other types. The seed plants, independent of water for the purpose of zygosis, and adapted to secure the greatest protection for the developing sporophyte, as well as for its maximum dispersal, have a very great advantage over the "lower"

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[1] The advantage of asexual reproduction lies in the fact that the species is much less likely to be exterminated if the vegetative phase of the plant's life is emphasized and a wide dispersal secured. Moreover, the formation of spores enables the species to tide over periods of unfavorable conditions.

forms, and as a consequence we find them the dominant type to-day.

MORPHOGENESIS

The goal of the reproductive process is the formation of a new individual. In asexual reproduction, particularly by budding, it is often a matter of great difficulty, and, perhaps, of minor importance, to determine where the limits of individuality lie. In those forms which develop sexually, the individual comes into existence with the fusion of the gametes (or of their nuclei) to form the zygote. In other words, the zygote *is* the new individual, however little it may resemble what we are accustomed to call the specific type. Before it can reproduce a second generation, however, it must be transformed into that type. This it does by a series of remarkable changes (see page 158 ff.) accompanied by growth, to which the name *Morphogenesis* is given.

Regeneration. — The phenomenon of morphogenesis is not only discoverable in the *acquisition* of the specific form, that is, in development, but also in the *restitution* of that form when it is altered or destroyed. Thus, if one cuts off the leg of a salamander or of a crayfish, a new growth of tissue will take place at the cut surface, and this new tissue will differentiate into a new leg which is the duplicate of the one destroyed, or, if not the exact duplicate, at least conforms exactly to the specific type. This function of the organism is known as *regeneration*. It is not found in all organisms, but is particularly characteristic of the "lower," *i.e.* less specialized types. For example, although the leg of a salamander will regenerate as described, as will also that of a frog tadpole, that of a mature frog will not. Regeneration is also found in plants. A leaf of *Begonia*, if put in water, will grow roots and regenerate the whole plant. From one point of view there is nothing fundamentally different in the differentiation of a tissue-fragment artificially sundered from the organism into a new organism, and the similar differentiation of a tissue-mass (bud) naturally sundered from a parent organism; or, indeed, of a single cell, whether spore or gamete, thrown off from such an organism. In each case there is the achievement of a certain specific type, by differentiation from an apparently

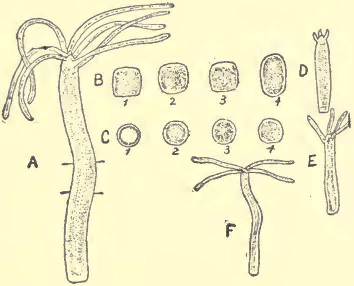

Fig. 67. — Regeneration in *Hydra:* *A*, normal *Hydra* (lines show where piece was cut out); *B*, 1–4, changes in a piece of *A* as seen from side; *C*, 1–4, same as seen from end; *D*, *E*, *F*, later changes in same piece. — (From Jordan and Kellogg, after Morgan.)

undifferentiated mass of living matter, derived from an organism which also conforms to that specific type.

Regulation. — Redifferentiation, in the case of injury or alteration of form, is not always accompanied by growth of new tissue. If a *Hydra* be cut in two, each half will transform into a complete

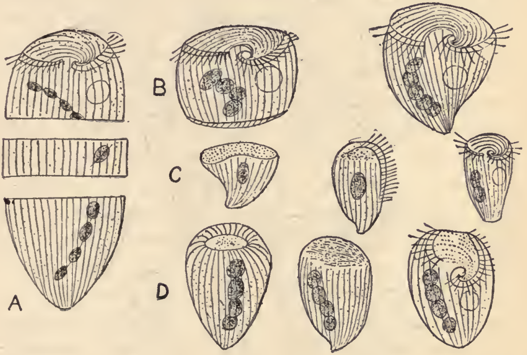

FIG. 68. — Regeneration of *Stentor:* *A*, cut in three pieces; *B*, row showing regeneration of the anterior piece; *C*, regeneration of middle piece; *D*, that of posterior piece. — (From Jordan and Kellogg, after Morgan.)

Hydra, half the original size. Here there has been no new growth, but a readjustment and shifting of mutual relations of the old tissues of the animal. Among the larger Protozoa, such as *Stentor*, the same thing occurs if the cell be cut in fragments. It is necessary, however, for each fragment to contain a portion of the original nucleus in order that the transformation into a typical protozoan may take place. Such a transformation of the old tissue, unaccompanied by growth, is called *regulation*. A striking example is found in the reaction of young embryonic stages. If, for example, the blastula of a sea-urchin be cut in two, each half-sphere will close over, round up, and form a perfect blastula, half the original size. Each of these goes through its normal transformations, and the end-result is two individuals instead of the single one that began its course of development.

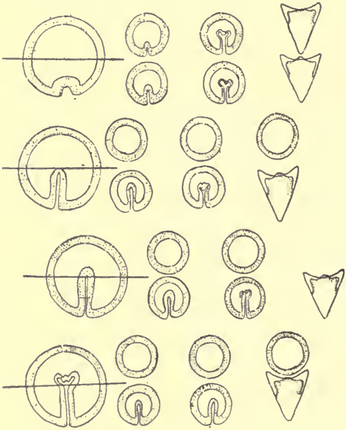

Fig. 69. — Regeneration of the blastula and gastrulæ of sea-urchins; the line indicates where the blastula or gastrula was cut in half; the smaller figures show results of the regeneration (regulation) of the two halves of each. — (From Jordan and Kellogg.)

In certain species a similar sequence of events occurs as a natural incident of development. Some forms of parasitic wasps lay eggs within the bodies of caterpillars, the young larvæ feeding on the caterpillar tissues, and finally emerging to spin cocoons on the surface, within which they carry out their final metamorphosis. It has been discovered that only one egg may be laid thus within the caterpillar, but that it fragments into scores or hundreds of portions, from each of which a perfect parasitic wasp develops. This is known as *polyembryony*. To recur again to the sea-urchin blastula, mentioned above, — it is clear that the factor which determines whether one individual or two is to be the result of the process of development lies somehow in the reciprocal relation of the parts of the blastula. This may be illustrated in another way. If the zygote, after the first cleavage, be placed in sea-water which lacks calcium, the two cells will separate, and, if replaced in normal sea-water, each will develop into a perfect individual. As in the previous case, two individuals arise from one zygote. Here it is clear that the absence of contact with the one blastomere determines that the substance of the other shall differentiate into one individual instead of into half a one, as it ordinarily would do. The result is, however, always the specific type

Heteromorphosis. — Although the regeneration of a new appendage or other part in nearly every case conforms to the specific type, and the process is essentially one of "restitution," yet occasionally the formative forces get off the morphogenetic track, and a wholly abnormal structure results. In certain crustacea, such as the crayfish, if the experimenter cuts off one of the eye-stalks, another will grow to replace it, but if, in addition to severing the eye-stalk, he also destroys the deeper-lying ganglion, the resultant growth is not an eye-stalk at all, but an antenna-like structure. (See fig. 70.) It is interesting to find that the new organ is still of the crustacean type. Such a diversion of the normal path of differentiation is termed *heteromorphosis*.

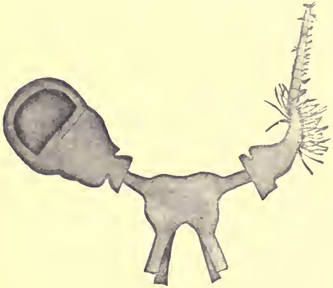

FIG. 70. — Regeneration of antenna-like organ in place of eye-stalk, in *Palæmon*. — (From Morgan, after Herbst.)

Theories of Morphogenesis. — The nature of the changes involved in the ontogeny of both plants and animals has been briefly outlined. The question arises: Why does the germ always give rise to precisely the type characteristic of the species and no other? Nothing that our microscope can tell us of the young embryo within the eggshell of a pigeon or a sparrow gives us the slightest clue as to why the culmination of the development of one is different from that of the other. More fundamental is the question: Why does the shapeless germ take form at all? Nothing that we can learn of its nature or its structure gives us any reason for believing, *à priori*, that it will shape itself into an individual that resembles its parents. This is an old problem, and its solution was attempted long before our modern instruments for research gave us the insight into developmental processes we now possess.

Preformation. — Suggested perhaps by the structures found within the flower-bud, or the insect chrysalis, the idea was long current that the germ contains within itself the whole organism in miniature and that development consists, simply, in an unfolding and enlarging of this preformed individual. The chief elaborator of this speculation was Bonnet (1720–1793), but such a great naturalist as Cuvier also subscribed to the doctrine.[1] Since the generation " A " was preformed in the generation " B," then its descendants must also have been there preformed, and so on. The germ-plasm, therefore, was conceived of as a sort of nest of Chinese

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[1] There was a division of opinion as to whether the preformed individual existed in the egg or in the sperm. Some held that the former is the case and that the function of the sperm is merely to fructify or "fertilize" the dormant egg. These speculators were denominated "ovists." On the other hand the "animalculists" contended that the egg is merely dead matter serving for nourishment, whereas the sperm is active and "alive." Moreover, with the primitive microscopes of the time, they had no difficulty in distinguishing head, arms, legs, and other structures in the sperm.

boxes, each one inclosing a series of increasingly smaller ones. Indeed the theory was called the "encasement" theory.

Epigenesis. — Wolff, the father of modern embryology, investigated the developing chick in the shell, discovering, among other things, that the heart actually comes into existence after development begins, and was forced to conclude that there is no evidence whatever of the preëxistence of the chick in the germ of the egg. In his *Theoria Generationis* (1759) he advanced the hypothesis of *epigenesis*, according to which the development of the germ involves the coming into existence of new structures with each generation. It was thus in direct conflict with the preformation concept held by the majority of eighteenth-century naturalists and philosophers. As for the means of this epigenetic development, he conceived of a specific internal energy or force (*vis essentialis*) that permeates living matter. Development (in the hen's egg) is not brought about by the heat of incubation, but by the operation of this somewhat mystic internal force. Wolff's results and speculations were a long time in gaining acceptance, but the gradual improvement in microscopes, and in technique, made it impossible to accept the naïve preformation of the earlier school, and the biological world became persuaded to the epigenetic way of thinking, without, however, accepting the "*vis essentialis*."

Weismannism. — In the course of time the pendulum again swung back toward the preformation standpoint. The increase in knowledge of the data of heredity, and a more exact understanding of the cellular phenomena of zygosis and ontogeny, forced speculative biologists to refer back the structures that develop in morphogenesis to some sort of preexisting structure in the gametes. Under the hand of *Weismann* (1834–) this became an elaborate architecture of determining particles of ultra-microscopic size, each of which is the causal agent in bringing about the development of some part of the organism. Weismann laid much emphasis on the concept of the continuity of the germ-plasm, in contrast to the soma, a matter already discussed. Development thus becomes a mere sorting out of determinants, and the organism is a sort of mosaic. One obvious corollary of such an hypothesis is the fact that nothing that may befall the soma after development begins can have any influence in modifying the result of development in a succeeding generation, since each generation develops in strict accordance with the determinants in the germ-cells. Most experiments seem to prove that this is so. On the other hand, the facts of regeneration and regulation, just cited, are a strong argument against such an inflexible mosaic development. For this and other reasons, the elaborate and complicated architecture which Weismann postulated to exist in the germ-cells is not considered by modern biologists really to exist. Nevertheless, for many reasons, particularly on account of the discoveries in Mendelian inheritance,[1] a great many biologists believe that the development of the structural characteristics of animal and plant individuals is dependent upon the presence of "something" in the germ-cell to which the name *determiner* is given. This determiner is a physical entity of some sort, however, and very different from the *vis essentialis* of Wolff.

Vitalism and Mechanism. — The more exact becomes our knowledge of the processes of differentiation and development, the more wonderful appears the delicate adjustment of forces that brings about the final result. The correspondence of time and place in development is at present particularly difficult to comprehend. Why, for instance, does an organ, let us say a finger, develop at precisely the time and place necessary to produce a symmetrical whole? Why does an organ develop in apparent anticipation of a subsequent need? The *vitalists* believe that no known laws of matter can account for the adaptation of means to the end, which we are constantly confronted with in the study of morphogenesis, and that it is necessary to postulate a *non-mechanical principle* or "vital force," to which various names are given, which is a guiding and controlling agency in directing the course, not only of development, but of life processes in general. A sculptor in modeling a statue must have a pretty clear idea in his mind of just what he expects to

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[1] See next chapter.

realize in the completed work: he works toward a definite end, and his preliminary efforts are conditioned by the sort of final result he wishes. To many observers the processes of development seem equally conditioned upon the nature of the final result, and it is hard to see how such events could come to pass without the help of some guiding agency, like the sculptor in the previous comparison. Such a point of view is called teleological. Human action is so constantly purposive that the untrained mind unconsciously reads into all the activities of Nature a similar purpose. A bygone generation, but by no means an unintellectual one, could see no way of accounting for the movements of sun, moon, and planets except by postulating the assistance of angels who pulled and pushed them along their appointed courses. With the increase of knowledge of celestial mechanics it became clear that the intervention of the imaginary angels is not necessary, and the explanation of the movements of heavenly bodies became an impersonal or mechanical one. In the same way, to "explain" the complex processes of development, it is not necessary to call upon the guiding help of some hypothetical vital force, even though our knowledge of developmental mechanics is still far too inadequate to explain the observed phenomena.

One of the most prominent students of the relations of plants to their surroundings[1] says: "Each year the list of 'vitalistic activities' of plants

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[1] H. C. Cowles.

becomes more and more restricted through the establishment of a definite physical or chemical cause for what had been thought to have a vitalistic explanation, while never in the history of science has any phenomenon, once explained on a physical or chemical basis, later been found to be vitalistic."[1]

Summary. — In each species of plant or animal there is a continuous and unbroken succession of individuals that constantly replace one another. There is no authentic instance of any individual form of life coming into existence except from a preëxisting individual. The reproductive process is essentially one of discontinuous growth. In its simplest expression it involves the cutting in two of a parent organism to produce two "daughter" individuals. Instead of a half of the parent organism, the source of the new individual may be a portion of the parental tissue (bud) or a single cell (spore or gamete). In the case of the spore the new individual arises by direct growth and metamorphosis, but in the case of the gamete it arises from a zygote, which is the result of the partial or complete fusion of two gametes. In any event the specific form of the new individual is attained by differentiation from a relatively generalized to a

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[1] The author is aware that the above paragraph gives a very incomplete presentation of the vitalistic standpoint, particularly of that of the so-called *Neo-Vitalists.* There are many kinds and degrees of vitalism, but to go into the subject in detail is quite outside the compass of a work of this sort. The interested student is referred to the works of Driesch, Bergson, Reinke, Lovejoy, etc.

relatively specialized condition. There is a striking parallel in the course of the differentiating process in the ontogenesis of all species. The similarity of the steps in any two different forms is in direct ratio to the closeness of their relationship. Sexual reproduction (by gametes) is apparently an incidental specialization and not a necessity for the accomplishment of the reproduction process, since experiment has shown that the egg contains within itself all the required potentialities for individual development. It is probable that the same would be also true of the sperm except that specialization has deprived the latter of the necessary food supply to serve as a source of energy. The accomplishment of the specific form is not only brought about by the differentiation of a specialized cell, normally produced by another individual (ontogenesis), but also is manifest in the restoration of structures in the same individual, when these are abnormally altered or destroyed (restitution).

CHAPTER VII

VARIATION AND HEREDITY

Variation. — When we see twins that resemble each other closely, or two unrelated individuals that have many features in common, our attention is at once attracted, and the fact that the phenomenon excites our interest attests its comparative rarity; in other words, we are accustomed to the fact that individuals do *not* resemble one another, and the occasional exception is therefore conspicuous. If we apply exact measurements or other criteria to any sort of plant or animal, or to a structural part, and compare with similar measurements on other individuals, we find that the same thing holds true, — that variation is a universal phenomenon, and duplication almost non-existent.

The analysis of this fact of universal variation resolves itself into a comparison of structures, — the components, so to speak, that go to make up the individual. Thus, if we wished to compare the individual seeds in a handful of beans, we should describe their size, shape, color, texture, etc. These components are technically called "characters." It is obvious that a complex individual may be resolved into a large number of such characters, displaying all sorts of variations when compared with other individuals. These may be described and catalogued, but words alone will hardly suffice to discriminate the finer shades of distinction between so many classes. To seek order in such a chaos, some sort of mathematical basis must be devised.

If we study a group of a hundred men with regard to a single character, such as stature, we find, of course, that all the individuals fall within rather definite limits, from the shortest man to the tallest, and we might classify them by arranging them in a row in the order of height. The line connecting the tops of the heads of such a row of men should be irregular and jagged and would defy analysis. Suppose, however, that we group such a lot of men in classes corresponding to the various statures, and place a representative of each class with his heels on a base-line. Then, grouping all of a class together (see fig. 71), one in front of another, we would find that the line connecting their heads, when viewed from above, is of a very different sort compared with the former one. Briefly, the shortest rows, that is, the fewest individuals, would be found in the shortest and tallest classes, and the longest rows in the intermediate classes. Viewed from above, the outline marked by their heads would describe a fairly regular curve, reaching its highest point in the middle, and curving down to the base-line in both directions. If a thousand individuals instead of a hundred were thus arranged, the line would be more even, since individual differences would tend to merge in the general average. If one were to fire a thousand rifle shots at a target and then sort out the results and classify them with regard to the accuracy of the hits, it would be found that the most accurate and the least accurate ones are fewest in numbers, and that the greatest number of hits is somewhere in between. If we plot out the result on paper, in the same way that we arranged the men above described, a similar curve will be secured. The same result will be obtained from any large array of data, the distribution of which depends upon chance. An ingenious device invented by Galton illustrates this mechanically.

FIG. 71. — Bird's-eye view of forty men arranged in files by classes of stature. — (Davenport.)

A shallow oblong box (fig. 72) is constructed, one side of which is of glass. Toward one end a number of longitudinal compartments are formed of strips of tin; at the other end, a sort of funnel is constructed in the same way. Between the two is a field of pins inserted alternately. The apparatus is provided with a handful of shot before the glass cover is put on. When the box is inverted, the shot all run back into the compartment behind the funnel.

> "Then, when the box is tilted, the shot passes through the funnel, and issuing from its narrow end, scampers deviously down through the pins in a curious and interesting way, each of them darting a step to the right or left as the case may be, every time it strikes a pin. The pins are disposed in a quincunx fashion, so that every descending shot strikes against a pin in each successive row. The cascade issuing from the funnel broadens as it descends, and at length every shot finds itself caught in a compartment immediately after freeing itself from the last row of pins."

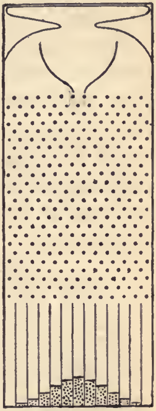

Fig. 72. — Galton's mechanical device for illustrating the law of the frequency of error, and the distribution of variates in the normal curve.

When we examine the disposition of the shot in the compartments, we find that the greatest number is to be found in the middle compartment (if the apparatus be held vertically), and that the compartments on either side contain a diminishing number. In other words the line that connects the tops of the columns describes the same sort of a curve [1] that we secure when we plot out the heights of a large number of men.

Nearly all the obvious variation of organisms is of the kind just described. Mathematical analysis gives no clue to the nature of the *individual variate*, and for this reason such variation is frequently called *fortuitous, i.e.* random or unpredictable. Nevertheless the mathematical values obtained from the analysis of a mass of such data are very accurate and certain.

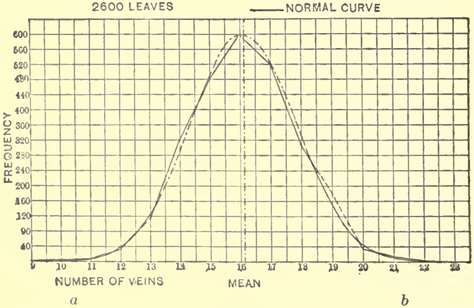

FIG. 73. — The Normal Curve. Veins in beech-leaves. — (From Davenport, after Pearson.)

Types of Variation Curves. — The theoretical or normal binomial curve is perfectly symmetrical (fig. 73). The classes may be marked off along the

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[1] The curve is that known in mathematics as the binomial curve (the expansion of the expression $[p + q]^n$).

base-line (*a–b*); in the diagram these run from 9 to 23. These figures happen to represent the variation in the number of veins in beech leaves, but they might represent the limits of weights of seeds in grams, or the number of spines in a fish's fin, or any other measurable character. The number of variates in each class is represented by the cross-lines, each line standing for forty individuals. It will be noted that the greatest number of veins falls on 16, which is very nearly midway between 9 and 23. This middle point is called the *mode* or *mean*. Again, there is a point on each half-curve where the curvature changes from concave to convex (point of inflection). Let us now compare the curves in fig. 74. In both of these curves the mode is the same. The higher curve, compared with the lower, shows that the variates in the former array are *concentrated*, as it

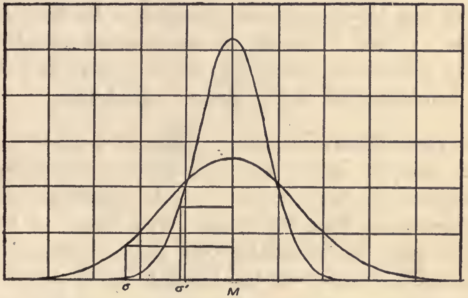

Fig. 74. — Two symmetrical curves illustrating the value of "σ" as a measure of variability (see text).

were, about the median dimension, whereas in the flatter curve they are distributed more evenly along the whole base-line. In other words, the bulk of the individuals of the first lot are much alike, or, as we say, are not so variable as in the other lot. It is evident that the flatter the curve, the farther away from the modal axis (M) moves the point of inflection. The measure of the line connecting this point and the modal axis (designated by the Greek letter σ) thus becomes the measure of variability, being greater in proportion as the curve is flatter, *i.e.* in proportion to the greater variability.

Asymmetrical Variation. — In actual observations the variation curve for organisms is rarely quite symmetrical; that is, the mode is somewhat nearer one extreme than the other. The index of variability may be calculated for such curves as for symmetrical ones. If the mode is much nearer one extreme than another, the curve is spoken of as "skew." Such a curve frequently indicates that selection has taken place in the material examined, and the variates have been eliminated disproportionately.

Discontinuous Variation. — In measuring the dimensions of an organ or in estimating weights, the number of classes obtainable is limited only by the accuracy of our own observations, and the gradations of variation are continuous, as is indicated by the symmetrical curves which we usually obtain. Such variations as the above are due to the variability in the material or substance of the organs and are therefore called *substantive* (Bateson). On the other hand, the *number* of parts may vary, as with flower-petals, or the joints of an appendage, or body-segments (as of a worm). Such variation is termed *meristic.* It is clear that there can be no intermediate between a three-leaf clover and a four-leaf clover. The fourth leaf is a perfect leaf, no matter how small it may be. Meristic variation differs, then, from substantive variation in being discontinuous instead of continuous.

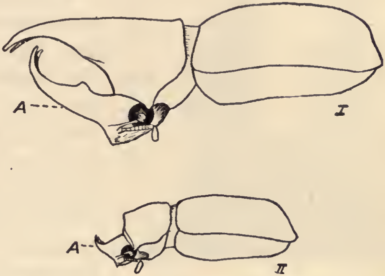

FIG. 75. — Rhinoceros beetles (*Xylotrupes gideon*); *I*, "high" male; *II*, "low" male; *A*, the cephalic horn. The legs are omitted for the sake of clearness. — (After Bateson.)

Discontinuity of variation, however, may be discovered in substantive as well as meristic characters. When we plot a curve of measurements for a character, we sometimes find that it apparently shows two modes, or is "double-humped." (See figs. 75, 76.) Such a curve is impossible to analyze by the usual methods, for it shows that the material is not homogeneous. In reality we have two groups, with two modes, but members of both groups are mingled within the range of the classes that are common to both, and in consequence we cannot determine the limits of the curves that intersect.

An example of this is figured below. In rhinoceros beetles there are two long horns which project forward from the head and the thorax. Bateson measured the horn on the heads of some 342 beetles and found that, with respect to this character, the insects grouped themselves in two classes, the curve of variation being a "double-humped" one. With respect to the length of the wing-covers, however, the same 342 beetles were shown to be homogeneous, the curve for this measurement having but one mode. Again, in a certain Chrysanthemum, De Vries found that, although the number of ray-florets (often miscalled petals) of the flower varied from

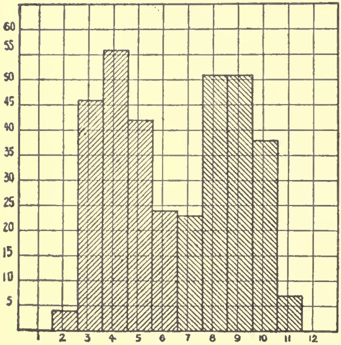

FIG. 76. — Polygons of variation based upon the measurements of 342 rhinoceros beetles. Two modes are evident, one about 4 mm., the other about 8½ mm.

12 to 22, yet the curve of variation proved itself to be a double-humped one (see cut), with one mode for 13 florets and another for 21. De Vries rejected all the flowers of the latter class, and planted the seeds of the 12- and 13-rayed flowers. The result is indicated in the third curve, " C "; all the flowers were of the 13-rayed variety, and the 21-rayed plants had been eliminated. The bearing of this result will be discussed further on in another connection.

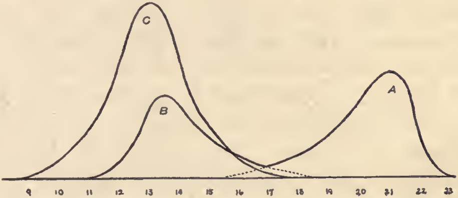

Fig. 77. — Discontinuous variation in *Chrysanthemum segetum* (see text).

Mutations. — Discontinuous variation may be qualitative as well as quantitative. Although such variations are conspicuous and striking to us, they are probably of the same sort as the merely quantitative or meristic variation. This kind of variation has long been familiar to gardeners and horticulturists under the name of "sports." A classical example studied under experimental conditions is the evening primrose (*Œnothera lamarckiana*). This species is supposed to have been introduced into Europe from America, although it is no longer found wild here. Professor De Vries secured some wild plants from a field near Amsterdam and cultivated the stock in his garden for eight generations. He began with nine plants, from the matured seeds of which, two years later (since the plant is a biennial), he grew some 15,000 plants. Ten of these were of a different appearance from the rest, and these he carefully segregated. Five of them were dwarf, with small leaves but full-sized flowers, and these he named *nanella;* the other five had broad leaves and a luxuriant growth, and the flowers were all pistillate, and hence could not produce seed, except when crossed with another variety; this form he called *lata.* Both *nanella* and *lata* were found thereafter in every culture from *lamarckiana* seed, until the seventh generation, and in every case, when self-fertilized, the former "bred true." In the third generation a new form appeared which he called *rubrinervis*, and in the next, three others, *oblonga*, *albida*, and *gigas.* The first was characterized by

MUTATIONS OF *Œnothera lamarckiana* (FROM DE VRIES)

GENERATION	GIGAS	ALBIDA	OBLONGA	RUBRINERVIS	LAMARCKIANA	NANELLA	LATA	SCINTILLANS
I					9			
II					15,000	5	5	
III				1	10,000	3	3	
IV	1	15	176	8	14,000	60	73	1
V		25	135	20	8,000	49	142	6
VI		11	29	3	1,800	9	5	1
VII		0	9		3,000	11	5	
VIII		5	1		1,700	21	1	

reddish veins in the leaves, *oblonga* by narrow leaves, and *albida* by whitish ones. *Gigas* had stems nearly twice as thick as *lamarckiana*, covered with dense foliage. All of these forms reappeared in subsequent cultures (compare the accompanying table), and all bred true to type.

De Vries also found two plants of *lata* growing wild in the field, as well as one of a different type with smooth leaves, which he called *lævifolia*. This form not only bred true when segregated, but developed other types, *lata*, *nanella*, *rubrinervis*, and two others that had not appeared from the *lamarckiana* seed.

The various types of evening primroses described above are good examples of discontinuous variations which have been watched, as it were, in the making. Such variations De Vries believes to be very different in nature from ordinary fluctuating variations, and to them he gave the name *mutation*.

Correlated Variation. — Since all the parts of a normal organism, at least of an animal, function as a unit, this harmony of action demands a somewhat similar harmony of structure. We should expect to find that organs which function together would vary together. The analysis of comparative measurements proves this to be a fact. The abstract index of variation of one organ may be compared with that of another in order to get a single *coefficient of correlation* (usually designated "*r*"). The methods for securing this result are somewhat complicated and will not be entered upon here. The degree of correlation, *i.e.* the value of " r," is usually expressed in fractions of unity; in other words, if $r = 1.0$, then the correlation is complete; if $r = 0.0$. then there is no correlation. A correlation of .25 or less is usually considered too low to be significant, whereas one of .75 or more is very high. Following are some values of r for various dimensions of man and the flowers of the Celandine (Pearson).

Stature and upper leg bone	.80 to 81
Stature and upper arm bone	.77 to 81
Stature and fore arm	.37
Stature and cephalic index	.08
Cephalic index and intelligence	.029 to .19
Stamens and pistils (Celandine)	.43 to .75
Stamens and sepals (Celandine)	.06 to .02
Stature, fathers and sons	.39
Brothers (various characters)	.49

There is every reason to believe that similar correlations exist between physiological characters or between a physiological and a morphological character. The inherent difficulties of detecting and measuring physiological characters limit our knowledge in this respect. In the hormones which are manufactured in various organs and transported to other parts to excite physiological response, we can picture a possible mechanical basis for such correlations. It is obvious that they may constitute an even more significant factor in the existence of the organism than morphological correlations. An example of this sort of correlation is afforded by

Professor Pearson's studies upon the poppy, in which he found a very marked correlation between the fertility of the plant, as indicated by the seeds developed, and the number of stigmatic bands on the seed capsule.

Effect of Life Conditions upon Variation. — It has been shown, both by comparative studies on plants and animals at different ages, and also, experimentally, by varying the external conditions, that the younger stages of ontogeny show a much greater range of variability; in other words, that there is a progressive reduction of variability in development. It must be kept in mind constantly that general statements of this sort apply to masses of individuals and not to single individuals. The weeding out of the extreme variates in the course of development would bring about a similar result.

Suddenly and profoundly altering the conditions of life appears sometimes to increase the variability of organisms. The English sparrow was imported into America about the middle of the last century, and its new surroundings proved so favorable that it soon spread over the whole country. The eggs of 868 sparrows from America and an equal number from England were studied, and it was found that the former were considerably more variable both in size and in color. Whether one is justified in extending such a conclusion into a general law may be questioned.

Thus it has been long thought that domestication increases the variability of organisms. Without doubt a greater range of characters is permitted to survive by the florist or animal-breeder than would be found in a state of nature, but the innate capacity for varying, the true variability of the species, does not appear to be altered.

In some way not understood the climate of a region has a marked influence upon the variability of the plants and animals inhabiting such a region. A botanist has compared some twenty-nine kinds of trees grown in America and Europe under practically the same conditions. His results are quoted by Darwin as follows: "In the American species he finds, with the rarest exceptions, that the leaves fall earlier in the season, and assume a brighter tint before they fall; that they are less deeply toothed or serrated; that the buds are smaller; that the trees are more diffuse in growth and have fewer branchlets; and lastly, that the seeds are smaller, — all in comparison with the corresponding English species."

Causes of Variation.— Variations may be of two kinds: those that are induced by the direct action of the surroundings and those that arise spontaneously "from within" the germinal substance. The former are called *somatogenic*, inasmuch as they affect only the soma. As we shall see a little farther along, such characters affect the individual without being "handed on" to its posterity, and hence, from the standpoint of the race, are transitory in nature. On the other hand, variations in the germinal substance, in the nature of things, will affect future generations. Such are called, therefore, germinal or *blastogenic* variations.

There have been numerous theories dealing with the *architecture* or organization of the germ-plasm, which account for the spontaneous appearance of new characters, but all such hypotheses are founded upon abstract speculations and yield no verifiable explanation. Nevertheless the knowledge that we have gleaned through observation and experiment, of what goes on in the germ-cells just prior to the initiation of the ontogenetic process, is sufficient to afford us a good clue to what *may* be the source, or at least one source, of germinal variations.

It will be recalled that both gametes undergo a process of maturation just before zygosis takes place, in the course of which the amount of the chromatin in the animal egg is reduced and the number of chromosomes in both gametes is halved. This phenomenon is known as reduction. By it there is frequently, perhaps always, produced two kinds of male gametes and two of female gametes. The possibilities of fusion between these two sorts of gametes are fourfold. But more than this; in the extremely complicated process of mitosis it is very unlikely that the chromosomes should in every way be exactly halved, and since we believe the nature of the organism to be determined in large measure by the chromatin substance which is passed on in the germ-cells, the potentialities of the zygote may be highly modified by very slight changes in the germinal substance brought about by such unequal cleavage. Furthermore, it is believed by many that there is an individuality of the chromosomes, such that it is not a matter of indifference in what position they may lie in the conjugation known as synapsis, which occurs just before reducing division of maturation. It has been shown that *if* the chromosomes are all qualitatively different, then the following relations hold: If there are two chromosomes in the somatic cell and hence but one in the reduced gametes, there are two possible combinations in the gametes and four in the zygotes; if there are eight in the somatic cells, there will be 16 possible combinations in the gametes and 256 in the zygotes; if 16 in the somatic cells, then there will be 65,536 possible combinations in the zygote; if 32 in the somatic cells, there may be over 4,294,467,296 possibilities in the zygotes. It would seem, therefore, that on a basis of chance alone abundant opportunity for blastogenic variation is afforded by the mechanism by which the reduction and subsequent recombination of chromosomes is brought about in maturation and zygosis.

HEREDITY

Heredity and Inheritance. — All living creatures, as we have seen, are descended from ancestors which they resemble more or less closely. The facts of variation teach us that the resemblance is never an actual duplication, yet all organisms " conform to type," and in most cases, except in those in which a marked alternation of generations has been developed, the resemblance is closest between the progeny and its immediate ancestors. This fact of resemblance between relatives is called *Heredity.* It has been defined as " the genetic relation between successive generations." In popular writing we often read of " The Law of Heredity." In the sense of an external constraining influence that creates or compels such a resemblance, there is no such thing, of course. Laws of that sort do not exist in the world of Nature. As a matter of fact, Heredity implies merely a comparison between related organisms and is not a " thing in itself."

It will be recalled at once that such resemblance may be specific; that is, a particularly long nose or a certain cast of feature may be the common possession of both father and son. Such physical traits, by an easy-going analogy, are naturally classed in the same category with material heritage such as property and lands, which descend from father to son. It must be kept in mind, however, that this is an analogy only. The physical features of the individual are the result of development from a relatively undifferentiated germ-cell. They were nonexistent in the zygote. On the other hand, these characteristics, as we shall see later, may be passed on without even appearing in visible form, to reappear in a subsequent generation. For this and many other reasons it is difficult not to believe that the characteristics of the individual inhere in some way in the physical make-up of the germinal substance. Whatever this substance may be, it, with its accompanying potentialities, is spoken of as the *Inheritance* of the individual. The term *Heredity* is applied to the larger phenomenon, by virtue of which such genetic resemblances universally occur among organisms. Inheritance is concrete, heredity is abstract.

Individual Heredity and Racial Heredity. — All the individuals of any given sort of animal or plant resemble one another more or less closely, else we would not be able to group them together. For instance, all white oaks look sufficiently alike so that we may distinguish them easily from other oaks. In the same way, the physical characteristics of a Chinese or an Englishman are sufficiently pronounced so that either race is easily recognizable; yet the similarities that class them both as human beings, on the one hand, and the peculiarities that distinguish them as individuals, on the other hand, are equally evident. There are grades or degrees of physical resemblance which correspond, in general, with the closeness or remoteness of relationship of individuals or groups.

The reason that this is so, is that the characteristics of an individual are not alone its inheritance from two parents, but also from a great number of grandparents and other ancestors many generations back. It is obvious that there must be much mixing and intercrossing in the remote parentage of any individual. Thus there is a racial inheritance, which is the common possession of all the individuals of any group or race. When we try to picture the characteristic features of this sort of heritage, we find that we must abstract the qualities of a great number of individuals and make a sort of composite or average of them, *i.e.* such a description is that of an ideal individual instead of a real one. We unconsciously do this whenever we form a mental picture of an organism, such as a trout, or an apple tree, or a butterfly.

Galton's Law of Ancestral Inheritance. — We have found that one fruitful way of comparing the likeness or difference between two groups of individuals is by calculating the abstract index of correlation of the variations. Correlating the resemblances between parents and offspring gives us an index of the degree of inheritance which we may assume the latter derive from the former (on the average, not individually). Sir Francis Galton, a famous student of heredity, calculated in this way the degree of inheritance received by the offspring from parents and from more remote ancestors, and concluded that, *on the average*, the individual receives one half his heritage from his two parents, one fourth from his four grandparents, one eighth from his great-grandparents, one sixteenth from the great-great-grandparents, and so on. Subsequent calculations have modified these fractions, increasing the percentage derived from the immediate parents and decreasing that from more remote ancestors. But it seems to remain true that half or more than half of the individual's inheritance is derived from his immediate parents.

The sort of characteristics with which Galton worked were such as vary continuously; for example, stature and other measurable qualities. It is a frequent characteristic of such structures, that they blend or mix in inheritance. The children of tall fathers and short mothers tend, on the average, to be neither tall nor short, but rather intermediate in height. It has been found that this is not at all true of a great many kinds of inherited characters. The eye-color of a child whose mother has blue eyes and his father brown eyes will not be a blend or a mixture of the two colors, but will be like either one parent or the other. (There is an occasional exception.) Again the cross between a white flower and a red flower will frequently be striped red and white. In such cases, it is evident that Galton's law of ancestral inheritance does not apply. It is customary to call the last type particulate inheritance, the second type (such as eye-color) alternative inheritance, and the first type, blended inheritance. Whether or not there is any fundamental difference between the three types has not been fully established. Recent breeding experiments with both plants and animals have shown that an unexpectedly large proportion of inheritance is of the alternative type, and a correspondingly small proportion truly blended or particulate.

Filial Regression. — Galton also worked out, by statistical methods, a law which he named the law of filial regression. If we take the mean height of a group of fathers, selected because they are more than normally tall, and compare it with the mean height of their sons, we shall find that the latter average nearer mediocrity; that is, they "regress" toward the normal. Regression does not mean degeneration, but merely a shifting toward the mass-center of the type. It may be upward as well as downward, *i.e.* the sons of short fathers, on the average, tend to be of somewhat greater stature, again a shift toward the mean of the type.

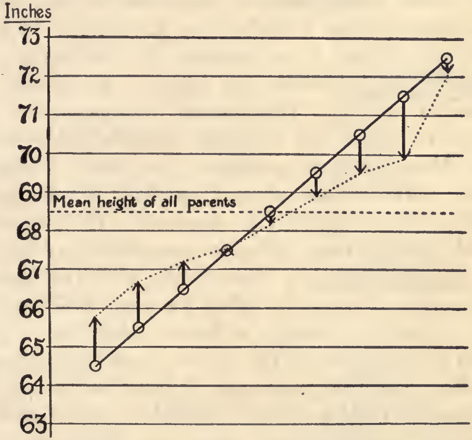

Fig. 78. — Scheme to illustrate Galton's Law of Regression. — (From Walter.)

Effect of Selection in Heredity. — The fluctuating variations which group themselves in a probability curve have been especially noticed in domesticated plants and animals, although they are probably no more or less numerous in the wild types. In the former, man has been long accustomed to pick out or " select " the particular type that he favored for breeding purpose, knowing that the progeny will be similar. Thus, it is desirable in the culture of sugar-beets to secure as high a percentage of sugar as possible. The amount of sugar which the beet-root stores up, although modified by external conditions, such as sunshine or its lack, is due in great part to the inherent qualities of the seed, that is, is an hereditary character. In unselected stock the percentage of sugar is usually 7 per cent to 14 per cent. If only those beets with the highest percentage of sugar be taken for seed, it is possible to increase this average in two to three years (that is, to shift the mode of the curve toward the maximum extreme), until a percentage of about 20 per cent is attained. But, curiously enough, further selection will not increase that percentage, and moreover constant selection is necessary in order that this maximum be maintained. Such an experiment shows, as did Galton's calculations, that the bulk of inheritance is derived from the immediate parents (otherwise selection would not alter the mode so rapidly), and, secondly, that there is a definite limit beyond which selection cannot alter the degree of inheritance, or perhaps, we may say, beyond which the preponderating influence of the immediate parents cannot overcome the cumulative weight of the mediocrity of the more remote ancestry.

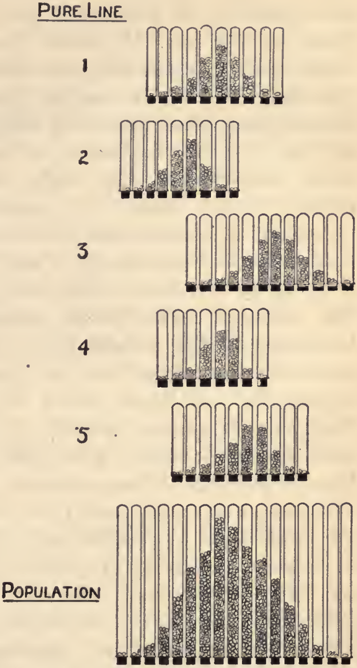

FIG. 79. — Diagrams showing five *pure lines* and a *population* formed by their union. The beans of each pure line are represented as assorted into inverted test tubes making a curve of fluctuating variability. Test tubes containing beans of the same weight are placed in the same vertical row. — (From Walter, after Johanssen.)

Pure Lines in Heredity.—Approaching the problem from a different angle, a Danish biologist, Johanssen, experimented by measuring the effect of selection upon a form in which cross-fertilization may be eliminated. The common garden bean is adapted for such an experiment, since it is normally self-fertilized. He accordingly measured the breadth, length, and weight of a quantity of beans and plotted the variation curve for the lot. He found that it followed the normal curve, *i.e.* the variations were of the fluctuating sort, grouping themselves about a mean. He then selected beans from both extremes for planting, and saw to it that the flowers on the resultant plants were self-fertilized. As might be expected, the progeny "took after" the parents; the beans of the second generation that were descended from the lightest beans were all of less weight, whereas those from the heavier were all heavier than the average. The variation curves for the progeny of each bean were also of the normal type, but with a much narrower class range than the curve for a miscellaneous lot of beans taken at random. From these smaller groups, each the progeny of a single seed, extreme variates were selected and planted. But the progeny of these seeds, when weighed, were found to group themselves in a curve with essentially the same mode as that of their progenitors. That is, within the group of plants descended from a common (self-fertilized) ancestor, selection has no influence, one way or the other, in shifting the mode for the next generation. Johanssen called these smaller groups within the mass of the species pure lines, or genotypes, in contrast to the larger group which all together they go to make up, and which he called the phænotype. Ordinarily, cross-fertilization is continually mixing one pure line with another, and as the greater number of such pure lines group themselves about the mean of the whole mass, the curve for any random lot of individuals is a normal curve. Artificial selection, however, picks out not only extreme individuals, but, at the same time, extreme "pure lines." Since the latter are, themselves, unmodified by selection, a rational explanation is at once offered to account for the puzzling fact that a race, such as the sugar beet, may respond promptly to selection, but refuse to respond at all beyond a certain point.

Similar results have been obtained for protozoa (*Paramecium*), in which the habit of asexual reproduction enables the experimenter to isolate his pure lines and do away with the disturbing effects of crossing. A mutation or discontinuous variation might be explained, perhaps, as a coming into existence of a new "pure line," though by what method, or from what cause, we at present cannot say.

Unit Characters and Mendelian Inheritance. — The statistical study of inheritance deals only with organisms in the mass, and its conclusions are inapplicable in individual instances. The more precise its results, the more abstract they become. But heredity is, after all, a personal matter, and it is of the greatest interest to discover, if possible, just what are the laws that determine the distribution of inherited qualities in individual instances. Within recent years very remarkable progress has been made in the solution of this problem, although, as is so frequently the case, the increase in knowledge has chiefly served to reveal the immensity of the fields that yet remain to be explored.

The beginning of this line of work we owe to the efforts of a monk named Mendel, who worked in the cloister garden of his monastery at Brünn (Austria), in the middle of the last century. The results of his experiments were published shortly after the publication of Darwin's famous "Origin of Species," and were so completely eclipsed by the controversies arising out of that famous hypothesis, that they were buried in obscurity, until the facts were rediscovered at the beginning of the present century.

The material that Mendel worked with was the common garden pea, which affords a number of diverse and easily recognized characters, such as the habit of the plant, the color of the flower and of the seed, the nature of the seed-coat, etc. When Mendel crossed (hybridized) peas that differed with respect to these characters, he found that such characters behaved as independent units. Thus, in his first and classic experiment, two strains of peas were crossed, a tall and a dwarf. The matured seeds of this cross were saved and planted. The plants that grew from them were all tall. It made no difference whether pollen of the dwarf were used on the stigma of the tall, or *vice versa*, the result was always the apparent extinction of the dwarf characters, — the plants were all tall. When, however, the flowers of these tall (hybrid) peas were self-fertilized and the matured seeds planted, the resulting plants were of two classes. Some of them were tall and some dwarf, like the original, in the approximate proportion of three of the former to one of the latter. Again self-fertilizing the flowers on the various plants, he found that the seeds from the dwarf plants developed dwarfs, and this was repeated in subsequent generations, whereas some of the tall plants developed only talls (*i.e.* " bred true "), and others developed both talls and dwarfs, again in the ratio of three to one.

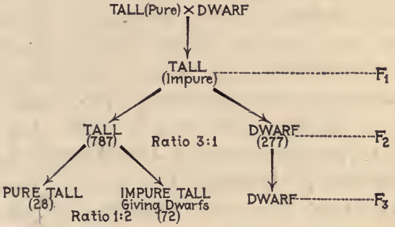

FIG. 80. — Diagram of the ratios obtained by Mendel in crossing tall peas with dwarf. — (Punnett.)

Two important facts are brought out in this experiment. First, the characters " tallness " and " dwarfness," whatever their predetermining cause[1] may be, exist in the gametes as segregate entities, sorting out in mathematical ratios in each generation. To such, the name " unit characters " has been

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[1] " Tallness " in peas differs from tallness in human beings in that it depends upon the characteristic length of internode between the joints where the leaves are given off, *i.e.* the dwarf pea is not a miniature pea but a different kind of a pea with regard to this one character.

given. Secondly, these two "units characters" bear some relation to each other, such that one may be suppressed, as it were, and fail to develop in a given generation, and, at the same time, be passed on to another generation, there to become manifest. Characters that are thus linked together in couples have been called by recent investigators "allelomorphs." Tallness and dwarfness in peas are therefore hereditary qualities that fall in the category we have already called alternative inheritance. Since, in the presence of the former, the latter is unable to manifest itself, Mendel used the adjective *dominant* for the tall character, and *recessive* for the dwarf. A diagram will serve to make this clearer. T indicates the tall character, D, the dwarf character, the parenthesis denoting the recessive or latent condition of the character. The first hybrid generation is called the filial generation, F, the second, F_2, and so on.

In considering the F_2 generation, in which the dwarf character reappears, it is also evident that there are two classes of talls. For subsequent breeding (always with self-fertilization) shows that whereas one third of the talls, like the dwarfs, always breed true, the other two thirds (one half of the whole number) contains the dwarf character in a latent or recessive form, since the latter reappear again in the same ratio, 3 : 1, as that of the previous generation.

If we assume that the gametes, whose fusion produces the zygote and hence determines the characters of the individual, are always " pure " for one or the other of such a pair of alternative characters, then the dwarfs in the F_3 generation may arise from the fusion of two gametes, both of which contain the " factor " for dwarfness. They breed true because the factor for tall is absent. We are accustomed to speak of such an individual as *homozygous* for such a character. The same could be said of the talls that breed true. All of the gametes produced by such a homozygous individual would be of one and the same kind. On the other hand, if a gamete that carries the factor for tallness fuses with one that carries the factor for dwarfness, the latter would become recessive and the indiviual would be tall, but the gametes developed by such an individual might be of the two kinds, one carrying the factor for the tall, the other for dwarf. An individual of this sort is called *heterozygous* for such a character. Remembering that the purity of the gamete with respect to these characters is postulated, and that each kind is produced presumably in equal numbers, if fertilization occurs at random, then by the law of chances there would be twice the opportunity for heterozygous as for

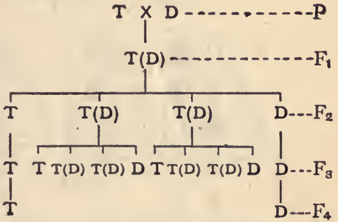

Fig. 81. — Diagram of the results of crossing tall and dwarf peas; see text. — (From Punnett.)

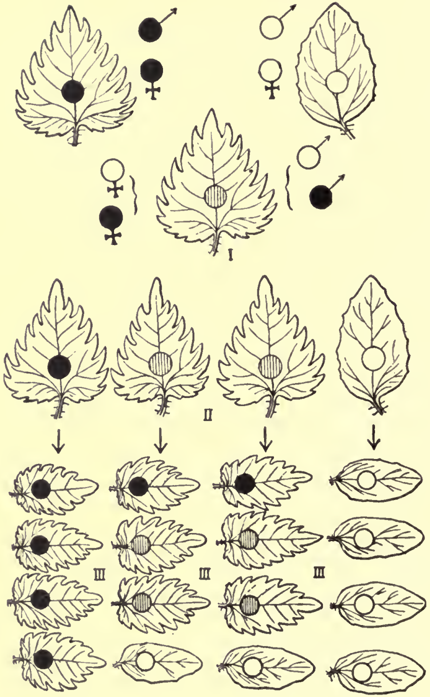

Fig. 82. — Mendelian inheritance in nettles: *I*, the leaves of the two parents, *Urtica pilulifera* (at the left) and *Urtica dodartii* (at the right); the serrated type of leaf is dominant; *II*, the leaves of the hybrid's offspring (F_2 generation); the pure gametes are represented by the black and white disks, and the "impure" by the cross-barred disks; in *III*, the F_3 generation, their descendants are constant (right and left), the other two fourths sorting out as before. — (From Hertwig, after Strassburger.)

homozygous fusions to occur. A glance at the diagram (fig. 83) will make this clear.

One fourth would be pure recessive (DD), two fourths impure dominant ((D) T) and (T (D)), and one fourth pure dominant (TT). Now T (D) and (D) T are identical and contain the recessive (D), which in a subsequent generation sorts out in a similar fashion, giving homozygous dwarfs and talls, and heterozygous talls. The last two classes would be indistinguishable on account of the dominance of the tall character, but would sort out very differently in continued breeding, as experiment shows. In Mendel's original experiment he got 787 dwarfs and 277 talls in the first filial generation, and of the latter 28 were pure in the succeeding generations. In other words, the actual experimental result bore out strongly the hypothesis formulated, which is based upon the assumption of the purity of the

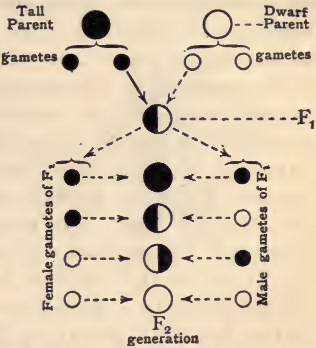

FIG. 83. — Scheme of the possible zygoses of the gametes of two parents that differ with respect to one character, such as the tallness and dwarfness of Mendel's peas. The two parents breed true, that is, have but one kind of gamete (homozygous). There are four possible combinations and hence four theoretical types of zygotes. Owing to the phenomenon of dominance, three of these cannot be outwardly distinguished from one another. — (Punnett.)

gametes on the one hand, and, on the other, the segregation of the unit characters in the zygote and their chance union in subsequent zygoses. Subsequent investigation has shown that the problem is by no means so simple as might be inferred from the behavior of Mendel's peas. The "dominance" of one unit-character over another has been shown to be imperfect or non-existent in many cases, and, more striking still, the character of the first hybrid generation is not infrequently quite different from either of the immediate parents. A remarkable instance has been worked out in some breeds of the domestic fowl. The following quotation from Punnett's "Mendelism" gives the essential facts:

"Many of the different breeds of poultry are characterized by a particular form of comb, and in certain cases the inheritance of these has been carefully worked out. It was shown that the rose comb (fig. 84, *B*), with its flattened papillated upper surface and backwardly projecting pike, was dominant in the ordinary way to the deeply serrated high single comb (fig. 84, *C*) which is characteristic of the Mediterranean races. Experiment also showed that the pea comb (fig. 84, *A*), a form with a low central and two well-developed lateral ridges, such as is found in Indian game, behaves as a simple dominant to the single comb. The interesting question arose as to what would happen when the rose and the pea, two forms each dominant to the same third form, were mated together. It seemed reasonable to suppose that things which were alternative to the same thing would be alternative to one another — that either rose or pea would dominate in the hybrids, and that the F_2 generation would consist of dominants and recessives in the ratio 3 : 1. The result of the experiment was, however, very different. The cross rose × pea led to the production of a comb quite unlike either of them. This, the so-called walnut comb (fig. 84, *D*), from the resemblance to the half of a walnut, is a type of comb which is normally characteristic of the Malay fowl. Moreover, when these F_1 birds were bred together, a

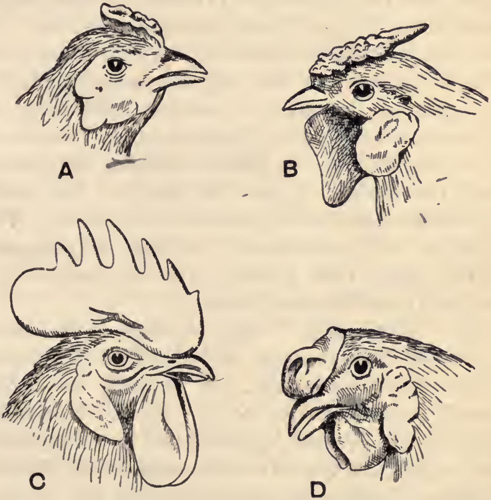

Fig. 84. — Fowl's combs: *A*, pea; *B*, rose; *C*, single; *D*, walnut.

further unlooked-for result was obtained. As was expected, there appeared in the F_2 generation the three forms, walnut, rose, and pea. But there also appeared a definite proportion of single-combed birds, and among many hundreds of chickens bred in this way the proportions in which the four forms, walnut, rose, pea, and single, appeared was 9 : 3 : 3 : 1. Now this, as Mendel showed, is the ratio found in an F_2 generation when the original parents differ in two pairs of alternative characters, and from the proportions in which the different forms of comb occur we must infer that the walnut contains both dominants, the rose and the pea one dominant each, while the single is pure for both recessive characters. This accorded with subsequent breeding experiments, for the singles bred perfectly true as soon as they had once made their appearance."

The "Mendelians" have devised an ingenious hypothesis which explains very plausibly the findings in the above experiment, but to carry the details further would take us too far afield. The single comb, however, that appeared in the experiment just quoted is the sort of a comb possessed by the wild jungle-cock, which is considered to be the ancestor of all our domestic breeds. Its unexpected appearance after perhaps thousands of generations of fowls in which it was absent, that is, replaced by another variety of comb, is spoken of as a *reversion* or throw-back. This puzzling phenomenon is familiar to all animal and plant breeders. With the light which the studies of Mendelian inheritance have thrown on the subject, it is reasonable to believe that reversions are merely the reappearance of unit characters which have been latent, generation after generation, because the proper combination of causal factors or the removal of an inhibiting factor has not occurred in mating. The factor has been "passed on," however, from parent to offspring under the surface, so to speak, until the disturbing hand of the experimenter has set new combinations or removed the inhibitions.

Sex-limited Inheritance. — Experiments have shown that, in many cases, the correlations of somatic characters are only explicable on the assumption that the factors for these characters are coupled or linked together, and that one is not manifest without the other. A striking example of such a correlation is found in the fact that certain characters are only manifest in one sex although transmitted through both sexes. This involves the further assumption that sex itself is a Mendelian allelomorph, an hypothesis that had been advanced earlier on cytological grounds. Thus, color-blindness in human beings is a condition much more prevalent in men than in women, and it has been found that whereas a woman, a daughter of a color-blind man, may not reveal this character herself, she will transmit it to her sons, who will be color-blind. On the other hand, her daughters, though capable of passing on the trait, will, themselves, not be affected.

A more striking example is found in the little pomace fly, *Drosophila*, which Professor Morgan has investigated with remarkable results. This little fly is easily bred in captivity on fermenting bananas, and as its life cycle is very short, it is possible to obtain generation after generation the year round, and in immense numbers. A number of mutations have been obtained involving various somatic characters, such as eye-color, length of wings, etc., which breed true. In nearly every instance, however, these characters are sex-limited; that is, although transmitted through either sex, they become manifest in only one.

Economic Aspects of the Subject. — Previous to the discovery of the laws of Mendelian inheritance, animal and plant breeders were accustomed to choose the types they desired and "breed to" them; in other words, to practice strict artificial selection. The fixing of the type in this way was a slow process and its stability always problematical. The application of the laws of Mendelian inheritance has changed the procedure of the modern experimental breeder and has substituted certainty for previous uncertainty in the result, and at the same time greatly shortened the time required to attain the desired form. A concrete example will make this clearer than any general discussion. "Taken as a whole, English wheats compare favorably with foreign ones in respect of their cropping power. On the other hand, they have two serious defects. They are liable to suffer from the attacks of the fungus which causes rust, and they do not bake into a good loaf. This last property depends upon the amount of gluten present, and it is the greater proportion of this which gives to the 'hard' foreign wheat its quality of causing the loaf to rise well when baked. For some time it was held that 'hard' wheat with a high glutinous content could not be grown in the English climate, and undoubtedly most of the hard varieties imported for trial deteriorated greatly in a very short time. Professor Biffin managed to obtain a hard wheat which kept its qualities when grown in England. But in spite of the superior qualities of its grain from the baker's point of view, its cropping capacity was too low for it to be grown profitably in competition with English wheats. Like the latter, it was also subject to rust. Among the many varieties which Professor Biffin collected and grew for observation he managed to find one which was completely immune to the attacks of the rust fungus, though in other respects it had no desirable quality to recommend it. Now as the result of an elaborate series of investigations he was able to show that the qualities of heavy cropping capacity, 'hardness' of grain, and immunity to rust can all be expressed in terms of Mendelian factors. Having once analyzed his material, the rest was comparatively simple, and in a few years he has been able to build up a strain of wheat which combines the cropping capacity of the best English varieties with the hardness of the foreign kinds, and at the same time is completely immune to rust."[1]

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[1] Punnett, "Mendelism," Chapter XIV.

The Inheritance of Disease. — Disease, to primitive man, must have seemed a very mysterious thing, a fiend or evil god to be placated or exorcised. Popular therapeutics in some parts of the world is still based upon such an hypothesis. Even in civilized society, the belief is still widely prevalent that disease is a sort of entity, to be gotten rid of, not perhaps by the bells and the tom-toms of the medicine man, but by the agency of drugs. Our grandmothers thought that boils were " better out than in," and took noxious doses for the purpose of " cleansing the blood " of them. We now know that disease is a *process*, not an *entity*. When my watch loses time because it needs cleaning, we might say that it runs "abnormally." The dust in the works is the cause of the condition, but it itself is not the abnormality; the abnormality is the slowing down of the movement. In the same way, abnormalities in the " running " of the human machine are due, in the majority of cases, to the presence therein of foreign bodies which bring about the altered conditions. Usually these microbes are bacteria, though sometimes they are minute protozoa. They are merely parasites that, in striving to get a living for themselves on the tissues of their host, produce poisons as an incidental result of their activity. These poisons produce the alterations in metabolism we call disease. If we can get rid of the active agents, the disease is cured, provided the damage has not gone too far. This may be done either directly (sterilization) or indirectly by a reaction which we call the development of immunity. This power has been previously mentioned. There is another class of disease-process for which we have not found a causative agent. This consists in the overemphasis of a metabolic process, itself normal, which only leads to trouble when the balance of the organism is thereby upset. Thus the laying down of fat, which is a normal and necessary bodily function, may become overemphasized and lead to a condition of obesity or even "fatty degeneration." The local overdevelopment of connective and epithelial tissues produces tumors, etc.

A third class of disease is concerned with the nervous system. Here the difference between normality and abnormality is very hard to define, but since the days of witch-burning and exorcism have passed, no one believes that insanity is anything more than a condition, not a thing, whatever may be the "derangements" of the nervous system in which it has its origin.

Owing perhaps to unconscious suggestion, due to the methods of insurance companies, there is a rather strong popular belief in the heritability of disease, a belief which, in most cases, is unfounded. If we recall the mechanism of inheritance and the fact that the organism derives its individual heritage through a single cell, the gamete, and reflect that disease-conditions are practically always manifested in the soma, it becomes evident that disease cannot be inherited unless there is something passed on in the germ-cell itself, which is involved in differentiation and later becomes a causative agent for disease. Since we must look upon disease as a process, and a process brought about, in the majority of cases, by the activity of poison-producing, parasitic bacteria, it is evident that there cannot be anything in the germ-cell, even of a diseased person, to produce the disease unless the germ-cell itself contains the microbe. With one or two exceptions this is not the case, since the disease-producing bacteria are usually localized in certain regions of the soma. Equally obviously, disease-processes that are merely alterations of normal metabolism cannot, in themselves, be inherited.

On the other hand, the disease-process is usually a sort of resultant of a parallelogram of forces, of which the strength of the invading microbe is opposed to the resistance of the victim. Now, not only may the resistance, *i.e.* the power of the body to produce substances that counteract or nullify the effect of the toxins, differ markedly in different individuals, but also this power, being a function of the physical organism, may be inherited in varying degrees. We are therefore justified in speaking of the inheritance of a *tendency* toward certain diseases, although what we really mean is the inheritance of a low resistance on the part of the body to the disease, and the consequent ease with which the disease is contracted. For in every case there must be a new infection in each generation. It is believed that even leprosy, one of the most dreaded of human afflictions, the

" taint " of which, in popular thinking, is indissolubly linked with the idea of its transmission, is not really inherited,[1] but is in each case a new infection.

The variation in the degree of specific immunity or resistance to certain diseases may be racial as well as individual. Thus it is frequently stated that various children's diseases, such as mumps, measles, etc., which with us are annoying, but by no means dangerous, affections, when introduced among isolated populations, such as those of the South Sea Islands, develop a virulence unknown among us, and may carry off whole communities. The " resistance " of strains or varieties of plants to disease is quite comparable to that of animals. The inheritance of resistance to the fungus-disease, " rust," to which wheat is subject, has just been mentioned. Without doubt a similar immunity-factor for various human diseases will be discovered in the near future.

Inheritance of Defects. — Nevertheless, observation teaches us that certain human conditions usually classed as diseases are indeed directly inherited. Deafness and color-blindness are found to be transmitted in the same way that hair-color or eye-color is. Hæmophilia, the name given to the condition in which the blood does not clot and on account of which the victim may bleed to death from a scratch,

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[1] "It is quite certain that the children of lepers born out of leper districts, in England or the United States, for example, never inherit it" — Quoted by Thompson from Hutchinson in Allbutt's "System of Medicine," I, 1896.

is another example. So is hyperdactylism, in which there is an abnormal number of toes or fingers. But these are physiological and structural *characters*, and not disease-processes in the true sense. They are merely characters unsuitable for preservation. We would not discover their hereditary character except that they are preserved through the altruistic endeavor of man, just as De Vries in his garden preserved the more delicate mutants of his evening primroses which otherwise would have been crowded out of existence in competition with the sturdier races. Such atypical racial characters are probably much more numerous than we are accustomed to think. They include not only structural and physiological items, but psychical and moral ones as well. While insanity, of itself, cannot be inherited, yet the structural basis for insanity, that is, an abnormal nervous system, is inherited just the same as any other structural character. Thus " innate depravity " is by no means a figure of speech, and " feeblemindedness " is very persistently inherited with all its accompaniments of mental and moral obliquity.

Eugenics. — Man, in contrast to the rest of organized nature, largely controls his environment instead of being controlled by it. Nature's eliminations are frequently nullified by his altruism. In preserving his " unfit," however, he is imposing a very heavy burden of support upon the fit and normal members of the race. It has been found that these so-called unfit members of society are fully as productive in rearing offspring as other classes. More than this, statistics show that the children of the most superior classes of humanity, both morally and intellectually, are very largely outnumbered by the mediocre or inferior. In other words, the superior classes, the cream of the race, are not continuing their heritage, and were it not for constant reënforcement from the "lower" grades of society, the so-called intellectual element would soon be self-exterminated. Professor Pearson estimates that twenty-five per cent of the mothers in Great Britain produce fifty per cent of the next generation. It is a matter of much moment to civilized man from what classes the coming generations are to be born. So far as statistics may be depended upon, it would seem that the proportion of defectives, comprising all sorts of persons who, on account of physical, moral, or mental abnormalities, are a burden to society, is steadily and rapidly increasing.

Much attention is being given nowadays to this problem and its solution. Francis Galton, who first called attention to the subject, invented the word "Eugenics," which he defined as "the science of being well born." If man proves himself able to cope with the problem, it will be because he has analyzed and tested the facts of heredity, the knowledge of which, alone will enable him to improve the human race, or prevent it from slipping back from the present standards of civilization.

CHAPTER VIII

ORGANIC RESPONSE

Environment. — Except in abstract thought, a living organism cannot be dissociated from the rest of the universe of which it forms a part. This "rest" we call the *environment.* It includes all external matter, the presence or absence of which, or the alteration of which, produces any sort of a change in the organism itself. The spatial limits included under the term environment are wholly relative. Thus, the soil-environment of a tree is very limited in extent, whereas the sun, in spite of its very great distance from the earth, forms a very essential part of its environment as well as that of all living forms. The community in which a man lives forms a significant part of his organic environment, since the presence or absence of other people affects and conditions his own actions. A few centuries ago such a social environment would have been very limited in extent on account of the isolation of communities. Nowadays, thanks to telegraph and newspaper, human activities in any part of the world may alter or affect the actions of any one; hence this sort of environment has greatly extended.

In a more limited sense, however, we usually apply the term environment to an organism's immediate surroundings; — the water, for instance, in which a fish swims, including in it such factors as temperature, light, chemical substances, pressure, etc. We have seen that the most impressive characteristic of living matter is its ceaseless flux and flow. This, however, is not only true of such unstable things as living organisms, but is also true, according to the story of Geology, of mountains and continents. The only permanent thing in the Universe, organic or inorganic, is its eternal changefulness. We have seen, too, that the existence of an organism or the existence of an aggregate of organisms is dependent upon a most delicate balance of innumerable "forces." But these forces may act external to the organism as well as internal; that is, they may be of the environment. Any change in the environment may thus produce a corresponding change in the balance of the organism. Such an environmental change may be called a *stimulus*. The readjustment in the organism due to such environmental change may be of two kinds. It may be a simple alteration of relations comparable to the crystallization of water with the lowering of the temperature to the freezing point, in which case we speak of it as a *physical response.* On the other hand, it may involve the release of energy stored up in the protoplasm, which manifests itself in ways peculiar to and dependent upon the organization of the latter. This second type of response is called the *organic response* or *reaction.* The stimulus in such a case may be compared with the impact of the hammer which explodes the cartridge. The most usual environmental changes producing organic responses are those of temperature, chemical conditions, light, electricity, and mechanical contact. This fundamental ability of the living matter to respond to stimuli is known as *Irritability*.

THE USUAL CONDITIONS OF ENVIRONMENT

Temperature. — For all living things a certain degree of warmth is requisite, but organisms vary greatly in this regard. For every organism there is an *optimum* temperature at which it grows and thrives best, and this is apt to be the usual temperature in which the organism naturally occurs. Plants and animals of the tropics require a higher degree of heat than do those of temperate zones, and when we transplant them they need "hothouses" in order that they may thrive. There is also for each sort of organism a minimum and a maximum temperature. Since protoplasm is so largely made up of water, its temperature cannot fall below 32° Fahrenheit, if life is to be maintained.[1] As we shall see further on, the protoplasm of some kinds of animals and plants may be protected against such conditions and hence may be unaffected by freezing temperature. It is equally obvious that the temperature of boiling water will destroy living matter by

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[1] The death of the living matter is due, in all probability, not so much to the alteration of the temperature *per se* as to the fact that the freezing of the water into needles of ice rends and tears the fundamental structures of the cell beyond repair.

coagulating its proteids, although authentic instances are known of lower plants and animals living in hot springs at a very little below boiling temperature.

Light. — As we have seen, sunlight is an absolutely essential condition of life for all green plants, and hence secondarily for all organisms, and the effect on plants of the alteration or absence of light is very marked. But sunlight is a destructive agent for many groups of molds and bacteria, particularly of many pathogenic forms, and in consequence man and the higher animals are very dependent on its cleansing and purifying influence. Sunlight destroys the " germs " that otherwise would threaten them with extermination through disease.

Chemical Environment. — Since the nature of the soil varies with its chemical composition, the organisms living in the soil are affected so far as these chemical substances are in solution. As combinations and recombinations of chemical substances are easily brought about and constantly occurring in the soil, the organism in general is very delicately adjusted to its chemical environment and influenced by it.

In the air we have both chemical and physical agencies to take into consideration. Not only its pressure (some 15 lbs. to the square inch), but more particularly its movements, have an important general influence on the organism, both plant and animal. In addition, the composition of the atmosphere has an important and more significant bearing on the conditions of life for all organisms. The oxygen, which constitutes 20 per cent of ordinary air, is absolutely essentially for practically all living things.[1] The nitrogen, as we have seen, is the raw material which the soil-bacteria transform into salts available for plants. The CO_2 is the source of the carbohydrates. Almost equally important in its effect on organisms, particularly plants, is the amount of moisture in the atmosphere. The difference in appearance between the vegetation of a dry arid region and one supplied with abundant moisture is familiar to every one. Of course, there is a very intimate relation between the moisture of the soil and that of the adjacent air, but the general appearance of a region is largely determined by the moisture brought to it by the wind in the form of rain-clouds.

The Nature of Organic Response. — From one point of view an organism may be considered to be always in a condition of stimulation, which we call *tone*. There must always be a certain amount of heat, for example, to make life-conditions possible. The increase or decrease of the external temperature, however, causes a readjustment on the part of the organism, which is the evident or perceptible *reaction*. This response may be of two sorts. On the one hand, the vital phenomena may be changed in character, or qualitatively, especially if the reaction is a very violent one, but more often they are merely

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[1] With the exception of the anaërobic bacteria, which get their oxyge in other ways.

changed quantitatively, *i.e.* increased or decreased, whence the reactions are sometimes termed excitations and depressions. The chemical stimulus of substances known as narcotics produces a depression of protoplasm. Increase of heat produces excitation, decrease (cold), depression. For each kind of protoplasm there are minimal and maximal limits of stimulation within which it displays its characteristic vital phenomena, but the *nature* of the reaction to any stimulus whatever is of course dependent upon the peculiar characteristics of protoplasm itself; in other words, upon its organic make-up. In proportion as protoplasm becomes specialized the nature of its response becomes more and more restricted. Any stimulus applied to a muscle, *e.g.*, causes the same sort of a response (contraction) whether the excitant be electrical, thermal, mechanical, or chemical. This specificity of response is sometimes known as the *law of specific energy.*

Electric Response. — In the majority of cases we recognize the existence of a stimulus and a response by a change of form, but excitation and response may be present without being evident to our senses. A nerve when stimulated shows no change in itself even though it transfer its stimulation to the muscle with which it is connected. Nevertheless if we lay across a nerve two electrodes, connected through a galvanometer, and stimulate the nerve by pinching it, we will see by the deflection of the needle of the galvanometer that an electrical change has taken place in the protoplasm of the nerve.[1] Similar electrical changes may be observed in other tissues as well, but only when alive; a dead nerve or a narcotized nerve gives no such reaction. This electric response, which may be demonstrated also in plants, has been referred to as the critical sign of life. But Professor Bose of Calcutta has shown that metals give a quite similar response, provided all strains have been removed by annealing. A tin wire thus treated, and "stimulated" by mechanical, thermal, or chemical means, will show the same phenomena of response that a nerve or a plant does. Bose's conclusions, which are very far-reaching, are that there is no essential difference between organic and inorganic matter, with respect to response. The difference between living and dead protoplasm, he thinks, is probably the condition of the absence or presence of permanent molecular strains, which is another way of saying that dead protoplasm is relatively stable, whereas the primary characteristic of living matter is its lability. The primary distinction between the response of living and of non-living matter, as already pointed out, lies in the fact that, in the former, the energy released by the response may be many times greater than that of the stimulus.

Individual Response to Unsymmetrical Stimuli. — Heretofore we have considered environmental stimuli in a general way, as affecting all parts of the

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[1] It has also recently been demonstrated that a stimulated nerve gives off CO_2, indicating the nature of the chemical reactions taking place within its substance.

FIG. 85. — Orientation of Nasturtiums toward the source of light: *I*, two plants growing in diffuse daylight; *II*, the same plants after a few hours' exposure to light from the window (at the left).

organism at once. It is evident, however, that many classes of stimuli — for example, rays of light, and currents of electricity — may affect only one part of the organism at a time, producing necessarily an unsymmetrical stimulation. If the more strongly stimulated side were concerned in movement, a change in direction would result. If, for instance, the stimulation should produce an increase of muscular or protoplasmic contraction on that side, the effect would be to turn the organism around until it should reach a position in which both sides were stimulated equally; in other words, to *orient* the organism. If, now, the progressive movements still kept up, the direction of the progression of the organism would be toward the source of stimulation. If the stimulus were a depressant instead of an excitant, the orientation would be reversed; that is, the reaction would be negative.

Recent experimental work has revealed an extraordinary range of responses of this sort among all kinds of animals and plants. The most familiar perhaps is the tendency of green plants to face the source of light. In some cases, as in the sunflower, the plant-head follows the sun as a compass-needle the magnet. The behavior of the unicellular "swarm spores" or of the motile gametes of the lower algæ is quite similar. They gather in a mass at the side of the dish exposed to the window. In the insect world the fascination of the moth for the flame has become proverbial. At first glance one might think that a wide gap exists between the mechanical bending of a plant and the movement of a free-flying organism, but careful experiment has shown that it is not curiosity that leads the moth to the candle, nor the exercise of a choice of any sort, but rather a mechanical orientation which the insect is powerless to control. Again, if microörganisms, such as *Paramecia*, be placed in a narrow trough of water through which a weak current of electricity is passed, they will orient themselves in the direction of the current and swim to one or the other of the two poles (usually the negative). This action is equally as unvolitional as the response to the source of light and may be reversed as often as the direction of the current is reversed.

We know very little of the nature of the mechanism underlying this phenomenon. Nor-

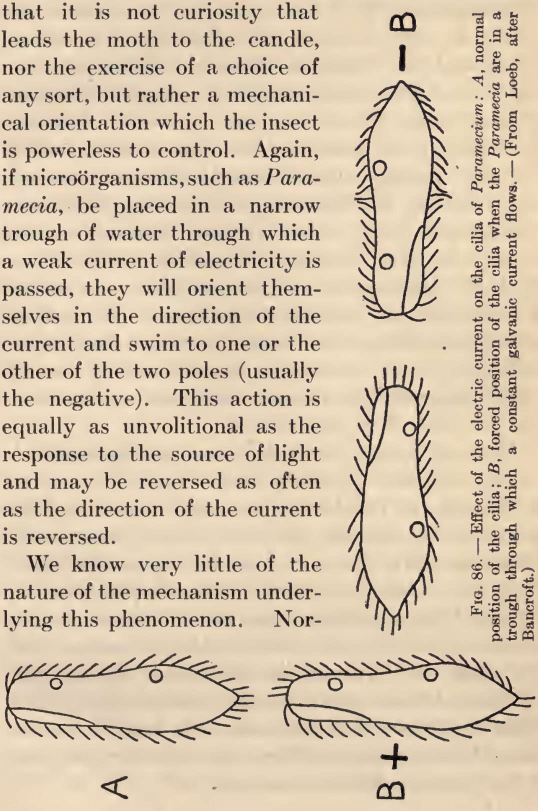

Fig. 86. — Effect of the electric current on the cilia of *Paramecium*: *A*, normal position of the cilia; *B*, forced position of the cilia when the *Paramecia* are in a trough through which a constant galvanic current flows. — (From Loeb, after Bancroft.)

mally the cilia of *Paramecium* beat in a continuous and specific manner, and the course of the organism through the water is determined by the shape of the cell-body itself. It is as incapable of modifying this movement as a man in a rowboat would be of altering that of the boat's movement. In the latter case the oarsman can only propel his craft forward, backward, or in a curve, depending upon his pulling the oars, pushing them forward, pulling on one oar more than on the other, or finally pulling on one oar and pushing on the other. Indeed these movements reduce to two, pushing and pulling. Now if we postulate that areas of the ciliated surface of *Paramecium* are capable of local and independent stimulation, then the stronger or weaker beat of the cilia due to such stimulation in certain regions would orient the organism, its own movements determining the direction of its progression.

The mechanical nature of such tropic responses is evident in cases in which the "tropism" may be arbitrarily reversed by the experimenter. Thus many small animals, like the swarm-spores mentioned, gather on the side of the dish toward the light. That this is not the expression of a choice or preference of the organism for one sort of illumination in contrast to another is demonstrated by the fact that changing the temperature, increasing the salinity (of sea-water), or even agitating the water, may bring about a reversal of the response. In such a way we alter the physiological state of the organism and cause it to react in a different manner.

Some biologists believe that the majority of reactions to stimuli, such as light, heat, diffusion of chemicals, electricity, etc., are based upon some such automatic mechanism. We should be very cautious, in any event, in interpreting such movements in terms of human experience, and ascribing choice and volition to organisms that exhibit such a response. On the other hand, the careful study of the behavior of a number of microörganisms has shown that the same individual will not react at all times in the same way to the same stimulus, which it would be compelled to do if the response were absolutely mechanical. The nature of the response is dependent upon the " physiological state " of the organism at the time of stimulation. But this does not mean that such responses are *purposive*, even if they are to the advantage of the organism possessing them.

Adaptive Response. — We are familiar with many ways in which our own bodies accommodate themselves automatically to environmental change. The greater demand we make upon a muscle, the more the muscle increases and grows to meet that demand. Those parts of the skin which are exposed to friction develop horny, protecting calluses. If, through disease, one kidney becomes ineffective or functionless, the remaining one grows larger (hypertrophy) in order the better to carry out the double burden laid upon it. These examples indicate how very plastic even such an organism as highly specialized man may be. The changes mentioned, and many other similar ones, are responses to external stimuli of various sorts, although we have no knowledge of the means by which the stimulus brings about its resultant reaction. Such reactions, however, differ in an important way from those mentioned in the previous section in that they are advantageous to the organism exhibiting them, often even to the extent of determining its preservation from destruction. A striking example of adaptive response to environmental change is found in the African chameleon and in its American representative, the lizard *Anolis*, of Florida and the Southern States. This creature displays a wonderful capacity for color change. Normally bronze, it runs through olive to pale green or turquoise blue. This change is produced by the migration, up and down through the dermis, of black pigment cells. Both heat and light are factors that bring about these color changes. Just to what extent the color changes of *Anolis* are advantageous to the lizards in causing them to resemble their backgrounds is a little difficult to estimate. There is not much question, however, that in some other forms, in which the changes are accomplished more slowly,

FIG. 87. — *Anolis*, the American chameleon.—(Coleman.)

such as the shore crabs, the tree-frogs, and the flat-fishes, the color change is protective and brought about under the direct influence of the environment. Another striking effect of temperature is that produced by cold upon hairy animals. The small shaggy ponies of Shetland and Iceland, while in their native land, are provided not only with the ordinary hair characteristic of horses everywhere, but also with a dense woolly fur underneath, which serves to keep them warm in very cold weather. When brought into a warmer climate, however, one year suffices to shed this dense coat, and thereafter the hair is no different from that of other horses.

Immunity. — One of the most striking examples of individual adaptation is found in the manner in which the higher organisms (or at least the warm-blooded ones) react against infectious diseases. An organism that is non-susceptible to a specific microbic disease is said to be immune to that disease. This immunity may be " natural " or it may be " acquired." It is probable that all natural immunity has been acquired during the lifetime of the race, through the automatic elimination of the non-immune individuals. Artificial immunity, on the other hand, is the individual affair of the organism. In pathology, two kinds are recognized : active immunity in which the tissues of the body react directly against the toxins of the invading bacteria, and passive immunity, which is conferred upon the individual by the injections of blood-serum from another actively immune animal.

The latter is the basis of the " anti-toxins " that are now so extensively used in combating infectious diseases. It is only the active immunity that concerns us here.

When disease-producing bacteria gain entrance to the body and begin to multiply, the products of their metabolism produce a poisoning or " toxic " effect, either upon the whole organism or upon certain organs, such as the nervous system. The body doubtless reacts in several ways. Thus it has been shown that the leucocytes devour the invading microbes and thus defend the organism from attack. But the most striking phenomenon is this: that the presence of the toxins stimulates the body to produce substances called " anti-bodies," which are carried by the blood and appear to combine with the toxins and nullify their poisonous effect. Once having been stimulated, the body continues to produce the anti-bodies after all disease-symptoms have disappeared. In this way, it is immune against a second attack, whereas it was susceptible before.[1] Moreover, the blood-serum carrying these anti-bodies may be drawn from one animal and injected into another, thereby conferring the passive immunity mentioned above.

Morphogenetic Response. — In the previous section, with a few exceptions, we have considered the reactions of the individual to stimuli that are, as a rule, of short duration, or at any rate produce no

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[1] In the human species it will be recalled that there are some diseases of which this is not true.

permanent alteration of the structure or form of the organism after their cessation. There is another type of response, however, which results in a permanent structural change and may therefore be called morphogenetic.

Non-adaptive Morphogenetic Response.—A great many experiments have been tried by different observers to test the effect of various sudden environmental changes on developing organisms. Abnormal conditions of heat and cold, humidity and dryness, food, etc., have been found to produce remarkable alterations in the color patterns of various butterflies and beetles. Standfuss, Fischer, and others have found that if chrysalids of moths or butterflies are kept in an ice-box prior to emergence, the perfect insects develop many "aberrations," *i.e.* the color markings of the butterflies are different from the usual type, often to a striking degree. It is very interesting to discover that these artificially produced aberrations are very similar to such as occur in nature and have received names in collections. Particularly is this true of such species as have "winter" and "summer" forms. In most cases, doubtless, the effect of the change in temperature is to directly alter the chemical processes taking place in the color-producing cells of the integument. As a general rule the effect of a slightly increased temperature is to hasten the activity of the color-producing enzymes and hence to increase the intensity of the color. With slightly lowered temperature the reverse is the case. It has been amply demonstrated that there is nothing *specific* in the effect of these variations in the environmental complex. Extreme heat and extreme cold will most often produce identical effects. Tower, in the course of long experimentation with the potato beetle, has shown that the exposure of the developing insect to moist conditions produces a dark (melanic) beetle, whereas the relative absence of moisture produces a corresponding lack of pigment (albinism). It is interesting to discover that the beetles found in nature in dry countries such as the southwestern United States are albinic, whereas those found in clayey soils in northwestern United States are melanic. The same conditions evidently have produced the same result, both in the laboratory and in a state of nature.

Influence of Food. — It is well known that many flowers may be artificially colored by allowing them to soak up various dyes. The presence or absence of numerous other chemical substances in the soil also produces a difference in habit of growth, size, color, etc. A considerable amount of lime, *e.g.*, will induce a hairiness on leaves and stems together with a more abundant foliage. It has been observed, too, that caterpillars fed on a different food plant from that to which they are accustomed sometimes develop into moths and butterflies with quite different color markings from the normal, although there is no relation between the color markings and the specific food plant. The color of the caterpillar in many species, however, is due to the color of the food plant. The egg of the honey bee develops either into a queen or into a worker according to the nature and quantity of the food that is supplied the larva by the attending bees.

General Adaptation. — To the man who stops to look below the surface of things one of the most wonderful aspects of nature is the apparently perfect way in which all living organisms are suited to the particular sort of environment in which they are found. As soon as one realizes that the environment is not a permanent, changeless sort of a thing, but is as plastic and impermanent as the organisms themselves, the marvel grows that so many forms of life should be or should have become adapted to a particular sort of environment at a given time. And the more thought that is given the matter, the more it is realized that this adjustment is one of the fundamental problems of biology. We have seen that the individual, as a rule, responds very quickly to any alteration of environmental conditions, but experiment also shows conclusively that the response is only individual and that the abstraction we call race, or species, is unaffected thereby. How, then, does it come about that the species is so admirably adapted? Two answers have been offered to this problem, the Darwinian and the Lamarckian, and this theoretical aspect of the phenomena we shall consider in the next chapter, contenting ourselves for the present with reviewing some of the more striking examples of adaptation. It must not be forgotten, however, that all species, except, perhaps, such as are in the process of extinction, are very adequately adapted to the particular environment in which they are found, else they would not be existent at all.

SOME TYPES OF ADAPTATION

Aquatic Organisms.—All the animals that live in the water show a certain general form and structure

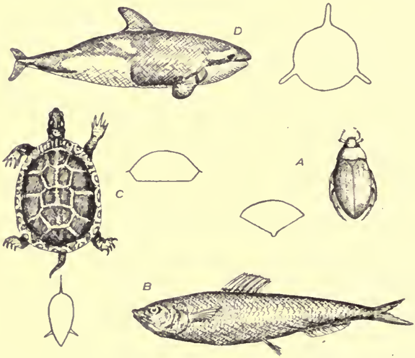

FIG. 88. — Types of aquatic adaptation, showing convergence toward a boat-like structure in diverse and unrelated groups of animals. The outline opposite each figure is a diagrammatic cross-section: *A*, diving beetle; *B*, herring; *C*, mud turtle; *D*, killer whale (a warm-blooded animal most nearly akin, perhaps, to the cud-chewing mammals or perhaps to the ant-eaters).

that enables them to go the more easily through the resistant medium in which they live. If we examine a diving beetle (fig. 88, a), a fish (fig. 88, b), a turtle

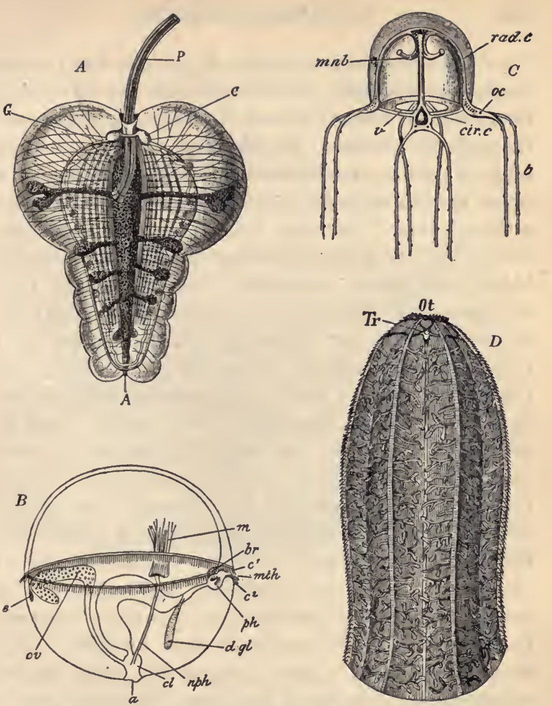

FIG. 89. — Convergence toward a globular form in unrelated pelagic organisms: *A*, *Pelagonemertes*, a *Nemertean* worm which floats on the open sea; its congeners are very elongate and "worm-like" and live near the shore; *p*, proboscis; *g*, proboscis sheath; *c*, cerebral ganglia; *B*, *Trochosphæra*, a *Rotifer*, allied to the worms, which swims by means of a circlet of cilia, c^1, c^2; *C*, a free-swimming medusa (*Bougainvillea*) typical of the phylum *Cœlenterata;* *D*, a *Ctenophor* (*Beroe*), a member of a group that is but distantly related to the *Cœlenterata*, with which, however, it is usually included in textbooks; *ot*, balancing organ; *tr*, funnel of the digestive canal. — (*A* and *D*, from Sedgwick; *B* and *C*, from Parker and Haswell.)

(fig. 88, c), or a whale (fig. 88, d), we see that in each there is a swelling, curving contour like that of a boat, which offers the least resistance to movement through the water. In addition, a sharp cutting edge or keel is sometimes developed. Although the forms mentioned have very little else in common, and although their " relatives " differ much from one another, yet in accommodation to a free-swimming habit they have " adopted " each a general type of structure. This sort of a resemblance between organisms otherwise unrelated, in adaptation to a common environment, is called *Convergence*. In those marine forms which float semipassively in the open sea (pelagic organisms) convergence may be carried to a greater extreme. (Compare fig. 89.) Here two factors have been of significance in each type: (*a*) the necessity for decrease in specific gravity and (*b*) a minimum increase of surface for the maximum of bulk. A sphere is the shape that ideally fits the latter condition, and we find that pelagic organisms in general tend toward a spherical form. The former condition has brought about an elimination of a great part of the solids in the organism, and the result is a form which contains a very large per cent of water and is usually semitransparent.

Aërial Adaptations. — The development of winglike structures has enabled representatives of various diverse groups of organisms to maintain themselves in the air. The whole group of insects is preëminently of this class, and of the vertebrates, the birds, although the bats, among the mammals, share with the birds the conquest of the air. But in some other groups as well, special types of aërial or semi-aërial forms are thus endowed. In the flying-fishes the pectoral fins are long and expanded, so that the fish, after attaining headway in the water, can shoot above the surface and, spreading the fins, soar like an aëroplane for long distances.

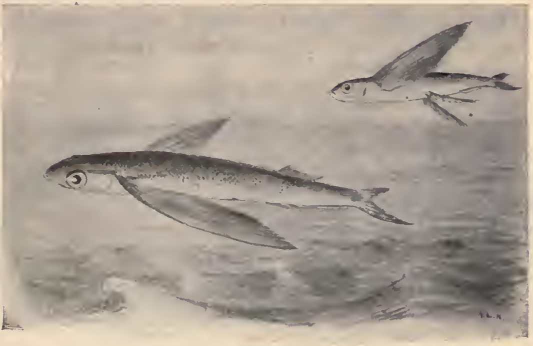

FIG. 90. — Two kinds of Flying Fishes. These fishes escape from their enemies by leaping into the air and sailing long distances. — (From Jordan and Kellogg.)

Subterranean Adaptations. — In the keen competition that exists among the various types of animals for a foothold and a chance to propagate their kind, not only the surface of the earth, the air, and the water have become filled with life, but, in the course of evolution, various different and wholly unrelated forms have become adapted to live under the earth itself. Omitting the Protozoa in the soil, of which, as yet, we know but little, and the animals that merely burrow in the ground for protection, we find that these various and diverse forms have all become modified in much the same way. In the water of subterranean caverns we usually find various crustacea (crayfish and their relatives), salamanders, and fishes. In every case these are blind, the same conditions apparently having produced the same consequence in all. In the absence of light eyes are useless, and Nature brings about their atrophy (just how, is a matter of speculation upon which biologists are not agreed). On the other hand, in the abysses of the sea, the weak light that filters down from the surface is apparently sufficient to make vision possible, and we do

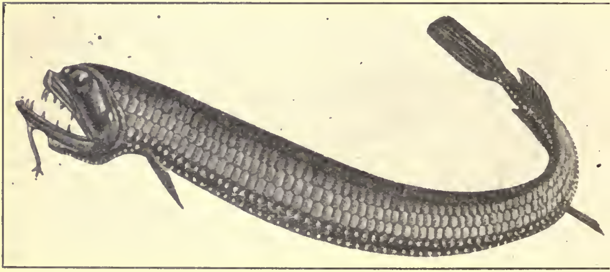

FIG. 91. — A deep-sea fish (*Stomias boa*) with luminous organs (photophores) along the sides. — (From Hickson, after Filhol.)

not find blind fishes in such a situation. In many of these forms "phosphorescent" organs or photophores are developed which function either as lures or as recognition lights or for the purpose of actually furnishing an artificial light for the creature's needs.

The ants are relatives of the wasps and bees, although their lives are mostly spent underground in the complicated galleries which they excavate. Their well-known structure is evidently well adapted to the peculiar life of the ant-nest. It is of great interest to discover that representatives of other groups of insects are found in ant-nests, and spend their lives underground. These include beetles, flies, crickets, roaches, and other types, but all of them, in accommodating themselves to the conditions of ant-life, have become altered (racially, of course, not individually) to such an extent that they have come to resemble ants and have lost their resemblance to related species of their own kind.

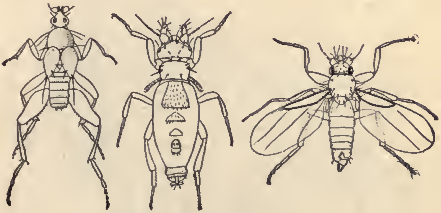

FIG. 92. — Ant-guests: Flies that live in ant-nests and are adapted for life underground; the one at the right is a male, the other two females. — (From Kellogg, after Wheeler.)

Protective Adaptation. — Some one has classed free-living animals in two groups, the preyers and the preyed-upon. Of course, many types would belong to both classes, but some find it easier to run away than to fight, and their chief characteristics are those which serve for protection rather than for aggression. Some, like the turtles or the majority of the mollusks, possess an armor within which they can withdraw, or like the porcupine or the spiny puffer-fish, an armor that wards off the aggressor. Others, like the hermit crab, which utilizes the protection of empty snail-shells and is modified in accordance with that peculiar mode of life, get their armor second-hand. An interesting adaptation for protection is that of the cuttle-fish and "devil-fish" (Octopus), which secretes quantities of an inky

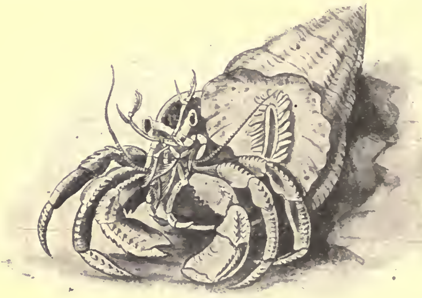

FIG. 93. — Hermit-crab (*Pagurus*) in a snail shell, with a sea-anemone attached to the shell. — (From Jordan and Kellogg, after Hertwig.)

fluid. When one of these mollusks is attacked, it beclouds the water by spurting out this fluid, and, under cover of this protection, makes its escape.

Protective Coloration. — Most striking of all adaptations whereby animals escape their enemies is that of protective coloration. A bird darts into a thicket and, strain our eyes as we may, we cannot see where it has gone. A grasshopper is started up and whirs away, conspicuously visible on account of the brilliant coloration of its wings, only to disappear utterly from sight as it drops back again into the grass. The bright colors are covered up, and the coloration of the outer surface of the body merges into that of the creature's surroundings. Not the least effective element of its disappearance is the sudden and bewildering contrast between the conspicuousness of the insect's appearance at one moment and its inconspicuousness at another. This condition extends to many unrelated types of animals. Along the white sandy stretches of the sea-shore, or the bare rocks and sands of the desert, practically all animal life partakes of the same whitish, inconspicuous ground-color. In the leafy depths of the forest the inhabitants are likely to be green as well. Familiar examples of forms that show such protective coloration are the tree-frog and the katydid, or the fishes that live among the sea-weeds in a tide-pool. Often an animal that appears to be most conspicuously marked when isolated on a museum shelf merges perfectly into its environment when it occupies its natural surroundings. Examples of this are grouse and woodcock and even domestic poultry.

Specific Resemblance. — The sort of protective resemblance just described is of a general nature; that is, the animal merges into the general background of its surroundings without resembling in particular any one element of its environment. Sometimes, however, the protective resemblance takes a more specific form, and an animal is found to resemble some specific object in its environment rather than the general background. Thus, the katydid's wings are veined in such a way as to resemble very closely a green leaf, and a common moth-larva not only mimics a dry twig in color and shape, but has the habit of extending its body out into the air from a branch so as to make the imitation almost perfect. Such examples may be found almost anywhere in the woods and fields, but they appear to be especially plentiful in the tropics.

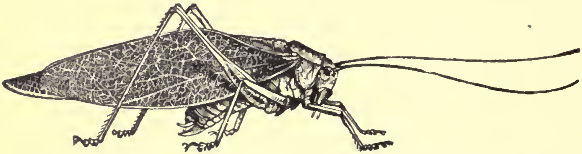

Fig. 94. — The Katydid (*Microcentrum*). The wings are colored and veined like the leaves of the vegetation in the midst of which the insect hides. — (After Riley, from Kellogg.)

Aggressive Coloration. — While many animals seem to escape detection by making themselves as inconspicuous as possible, others would appear to court observation. Wasps and bumble bees fly about unmolested, and many brilliantly striped and spotted bugs take no pains to conceal their conspicuous presence. This habit is likely due to the fact that they are not unprotected. The experience of stings in the one case or of a bad taste and odor in the other may make such an impression on an insect-eating animal that similar insects would thereafter be avoided. The bright and conspicuous colors would thus be a sort of advertisement or danger signal. The more conspicuous the color pattern, the less likely would the insect be eaten by mistake and the more valuable its livery. This would of course not help the insect so unfortunate as to be attacked, but the others of his kind would profit by the mistake. The victim, so to speak, would be sacrificed for the sake of educating its enemies to leave its relatives alone.

Mimicry. — The advantage enjoyed by such an advertisement is in some cases shared by other species that have no natural means of defense. Thus many bees and wasps are "imitated" so closely by certain flies as to make it almost impossible to tell one from another when on the wing. The same kind of natural fraud is found among butterflies. A familiar example of widespread occurrence in America is the mimicry of the Monarch or Milk

Fig. 95. — The mimicking of the inedible Monarch butterfly by the edible Viceroy. The upper figure is the Monarch (*Anosia plexippus*); the middle figure, the Viceroy (*Liminitis archippus*); the lower figure is another species of the genus *Liminitis* (*L. arthemis*) which is supposed to be the type from which *archippus* has been derived. — (From Jordan and Kellogg.)

weed butterfly, *Anosia*, by the viceroy butterfly, *Liminitis* (see plate). The larva of the former feeds upon the milkweeds, and it is supposed that its body-fluids partake of the disagreeable taste of the food-plant, and that on this account, being conspicuously colored, it is avoided by butterfly-hunting birds. Another group of butterflies not at all closely related to *Anosia* is the genus *Liminitis*, of which some seven or eight species are found in North America. All of these but two are marked with a white stripe across each wing and are very different in appearance from *Anosia*. The important exception is *Liminitis archippus*, which resembles *Anosia* so closely in general appearance that unless one were an entomologist he would hardly think of discriminating the two when on the wing. The advantage to *Liminitis archippus* of its masquerade may be inferred from the fact that whereas *Anosia* ranges over nearly the whole of North America and the viceroy also, the other species of *Liminitis* have very restricted and comparatively narrow ranges.

For such mimicry to be successful it is necessary that the mimic should vary widely from the type of its congeners and that it should be much less abundant than the "model." Natural Selection[1] has usually been called upon to explain such a phenomenon, but the theory offers many difficulties in such a case, and scientists are far from agreed upon an explanation. The fact of mimicry is, however, indisputable.

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[1] See next chapter.

The Care of the Young. — Another type of adaptation of very great value to the species in which it is developed is that involved in parental solicitude and care for progeny. Among the lower forms, particularly the invertebrates, the rule is for the mother animal to lay an enormous number of eggs and trust to luck, so to speak, that enough survive to maintain the position of the species. In many of the insects, however, this is not at all the case. The workers in a beehive or an ant hill attend and feed the helpless grubs until they are ready to shift for themselves. Among certain of the wasps, the mother, although depending for her own food upon nectar sipped from flowers, yet catches flies for her carnivorous young. Finally we have a situation such as is to be observed in *Zaitha*, one of the water bugs, in which the female seizes the weaker male, and in spite of his struggles, glues her eggs all over his back, transforming him, for the time being, into a nurse.

Fig. 96. — Water Bug (*Zaitha*). Male carrying eggs on its back. — (From Jordan and Kellogg.)

A somewhat similar example is to be found in the Surinam toad, *Pipa*. In this species, the female places the eggs on her own back, where they sink in, forming little pits that close over. When ready to hatch, the covers break off and the baby toads wriggle down to water to complete their metamorphosis. In another kind of toad, *Alytes*, the male wraps the strings of eggs around his legs and carries them until they hatch. One of the most remarkable of these habits is that of certain fishes which carry their eggs in the mouth until they hatch. The large "Gaff Topsail" catfish common along the Atlantic Coast, and other sea catfishes, have this habit, the eggs being carried from the time they are laid until the young fish is able to swim about by itself, at least three weeks, and in some cases probably much longer. As in the other cases, it is the male that does this, and during this period, of course, he takes no food.

FIG. 97. — The Surinam Toad (*Pipa*). — (From "A Textbook in General Zoölogy," copyright 1907, by Glenn W. Herrick. Permission of the American Book Co., Publishers.)

The most familiar example of parental care for the young is found in the birds, nearly all of which display this characteristic to a greater or less degree. Some sea birds lay their eggs on the bare rocks and pay no more attention to them thereafter. The majority of birds, however, build some sort of a nest, and in some cases this is of elaborate design. In many cases both male and female share the labor of brooding the eggs and bringing food to the fledglings.

Environmental Adaptations of Plants. — Since plants have not the advantage animals enjoy of moving from place to place, they are profoundly modified by the nature of the soil in which they grow. If this is rich and fertile, their growth is luxuriant; if dry and poor, they are stunted, and the aspect of two regions may differ very greatly on this account. Temperature also plays an important part, the vegetation of the arctics and of alpine regions being also stunted in comparison with the more luxuriant growth of warmer regions. But the abundance or scarcity of water probably plays the most significant rôle in determining the character of the vegetation in any region.

As previously noted, the plant world probably took its origin in the water and secondarily migrated to the land. Large groups, however, are still confined to the former medium. These constitute the familiar type of the water plants or *hydrophytes.* They are characterized by soft and succulent tissues with scant supporting tissue, since they are supported by the medium. Some float freely on the surface, such as the familiar "duck-weed" or *Lemna*. Others are entirely submerged, though often rooted to the bottom. Such plants have a great development of leaflike or chlorophyll-bearing tissue, which makes up for the deficient supply of sunlight beneath the surface of the water. Some of the marine algæ of this class grow to enormous dimensions and develop floats which buoy them up. At the other extreme from the hydrophytes we have the *xerophytes*, comprising vegetation characteristic of deserts, where water is extremely scanty. Only those forms that are able to avail themselves of the meager supply of water in such a situation, have been

FIG. 98. — Hydrophytic vegetation.

Fig. 99. — Xerophytic vegetation.

able to exist and maintain a foothold. Such plants usually absorb very rapidly such rain as falls, or else have very long tap-roots that penetrate deeply into the soil and take up the maximum amount of water. Thus one of the morning glories (*Convolvulus*), which grows on the dry western plains, instead of developing into a delicate, weak-rooted, climbing vine, as do most of the *Convolvuli*, grows as a sort of bush, a foot or so high, and sends a huge root down twenty or thirty feet into the soil.

Another advantageous structure found in plants of such regions is one which brings about the *storing up* of water. Succulents or fleshy plants have a large amount of parenchyma tissue which holds water as a sponge. This is true of many species of cactus. In addition, such plants usually have the exposed surface reduced to a minimum. This retards and lessens the loss of water through evaporation. In Cacti of various sorts the stem is succulent, and the leaves, as such, are absent. Xerophytes are also adapted to economize the water they have in store and undergo long periods of drought. An extreme example is the well-known " Resurrection plant " (*Selaginella*), which grows on the sides of rocky cliffs in Mexico and may be pulled up and dried for years, only to uncurl and freshen up again in a few hours when placed in a saucer of water.

Midway between the two extremes just described, the hydrophytes and the xerophytes, are the plants we are most familiar with, the *Mesophytes*. These are adapted to various degrees of temperature or of changes of moisture, growing most luxuriantly in the greatest degree of warmth and moisture as in the humid climate of the tropics. In the abundant vegetation of these regions there has arisen a sharp " struggle for light " which has brought into being a great variety of climbing-plants and vines, and of aërial plants that depend for water upon what their hair-covered aërial rootlets draw from the moist atmosphere.

Adaptations for Seed Dispersal. — Unable to move from the place in which they are rooted, plants are nevertheless able to spread their various species over available territory with great rapidity, chiefly on account of special adaptations in connection with the dispersal of their seeds.

Many seeds are formed to float in the wind and are transported long distances in this way. A familiar example is " thistle down " and the cottony seed of the milkweed. Often the seed is winged, as in the case of the maple or the catalpa. In some cases, the whole plant is transported by the winds. On the western plains, the Russian thistle or " tumble-weed " (there are several sorts) grows into a large globular bush which breaks off close to the ground when ripe and goes rolling across the prairie, scattering its seeds as it goes, until brought to a standstill by a fence.

Other seeds are wonderfully adapted to stick to anything that touches them, particularly the furry coat of animals. The " beggar's lice " (*Desmodium*) has a flat seed, covered with stiff hooks which cling tenaciously. Another familiar example is the sandbur (*Cenchrus*), with its pod covered with spines.

The usefulness of bright-colored and succulent fruits to the plant which produces them is supposed to consist in the fact that birds which eat them transport the hard seeds within the fruit to a distance from the parent tree.

Associations of Animals. — Among the most primitive animals the individual lives its own life without reference to any other individual, although favorable conditions or abundance of food often brings numbers of the same species together in a given locality. In many species, however, we frequently find animals associating themselves together in groups, apparently from mere love of company or gregariousness. But the mutual advantages of self-protection afforded by such a relation are not inconsiderable. Many fishes swim in " schools " of thousands of individuals. Deer and antelope feed in herds, and many kinds of birds in flocks. Under such circumstances it is very difficult for an enemy to approach, without some member of the company giving the alarm. The same sort of association also serves an aggressive purpose. Wolves and dogs hunt in packs, and it is related that the pelicans of the Gulf of Mexico form in a circle, narrowing toward the shore, and by splashing the water, drive in the fish to shallow water, where they are easily captured. The social instincts of such insects as the ants and bees are deservedly famous, the division of labor involved in the getting and storing of food and the rearing of young being carried to a point that equals the standards of human savages. Instances of simpler associations of individuals of the same species might be multiplied indefinitely.

Commensalism. — The relations that exist between different species in the same environment are usually of a quite different character. Animals are, as a rule, either indifferent to or hostile to individuals of other species. There are many exceptions, however, to this statement. Species of widely separated groups have in many cases entered into partnerships more or less intimate. In the simplest form of this sort of association, one species attaches itself in some way to a larger or stronger one to profit by the protection afforded or the food supplied. An example is found in the suckfish (*Remora*), which has the dorsal fin modified into a sucking disk, by which it attaches itself to sharks or other voracious fishes, living on the fragments that escape its companion's mouth. In another case, a delicate transparent fish called *Fierasfer* is found in the interior of Holothurians (sea cucumbers) or between the gills of mussels, where it gets the darkness and protection that is thereby afforded. A more familiar example is the relation that exists between a crustacean, *Caprella*, and various hydroids, particularly *Pennaria*. Here protective resemblance comes into play to such an extent that it is very difficult to discern the *Caprella* on the hydroid colony even when one is looking for them. To the safety afforded by this protective resemblance may be added the protection of the stinging nettle cells of the hydroid. Such a relation, which profits but one party to the association and on the other hand does not injure the other, is termed *mutualism* or *commensalism.* In other, cases both sides profit by the connection. A very familiar example is the relation that exists between the aphids and ants. The former secrete a jelly-like substance called "honey-dew," which the ants are very fond of, and in order to maintain a supply, the ants keep the aphids in flocks, as men do cattle, tending them, carrying them back if they stray, and "milking" them by stroking them with their antennæ, thereby

FIG. 100. — Rose Aphids visited by ants, natural size from life. — (From Kellogg.)

hastening the secretion of the desired substance. The ants will usually fiercely attack trespassers, and the aphids are thus assured of a protection which nature has denied them, in return for which they supply their keepers with food. An instance of the persistence with which the ants look after their "cattle," is afforded by a discovery of Professor Forbes. In the Mississippi Valley, a member of the aphid family called the "corn-root louse" infests the roots of maize. Its eggs are laid in the ground in autumn and hatch out the following spring. Rotation of crops and other methods of combating the pest were unsuccessful, until it was discovered that the little brown ant (*Lasius brunneus*) takes the aphids when they hatch and before there are corn-roots to feed on, and "with great solicitude carefully places them on the roots of certain kinds of knot-weed (*Setaria* and *Polygonum*) which grow in the field, and there protects them until the corn germinates."

In other cases the association is not so advantageous. Certain species profit by the industry of others without giving an adequate return. A classic example is the cuckoo, which lays its eggs in other birds' nests, to be brooded and reared vicariously. The bee-moth, if it can escape the sentry at the door, enters the hive and lays its eggs, appropriating room and food that the bees need for themselves. In such a case the "host" is injured, but only indirectly. It is only a step, however, to a condition in which the host is directly injured by the activity of the species which attaches itself to it. Such a condition is called parasitism, and it is very widespread throughout the animal kingdom. Rather arbitrarily, zoölogists discriminate between parasites that attach themselves to the outside of their host (ectoparasites), and those that dwell within the body of the host (endoparasites).

Parasitism in Protozoa. — A large and important group of the Protozoa (the Sporozoa) has adopted an exclusively parasitic mode of existence. The most familiar as well as the most important example is the *Plasmodium malariæ,* which is parasitic in the blood of man and also in a certain species of mosquito (*Anopheles maculipennis*). This introduces us at once to a remarkable feature of parasitism which we find in nearly all the groups, the alternation of two very different hosts in which portions of the life-cycle of the parasite are spent.

The malaria-producing parasite lives in the red blood-cells of man (an allied form is found also in birds). It reproduces rapidly by multiple fission (sporulation), each new individual attacking a corpuscle, until, in extreme cases, nearly every blood-cell in the victim is parasitized. The characteristic fever of malaria is apparently due to the liberation of some toxin produced by the parasites simultaneously with their sporulation. In addition to the asexual reproduction just described there are also produced gametes, of two sizes, analogous to sperm and ova. The vegetative phase has some-

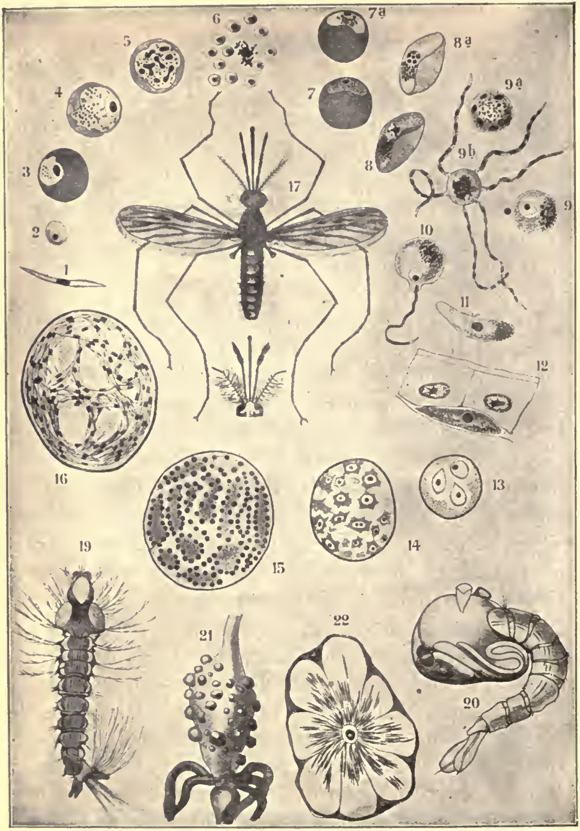

Fig. 101. — The Life Cycle of the Malaria-parasite. 1, the organism (sporozoite) introduced by the mosquito bite into the human blood; 2, the same free in the blood; 3–5, changes which it undergoes within the red blood-cells; 6, spores (merozoites) formed by division, with the attendant destruction of the blood-cell; this cycle 2–6 may be repeated many times, but eventually spores develop in the blood-cells into sexual forms; 7, 8, 9, development of a macrogamete or female element; 7*a*, 8*a*, 9*a*, 9*b*, development of microgamete or male element; 10, conjugation of the two sexual cells; 11, the resultant zygote; 12, zygote that has entered the body of the mosquito and has worked its way to the wall of the latter's stomach, — it lies at the base of two cells; 13–16, transformation of zygote into an oöcyst filled with spores; 17, adult female malarial mosquito (*Anopheles*), head of the male below; 19, larva; 20, pupa; 21, stomach of mosquito, showing cysts produced by the parasites; 22, cross-section of salivary gland of mosquito, showing the cells full of spores which have wandered in from the cysts of 21 and are now ready to pass into the blood with the bite of the mosquito.

what the appearance of a tiny amœba, but in the sexual phase the parasite withdraws to one side of the blood corpuscle in a characteristic crescent-like shape. It is now called the gametocyte. If now an *Anopheles* mosquito bites a man suffering from malaria, the parasitized blood is drawn up into the stomach of the mosquito, where the gametes free themselves and conjugate. The active zygotes then penetrate the stomach wall and become encysted, giving rise to an enormous number of motile spores. These find their way to the salivary gland of the mosquito, and thence into the blood of the man whom the mosquito bites. Once introduced, they attack the red blood-cells, and the cycle begins again.

Parasitism in Worms. — The heterogeneous group of " worms " includes several grand divisions that are almost wholly parasitic in their mode of life and have become correspondingly modified in structure. An American species that has recently become notorious is the " hookworm " (*Necator americanus*) that is widely distributed over the Southern states. The larvæ of this microscopic worm lives in the ground and finds entrance through the skin of its human victim. It then makes its way through heart and lungs to the alimentary canal, where it attaches itself to the wall, feeds on the blood of its host, and reproduces prolifically. As a result, the host soon begins to show the effects of malnutrition and anæmia. This takes the form of a loss of energy and vigor and a "shiftlessness" for which the "poor white" of the South is famous. The group to which this worm belongs is known as the Nematoda. They are all round, often thread-like, with a thick cuticle, and they infest many kinds of animals besides man. Another intestinal parasite of a different sort is the tapeworm, a representative of the "flatworms" or Platodes.

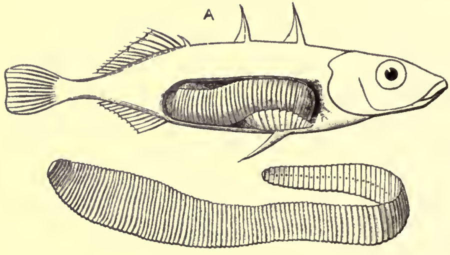

Fig. 102. — Parasitic worm in the body-cavity of a stickleback; *B*, the worm extended, enlarged $1\frac{1}{2}$ times. — (Gamble.)

This is a ribbon-like worm of which the body is broken up into a great many segments, all of them, except the head segment, practically similar. This worm, like the hookworm, attaches itself to the lining of the alimentary canal of its (vertebrate) host and is thus constantly bathed by the digested food which the latter provides. Relieved of the necessity of getting its own food, it has no need for sense organs or for apparatus for eating, digesting, or storing food. Digestive system and sense organs have accordingly disappeared through "degeneration." The fact of degeneration is a familiar accompaniment of the habit of parasitism, though the method by which it comes about is little understood. As in the malarial parasite, there is an alternation of hosts in the life cycle of the tapeworm. In most cases the completion of this cycle requires that one host shall be eaten by the other. It follows therefore that such parasites are most numerous in carnivorous animals.

Parasitism in Insects. — Another group in which parasitism flourishes is the one that has become adapted to all possible modes of existence except that under the sea, — the insects. A few insects are parasitic on other animals (*e.g.* the bot-fly), but the majority parasitize other insects. A very large group of the Hymenoptera (ants, bees, and wasps) are parasitic, and many of them specialize on the

FIG. 103. — Caterpillar of *Sphinx* moth with cocoons of a parasitic wasp attached. — (Sanderson and Jackson.)

caterpillars of various moths and butterflies. Eggs are laid within the body of the living caterpillar, which is frequently packed full of the resulting larvæ. These go through a rapid development and, working their way through the outer skin, emerge from the caterpillar and spin a cocoon on the outside. Others wait until the caterpillar has become a chrysalis, and pupate within the pupal case of the host. There emerge in due time, not a butterfly, but a number of parasitic wasps. Not infrequently the parasites themselves are parasitized, and even these secondary parasites by tertiary ones. In some cases it has been discovered that the original parasitic wasp may lay but one egg in the larval host, but that this egg fragments into scores of others (polyembryony), each of which develops a perfect parasite. In these forms the parasitic condition is passed during the developmental stages, and the mature wasp, using all its senses, shows no trace of degeneracy. There is nothing degenerative about parasitism *per se*, but the condition is merely a form of " adaptation," an economy of nature resulting in simplification of structure through the loss of useless parts.

Sacculina. — An extreme case of the degeneration incident to parasitism is found in a crustacean, (*Sàcculina*), parasitic upon several species of crabs. In its mature condition this creature has the form of a bag, which is found attached to the abdomen of its host, the crab. The bag is full of eggs which hatch into typical crustacean larvæ. It has been found that these swim about until they encounter a crab, to which they attach themselves at the root of a hair. The little larva then forces an entrance into the body of its host and begins to grow, as a plant forces its roots into the ground. At the same time it casts off bodily the abdomen with its attached appendages, and its larval sense-organs, including those of sight, begin to retrogress and soon disappear. There is no need for digestive organs, as the

FIG. 104. — *Sacculina* attached to the abdomen of a crab: *ks*, the sac-like parasite giving off root-like processes that permeate the body of the host. — (From Lang, after Delage.)

parasite draws its sustenance from the tissues of the crab by the penetrating, root-like ingrowth mentioned. The latter eventually pervades every part of the crab's body, and of course soon causes its death, but not before the bag-like *Sacculina* has matured its eggs, and thus insured the possibility of another generation.

Association among Plants. — Nearly all the degrees of association that exist among animals are also paralleled in the plant world, modified, of course, by the very different conditions that obtain among plants. Plants of the same species are often found associated together, but this is usually the result of accident or of similar favorable conditions, and is, of course, not comparable to the gregariousness of many animals. On the other hand, plants of different species are sometimes associated together in a true symbiosis. One of the most remarkable of these is the association between the roots of leguminous plants and the nitrogen-fixing bacteria, which has already been described in a previous chapter. (See p. 76.) A somewhat similar symbiosis is found between the roots of trees, such as oak, walnut, apple, maple, etc., and an investing fungus. The latter covers the root as a mantle or sheath or else penetrates the cells of the root cortex. The delicate branches (hyphæ) of the fungus function as root-hairs for the host-plant.

Lichens. — An equally remarkable association between two diverse forms of plants is that of a fungus and an alga, in the structure known as lichens. Lichens are found incrusting rocks and tree-trunks and are frequently beautifully colored. They consist of a fungus mycelium, surrounding various unicellular or filamentous algæ. The alga, by virtue of its chlorophyll, synthesizes carbohydrates, which the fungus appropriates. On this account the condition is sometimes referred to as *helotism*, since the relation is that of master and slave.

FIG. 105. — The building up of a lichen (*Physcia paratina*) out of the alga and fungus; *A*, germinating ascospore (*sp*); the filaments of the fungus have seized upon two cells (*a*) of *Cystococcus humicola; B*, more advanced stage; *sp*, ascospores which have produced a web of filaments (hyphæ), enveloping the algal cells in every direction. Magnified about 400 times. — (From Scott, after Bonnier.)

Parasitism in Plants. — As in animals, plants are, in some cases, parasitic upon other plants.

Especially is this true of the fungi. Fungus spores of various sorts fall upon leaves or stems of a green plant, and germinating, gain access to the interior through stomata or injuries in the bark or by directly

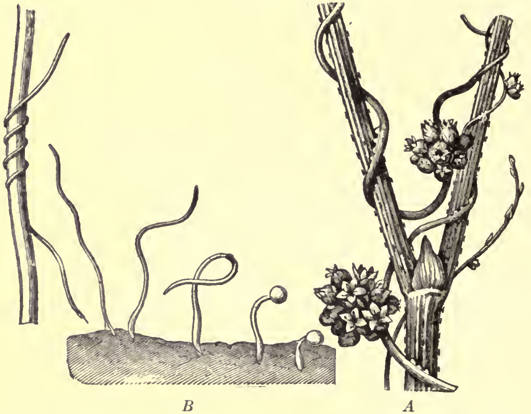

FIG. 106. — *A*, European dodder twining about a hop stem. All but the uppermost coils show the groups of wartlike swellings from which haustoria penetrate the host stem. Natural size. *B*, germination of same. The various stages are arranged in order from right to left. In the last stage the seedling has found a suitable support and has absorbed all the reserve food in the thickened lower end, which has withered and died. Magnified about two diameters. — (From Barnes, after Kerner.)

dissolving the outer tissue, and, once gaining a foothold, grow and ramify in all directions, producing blight, rot, or abnormal growths (tumors). Familiar examples are the " rust " and " smut " of wheat and corn.

Higher plants in several instances have adopted parasitic habits and have thereby become profoundly modified, usually in a "degenerative" way. The dodder is a climbing plant related to the morning glory. Its seeds germinate in the usual way, but soon the seedling attaches itself to another plant, and casting off its attachment to the ground, feeds thereafter on the juices of its host, which it sucks up through organs called haustoria, that grow fast to the leaves and stems of the host-plant. The mistletoe is another (semi-) parasitic seed plant that grows upon the oak. Unlike the dodder it has no ground-roots, the seeds being carried by birds from tree to tree, where they catch in crevices in the bark, and sprout.

Association of Plants and Animals. — Nearly all the grades of association that have been described for plants or for animals are also found to exist between plants and animals.

Many crabs are protected by growths of seaweeds which cover their carapace. When these are removed, the crabs plant others. Although the algæ are passive members of this partnership, yet, of course, they do not suffer by the association.

In other cases, certain algæ exist in a combination with simple forms of animal life that is quite analogous to the fungus-alga relation just described for the lichens. The yellow variety of Hydra owes its color to the presence within its endodermal cells of a symbiotic alga. Ciliate Protozoa, sponges, and even some of the smaller worms, also contain similar algæ, usually of a green color. These are called Zoöchlorella, and they function by synthesizing carbohydrates for their animal hosts.

Of course, plants suffer from the attacks of herbivorous animals, and not infrequently such animals, if small, live on the plant upon which they feed (the aphids, for example). To call this parasitism would be, however, a rather forced use of the word. On the other hand, animals are subject to the attacks of multitudes of plant-parasites. These belong to the great group of the Fungi, and most conspicuous among them are the bacteria. By no means all of the bacteria that live on or in the animal body are disease-producing, yet the great majority of diseases to which man and the other mammals are subject are produced by bacteria that find entrance to the body and multiply there.

Grafts. — A condition which may be called artificial symbiosis occurs in grafting. The graft or scion is a twig or bud or some other portion of a plant which is inserted into the stem of another (related) plant, the stock, with which it enters into an intimate physical relation, and the two behave thereafter as one plant. The individual characteristics of both elements are usually preserved. Thus a pear graft on a quince stock produces only pears, and different sorts of fruits may be grafted upon the same stock. An application of this principle saved the Bordeaux vineyards from extermination not many years ago. The *phylloxera*, a relative of the corn-root aphis already described, infests the roots of grape-vines. The introduction of this pest into French vineyards threatened their rapid destruction until it was discovered that the wild varieties of American grapes are immune to the insect. American stocks were planted, upon which were grafted the French varieties of grape, thus defeating the *phylloxera*, while at the same time preserving the peculiar qualities of the French fruit.

Grafting is also possible between animals. Tadpoles, moth-pupæ, worms, etc., may be cut in pieces and fastened together in all sorts of ways without destroying individual life and growth. Even in mammals, various organs have been transplanted from one animal to another (of the same species) without loss of function. A practical application of the same principle is used by surgeons in starting a healing-process in large burns on the human body by the grafting on of bits of skin taken from another person.

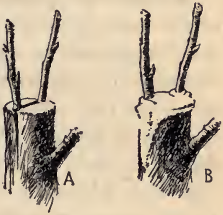

FIG. 107. — A common method of grafting: *A*, insertion of two scions into cleft of stock at cambium (growing) region; *B*, wound protected with wax to prevent drying out of tissues. — (From Curtis, after Bailey.)

CHAPTER IX

SPECIES AND THEIR ORIGIN

Meaning of Species. — Throughout our discussion of the various phases of organic phenomena we have been compelled to use the word "species" without defining it, although its meaning must have been more or less evident from the context. Indeed, there is no term in general use in Biology, the meaning of which is so vague or so variously interpreted, and the definition of which is so difficult. The Latin word "species," which has been directly incorporated into English, means, primarily, "form" or "appearance," the visible structure by which anything may be recognized; hence, by inference, the word came to mean "sort" or "kind."

Until the early decades of the eighteenth century, practically all serious scientific writing was in Latin, and the word "species," when used in describing different kinds of animals or plants, had no technical connotation. The early naturalist, in naming an unusual form, proceeded as any person would in describing a friend; that is, he summarized its salient characteristics in a brief sentence. The lion was the "Cat with a tuft at the end of the tail."[1] The

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[1] "*Felis cauda in floccum definente.*" M. J. Brisson, "*Regnum Animale: Quadrupedum,*" p. 194. 1756.

tiger was the "Yellow cat, variegated with long black stripes."[1] The black (water) oak was the "Maryland oak with leaves three-lobed like the sassafras."[2]

It is obvious that this was a very clumsy and unsystematic method, if the forms to be described were at all numerous. Particularly was it impossible to be certain whether or not two writers were discussing the same thing. As new forms of animals and plants were discovered the confusion became worse. Finally, in the middle of the eighteenth century, order was brought out of the chaos by Linnæus. This great Swedish naturalist worked out and published a classification of all known forms of animal and plant life, — the famous *Systema Naturæ.* Not only was each kind or "species" described in a brief "diagnosis," but each was given a double name. Thus, all the members of the Cat tribe were called *Felis*, and the group was called a *genus* (plural, *genera*). Each kind of cat was then given a specific name; thus, the house cat was called *Felis domestica;* the lion, *Felis leo;* the tiger, *Felis tigris;* the black oak, *Quercus nigra*, etc., the technical designation of the form being compounded of a generic and a specific name. This *binomial nomenclature* has been used ever since Linnæus' time, and affords an elastic and easily intelligible system. Not only are closely similar species grouped

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[1] "*Felis flava, maculis longis nigris, variegata.*" *L.c.* p. 195.

[2] "*Quercus Marilandica, folio trifido ad sassafras accidente.*" M. Catesby, "Natural History of Carolina," I, p. 19. 1731.

together in a genus, but similar genera are in turn assembled in *families*, and families in *orders*. The genera and other larger groups were, of course, artificial and abstract categories. Not so the species, in Linnæus' mind. He says, "There are as many species as the infinite Creator produced in diverse form in the beginning, and these forms, according to the recognized laws of reproduction,

Fig. 108. — Carolus Linnæus (1707–1778).

have produced others always like themselves."[1] This conception of the fixity and permanence of species was not always held so firmly as it was during the eighteenth and the first half of the nineteenth centuries. Milton and the type of mind of which he was the spokesman doubtless had much to do with riveting this idea, essentially a theological dogma, upon the popular mind.

Any branch of natural science has its beginning in the classification and assembling of data. The number and diversity of forms of plant and animal life have proved so great that until quite recently the energies of naturalists were almost exclusively directed toward the classifying and naming of species. This has been done largely on the basis of "outward form," and the methods of the scientist are not different in kind from those of the non-biologist. If, for example, the latter should be given a basket of fishes of all sorts, he would have little difficulty in picking out by sight the various kinds, and he probably would make but few mistakes. If the basket should contain exclusively fresh-water fishes, it might be considerably more difficult to sort accurately the various kinds. One's ability to do so would depend a good deal upon his quickness of eye in appreciating details of structure. These details are the same ones that have already been denoted "characters" in another connection. Con-

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[1] "*Species tot sunt, quot diversas formas, ab initio produxit infinitum Ens, quæ formæ secundum generationis inditas leges produxere plures, at sibi semper similis.*"

sciously or unconsciously we arrange the individuals of a group by the common possession or lack of possession of certain visible characters. Such a method of discriminating species has been called the *diagnostic* method. It is obvious that the individual judgment must play a large part in deciding the importance or constancy of such characters. A species judged by such a method cannot have any wholly accurate definition, so long as the personal equation enters so largely.[1]

When we trace resemblances between human beings, we usually adopt a similar method, that is, we catalogue their physical characters and group the individuals by their common possession of such characters. Thus, in spite of individual peculiarities, we have no difficulty in distinguishing a Swede from an Italian, nor a Chinese from both. The first two resemble one another, in spite of their differences, more than they resemble the Oriental. In the same way, a child frequently resembles its immediate parents, more rarely a grandparent, and much more rarely a cousin, an uncle, or a more remote relative. We accept it as a matter of course

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[1] In the middle of the eighteenth century Buffon proposed a criterion of species that avoided this difficulty. He held fertility in crossing to be the test of specific identity. If two forms were sterile when interbred, they were distinct species; if not, they were varieties of one species provided the hybrids themselves were not sterile. This essentially scientific hypothesis, which for clearness and workableness has much to commend it, had the curious result of emphasizing the concept of Special Creation, since if it were uniformly true, it is hard to see how new species could ever arise.

that close relatives on the whole look much alike, or at least resemble one another much more than do remote kin. It is for the same reason, in a larger way, that the diverse types of Europeans are nevertheless more alike than are Europeans and Mongolians. The different races of mankind are usually classed as one species for reasons that we will not enter upon here, but the same phenomenon is found in all lower animals and plants. Individuals of common descent thus constitute groups which in very many cases are identical with those segregated by the diagnostic method, on the basis of a common possession of characters. Here, then, we have another criterion of species, *community of descent.* Species may be not only forms which share in common certain physical characters; by the same token they also share a common ancestry.

Polymorphism. — The importance of the latter factor becomes evident when we consider the phenomenon of dimorphism and polymorphism. Many species of insects are known in which one sex occurs in more than one form. Thus, in one of our common American butterflies, *Papilio turnus,* the "tiger swallowtail," the male is brilliant yellow with vertical stripes on the forewings. In the northern range of the species (Canada and the North Central States), the female is similar to the male, but in the Southern States, in addition to the yellow females, occurs also a black form without the stripes, or with faint indications of them. For a long time this form was considered a distinct species, on a "diagnostic" basis, and was given the name "*glaucus*." When it was found, however, that eggs laid by yellow females developed into both *glaucus* and typical *turnus*, and, conversely, that eggs laid by *glaucus* developed also into *turnus*, it became necessary to consider them one species. The different forms which are assumed by those animal species in which a marked alternation of generation occurs, and the different types or castes of ants and their relatives, are further examples of morphological diversity in the same racial inheritance.

FIG. 109. — Tiger swallowtail butterfly, showing the two forms of females: the upper one is the typical "*turnus*," the lower one is the "*glaucus*" type. The contrast is made much more striking by the coloration, which is yellow and black in the *turnus* form and solid black in the *glaucus* form. — (From "Elements of Biology," copyright, 1907, by George William Hunter. Permission of the American Book Co., publishers.)

In many cases species are not so sharply set off from one another as in the above example. Often the characters are based on measurements. This is particularly the case with birds and mammals. In such forms it is often found that series of individuals from different zoögeographical regions will differ markedly in such characters. It then becomes a question

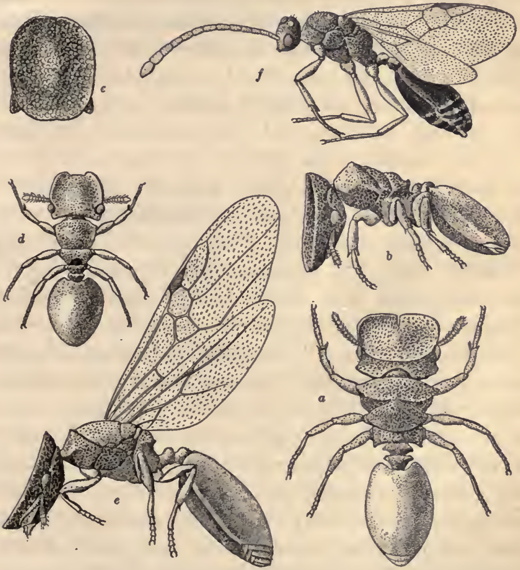

Fig. 110. — Polymorphism in ants (*Cryptocerus varians*): *a*, soldier; *b*, same in profile; *c*, head of same from above; *d*, worker; *e*, female; *f*, male. — (From Wheeler's "Ants," published by the Columbia University Press.)

whether intermediate forms may be found which will insensibly grade both ways into the two types. If such are discovered, then we consider the aggregate to be one species and the divergent types to be "geographical races," or "varieties." The criterion by which we decide whether or not a given aggregate of individuals is a "true species," or only a variety, is that of lack of intergradation of one or more (not necessarily all) characters. But it will be seen that the increase of our acquaintance with a certain group of related species may necessitate a constant revision and rearrangement of them. Let us consider for a moment an imaginary species of bird, extending, let us say, from the Atlantic coast to the Rocky Mountains, representatives of which show a wide range of measurements in the bill. Suppose that the eastern representatives have a bill averaging two centimeters in length, whereas the western ones have a bill averaging four centimeters, but with every gradation between the two extremes. Assuming that this is the only significant difference between them, we should consider the whole aggregate to be one species, with two well-marked geographical varieties. But if some one were able to willfully wipe out of existence the individuals from the middle districts (as the passenger pigeon has been wiped out within the memory of the present generation), then a later naturalist, who was ignorant of that fact, would be justified in considering the eastern and western forms distinct species. On the other hand, an earlier student who might have retained specimens of the exterminated intermediate types, would certainly continue to consider them all one species. In a way, either would be right, for the illustration shows that the concept of species is an abstract one. The species is real enough, but the criterion of the species exists in the student's mind, just as does that of the genus or the higher groups. Such species, frequently called *Linnæan species,* are but convenient categories for classifying aggregates of plants and animals which closely resemble one another and are of (assumed) common descent.

Elementary Species. — It will be recalled that there is considerable evidence for the belief that discontinuous variations or mutations are of a very different sort from fortuitous variations. Their constancy, their abrupt origin, and their behavior in heredity, sharply set them off from the latter. De Vries called his mutants "elementary species." He believes that they are not in any sense the product of environmental influence, as geographical "varieties" may be, but are distinct entities. There have been found over two hundred such species of the "whitlow grass," *Draba verna,* and more than that of the hawthorn (*Cratægus*). It is obvious that to separate and name all of these would defeat the purpose of classification, which is to reduce chaos to order, and complexity to simplicity, so the Linnæan species will probably continue to be used as the practical units of the classifier.

The "pure lines" or genes which have been discovered in both plants and animals are probably the real units of organic nature, the centers of stability of the systems we call specific units. In the forms which reproduce sexually — and they are, of course, the majority of organisms — the interweaving and mingling of diverse genes in each generation is such as to render almost futile the hope that they can ever be unravelled and described. The Linnæan species or phænotype is like a tangled and knotted skein of yarn, each strand of which maintains its individuality, while commingling in closest union with the rest.

The Origin of Species

To Linnæus and his followers, the origin of his species presented no problem. They had been created as such in the beginning, and had persisted until the present. The relatively small number of species known to him made this seem reasonable, although it is likely that, had he been familiar with the enormous number of forms now known, he would not have been impressed otherwise than with the additional evidence of the omnipotence of the Creator. There is very good reason for believing, however, that the doctrine of Special Creation, as it has come to be called, is not tenable. Practically all modern biologists believe that the species of animals and plants now on the earth have not always been here in their present form, but that they have become transformed from other preëxisting types and that the constant changefulness that characterizes the life of the individual is equally characteristic of the race. In the nature of things, direct evidence for such an hypothesis is not abundant, but the inferential evidence is overwhelming, and one can hardly work with natural objects at first hand without being constantly impressed with it. Since life does not exist apart from living organisms, and since organisms are always found in the aggregates we call species, the question of the evolution of life is wrapped up in that of the evolution of species, and the origin of new species is its central problem.

Evidence for the Evolution of Species in the Past

The age of the earth is very great, and for only a fraction of its life has it been habitable for living organisms. Yet, looking back from the present day, an enormous vista of time opens up during which we find evidences in the rocks of the existence of animal and plant forms, the great majority of which are now extinct. Only the scattered fragments have been preserved.[1] When, however, we piece together this

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[1] "The affinities of all the beings of the same class have sometimes been represented by a great tree. I believe this simile largely speaks the truth. The green and budding twigs may represent existing species; and those produced during former years may represent the long succession of extinct species. At each period of growth all the growing twigs have tried to branch out on all sides, and to overtop and kill the surrounding twigs and branches, in the same manner as species and groups of species have at all times overmastered other species in the great battle for life. The limbs, divided into great branches, and these into lesser and lesser branches, were themselves once, when the tree was young, budding twigs; and this connection of the former and present buds by

record, we find that without exception it tells the story of one type replacing another, and of simple types giving place to more and more complex. Patiently, fragment by fragment, the records of the rocks have been brought together until we now have, for example, the nearly complete genealogy of the horse, dating back to a five-toed ancestor, not much bigger than a rabbit.

History of the Elephant. — A very good example of the successive changes in the transformation of one type into another is to be found in the elephant and its genetic predecessors. The ancestor of the modern elephant, the remains of which have been

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ramifying branches may well represent the classification of all extinct and living species in groups subordinate to groups. Of the many twigs which flourished when the tree was a mere bush, only two or three, now grown into great branches, yet survive and bear the other branches, so with the species which lived during long past geological periods, very few have left living and modified descendants. From the first growth of the tree, many a limb and branch has decayed and dropped off; and fallen branches of various sizes may represent those whole orders, families, and genera which have now no living representatives, and which are known to us only in a fossil state. As we here and there see a thin, straggling branch springing from a fork low down on the tree, and which by some chance has been favored and is still alive on its summit, so we occasionally see an animal like the *Ornithorhynchus* or *Lepidosiren*, which in some small degree connects by its affinities two large branches of life, and which has apparently been saved from fatal competition by having inhabited a protected station. As buds give rise by growth to fresh buds, and these, if vigorous, branch out and overtop on all sides many a feebler branch, so by generation I believe it has been with the great Tree of Life, which fills with its dead and broken branches the crust of the earth, and covers the surface with its everbranching and beautiful ramifications." — Darwin, "The Origin of Species," Chapter IV.

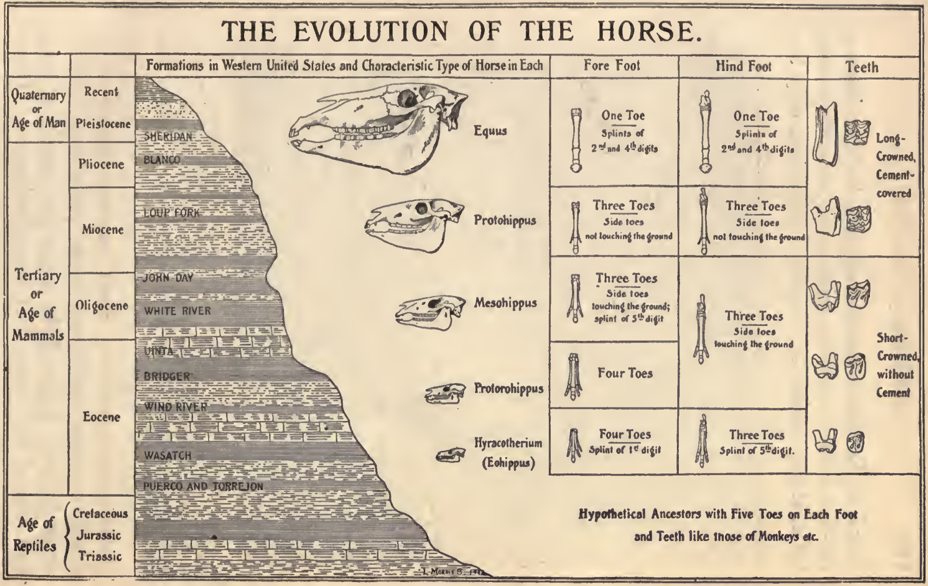

FIG. 111. — Diagram of the evolution of the horse. — (From Matthew.)

found in Egyptian deserts, appears to have been a pig-like animal about as big as a cow, with a very little, if any, snout or "trunk" (of course only the skeleton is preserved). Both jaws were heavy, with peculiar molar teeth and large prominent incisor or tusk-teeth, those of the lower jaw nearly as long as those of the upper, but more horizontal. These

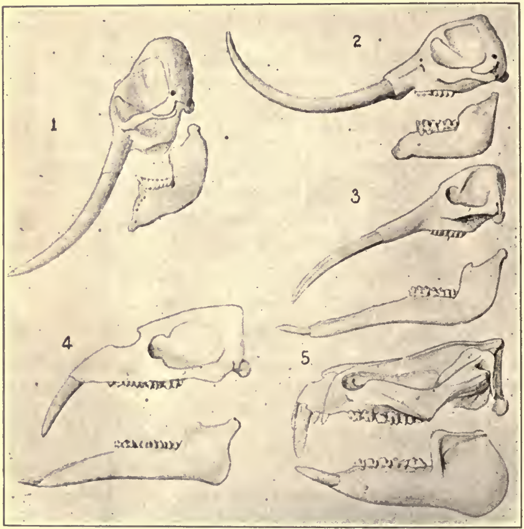

FIG. 112. — Profile views of ancestors of the elephant: *1*, the Indian elephant (modern); *2*, the American mastodon (Pleistocene); *3*, *Tetrabelodon* (Miocene, France); *4*, *Paleomastodon* (Eocene, Egypt), *5*, *Meritherium* (Eocene, Egypt). — (From Lankester's "Extinct Animals," after Andrews.)

remains, which have been named *Meritherium*, are found in Eocene[1] formations.

In the same strata are found also fossils of another type which has been called *Paleomastodon*. In this form, we find the same sort of molar teeth, but the tusks of the upper jaw are much longer than those of the lower. In the Miocene era, much later than Eocene, we find the *Tetrabelodon*, which is characterized by a very great horizontal extension of the long upper incisors, now to be called tusks, and a corresponding extension, not of the lower incisors, but of the lower jaw itself. The head of this animal was apparently extended in a long bony projection, composed of the two tusks and the lower jaw, on which doubtless rested an extension of the upper lip in the form of a snout or trunk. Back in the jaws, we find the typical molars. In America, we find quantities of the skeletal remains of *Mastodon*, a huge elephant-like creature in which the lower jaw has greatly shortened, the lower incisors have disappeared, and the upper ones (the tusks) are enormously enlarged, curving up and inward. Back in the jaw we find the same type of molars, reduced in number and increased in size. Finally, in the modern elephant, we have an animal with a greatly "foreshortened" skull, in the lower jaw of which there is only room for one single ribbed molar tooth at a time. The upper incisors or tusks are large, and curve downward, and between them is the long sensitive

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[1] The Eocene period, the earliest of the Cenozoic era, dates back probably three million years.

flexible trunk which compensates for the clumsiness of the rest of the body.

In this survey it is not implied that each of these forms turned one into another, but they do indicate the very probable path of transformation which the elephant has followed in its derivation from the more usual type of mammals.

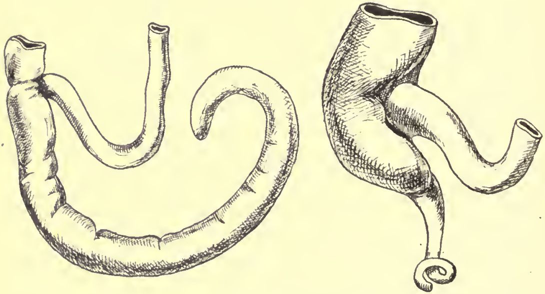

FIG. 113. — Appendix vermiformis of kangaroo (at left); of human embryo (at right). — (From Jordan and Kellogg, after Wiedersheim.)

Vestigial Structures. — Another sort of evidence for the transformation of species is to be found in the possession, on the part of animals now living, of useless vestiges that correspond with similar functional structures possessed by more primitive types which may be assumed to resemble the ancestors of present-day species. The most striking of these structures are the gill-clefts, reminiscent of an aquatic life and characteristic of fishes, but likewise developed in the embryos of reptiles, birds, and mammals, — even man himself, although in the higher vertebrates they soon close over. Numerous other such vestiges might be cited. The vermiform appendix is a now useless or even dangerous legacy from some herbivorous ancestor. Another useless relic of the ancestral past is the muscular equipment of the human ear, sometimes so complete (or so well innervated) that their possessor has a quite unhuman capacity for moving that organ. Indeed, some one hundred and eighty vestigial organs have been recorded in man (Wiedersheim). In plants, likewise, are to be found many such survivals. Thus in the Cycads, belonging to the most primitive group of the seed-plants, the sperm-cell is provided with cilia like those of an alga, which are, however, useless, since zygosis does not take place in the water. Vestigial structures, such as have been just described, were likened by Darwin "to the unsounded letters in many words, such as the 'o' in leopard, the 'b' in doubt, and the 'g' in reign, which are quite functionless, but tell us something of the past history of the word." [1]

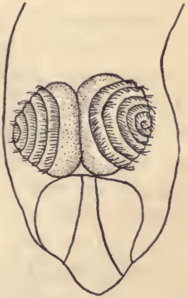

FIG. 114. — Two ciliated sperms of *Cycas revoluta* just previous to their breaking away from each other to swim in the watery secretion of the pollen tube. — (After Miyake.)

The Origin of Species. — Granting that new species have come or are now coming into existence, by some

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[1] Quoted from Thomson and Geddes' "Evolution."

form of natural transmutation, we may ask what explanation has science to offer of the method of their appearance? Speaking generally, two different answers have been offered to this question: That of Lamarck, and that of Darwin.[1]

Darwinism. — The Darwinian theory of the origin of species rests upon three generalizations. First, in every species of animal and plant, even the very slowest breeding one, there is produced an enormously greater number of individuals than can possibly find food or foothold. Some of these, of course, survive as the persistent species, the rest perish.[2] This is the famous " struggle for existence," from which few, if any, individuals are exempt. Secondly, the fact of variation, which has already been discussed, calls to mind that in this horde of individuals every possible sort of variation will be found. Some of these will be favorable to survival, others a handicap; obviously, when competition is so fierce, the chances are strong that the individuals which possess the unfavorable variations should go down before those endowed with the favorable ones. For example, a slight difference in the speed of an

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[1] Some would add also De Vries' theory of Mutation, mentioned in a previous chapter.

[2] An ordinary mosquito hatching from the egg reaches maturity and lays her own eggs ten days afterward. A single female lays about four hundred eggs, half of which become females. If a single female should hatch on April first and lay her quota of eggs ten days later, on July 1, ninety days later, if all lived the progeny would number 102,914,592,864,480,008,004,001 mosquitoes!

animal may determine which of two will be killed and eaten and which escape; a slight difference in resistance to low temperature will determine which of two plants will be killed by frost and which survive. This universal phenomenon was termed by Darwin, "The Survival of the Fittest." It may be better called, perhaps, the survival of the best adapted, since the criterion of survival, or of "Natural Selection," as Darwin called it, is the degree to which the organism is adapted to its environment. Since "like tends to produce like," Darwin held that the individuals that have survived on account of their favorable variations will tend to reproduce individuals of the same type. But the inorganic environment is no more stable than organic nature. Excluding the titanic changes which, Geology teaches us, have been going on for long periods of time, the minor changes of climate and physical conditions are constantly nullifying the delicate adjustments that have come into existence through the natural selection just described. New criteria for the selection of the survivors in the struggle will become operative, and in consequence a different type will be preserved. It is not even necessary for the environmental changes to become profound. As we have seen, in connection with fortuitous variation, free interbreeding tends to maintain a single mode, but if a group of variants should be segregated and prevented from mutual intercrossing, no other factor than chance need be called upon to bring about a divergence of two modes. Darwin's attention was attracted to the problem in the first place by observing that in the various islands of the Galapagos group, off the western coast of South America, although numbers of genera of land animals are to be found on each of the islands, as well as on the mainland, yet each island has its own species, differing slightly, but definitely, from those of adjacent islands. There is little doubt but that at one time the islands were all connected with one another and with the mainland, and populated with one species of rabbit or of grasshoppers or other forms. When the islands came into existence through the depression of the land, the consequent segregation and isolation of the different groups, and their enforced inbreeding, called into being the new and divergent types now to be found there.

Such a segregation need not even be physical. A mutual infertility may arise between groups of a species in a common habitat which would just as effectively segregate them, so far as reproducing the species is concerned, as if a physical barrier were erected.

Darwin's hypothesis of Natural Selection is thus a theory of the origin of species (evolution being assumed) through the mutual relation of organisms to their environment, such that the unadapted are eliminated and a changing environment produces changing types. Its most important feature is the emphasis which it lays upon the passivity of the organism itself. The selection is purely mechanical, and the conclusions as regards the first two premises (the enormous overproduction of individuals, and consequent elimination) are incontrovertible.

Lamarck's Theory. — We have seen, in a previous chapter, that one of the fundamental qualities of living matter is that of response, and that environmental stimuli frequently call forth advantageous reactions (such as the callusing of the hand through friction). That the reaction may also be disadvantageous is, of course, equally true. Moreover, the fact that the organism is, as a rule, exquisitely adapted to the particular environment in which it is found is one of the most conspicuous facts of nature. Lamarck contended that the continued effect of such response made its impression on the inheritance of the organism, or, to use a technical phrase, that such "acquired characters" are inherited. *Use* and *disuse* thus play a large part in Lamarck's theory. From another standpoint, the will of the organism came into play, since he held that the *need* for the development of an organ is a causative factor in its production. Swimming birds acquired their web feet by spreading their toes to avoid sinking in the mud; the giraffe, its long neck by the inherited effect of generations of stretching after the leaves of trees. Of course plants are equally as well adapted to their environment as are animals, but any question of use and disuse, or particularly of such a psychical factor as need, must be ruled out in the case of plants. Lamarck, in this case, laid especial emphasis upon such factors as light, heat, moisture, etc.

Critique of the Darwinian Theory. — Darwin's work, "The Origin of Species," was published in 1859, and the entire first edition was sold on the day of issue. This was evidence of the acute public interest in the subject at that time. The publication was merely the spark in the powder magazine, for the idea of organic evolution had been in the air for a century and a half, and had been steadily gaining strength. The following ten or fifteen years were occupied with controversy and heated polemic, for the vital argument was not so much the hypothesis of Natural Selection as the theory of Organic Evolution versus the doctrine of Special Creation. As to the conclusion of the issue there could be no doubt, and when, finally, the theory of Evolution was definitely established, that of Natural Selection was accepted along with it, although of course the former did not necessarily involve the latter.[1]

The chief result of Darwin's great generalization was an extraordinary development of natural science and the extension of the field of biological inquiry in every direction. Darwin had spent his life in the patient accumulation of data on which he based his generalization, and he was not unaware

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[1] "History warns us, that it is the customary fate of new truths to begin as heresies and to end as superstitions; and, as matters now stand, it is hardly rash to anticipate that, in another twenty years, the new generation, educated under the influences of the present day, will be in danger of accepting the main doctrines of the "Origin of Species" with as little reflection, and it may be with as little justification, as so many of our contemporaries, twenty years ago, rejected them." — T. H. Huxley, "The Coming of Age of the 'Origin of Species.'" 1880.

of weak links in his own argument which he candidly avowed. These became more emphasized as time went on, and a host of investigators continually added to the facts that were most difficult to explain by the theory of Natural Selection. We have space for but a few of these objections. (1) The basis of elimination or preservation is the usefulness of the organ whose variations serve as the criterion for selection, but there are thousands of very stable characters which must be of wholly indifferent value to the organism. One of the largest groups of the ground-beetles is divided into two sub-groups containing hundreds of species by the invariable distinction of the possession of one microscopic hair above the eye or of two. (2) Again, while it may be recognized that the emphasis on a certain structure may be, so to speak, of selection value, yet the minute differences of fluctuating variations can hardly count one way or the other. Thus one author calls attention to the polar bear, whose white coat must be of great utility to him in stealing upon his prey unobserved. Without doubt, this species has evolved from a type of the more usual coloration, but " did the fortuitous appearance in his coat of a spot of white hairs as large as a dollar or a pancake give some ancient brown bear such an advantage in the struggle for existence as to make him or her the forerunner of a new and better-adapted sort of bear? " Darwin recognized this difficulty, but thought that the struggle for existence was so keen that the slightest difference, however slight, might decide between survival and extermination. (3) Allowing for the fact that certain small variations are advantageous to their possessors, and granting that of the hosts of individuals born into existence, but a minute fraction can hope to survive, yet in many cases chance must play a larger part in their extermination than the possession of any kind of morphological or physiological character whatever. (4) Most significant of all, perhaps, is the experimental demonstration that artificial (and by inference, natural) selection has narrow limits. Beyond a certain point (see p. 219) the pull of the mysterious factor of regression prevents any further progress in that direction.

Critique of the Lamarckian Theory. — The chief characteristic of man as distinguished from other animals is the fact that he " looks ahead " and shapes means to his own ends. It is difficult to avoid unintentionally attributing the same purposes to the abstraction we call "Nature" or the "species." Animals and plants react to many stimuli. Often these reactions are advantageous and these we note; frequently they are quite the contrary, and these we sometimes fail to remember. Man stores up food to provide for a future time of want. When a potato stores up starch in the tuber, what more natural than to think of it in the same way, — the plant is anticipating its own needs? But it has been discovered that the formation of tubers is directly due to the presence of an infecting fungus and does not occur in its absence.

The same dangers beset the path of the unwary who argue from the Lamarckian standpoint. The need for a useful organ is evident, but we are by no means justified in assuming that the "need" brought about the existence of the organ. Even man cannot "by taking thought, add one cubit to his stature." The Lamarckian argument rests upon the transmission, in heredity, of the results of environmental influences upon the soma; in other words, the "inheritance of acquired characters." On *à priori* grounds, Weismann sought to show that this was impossible, since the germ-plasm gives rise to the soma and is unaffected by its accidents. Moreover, the greatest variety of experiment has been attempted for many years, in an effort to secure the hereditary transmission of any sort of such acquired characters, with universally negative results.[1] One of the most elaborate of these was carried out by a German botanist who transplanted some 2500 different kinds of mountain plants to the lowlands and studied them for several years in comparison with their lowland relatives. He found that the alpine environment had made no permanent change in their habit or structure.

It is not even necessary to assume such a distinction as that between germ-plasm and soma-plasm, a distinction that is sometimes difficult to maintain, in order to appreciate the improbability of the inheritance of environmental effects. Animals and plants are complexes of matter whose

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[1] With one very doubtful exception.

nature is ultimately dependent upon some sort of molecular organization of which we are profoundly ignorant. But we are almost equally ignorant of the nature of the organization of the simplest chemical compounds. We know nothing, for instance, of the relation existing between the oxygen and the hydrogen that gives water its peculiar properties. These properties are inherent, and were they to alter fundamentally, our whole body of chemical theory would be upset. On the other hand, the manner in which these properties are revealed to us is determined primarily by external (environmental) conditions, *i.e.* those of temperature and pressure. We think of H_2O as a liquid because that is the form that our usual conditions of temperature and pressure cause it to assume. But the liquid state is, of course, no more characteristic of the compound than the gaseous or solid state. If we should keep a quantity of water at a temperature of 0° C. for a hundred years, we should have no reason for supposing that its liquid nature would be altered in the slightest if the temperature were finally raised ten degrees. Indeed, we may say that it is the specific characteristic of water to be a solid, a liquid, or a gas, at definite calculable levels of temperature.

In the same way, the adjustment of internal relations to external ones is a specific characteristic of the organism. To put it another way, the solid condition of ice is not "caused" or "produced" by the lowering of the temperature, except in a figurative sense. It is the essential nature of H_2O to be a solid at low temperature. In the same way the climatic conditions of the mountains do not cause the profound modifications in the habit of alpine plants in contrast to their congeners of the lowlands. The nature of the species is to respond, morphogenetically, in one way to one sort of environment, and in another way to another sort of environment without being intrinsically altered by either. For the succession of individuals is a continuous stream, and there is no absolute break between one generation and another. In other words the species, like the organism, has a unity unaffected by its surroundings. This consideration does not affect the idea that species do alter with respect to their intrinsic nature, and that in the course of time new species come into existence from preëxisting ones. It emphasizes, however, the significance of the internal factors involved and the relative unimportance (in a direct and permanent way) of the action of the environment.

In conclusion it may be said that biologists are by no means so positive in giving their allegiance to one theory or another of the origin of species as they might have been a generation ago. The concept of Evolution, that is, of the progressive changefulness of organic Nature and the descent of present-day species by modification of preëxisting types, forms the basis of all modern biological work. As to the *method* of the evolutionary process there are several opinions, and it may very well be that each is but a part of a true explanation, the complete key to which will be discovered only by subsequent researches. The painstaking and brilliant work of Darwin can never be set aside in spite of the fact that we may be compelled to doubt the universality of his theory of Natural Selection. Instead of his fluctuating variations, however, it may be that the basis for selection is something like Johanssen's "genes," or those vague units of organization that reveal themselves to us as Mendelian unit-characters. But we must have a far deeper insight into the physics and chemistry of the organism than is now available before we can begin to formulate an hypothesis as to the real nature of these units.

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Printed in the United States of America.