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EDITED BY J. REYNOLDS GREEN Sc. D.

BIOLOGY

BY PROF HARVEY GIBSON

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BY

R. J. HARVEY GIBSON, M.A.

Professor of Botany in the University of Liverpool

WITH
NUMEROUS
ILLUSTRATIONS

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PREFACE

In the following pages an attempt is made to outline some of the more important principles of the science of Biology, and to illustrate in simple terms the inter-relationship of structure and function in living organisms. Since Biology is founded on Physics and Chemistry, an elementary knowledge of these sciences is presupposed, such as may be gained from a study of the volumes of this series dealing with them. Similarly, the present volume is introductory to the Primers of Zoology, Botany, and Physiology, where the fundamental principles here dealt with are treated in greater detail in special relationship to plants and animals respectively.

It is quite possible that I may have omitted much that another author would have inserted, and enlarged on points which some might consider as out of place in a booklet of this size. Be that as it may, I can only hope that what I have written may prove of interest and service to those whose studies have lain in other departments of knowledge than Biology.

If errors of fact or exposition are not numerous (it is perhaps too much to hope that they are non-existent), it is due to the kindness of my friends and colleagues, Professors C. S. Sherrington, F.R.S., W. A. Herdman, F.R.S., and Dr. J. Reynolds Green, F.R.S., in reading and criticising the MS. or proofs of this work, and to them I tender my heartiest thanks.

R. J. HARVEY GIBSON.

LIVERPOOL, 1908.

SYNOPTICAL INDEX

CHAPTER I

INTRODUCTORY

No one, even though ignorant of Biology, can fail to recognise that living things may be arranged under one or other of the two categories, known familiarly as plants and animals; but although it is comparatively easy to appreciate the differences between an oak tree and a horse, and to recognise that these differences are sufficiently great to justify **Plants and animals.**

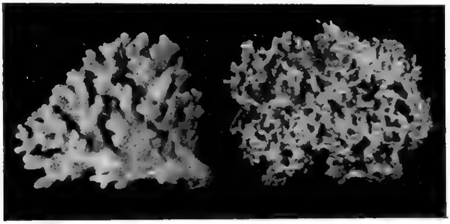
A  B

Fig. 1. A coral (A) and a coralline seaweed (B) ($\frac{1}{4}$ natural size.)

us in keeping such organisms far apart in any scheme of classification we may adopt, it is by no means so easy to say offhand what characters they possess in common. We recognise that they are both alive, but, without some expert knowledge, we are likely to find ourselves nonplussed if asked to say why we regard them both as alive.

When we come to consider organisms obviously of lower grade than horses or oak trees, such, for example, as corals and seaweeds, we may well find it difficult, without special training in zoology and botany, to decide to which of the two great classes above mentioned these organisms respectively belong. Even so great a naturalist as Linnæus included representatives of both in the same category. A seaweed like that shown in Fig. 1 looks, at first sight, not at all unlike the coral by its side. Both are, when alive, reddish-white in colour; both live in the sea;

A  B

FIG. 2. A, Flustra, a Polyzoon; B, Padina, an Alga. ($\frac{1}{4}$ natural size.)

both are attached to rocks; both are stony in texture and, in the main, composed of calcium carbonate; yet the living substance of the one is vegetable, of the other, animal. Albums of pressed seaweeds frequently contain specimens of marine animals, which in many cases bear a strong superficial resemblance to genuine seaweeds.

In studying the very lowest types of life we encounter even greater difficulties, and the trained zoologist or botanist may well hesitate before pronouncing a definite opinion on their essential nature. The remarkable Slime Fungi, for example, which find their home in tan-pits and on decaying timber, &c., are, under some conditions and at certain stages in their life-history, quite similar in appearance to some of the simplest animals, so much so, indeed, that many zoologists claim them as members of the animal kingdom (Fig. 3). It has even been suggested that all such lowly organised forms of life, about whose relationship to undoubted plants and animals difference of opinion exists, should be grouped into a sort of "no man's land," a territory inhabited by living things which do not, so to speak, exhibit any pronounced affinities to either of the adjoining nations. Without entering into a discussion of such dubious cases we may at present simply recognise the existence of the two great groups known as plants and animals respectively, each containing organisms of lower and of higher grade, and of gradually increasing complexity of structure, the two series diverging from a neutral region inhabited by forms that fail to show the distinguishing characters either of the one group or of the other.

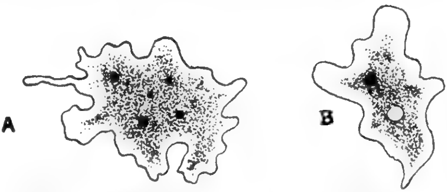


FIG. 3. A, Myxomycete (a Slime Fungus); B, Amœba (an animal). ×350.

Without at present making any attempt to enumerate the marks which distinguish plants, animals and neutrals, let us endeavour to find some character which all of them agree in possessing. **Vitality.** Obviously, they are all alive; they all possess vitality. But what is meant by vitality? The term is much more readily understood than defined in so many words, and hence it is fortunate that, for our present purpose, each one may work on his own individual conception of the meaning implied by the word and leave verbal interpretations alone; a study of the characteristics of living things will furnish us with a basis on which to formulate definitions subsequently. Meanwhile, let us begin by taking a summary view of the organisms themselves.

Before commencing any detailed study of the subject we must recognise that, if our aim be to understand the fundamental principles of Biology —that is to say, of the science which deals with living things—we must study organisms alive, not merely investigate the structure of their corpses; we must watch the machine at work, not simply pull it to pieces when it is at a standstill. A knowledge, however detailed, of the size, shape, minute structure, chemical composition, mode of manufacture and so on, of the several parts of a marine engine or of a chronometer, would give to one entirely ignorant of the uses of these instruments but a poor idea of the purpose for which they had been constructed, or of the part which each component unit played in the complex whole; the study of the form and structure of the machine must be accompanied by a study of its mode of action and of the manner in which its different parts co-operate in the performance of its functions. If this be true of apparatus relatively so gross, how much truer must it be of the infinitely more complex and delicate mechanisms we term plants and animals. To understand what an animal or a plant really is and how it lives, we have to study both its structure and the functions carried out by its several parts, in other words, both its morphology

Biology.

Morphology and physiology.

and its physiology: for the study of the structure of an organ will often suggest the function it fulfils, while the study of function not infrequently aids us in the interpretation of structure.

There are, however, several other lines of inquiry in reference to organisms that may be followed out with interest and profit. There are, for example, problems connected with the relation of the organism to its environment (Ecology), its occurrence on and migrations over the earth's surface (Distribution), and its genealogical relationship to other organisms obviously allied to it (Taxonomy), whether these be now living or represented by more or less perfectly preserved remains imbedded as fossils in the earth's crust. It would be impossible, without greatly increasing the size of the present volume, even to indicate the nature of these problems, let alone discuss them; nor is it necessary or expedient to do so, seeing that succeeding primers of this series will deal with certain of these questions in greater detail. At present we may confine our attention to the task of endeavouring to obtain some elementary conceptions of the principles of the science of life, and more especially those on which morphology and physiology are founded, in other words, to gain some idea of the structure of the living machine and of the way in which it works.

Ecology.

Distribution in time and space.

Taxonomy.

CHAPTER II

THE FUNCTIONS OF THE ORGANISM

ADOPTING, as our point of departure, the conception of an organism as a machine adapted to the performance of certain duties or functions, let us, first of all, inquire what, speaking generally, these functions are ? What are the essential kinds of work that all organisms carry out ? A little reflection will lead us to the conclusion that every living organism exhibits three fundamental capacities, viz., (1) The capacity for feeding itself ; (2) the capacity for responding to stimuli—to impulses from within or from without ; (3) the capacity for multiplying itself ; in other words, the three fundamental physiological characteristics of the organism are nutrition, sensitivity, and reproduction. Further, just as a butcher's knife, a cavalry sabre, an anatomist's scalpel, a surgeon's lancet, are all of them knives, and all alike fulfil the general purpose of making an incision, although each is constructed in the way best suited to produce the special kind of incision intended, so organisms show the greatest variety in constructive detail, in all cases adapted to carry out these functions in very varied ways. Let us, quite briefly, summarise what we understand these three general functions to consist in.

Functions of the organism.

Every organism must obviously be able to absorb from without certain materials which, however complex they may be in chemical composition, are still not themselves alive. These materials,

Nutrition.

after undergoing appropriate and usually very complex changes within the organism, having for their purpose the alteration of these substances into "food," are built up into the mechanism and become more or less permanent parts of it, or are employed in other ways, which at present need be referred to only in very general terms. If properly nourished the organism is able to perform work, not merely visible work, but also internal work not necessarily apparent to the senses; it repairs waste in its various parts, in many cases adds new parts or increases the size and complexity of parts already in existence —a series of phenomena commonly united under the term growth—and also lays aside surplus material over immediate needs in appropriate forms in some part of its body for use on a subsequent occasion.

During the entire course of its life-history the organism is exposed to an ever changing "environment," a term used to indicate everything, living or non-living, palpable or impalpable, outside it. The stimuli exerted by the environment may be in some cases injurious, but in other cases they are distinctly advantageous; these stimuli are constantly varying in character, in time of application, and in intensity. Manifestly, it must be of the utmost importance to the organism to be capable not only of appreciating these impulses, but also of responding to them in such a way as to protect itself from such as are hurtful, and to take every advantage of such as are favourable to its well-being. The most superficial observation, in fact, teaches us that the organism is sensitive to stimuli and capable of responding to them by movement, structural adaptation and so on. It must be noted, however, that the possession of sensitivity does not necessarily involve that power of apprecia-

Sensitivity.

tion of a stimulus which we are accustomed to term "sensation," at least we have no means of determining whether sensitivity in plants and in lower animals is accompanied by consciousness or not.

Reproduction.

Again, the organism, plant or animal, is, as observation tells us, one of many of the same kind, type or species. In some cases at the completion of, but in most cases, at some stage in its life-history, the organism makes provision for the continuance of the race by separating off a part of its body capable of giving rise, under suitable conditions, to a new organism of the same type. In some cases, the cooperation of two individuals is necessary for the formation of this unit, in other cases it may be produced by one parent only. The "germ," as we may for the present term this isolated part, is, in short, either simple in the sense of being a single part, segmented off from one individual, or compound, *i.e.*, the product of the fusion of two parts separated from two individuals or from two different parts of the same individual. In the latter case one of these parts is termed the male element, or sperm, the other the female element, or ovum. As every one knows, organisms produced by either of these methods show all the chief characters of their parent or parents, while at the same time exhibiting many, and often considerable, variations from the parental type. The offspring inherit the fundamental characters of the parent or parents, but show individual peculiarities or variations of their own.

Let us now quite briefly consider a couple of illustrations, one taken from the plant, and one from the animal world.

Growing on the surface of the soil of old flowerpots or in damp situations near farmhouses may frequently be found a dark green filamentous plant known as Vaucheria (Fig. 4), so named after the Swiss theologian and professor, Dr. Jean Vaucher. Structurally it consists of a sparingly branched thread, anchored to the substratum by short, branched, colourless filaments. Microscopic examination shows that each filament consists of a colourless wall lined by a viscid substance in which are imbedded very numerous ovoid green particles and a number of small rounded granules. The central space (or spaces) in each thread is occupied by a colourless fluid. The wall is in close contact with the damp soil, and its external layer is soft and mucilaginous, owing to absorption of the water with which it is in touch. **Vaucheria.**

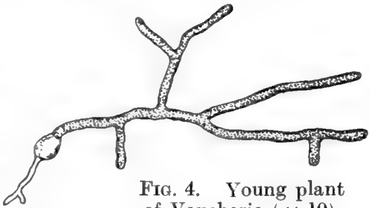


Fig. 4. Young plant of Vaucheria (× 10).

Manifestly such substances as occur in the soil, and are themselves soluble in water, might readily be absorbed by the wall, and so be transferred to the interior. Thus not only might the inorganic salts, of which the soil is in the main composed, find entrance, but gases also, which are soluble in water, might be absorbed by the filament. Let us assume for the moment that these bodies are absorbed through the wall; they would then at once reach the viscid substance lining the inner side of the wall, and might possibly be absorbed by it in its turn and passed on to the solution filling the central cavity or cavities. The viscid lining of the limiting wall is known as protoplasm and the central cavity as the vacuole, which latter is filled with sap. A chemical analysis of the sap shows it to be composed mainly of water, but to contain also variable quantities of salts and gases in solution, such as might have reached it from without, and also of certain other substances not derived, at least directly, from the exterior, which, since they are always found in association with living or dead organisms, have been termed organic compounds. Since the plant grows and, as we shall see presently, multiplies, it is obvious that the organic material must gradually increase in amount, and the only sources of supply of the raw materials required for the manufacture of such organic substances must necessarily be the soil, the water and the air. These raw materials must further undergo certain changes in the plant to make them of such a nature that they may be assimilated by the protoplasm—the only living part of the mechanism. Into these changes we need not at present inquire, though, later on, we shall find that the green particles, which are known as chloroplasts, play a very important part in the process. At present it will be sufficient for us to recognise the fact that Vaucheria must absorb certain materials from without and transform them into pabulum, which it uses for the increase of its body and for other purposes. It is to this series of phenomena that we give the name nutrition.

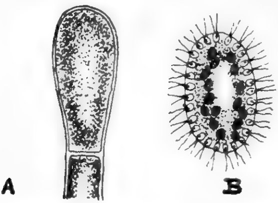


FIG. 5. Vaucheria. (A) Formation of a zoospore at the apex of a vegetative branch (× 25). (B) A fully developed zoospore (× 50). (After Oltmanns.)

At certain times and under certain conditions, the tips of some of the branches become darker in colour and partitioned off from the remainder of the filament by transverse walls similar to that which limits the entire plant. After a time these apices open and permit of the escape of the contents which, when free, are seen to have the form of ovoid green masses furnished with minute motile protoplasmic threads or cilia, usually distributed in pairs over the entire surface. These bodies, known as zoospores, move by the rhythmic wavings of their cilia and are able to propel themselves through the water for a short time. At length they reach a suitable situation, settle down, lose their cilia and become covered by walls similar to those of their parents. After a period of rest germination commences, when from the resting spore there arises a colourless and a green filament. The former branches and takes root in the mud; the latter also branches, but less frequently, and gradually elongates into a plant like that from which the zoospore originally sprang. Here we have a case of multiplication or reproduction, and since only one part is concerned, *i.e.*, the zoospore, it is spoken of as asexual reproduction (compare p. 8).

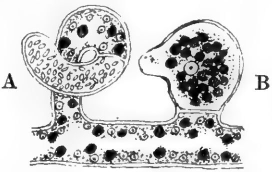


FIG. 6. Vaucheria. Formation of sexual reproductive organs: A, male; B, female (× 50). (After Oltmanns.)

At other times, however, the "germ" which corresponds to and, at that stage, superficially resembles the resting zoospore, is produced in an entirely different manner. From the side of the filament arise, close together in many forms, two short projections, at first somewhat like the beginnings of two ordinary branches. These projections are approximately alike in their early stages of development and both are green; but ere long one of them becomes swollen and somewhat pear-shaped and isolated from the main filament by a transverse wall. The other projection becomes hooklike and a partition appears just where the bend occurs. The region beyond this partition loses its green colour and its protoplasmic contents subdivide into many extremely minute ovoid particles, each of which, when examined under a high power of the microscope, is seen to be provided with two cilia pointing in opposite directions. When these bodies, known as sperms (or antherozoids), are ripe, they escape by an opening formed at the apex of the curved branch. Simultaneously the short adjacent projection becomes mature by the aggregation of the green contents into a central mass having a colourless apical region, in front of which the wall is much thinner and finally disappears, allowing part of the colourless portion of the contents to escape as a minute drop of mucilage. The sperms are attracted by this mucilage, and one of them finds its way into and fuses with the central green mass, which is known as the ovum. The product of fusion, or oosperm, as the result of this sexual reproduction may be termed, then becomes enclosed in a wall and behaves, after a period of rest, in a manner precisely similar to the zoospore, *i.e.*, it germinates into a new plant. The same result is thus arrived at in both asexual and sexual reproduction but in entirely different ways; in the asexual method one part only becomes the "germ" of the future plant, but in the sexual method the "germ" is the product of fusion of two parts, one the relatively large passive ovum, the other the minute motile sperm.

For reasons we shall afterwards appreciate, sensitivity to external stimulus is not so observable in the plant as in the animal; still, even in Vaucheria, it is capable of demonstration. Thus the zoospores may be made to move in definite directions in response to the stimulus of light. A bright light causes them to move away from, a weak light induces them to move towards, the source of illumination, while the mucilage which escapes from the short swollen branch containing the ovum attracts the sperm. Many experiments have been performed of recent years on Vaucheria (and on other plants equally low in rank) which go to prove that these plants are extremely susceptible to external influences, such as running versus stagnant water, salt solutions of varying strengths and chemical character, light and darkness, &c., to which influences they respond in various ways.

Frog.

Let us now consider an illustrative example from the animal world, *e.g.*, a frog. Obviously such an animal is of relatively much higher grade zoologically than Vaucheria is botanically, but it is a familiar and easily obtained organism, and illustrates certain characteristic features of the animal kingdom better than one of lower rank.

From the nutritive point of view we notice at once that the frog differs markedly from Vaucheria in that almost all the materials which it absorbs are organic; it makes but little use of the minerals in the soil, and does not employ the gases of the air at all as food materials. We shall find later (p. 43) that this is associated with the absence from its mechanism of the chloroplasts which we have seen to be one of the constituents of the filaments of Vaucheria. This organic "food" material is moreover taken in by a definite opening, the mouth, and not by the entire surface of the body as in Vaucheria; in its passage through a tract known as the alimentary canal, it undergoes certain complex changes, due to the admixture of secretions from glands which line or communicate with the alimentary canal, changes which are collectively spoken of as digestion. The digested substances are thereafter absorbed from the alimentary tract by a system of vessels, and are carried by their means to all parts of the body, the motive power being the rhythmic contractions of a muscular organ on the path of the circulation, viz., the heart. The mechanism of nutrition would thus appear to be much more complicated in the frog than in Vaucheria, but a little reflection will show us that the principle is the same in both cases, viz., the assimilation of certain organic substances by living protoplasm after these have been altered within the organism into suitable forms.

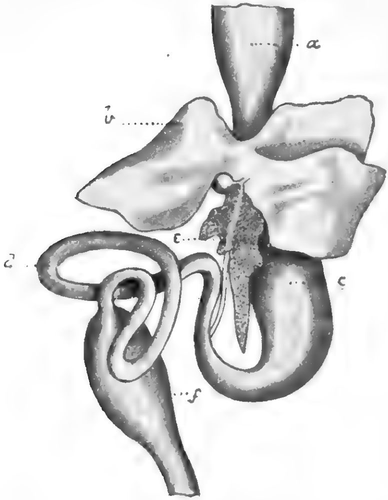


FIG. 7. Alimentary canal of frog: *a*, gullet; *b*, liver; *c*, stomach; *d*, intestine; *e*, pancreas; *f*, rectum.

Again, at certain seasons the frog multiplies its kind. In the interior of each individual certain special organs occur, in one individual an organ producing ova, in another an organ producing sperms. Sperms and ova are emitted from the male and female frogs respectively, and after the fusion of ovum and sperm, the product—or oosperm—passes through certain intermediate stages, and in time develops into a new frog. In the life-history of this animal there is no evidence of an asexual method of reproduction, such as has been noted as occurring in Vaucheria.

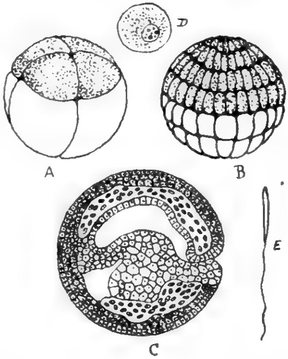


FIG. 8.—D, ovum; A, B, C, early stages in embryology; E, sperm of frog.

The feeble, but still observable, sensitivity to external influences which we recognised in Vaucheria is much more clearly exhibited by the frog. Not only is the general body sensitive to extremes of heat and cold and other climatic influences, but there are also specific organs developed for the express purpose of receiving special impulses; eyes for receiving light impulses, ears to receive sound impulses, special tactile organs in the skin for the reception of contact impulses, taste organs in the mouth and adjacent cavity for the appreciation of food, and so on. Moreover, we find a special system of conducting strands—nerves—having for their duty the transmission of impulses to a central organ, the brain, from which again another set of nerves transmit impulses generated there to motile organs—muscles—acting at some times on a jointed skeleton, and thus giving the entire organism the power of locomotion or permitting of movements in individual parts of the body. At other times the central nerve impulses are transmitted to glands, inducing or regulating secretion in or from them. Briefly put, the whole organism is sensitive in every part and capable of responding to stimuli of many different kinds. Further, in this case we are entitled to assume that the frog is able to analyse the impulses by which it is affected, that it is "conscious" of them; at all events we recognise that sensitivity has reached a higher stage in development than it has in Vaucheria.

Summary. It is quite unnecessary for us at present to go into further detail by way of illustration; it will be sufficient if we have learned to recognise in all organisms the power of self-nourishment, the power of reproduction, and the power of receiving and responding to stimuli and if, further, we have recognised that these powers are manifested by very different mechanisms iu the plant and in the animal worlds. We must also note that the green plant, even one so low in the scale of life as Vaucheria, must manufacture its organic food from inorganic constituents derived from the soil, water and air, before it actually employs such food as nutriment for its protoplasm, while the animal absorbs organic materials already manufactured; that plants (although not all plants) have both a sexual and an asexual method of reproduction, while animals (with relatively few exceptions) possess the sexual method only; and lastly, that plants are much less obviously sensitive to impulses from without than are animals. This last characteristic we shall find later on is associated with the feebler powers of movement and locomotion possessed by plants, and with their ability to manufacture their own food materials from inorganic constituents.

CHAPTER III

DIFFERENTIATION OF STRUCTURE AND DIVISION OF LABOUR

We have seen that plants and animals may be arranged in an ascending series, rising in the case of plants from such a type as that figured on p. 19 to the large and vastly complicated forest tree, or in the case of the animal world, from the simple Amœba (Fig. 3) up to such an elaborate mechanism as man himself.

The very lowest types of both series of forms, simple as they are, are yet living organisms capable of performing all the functions we have recognised in Vaucheria and in the frog. Each consists of a minute mass of protoplasm with a central granule or nucleus and, in some cases, one or more chloroplasts. Microscopic examination of a higher plant or animal shows us that each is composed of units of extremely varied size, shape and structure, yet every unit, at least when young, consists of protoplasm and a nucleus. Such a unit we term a cell, and we are thus able to say that some plants and animals—the lowest in the scale—are unicellular, while others—the majority—are multicellular.

Cells.

Let us glance first at unicellular forms and for that purpose we may select for study a simple animal, Amœba, often met with in fresh water aquaria, and the plant commonly known as Pleurococcus, which, together with forms closely allied to it, gives the familiar green colour to the bark of trees, rain butts,

Unicellular organisms.

damp walls, &c. For comparison we may also study a single cell from the human body, a white blood corpuscle or, as it is sometimes termed, a leucocyte.

Amœba.

The animal Amœba, under a high magnifying power, appears as a minute mass of protoplasm, granular in the centre and clearer towards the margin and provided with a nucleus. It creeps slowly over the substratum by sending out projections from its margin, technically called pseudopodia. Should it meet, in its progress, particles of organic substances suitable for food, it flows slowly round them and engulfs them. In its interior all that is

FIG. 9. A, Pleurococcus; B, Chlamydomonas. × 450.

nutritively serviceable is digested and absorbed, and the remainder is rejected.

Leucocyte.

A leucocyte from the blood is, to all intents and purposes, a small Amœba. Being constantly bathed in a nutrient fluid, viz., the blood, it is in a particularly favourable situation for obtaining fluid nourishment; still, it has been found that should extraneous bodies detrimental to the human organism find their way into the blood, the leucocyte is capable of engulfing and destroying them. The parallel with Amœba is thus fully maintained.

Pleurococcus.

The third type of unicellular organism we have chosen is, however, different in many respects from those already mentioned. In the first place, Pleurococcus (Fig. 9A) although it also consists essentially of protoplasm and a nucleus, is covered by a cell-wall of relatively firm consistence, through which no solid body can pass, and, further, it contains one or more chloroplasts, absent, with very few exceptions, from the cells of animals. Even where they do occur there is good reason to believe that they are in reality very simple plants allied to Pleurococcus which have taken to living in the bodies of these animals. We at once conclude that, as in the case of Vaucheria, all the materials used by Pleurococcus must be presented to it in the liquid or gaseous state and must be absorbed by and passed through the cell-wall. Moreover, these materials are in the form of the relatively simple inorganic bodies occurring in the situations where Pleurococcus grows and must be constructed into organic compounds before they can be assimilated by the protoplasm. This construction, as in the case of Vaucheria, is associated with the presence of chloroplasts.

Again, the existence of a more or less rigid cell-wall renders movement in the case of Pleurococcus impossible, although, in allied forms, the plant is capable of movement at one stage in its life-history through the agency of two motile threads or cilia (Fig. 9B). Still, in general terms, we may note that a dependence on ready-made organic food is associated with locomotion, while the power of constructing organic compounds out of inorganic materials occurring in the soil and air accompanies an absence of ability to move from place to place. This important relationship, too often minimised or ignored, will be discussed more fully later on (compare p. 68).

Nutrition and locomotion.

Turning from unicellular forms, let us consider the general structure of some organisms slightly higher in the scale of life, *e.g.*, a simple animal frequently met with in fresh water aquaria, and one of the commonest forms of seaweed, only too abundant on the bottoms of ships and known to sailors as "grass." The animal goes by the name of Hydra, and the plant by that of Enteromorpha. It is unnecessary for us to study the structure of either of these organisms in detail it will be sufficient for our purpose if we recognise that both are composed not of one cell but of many.

Multicellular organisms.

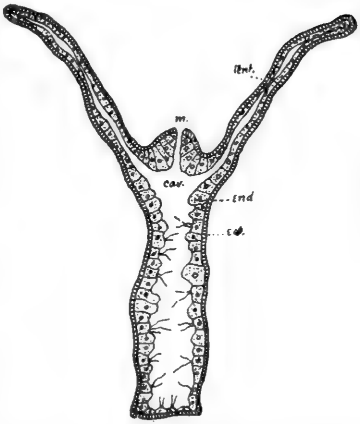


FIG. 10. Hydra : *m*, mouth ; *tent*, tentacle ; *cav.*, body cavity ; *end.*, inner layer of body wall ; *ect*, outer layer of body wall. (×20.)

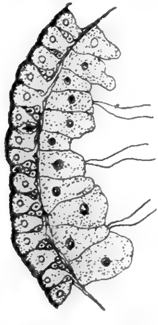


FIG. 11. Hydra. Transverse section of body wall. (×100)

Hydra.

In the case of Hydra, the body-wall consists of two distinct layers (Fig. 10). The cells of these two layers differ from each other in form and contents, although not very markedly ; those of the outer layer are smaller, more regular, and obviously perform different functions from those of the inner layer. They are primarily protective, for they contain stinging appliances, of the effect of which most people who have indulged in sea-bathing or fishing have had experience from contact with them in allied organisms such as some of the common jellyfish. The cells of the inner layer, on the other hand, are devoted to the absorption and ingestion of the organic materials which enter the opening at the top of the tubular body. At certain times some of the cells of the outer layer produce bodies which are presently recognisable as reproductive organs. In short, now that the organism has become multicellular, some cells take on one function, others another, while still retaining certain general powers, *e.g.*, that of self-nourishment. Again, it is obvious that as the duties of any particular cell become circumscribed and specialised, its form and structure become modified also, in order that it may carry out the work allotted to it in a more efficient manner. In just so far, however, does the cell in question become more dependent on its neighbours in other respects. Thus, a cell which devotes itself solely to the formation of reproductive elements must be fed by other cells which are specialised for carrying out nutritive duties and protected by others adapted to perform that function.

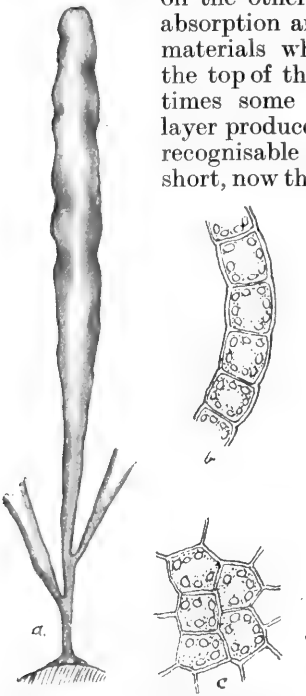


FIG. 12. Enteromorpha: *a*, portion of plant (natural size); *b*, body wall in section; *c*, in surface view.

Similarly, an examination of the green seaweed Enteromorpha shows us that while the body is in the main composed of a vast number of more or less similar green cells, some at the base of the tubular body are colourless and concerned with the fixing of the organism to the substratum, while some of the general body-cells are capable of taking on reproductive functions. The contents of these latter cells divide into minute ovoid bodies, each provided with four cilia and each capable of producing a new Enteromorpha.

Enteromorpha.

Differentiation of structure thus appears in forms of quite low grade, but it is only in plants and animals of much higher rank that we meet with complete illustrations of the principle hinted at in Hydra and in Enteromorpha. In plants like a rose or an elm and in animals like a frog or a rabbit we have to deal with organisms composed of countless myriads of cells, some more intimately connected with the duty of nutrition, even, it may be, with that of forming one special secretion to be used in the digestive process, some simply protective, as in the case of the external cells of the body, some purely supporting, as those which form the skeleton, some having for their function the elimination of excreta or waste materials or the formation of reproductive cells, and so on, and in every case the form and structure of the cells in question are specially adapted for the carrying out of the functions allotted to them. Moreover, we find that many cells of the same kind are associated together to form tissues. Thus we have in the animal, epidermal tissue, muscular or contractile tissue, glandular tissue, nervous tissue, and so on, and in the plant also glandular tissue, conductive tissue, epidermal tissue, &c. &c. Lastly,

Differentiated multicellular organisms.

Tissues.

many different kinds of tissues are bound together into yet higher units. Thus, such an organ as the liver consists not of glandular tissue alone, but of connective, vascular, and nervous tissues as well, and a leaf, in addition to the nutritive green cells of which it is mainly composed, possesses also epidermal, vascular and supporting tissues, arranged so as to carry out most effectively the purposes for which they were intended. Hence, as we study successively higher grades of plants and animals, we come to recognise that division of labour among cells is accompanied by specialisation of structure; that as the community of cells becomes larger and larger, duties previously carried out by all cells are now relegated to some cells only, and that these are, by their form, their contents or position, better adapted than others for the performance of these duties. We find also that there is a give-and-take among these cells, so that the nutritive cells nourish not only themselves, but all other cells requiring nourishment, while the protective cells protect not only themselves but also the nutritive cells which feed them. In a word, we learn to appreciate one great generalisation in biology, viz., that progressive specialisation of structure is accompanied by physiological division of labour. An instructive comparison may be drawn between a unicellular and a multicellular plant or animal on the one hand, and a human individual and society on the other. Just as the unicellular organism does everything for itself, so the isolated human individual—if, let us say, marooned on an uninhabited island—must be his own butcher, tailor, shoemaker, grocer, builder and what not. In a society, on the other hand, certain individuals assume one duty to the community, others another,

Division of labour and specialisation of structure.

and each by his training, education, even by his capabilities in hands, feet, eyes, &c., succeeds best in the trade or profession for which he is best suited. A false selection is followed sooner or later by failure, or at least by indifferent success, just as a glandular cell would form but a feeble protective agent, or a skeleton cell an ineffective contractile one. Further, a society is successful, a nation prosperous, only if there be harmonious co-operation between the units composing it, when they all, in a word, work for the common good; so, too, every cell in the healthy body must play its appropriate part in the general economy, and take its due share in the work carried on by the body as a whole. Should it fail to do so, disease in the organism results sooner or later. A strike or a revolution is a disastrous phase in the history of a society, it is equally disastrous in that of a cellular community.

Progressive differentiation in individuals.

As a result of this rapid survey of organic nature we have seen that we may distinguish successively higher grades of organisation in both plants and animals, beginning with unicellular types and passing through multicellular, almost undifferentiated forms to such as show complete differentiation of structure and division of labour. We have also seen that every plant and every animal starts life as a single cell—be it oosperm or zoospore, as in the majority of plants, or oosperm only, as in the great majority of animals. Obviously, the same general advance from the unicellular to the multicellular and from that to the completely differentiated condition must be met with in the life-history of every higher organism. Look, for example, at the early stages in the life-history of the frog. The oosperm is a unicellular organism just like the oosperm of

Vaucheria or the adult Amœba or (save for the wall and chlorophyll) Pleurococcus. By division of the original cell there arises a multicellular body which, because it is a primary stage on the way to something higher, we term an embryo. But such an embryo as that shown in Fig. 8 B, is composed of cells which are, speaking generally, similar to each other. Later on, these cells begin to differentiate, begin, in other words, to specialise both in structure and in function, and this differentiation is gradually carried to completion as the adult stage is approached.

We have thus sketched out in the life-history of the individual the same general advance that we see illustrated in successively higher groups of organisms, so that, in general terms at least, we may say that, assuming for the moment that organisms are genealogically related, the history of the individual is a very brief epitome of the history of the race.

CHAPTER IV

FOOD AS A SOURCE OF ENERGY

WHEN we carefully analyse a series of organisms by appropriate chemical methods, we find that twelve chemical elements are constantly present, viz., carbon, hydrogen, oyxgen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, iron, sodium and chlorine. Several others may be present in varying quantities in special cases, but these twelve elements are always to be distinguished, and the first four are especially prominent. These elements must have been introduced from without, and the building up and subsequent keeping in repair of the organism must involve their continued absorption, elaboration and incorporation. The ultimate sources of all the chemical elements in the organism are, directly or indirectly, three in number, viz., soil, water, and air.

Analysis of organisms.

Source of chemical elements.

One most important fact, too often neglected, must be especially emphasised at the very outset, viz., that no protoplasm, whether of plant or of animal, is able to assimilate such substances, either in their elemental condition or even when united to form such compounds as occur in the inorganic world. Only when they are united into the very complex groups which constitute what are known as organic compounds can the protoplasm actually incorporate or "assimilate" them, in other words, make them part of itself. But these organic substances are non-existent in Nature save in association with

Nature of "food."

plants and animals, as products of their activity when alive, or of their decomposition when dead. We thus appear to have landed ourselves in a "vicious circle": protoplasm—the essential basis of the living organism—can be supported only by organic compounds and yet organic compounds are formed only as a result of the activity of protoplasm. The problem before us, therefore, is, How are the necessary organic compounds originally formed? How are relatively simple inorganic materials synthesised into food acceptable to protoplasm? An attempt will be made to answer this question in Chapter VI., meanwhile, let us endeavour to find how "food," properly so-called, is a source of energy or of power to do work.

Daily diet.

A study of dietetics teaches us that an average man doing average work requires, during the twenty-four hours, in round numbers, 140 gr., or about 5 oz. of nitrogenous compounds or proteids; 100 gr., or about 3½ oz. of fat, and 420 gr., or about 15 oz. of such compounds as starch, sugar, &c., which are known to chemists as carbohydrates, because they contain (in addition to carbon) hydrogen and oxygen in the same relative proportions as they occur in water. Now, it must be at once apparent that, so long as it is alive, an organism, of whatever rank, is constantly doing work—whether it be external and visible or internal and invisible. But to do work, energy must be expended and this naturally involves a source of energy. How does the organism obtain the necessary energy, and in what form?

Energy.

Energy, so the physicists inform us, occurs in two states or conditions, potential and kinetic. A weight resting on a shelf possesses potential energy, in other words, though performing no work at the moment, it is capable of doing so. For example, if it be attached to a cord and the cord be put in connection with a clock mechanism, the weight, if swung free, is capable of making the clock go. Its potential energy now becomes kinetic or active. Physicists also tell us that energy may be recognised in several different forms, such as chemical energy, thermal energy, photic or light energy, electrical energy, &c. By chemical energy, for instance, is meant that form of energy which is exhibited when constituent units or atoms combine to form a molecule of a compound. Thus a molecule of water is represented by the formula H_2O, meaning that water is a compound of the two elements, hydrogen and oxygen, in the proportion of two atoms of hydrogen to one of oxygen. When these two gases are brought together, under certain external conditions, they combine with each other, and, in the act of uniting, energy is set free.

Conservation of energy.

Then again, the results of physical research have led to the conclusion that all these forms of energy are reducible to one, and that each may be changed, and, in Nature, is constantly being changed, into another. Still, no matter how or to what extent the change occurs, the sum of the energies in the Universe (if finite) is a constant quantity. It cannot be reduced and it cannot be increased, it can only be altered in form or in state. This is known as the Law of the Conservation of Energy.

Measurement of energy.

In order to obtain exact data as to the amount of energy expended we must fix on a standard by which to measure energy. Manifestly this must be relative only and in terms of one or other of the various forms of energy. But which one? We have already said that one type of energy may be converted into another. Physicists tell us that thermal energy is the only one into which all the others are convertible. For this reason energy is usually measured in terms of heat, and the unit of measurement is known as a "calorie." A calorie is the amount of heat required to warm one kilogram of water from 0°C. to 1°C. and it is possible to measure the energy of every body possessing it in terms of this unit. The energy of the living organism, as well as the energy of the various food substances absorbed by it, may, therefore, be estimated in calories. "The heat value of a substance is the amount of heat that is produced by its complete oxidation, and this amount is the same whether the oxidation be quick or slow, reached by a direct or by a circuitous path. It is, therefore, possible to estimate the amount of heat that must be produced in the body, by estimating the heat-value of the food daily consumed." (Waller). Thus, if the heat-value of 1 gr. of proteid be 5 calories, of 1 gr. of fat 9·07 calories, and of 1 gr. of starch 3·9 calories, the heat-value of the nitrogenous and non-nitrogenous food forming the diet of an average man doing average work (p. 28) for twenty-four hours must be, approximately, 3,300 calories. The total energy of the body appears (*a*) as work, (*b*) as heat, and it has been found that these bear to each other a ratio of about 1 : 4, so that the measurable heat of the body will amount roughly to about 2,640 calories. These values are only approximate, since some organic compounds are excreted from the body in an incompletely oxidised condition still possessing for that reason a certain heat-value.

The organic substances required by living protoplasm, whether plant or animal in its nature, for the performance of its functions, its nourishment and repair—used, in short, as "food"—are stores of potential energy. It is of the utmost importance that this should be clearly understood.

Food—a store of energy.

The various chemical elements that are found in the body may be grouped in series, so far at least as our present problem is concerned, according to their affinity for oxygen—their capacity for being oxidised. Thus, to take a couple of examples, carbon may be oxidised, *i.e.*, made to unite with the oxygen of the atmosphere, when heated to a temperature of at least 500° C. It may, as every one knows, be burnt, and the products of combustion are compounds of carbon with oxygen known as carbon monoxide and carbon dioxide, represented by the chemical symbols CO and CO_2 respectively. In order, however, that carbon may unite with oxygen, it must be raised, as we have seen, to a fairly high temperature. But at lower temperatures other bodies have a greater affinity for oyxgen than carbon has. For instance, the metal potassium will unite with oxygen at the temperature of the air, and form the familiar substance potash. If brought in contact with water, it will appear to burst into flame. This may be explained in the following way. Water consists, as we have seen, of hydrogen and oyxgen in the proportion of two units of hydrogen to one of oxygen, and these form an exceedingly stable compound. Potassium, however, has an even greater affinity for oxygen than hydrogen has, and it tears the oxygen from the hydrogen, and that, too, with such energy that the heat generated is sufficient to set fire to the

Oxidation and release of energy.

inflammable gas, hydrogen, now released from combination. The compound formed by the union of the potassium and oxygen, *i.e.*, potash, is represented by the chemical formula KHO, hydrogen having been ousted from its union with oyxgen and replaced by potassium, represented by the symbol K. The released hydrogen, combining with oxygen present in the air, forms water once more.

Deficiency of oxygen in organic compounds.

If we submit to chemical analyses the varied organic compounds used by protoplasm as "food" we find that they are relatively poor in oxygen, although most of their constituent elements are characterised by great affinity for it. The combinations in which they find themselves, however, interfere with their satisfying these affinities. They are, so to speak, clogged and hampered by their neighbours, and cannot readily unite with the element, oxygen, so abundantly present in their vicinity in the atmosphere. Let us look at a few examples. The red colouring matter of the blood, which is known as hæmoglobin, is a most complex body, and its formula, according to one authority, is $C_{600}H_{960}FeN_{154}S_3O_{179}$, meaning thereby that there are in the smallest possible particle or molecule of the pigment, 600 atoms of carbon, 960 of hydrogen, one of iron, 154 of nitrogen, 3 of sulphur, and 179 of oxygen. There is thus not nearly enough oxygen present to oxidise all these elements; for to completely oxidise one atom of carbon two of oxygen are needed; one atom of oxygen is required to oxidise every two of hydrogen, five of oxygen for every two of nitrogen, three of oxygen for every two of iron, and three for every one of sulphur. A little elementary arithmetic shows us that to completely oxidise all the elements present in one molecule of haemoglobin, over 2,000 atoms of oxygen are wanted, of which only 179 are present in the compound. Similarly, in the case of grape sugar, represented by the formula $C_6H_{12}O_6$, twelve additional oxygen atoms are required for the complete oxidation of the carbon and hydrogen, and for glycerine, $C_3H_8O_3$, seven more oxygen atoms are requisite.

Now let us imagine a crowd of persons unwillingly associated and restrained from joining hands with their own particular friends hovering round the outskirts of the crowd. Let us suppose that this restraint is suddenly removed, and that permission be given to friends and relations in the crowd to fraternise with friends and relations outside. The crowd will speedily break up into new associations, smaller groupings, and, if the affinity of individuals be great, considerable friction and heat may be generated in the process of regrouping. This analogy may be crude, but an effort of the imagination will enable us to conceive of an organic compound as such a crowd of units, and the oxygen particles in the atmosphere as their natural affinities outside. Let us make the conditions favourable for the satisfaction of these affinities and at once new combinations are effected, new groupings are established, heat being generated in the process of rearrangement. In the act of combining of the atoms of oxygen with those of carbon, of hydrogen, of sulphur and so on, energy is liberated—kinetic energy—and the position of separation of these elements from oxygen is therefore a position in which energy is potential—ready to be turned into kinetic energy when the combination is permitted.

Respiration.

Every organism, while alive, is constantly taking in oxygen in the process known as respiration, and this oxygen is conveyed to the regions of the body that are doing work, and therefore expending energy, there to unite with the elements of complex compounds poor in oxygen and themselves ready to unite with it, and so liberate energy in the kinetic form. It will thus be seen that, to the organism absorbing them, organic compounds form stores of potential energy, by the liberation of which the organism is able to do work, to exhibit vital phenomena —in a word, to live, provided always that oxygen gas be available for the oxidation of these compounds. It must not, however, be assumed that these various organic bodies are in all cases oxidised directly and undergo "combustion" in the ordinary sense of the term, like oil in a furnace; on the contrary, it is highly probable that it is the extremely complex protoplasmic molecule or aggregate of molecules that undergoes decomposition, and that the oxidation and abstriction of simpler decomposition products is intimately associated with the constructive or assimilatory phenomena already referred to (p. 27).

There are other ways of releasing the potential energy of an organic compound, although oxidation may be considered as the chief method. By dissociation a complex compound breaks up into two or more smaller and less complex groupings without the entry of any oxygen. There are also decompositions set up by certain secretions manufactured by the organism itself, but these and other methods need not be considered in the present relation.

CHAPTER V

THE TRANSFORMATION OF FOOD

THE complex organic compounds found in Nature are always, as we have seen, the products of animal or plant activity, for although a few organic compounds have been artificially manufactured, still as an economic source of "food" these may be considered, at present, at all events, as insignificant. Further, these organic substances are not, even then, in forms capable of being made use of at once by the protoplasm. They must be readjusted in their composition and constitution before they can be actually assimilated. For example, starch must be transformed into sugar, if for no other reason than to render it soluble, so that it may penetrate the walls of the cells; grape-sugar, again, is a food-stuff to yeast, but cane sugar is useless to it until it has been altered into grape sugar. Readjustments and alterations such as these, whether in the plant or animal—and many of them, as we shall see later on, are exceedingly complicated in their nature—are collectively termed digestion. The two essentials are (1) that the food shall have the appropriate chemical composition, suited, that is to say, to the wants of the organism, and (2) that it shall be in a state of solution.

Digestion.

Let us first of all consider digestion in one of the higher animals.

In animals.

The "food" in the process of mastication is mixed with and affected by a secretion formed by glands which line or open into the mouth cavity, and, after being swallowed, is mixed with other secretions derived from glands which line or open by ducts into the alimentary canal. By these secretions the food is altered in character, one secretion acting on one constituent, another secretion acting on another. In their progress through the canal the altered food-stuffs, now made assimilable, are slowly absorbed by vessels which permeate the walls of the canal, and are by them transferred, directly or indirectly, to the tissues.

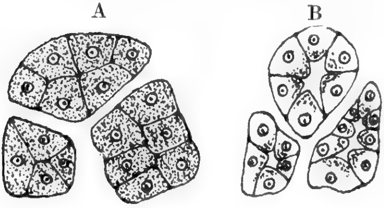


FIG. 13. Cells from a salivary gland : A, before ; B, after secretion.

In order that we may obtain some conception of the nature and mode of action of a digestive secretion, we may select that formed by the glands which open into the mouth-cavity—the salivary glands. The essential constituent of such a digestive secretion is an

Enzymes. organic body known as an enzyme or ferment. On examining a portion of one of the salivary glands under the microscope, we find (Fig. 13) that it is composed of an immense number of delicate protoplasmic cells, which, before the gland begins to secrete, are very granular. These cells are in communication, by means of minute intercellular channels, with one or more ducts which open into the mouth-cavity. As secretion proceeds, the granulation in the cells gradually disappears, and from the mouths of the ducts there exudes a colourless slightly opalescent fluid, familiar to every one as saliva. The granular substance in the gland cells is known as zymogen, or the enzyme-producer, the enzyme itself is termed ptyalin. If we make a very dilute starch mucilage by adding a few grains of starch to a wine-glassful of warm water and pour into this some saliva, keeping the whole at a temperature about that of the human body (*i.e.*, 100°F.), a gradual change takes place in the starch as the result of the action of the ptyalin upon it. If a few drops of a solution of iodine be added to a sample of the original starch mucilage, the mucilage takes on an indigo-blue colour, but no such colouration results from the addition of iodine to the sample which has been acted on for a considerable time by saliva. On the other hand, with the aid of another re-agent known as Fehling's solution (a mixture of Rochelle salts, copper sulphate and caustic soda in certain proportions) we can demonstrate the presence of a new substance, malt sugar, which, unlike starch, is soluble in water. The enzyme has effected the alteration of the starch into malt sugar, and one remarkable feature in the process is that the enzyme is not used up nor destroyed during the transformation. Further, a comparison of the chemical formulæ of starch and malt sugar shows that the enzyme has made the starch take up a molecule of water. Thus 2 $(C_6H_{10}O_5)$—starch—becomes $C_{12}H_{22}O_{11}$—malt sugar —by the addition of H_2O—water. Similar results may be obtained by preparing an extract of germinating barley, and causing it to act on starch. The ferment, which acts in the same way as ptyalin, in this case goes by the name of diastase.

Let us now attempt to gain some general idea of the nature of the alimentary canal of the animal and the enzyme-forming glands which open into it (Fig. 14). Into the mouth-cavity three chief kinds of organic food materials enter and are there masticated and mixed together, viz., proteids, carbohydrates, and fats (p. 28). There, also, they are mixed with saliva, and the starchy constituents are, to a certain extent, acted on by the ptyalin present in that secretion. The mixed food is then swallowed and transferred to the stomach, by whose rhythmic contractions it is again mixed with secretions derived from glands in its walls. The chief constituent of the secretion of the gastric glands is pepsin, and by it the proteids are attacked. After a period of gastric digestion, the food passes on to the intestine in whose walls another series of glands, intestinal glands, occur, which also add digestive secretions to the mixture, one, especially, changing cane sugar into glucose and fructose. Further, certain special glands, connected with the intestine by means of special ducts, add their secretions. One of these glands is the pancreas which has in its secretion a ferment which attacks any starch left unacted upon by the ptyalin, another which changes cane sugar into grape sugar and fruit sugar, another which attacks proteids and yet another which acts on fats. Another important gland is the liver, which con-

Alimentary canal and glands.

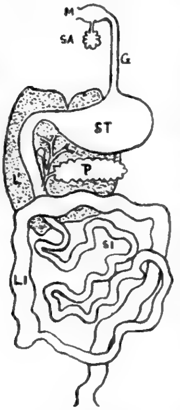


FIG. 14. Diagram of the alimentary canal and chief digestive organs: M, mouth; Sa, salivary gland; G, gullet; St, Stomach; L, liver; P, pancreas; Si, small intestine; Li, large intestine.

tributes bile—an antiseptic,—and an alkali which saponifies fatty matters. The food, in its passage through the alimentary canal, is thus materially altered, and, in the course of its journey, is gradually absorbed in its altered form by minute vessels which permeate the wall of the canal in all directions and is carried by them directly or indirectly to all protoplasmic cells of the body requiring nourishment. The undigested remainder is, in due course, voided as excreta worthless to the organism.

Nutrition in the higher plant.

Our next task must be to study, although more briefly, the problem of nutrition in the higher plant. Like the animal, the plant is composed of protoplasm and the products of its activity, and the food of the plant protoplasm, as of the animal protoplasm, must be organic in its nature. Moreover, much of this food, if stored as a reserve in insoluble forms, must be altered by enzymes and rendered soluble and appropriately prepared for assimilation.

At the very outset, however, we meet with a great difference between the two types of organism. As we have already hinted, the green plant itself manufactures its own organic food from inorganic materials, while the animal, being unable to do so, has to depend upon organic material made by the plant or absorbed by another animal from the plant. In a word, the plant makes what it wants, the animal takes what it can get. Manifestly, the digestive secretions and apparatus of the plant need not be so complicated or elaborate as those of the animal, for, being able to make what it requires, it has not so much altering to do afterwards. Nevertheless, the first formed compounds are not always in the most appropriate state for assimilation, and further, as we shall find later on, the plant has great powers of storage, and the storage form is naturally in most cases an insoluble one. The plant on that account also possesses enzymes, proteid, carbohydrate and fat-transforming ferments, manufactured in some cases in special glands, but more commonly in the cells which contain the substances to be transformed. Even in the animal, digestion may take place within individual cells, as, for example, of glycogen—a starch-like compound—in the cells of the liver. Fundamentally, therefore, the digestion of food in the plant and the animal is carried out on the same principles, and the only difference really lies in the mode of production of the secretions, associated with the absence of any specialised digestive tract in the plant.

FIG. 15. Drosera. (Half natural size.)

Carnivorous plants.

It must also be noted that there are certain plants (carnivorous plants) whose leaves are greatly modified in form from ordinary terrestrial types and which possess, at least in some cases, definite cavities or pockets into which insects are, by a variety of methods, induced to enter. These chambers are virtually stomachs and their walls are more or less lined by glands which secrete enzymes acting on and digesting the bodies of the insects so caught (Fig. 15). One instance must suffice to illustrate this type of organism. On boggy hillsides there is commonly to be seen a plant, known popularly as "Sundew," from the glistening drops terminating the numerous tentacles with which the circular or ovoid leaves are covered and fringed. Small insects, attracted by these drops and probably also by the reddish colour of the leaves, are caught by the secretion, which is sticky in character. The contact with the insect induces a movement of the tentacles towards the point of stimulation, so that the insect's body becomes bathed in the secretion. The contact also stimulates the glands at the ends of the tentacles to secrete a ferment comparable with pepsin, which attacks the proteids of the insect body and digests them, the products being afterwards absorbed by the leaf. The "pepsin" in the digestive secretion of the Sundew acts only in an acid solution, as in the case of the pepsin of the gastric juice of the animal's stomach.

CHAPTER VI

THE MANUFACTURE OF ORGANIC FOOD

On p. 27 we saw that it was only the green plant that was able to manufacture organic compounds from inorganic materials, for long erroneously spoken of as the "food" of plants. The "food" of the plant, just as much as that of the animal, must be organic in its nature, and since, in the liberation of energy, these compounds are constantly being reduced once more to simpler inorganic compounds by the process of oxidation, it follows that a mechanism must be forthcoming for the remanufacture of the complex compounds so destroyed, else the whole living machinery of the globe would come to a standstill. Further, not only must there be a constructing apparatus, but energy must be supplied to it else the mechanism would be unable to work. It must now be our task to inquire into the nature of this apparatus and the source of the energy—in other words, to study the chlorophyll machinery, the chloroplasts, referred to on p. 10, and the nature of sunlight.

Chloroplasts.

Our conception of the sequence of events that take place in the process of nutrition in plants and animals will become much clearer if we endeavour to realise that the chlorophyll apparatus is not necessarily a part of the plant only; there are many plants which are destitute of chlorophyll, and not a few animals which possess it. Indeed, a near ally of the species of Hydra which we studied from another aspect in a previous chapter, is, owing to the presence of chloroplasts in its cells, quite as green as any plant, and behaves, from the nutritive point of view, exactly like a green plant. Some forms allied, though distantly, to Amœba, to which we have referred above, also possess chlorophyll as do also some of the lower worms. It does not affect the physiology of the process whether these green particles are, as some biologists have attempted to show, plants living in intimate association with the animals in question, or, actual constituents of the animal itself, *i.e.*, not introduced from without.

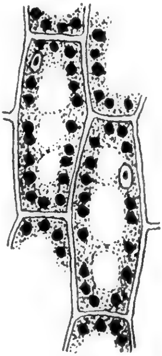


FIG. 16. Plant cells with chloroplasts. (× 300.)

Let us examine a chloroplast from the cell of a leaf. What is it made of, and how does it operate? In the first place, we may note that although some plants have chloroplasts in the forms of bands, stars, &c., in the vast majority of cases the chloroplasts are minute ovoid bodies, occurring singly or in large numbers in the cells which contain them (Fig. 16). Each consists of a basis of protoplasm permeated by an oily matter in which the chlorophyll, or pigment proper, is dissolved. The chloroplast is, further, in intimate relation with the protoplasm of the cell. Chemically, the pigment which can be extracted from the plastid by means of alcohol, ether and a variety of similar substances, is of extremely complex composition; indeed, it is probable that it is a mixture of several compounds. This apparatus does not perform its function of manufacturing organic substances save when exposed to sunlight, and we shall see later what particular rays of light are most useful to it. The cells containing chloroplasts are (with certain exceptions) found only in such parts of the plant as are exposed to sunlight, not only because it would serve no useful purpose to develop them underground or in deep-seated tissues, but also because, apparently in most cases, sunlight is itself essential to the formation of the pigment. In darkness the plastid is of a pale yellow colour, familiar to every one in the leaves of celery, or of grass which has been overlaid by a plank of wood or other opaque object.

Absorption from the soil.

The raw materials of the food of plants, as we have already seen, are derived from three sources, soil, water, and air. Let us consider, in the first place, absorption from the soil. The soil consists of a mixture of various minerals in the form of granules of varied size and shape, the interstices between which are filled with air and water. The minerals are more or less soluble in the water which circulates through these capillary channels, and round each soil particle there is an extremely thin film of water spoken of as hygroscopic water. From the surfaces of the finest roots, for a short distance behind the apices, arises a dense felt work of fine hairs—the root-hairs.

Root-hairs.

These root-hairs are really elongations of the surface cells of the root and find their way into the minute crevices between the soil particles, and come into intimate union with them (Fig. 17). The walls of the root-hairs, where they come in contact with the hygroscopic water, become swollen and mucilaginous, and any mineral matter dissolved in the water may pass through the wall of the root-hair and protoplasm lining it. This entrance takes place primarily in accordance with the physical law of osmosis. The soil water contains about $\frac{1}{10}$ per cent. or less of mineral matter in solution, whilst the fluid in the vacuole of the root-hair may contain as much as 2 or 3 per cent. of solid in solution. Physicists tell us that if an organic membrane—and the cell-wall is such a membrane—separates two fluids of different density, both of which are capable of passing through it, the less dense solution will pass through with greater rapidity into the more dense, than the more dense into the less dense, and hence the very dilute solution in the soil forces its way into the interior of the root-hairs. This entry of a more dilute solution renders the cell contents less dense than those of the cell next further inwards, and consequently a further flow from the outer to the inner cell occurs. This, however, will result in an increase in the density of the outer cell, permitting of the entry of more of the dilute solution from without. In this way a constant stream is set up from the soil outside to the interior of the root, where the solution enters the vascular system and is conducted upwards to the stem and distributed to all parts of the leaf. The solution that reaches the leaf is much too dilute for the chloroplastids to operate upon, so that arrangements must be made for its concentration by evaporation of the excess

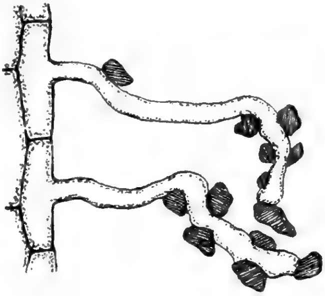


FIG. 17. Root-hairs, with soil particles attached. (× 250.)

water. This escape of water in the form of water vapour is known as transpiration. Let us see how this is effected. On the underside (as a rule) of the leaf occur innumerable minute apertures—known as stomata (Fig. 18). These are in communication with a complicated system of spaces between the inner cells of the leaf, through which latter also run the vascular cords. The excess water evaporates into the intercellular spaces whence it escapes to the exterior through the stomata.

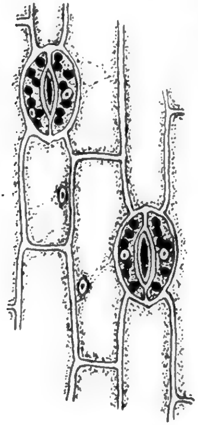


FIG. 18. Stomata. (× 250.)

Not only does water vapour escape by the stomata but air enters by them also, and one of the constituent gases in the air is carbon dioxide. In this way water, mineral matters and carbon dioxide gas are brought into the immediate neighbourhood of the chloroplasts.

These raw materials are, however, already fully oxidised and, as we have seen above, are, in that condition, useless as sources of energy. In the form of carbon dioxide the affinity of the carbon for oxygen has been completely satisfied, as also that of hydrogen for oxygen when in the form of water, and the same is true of most of the other salts absorbed and carried upwards by the water. The potential energy of position of separation has already been liberated by the union of oxygen with these other elements, so that to make the elements again valuable as stores of potential energy the combined oxygen must be got rid of and the position of separation of elements re-established by the formation of complex compounds deficient in it. How is this to be effected? The process requires an apparatus, and, further, the expenditure of a large amount of energy. The apparatus we have already seen is the chloroplast; the energy is derived from the sun.

A beam of sunlight may be analysed by means of a glass prism into rays of different colour. The rays as observed in Nature give us the colours of the rainbow—namely, red, orange, yellow, green, blue,

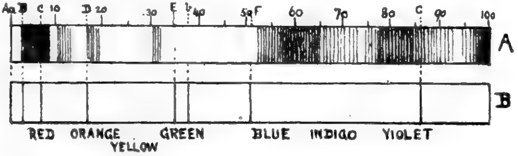


FIG. 19. A, absorption spectrum of chlorophyll; B, solar spectrum.

indigo, violet (Fig. 19). Let us now examine a solar spectrum by means of a spectroscope—and let us also make an alcoholic solution of chlorophyll and introduce, in a flat-sided glass vessel, a thin film of the solution between the source of light and the prism; we shall find that the previously continuous coloured band is now interrupted by a dark band in the red region, and also by paler bands in the yellow and green, while the violet, indigo, and part of the blue regions are almost completely wiped out. We speak of this incomplete band of colour as the absorption spectrum of chlorophyll, for we may assume that the chlorophyll absorbs some of the sun's rays and allows others to pass through. What

Solar spectrum.

Absorption spectrum.

happens to those rays which are absorbed? We are still very much in the dark on this subject, but in all probability the rays absorbed are transformed into some other form of energy and used by the protoplasm in the construction of organic substance. What we do know for certain is that, given the conditions above described, oxygen gas is evolved from the green leaf and almost immediately thereafter carbohydrates appear in the cell.

Photosynthesis.

We have now to ask what becomes of the energy of the solar rays which are absorbed? Undoubtedly, a large amount of it is used up in the decomposition of the highly oxidised mineral compounds, water and carbon dioxide, and in getting rid of the excess water absorbed by the roots, but part becomes stored as potential energy in the carbohydrates which have been manufactured. This constructive process is spoken of as photosynthesis.

Summary.

While the detailed stages of the photosynthetic process are as yet very imperfectly known to us, we are even more in the dark as to the nature of the further constructive efforts of the protoplasm by which higher compounds, such as proteids, are manufactured. We know, however, that for these higher constructive efforts no sunlight is necessary, and in all probability the energy required is obtained by the oxidation of primary organic compounds, and possibly of protoplasm itself (chemosynthesis), but into these recondite physiological problems it would be out of place to enter in such a preliminary sketch as the present. Thus far we have learned that the process of nutrition is fundamentally the same in plant and animal, but that the green plant adds a new department of work, entirely absent from the normal animal economy, namely, the manufacture of the organic matter necessary for nutrition. We have further learned that this organic matter has to undergo certain transformations, summed up under the word digestion, before it can be incorporated into the protoplasm of either kind of organism. At the same time it is worthy of note that the digestive apparatus is less complex in the plant than in the animal, because the green plant is able to construct the primary organic compounds best suited to its wants, whilst the animal, being unable to do so, must accept those already formed by other organisms, and these compounds are not always those most appropriate to its immediate necessities.

A few words of explanation must be added as to the modes of nutrition of non-green plants. Some of them are parasites living at the expense of living plants or animals; such plants are virtually thieves, since they appropriate the compounds manufactured by others for their own use. Parasites also occur in the animal world. Other organisms, again, belonging either to the vegetable or animal world, are either saprophytes, or saprozoa, that is to say, plants or animals which live on non-living organic substances, compounds which have been manufactured by living organisms, or which result from the decomposition of their dead bodies.

Parasites

Saprophytes and saprozoa.

There are, however, other types of nutrition in the plant world worthy of mention; it will suffice to specify two of these. Other plants, moreover, are symbionts, that is to say, organisms which live with others but not precisely at their expense, since, although they depend upon their partners for certain products, they give to their partners certain other products which they themselves have manufactured. There

Symbionts.

is thus a mutual give-and-take between them, the one helping the other.

Carnivorous plants. Finally, yet another type of nutrition is illustrated by the so-called carnivorous plant which, though green and rooted in the soil and thus in reality independent of organic nutriment, supplements its supplies personally manufactured by absorbing proteids and other organic compounds from insects and other small animals caught by one or other of the various mechanisms with which these carnivorous plants are provided. Many of them possess special digestive glands, and the enzymes produced by them show striking resemblances to those secreted by animals (p. 40).

Let us now attempt a summary in diagrammatic form of the whole problem of nutrition (Fig. 20).

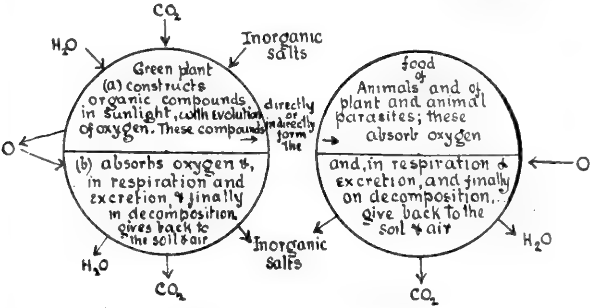


FIG. 20. Circulation of materials.

Circulation of materials. From this diagram it will be seen that kinetic solar energy acting on green cells in the presence of carbon dioxide, water, and simple inorganic salts brings about the formation of organic compounds which normally would go to the nutrition of the organism possessing such green cells. These compounds, however, may be appropriated by an animal or by a plant or animal parasite. In all these cases—the green plant, the normal animal and the parasitic plant or animal—the organic compounds formed by their decomposition when dead, form the food of saprophyta or saprozoa. The final products of decomposition of all dead organisms, as well as those resulting from the general liberation of energy in all living organisms are, as we shall see in the next chapter, carbon dioxide, water, and inorganic salts, which replace the original simple compounds absorbed by the green plant from the soil and air. There is thus a constant circulation of material from the inorganic, through the organic, back once more to the inorganic world. We shall see presently that there is also a circulation of energy.

CHAPTER VII

THE LIBERATION OF ENERGY AND THE EXCRETION OF WASTE

THE maintenance of life involves a continual expenditure of energy. This energy is derived directly or indirectly from the potential energy stored in organic compounds manufactured during photosynthesis and the further constructive activities of protoplasm. The potential energy becomes kinetic in the satisfying of the oxygen affinities of the elements of the organic compounds, as we have already seen in Chapter IV. The supply of oxygen is derived from the air and the process of intaking of oxygen, decomposition of organic compounds and excretion of the simpler and more or less fully oxygenated compounds are known as respiration and excretion. Let us look at these processes rather more in detail.

Composition of air.

The primary composition of the atmosphere must be our first concern. It consists essentially of three gases, nitrogen, oxygen and carbon dioxide. In an average sample of air these gases occur in the following (approximate) percentages, viz., nitrogen, 79·02 per cent.; oxygen, 20·95 per cent.; carbon dioxide, 0·037 per cent.

Relation of organisms to oxygen.

Detailed research has shown that all varieties of protoplasm ultimately die in the absence of free oxygen, and animal protoplasm is more sensitive in this respect than plant protoplasm. There are, however, some organisms of lower rank which can, for a considerable time or during their entire life, exist in the absence of free oxygen, being able to obtain any necessary supplies of that gas from compounds containing it. Most plant embryos, also, are able for a time to take the oxygen they need from like sources, but, generally speaking, we may say that free oxygen is essential to life. The chief compounds ultimately resulting from the oxidation of organic compounds are carbon dioxide and water.

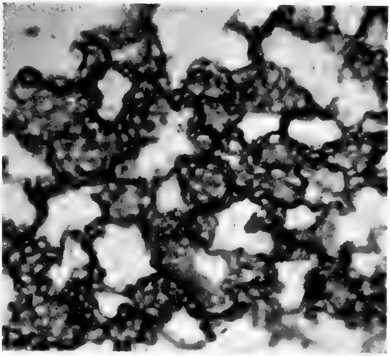


FIG. 21. A.r spaces in .ung. The darker lines are capillaries. (× 350.)

So long ago as 1757 Black showed that the final product both of combustion and of respiration was carbon dioxide, but it was not until Priestley, twenty years later, discovered oxygen, that it became possible to compare the two processes in detail, as was done by Lavoisier and De Saussure.

Respiration in animals.

As every one knows, in all the higher animals, oxygen, along with nitrogen and carbon dioxide, enters the lungs, gills or other respiratory organs, either as a free gas or in solution in water. In mammals, the respiratory organ, the lung (Fig. 21), consists of an immense number of minute cavities in whose walls lies a network of extremely delicate blood-vessels known as capillaries. The oxygen becomes associated with the hæmoglobin or red-colouring matter of the blood and forms a feeble compound with it, known as oxyhæmoglobin. This loosely combined oxygen is carried by the blood to such a seat of activity as, let us say, a muscle. There oxidation of muscle substance, or of organic compounds present in the muscle, takes place, thus liberating energy which enables the muscle to do work, *i.e.*, to contract. Amongst the substances formed as a result of this oxidation is the gas, carbon dioxide, which is transferred from the contractile cells to the blood, and thence by its means back to the lungs from which it is expired. The difference between the air inhaled and that exhaled shows approximately how much tissue destruction has taken place. Thus inhaled air consists approximately of 79 per cent. of nitrogen, 21 per cent. of oxygen, and ·04 per cent. of carbon dioxide, but exhaled air consists of only 16 per cent. of oxygen, and about 4 per cent. of carbon dioxide, the percentage of nitrogen—a neutral gas—remaining approximately constant.

Respiration in plants.

It may readily be shown that in plants the process of respiration is, in principle, fundamentally the same—the method of entry and exit of the gases, however, differs, for in them there is no special respiratory apparatus beyond the intercellular spaces in the tissues themselves. Air enters by the stomata in green parts or by special pores, left in older parts which have become covered with cork, known as lenticels, and diffuses to all parts which may require it, there to break down organic substances and so release energy required for carrying on vital processes. So, too, the carbon dioxide formed diffuses outwards and finds its way to the exterior by the same channels. During the day, while the green cells are exposed to sunlight, carbon dioxide united with water, *i.e.*, carbonic acid, is, as we have already seen, decomposed, and photosynthesis of primary organic compounds takes place. It will be at once manifest that this nutritive process must mask the respiratory process, if the amount of carbon dioxide required for photosynthesis be greater than that formed in respiration, and that the formation and excretion of carbon dioxide will not be apparent; the carbon dioxide will be decomposed and rebuilt by the green cells as soon as it appears in their vicinity. For that reason the green plant appears not to be respiring during the day; on the contrary, it appears to be giving off oxygen by day, and carbon dioxide by night. But this is easily explicable if we remember that during the night no photosynthesis is going on although respiration is, whilst during the day, although both photosynthesis and respiration are taking place, the carbon dioxide required for photosynthetic purposes so much exceeds in quantity the carbon dioxide produced by the tissues that none of the latter is able to escape, whilst, from it, as well as from the surplus carbon dioxide taken in, oxygen is released and exhaled as a by-product in photosynthesis. Hence the statement often made that one of the essential differences between a plant and an animal is that "whilst the animal takes in oxygen and gives off carbon dioxide, the plant takes in carbon-dioxide and gives off oxygen." Both statements, as a matter of fact, are perfectly correct, but the actual comparison is entirely misleading, since the taking in of carbon dioxide and giving off of oxygen is a nutritive or constructive process, whereas the converse process is respiratory or destructive. That respiration takes place in green plants by day as well as by night, is easily proved by the following experiment (Fig. 22).

Experimental demonstration of respiration.

Place a vigorously growing green plant beneath a suitable bell-jar (A) which communicates by means of two bent glass tubes with gas-wash bottles, and cover the bell-jar with black cloth or black paper to shut off sunlight from the plant. The two gas-wash bottles B and C, and D and E are half-filled with lime-water. The outer end of the bent tube B′ communicates with the air directly, but since

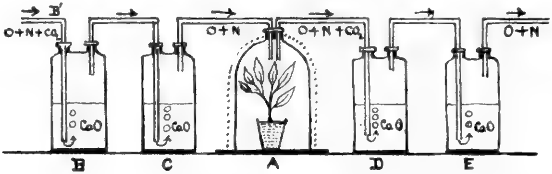


FIG. 22. Apparatus for demonstrating respiration in plants during the day.

the end of the tube inside the wash-bottle passes below the level of the lime-water, all the gas which enters the apparatus must pass through the lime-water in B. Now when carbon dioxide and lime-water meet, carbonate of lime (or calcium carbonate) is formed. This latter substance is insoluble in water and appears as a white precipitate in the lime-water. The second bottle (C) is interpolated between B and the bell-jar to catch any carbon dioxide that may have passed over unaffected by the lime in bottle B. On the other side of the bell-jar, the two bottles D and E also contain lime-water. If now any carbon dioxide be formed by the plant it will give rise to a white precipitate in bottle D, while bottle E is a trap for any carbon dioxide produced by the plant which has managed to pass bottle D. Bottle E is in connection with a pump or aspirator, by which air can be sucked through the whole apparatus. (Care must be taken that all joints are made absolutely air-tight and that the bell-jar is vaselined to a glass plate.) If the pump be started it will be found that bottle B becomes milky owing to the presence of carbon dioxide in normal air, but so long as C remains clear, we may be sure that the plant in A is receiving nitrogen and oxygen only. Since oxygen is being supplied, respiration is possible. Very soon bottle D, next the glass bell-jar on the other side, also becomes milky from the formation of calcium carbonate—the carbon dioxide being produced by respiration in the living plant. The same experiment may be performed with a frog or other small animal, which will live under the bell-jar, A, without suffering any injury or inconvenience, beyond imprisonment. Under these circumstances the bottle D will be found to become milky much more rapidly than when a plant is placed beneath the bell-jar, for respiration in an animal is, under ordinary conditions, much more vigorous than in the plant. It is, of course, immaterial in this case whether the bell-jar be darkened or not, since the animal has no photosynthetic power.

Excretion.

In addition to carbon dioxide, water and solid waste materials of various kinds are produced as the result of decomposition processes. Water as a waste product is got rid of as water vapour along with the transpiration water (p. 46) by the stomata in the case of the plant, and by glandular organs, such as sweat glands and kidneys in the case of animals. The solid waste substances, some of which are by no means reduced to their ultimate constituents, are also got rid of by the kidneys and sweat glands in animals. Several of these bodies are highly nitrogenous, such as urea, uric acid, &c. In plants the solid waste is stored either in parts of the body which are periodically thrown off, *e.g.*, leaves, bark, fruits, &c., or is permanently retained in tissues, such as old wood, otherwise of service only for mechanical purposes (p. 88). It is unnecessary for our present purpose to go further into these subjects since the task before us is to endeavour to master the principles of biology, not the details of the different physiological processes.

In Chapter VI an attempt was made to show graphically the circulation of matter from the inorganic world through the organic back once more to the inorganic. We must now try to express graphically the circulation of energy.

Circulation of energy.

We have seen already in Chapter VI (p. 48) that solar energy is in part stored as potential energy in the complex organic compounds formed by the green organism during the process of photcsynthesis, and that these compounds are used as " food," that is to say, as stores of potential energy, by the green plant itself, or by animals which feed on other animals, which feed, in turn, on green plants. In a word, we learned that the ultimate source of all " food " of non-green organisms is the green plant, and that we ourselves are dependent for our nutriment in the long run on the activities of chlorophyll. Further, we see that the ultimate source of the matter of which the body of the highest organism is composed is, ultimately, the soil, the water, and the air ; and that, in the process of tissue metabolism—as the sum of all these complex chemical changes is termed—and in the final decomposition of all dead bodies, the oxidised products pass back again to the sources from which they came, in all probability to be rebuilt into the tissues of another generation of green plants. The diagram now before us, aims at showing that a similar generalisation may be arrived at with reference to the circulation of energy in the Universe.

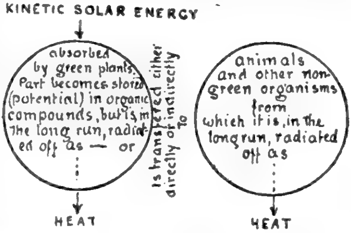


FIG. 23. Circulation of energy.

The solar energy becomes, in part, stored as potential energy in the organic compounds manufactured by the green organism. Whether these are oxidised in the green plant itself or in an animal which has used the green plant as food, or in a carnivorous animal which has preyed on a herbivorous one, the result is the same; the energy is gradually released. Before being radiated from the body in its final form as heat (the one form of energy, it will be remembered, into which all other forms are ultimately transformable), the potential energy of the food makes its appearance as mechanical, chemical or electrical energy. The energy, even in its final form, is not "lost," however, but becomes unavailable on its dissipation into space. There is thus both a balance of matter and a balance of energy in the Universe, and these two great generalisations are among the most important with which modern science has made us acquainted.

CHAPTER VIII

SENSITIVITY IN PLANTS AND ANIMALS

THE second characteristic or capacity exhibited to a greater or less degree by all organisms, we have termed sensitivity, or the power to respond to stimuli from without or from within (p. 7).

Let us first of all glance, quite briefly, at some of the chief types of stimuli to which organisms are subject. These will be found to be (*a*) mechanical, *i.e.*, those which might be popularly described as a push or a
Stimuli. pull; (*b*) chemical, where the stimulus lies not in the mass of the material, but in the chemical properties it possesses and which are able to induce certain alterations in the form, position or behaviour of the organism; (*c*) thermal, where the stimulus is of the nature of a more or less sudden change of temperature; (*d*) photic, the access of light or its withdrawal; and (*c*) electric, the influence of an electric current or shock.

Not only the nature, but also the intensity of the stimulus, must be taken into account, for we find that every vital process varies in its activity within wide limits, according to the intensity of the stimulus. Each process goes on best when the stimulus is of a definite intensity, but there is also a minimum, or liminal, intensity at which the process commences, and a maximum intensity at which it ceases. The best response is represented by the optimum intensity of the stimulus, but the optimum by no means always lies midway between the minimum and maximum.

Another important point which has to be noted is that only very rarely does one stimulus act alone; it is generally accompanied and affected by other stimuli, which may render the organism more or less sensitive to the special stimulus under consideration, or may affect the primary stimulus itself, either by diminishing or increasing its intensity.

Latent period.

The moment of application of a stimulus of any kind is followed by a latent or quiescent period during which no visible response can be detected. Doubtless, however, during this period (which may be of longer or shorter duration) certain molecular rearrangements and other changes are going on in the stimulated organ in preparation for the ultimate visible response.

Protoplasm.

The sensitive body in plant or animal is in all cases protoplasm—that mysterious substance whose analysis has as yet defied the ingenuity of chemists and biologists. We know only that it is an exceedingly complex mixture or aggregate of chemical compounds, whose relationships to each other in the living organism are but little known—though these constituent compounds must be arranged in an infinite variety of ways, as may be deduced from the varied behaviour of protoplasm under different conditions, from an analysis of dead protoplasm from different situations, from its microscopic appearance at different times, and from the mere fact that in one situation it constructs a bone, in another a nerve, in another a green cell of a leaf, in another a hair, and in yet another an enzyme.

Sensitivity in plants.

Let us now turn our attention to plant sensitivity more especially. The gradual origin of the belief that plant protoplasm is sensitive is of interest. The botanist Jung, in the seventeenth century, held that a plant was a living, but not a sentient organism—"Planta est corpus vivens non sentiens"—while early in the eighteenth century Linnæus formulated his famous aphorism—"Minerals grow, plants grow and live, animals grow, live and feel." Later still the English botanist Smith postulated for plants "some degree of sensation, however low." In our own day biologists in describing plant activities use terms derived from animal life, suggested, in the first instance doubtless, by superficial analogy, but justified by researches which all tend to show that Smith's view was fundamentally correct, and that plants, like animals, are sensitive to stimuli though perhaps the responses are not in all cases so rapid or so well marked. The reason for this sluggishness of response on the part of the plant will appear later. George Henry Lewes sums up the modern view when he says "that animal and plant organisms have with their common structure common properties, and if we call one of these properties sensitivity in animals, we must call it thus also in the plant" (Arthur, "Special Senses of Plants.").

Nature of the reaction.

We have thus found that protoplasm, whether derived from the plant or from the animal, is sensitive to stimuli. But three things strike us at once when we begin to study this subject in detail, viz., first, that two stimuli, qualitatively and quantitatively alike, may induce very different reactions in protoplasm of different kinds; secondly, that the same stimulus may induce very different reactions in the same protoplasm at different stages of its growth or under diverse general conditions; thirdly, that the same stimulus applied in different intensities, may excite very varied responses on the part of the same protoplasm. A few illustrations will make this clear.

First, the same stimulus may induce very different reactions in different varieties of protoplasm.—Select a young seedling whose shoot and root have attained a certain development and lay or suspend it, horizontally in a moist chamber, so that root and shoot are free to move (Fig. 24, *a-a′*). Both root and shoot are affected equally by the stimulus of gravity, yet after a few hours it will be found that the root has begun to bend downwards towards the earth's centre, while the shoot has begun to bend upwards and away from the earth's centre (Fig. 24, *b-b′*). The protoplasms of the root and of the shoot have thus responded differently to the same stimulus.

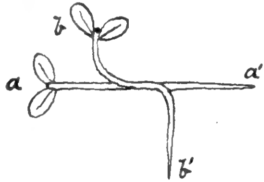


FIG. 24. Geotropic curvature in root and shoot of mustard. (Natural size.)

Secondly, the same stimulus may induce different reactions in the same protoplasm at different stages in its growth.—It will be remembered that in Chapter I. we referred to a very lowly organism (Fig. 3), known as a Myxomycete or Slime Fungus. If exposed to light in its young state the protoplasmic mass creeps slowly away from the source of light, attempting to hide itself, so to speak, in a crevice in, or in the shade of, say, a piece of bark. When fully ripe and ready to produce reproductive organs, however, it seeks the light, which it previously made every effort to avoid.

Thirdly, different intensities of the same stimulus induce different effects in the same protoplasm.—If a number of zoospores of such a seaweed as Enteromorpha (Fig. 12) be placed in a glass vessel standing on a window-sill, the zoospores aggregate on the side of the vessel nearest to the source of light. If a strong beam of light be now thrown on that surface of the vessel, the zoospores leave it and aggregate on the opposite and less brightly illuminated side. If the vessel be illuminated by ordinary diffuse light, the zoospores distribute themselves generally in the medium. The zoospores thus move towards weak light, away from intense light, but are indifferent to diffuse light.

Sense organs in animals.

Animal protoplasm responds with much greater rapidity and more markedly to stimuli than plant protoplasm, and it is quite unnecessary for us even to cite illustrations, for they are amongst those most familiar to us in Nature. One point, however, we must emphasise here, and it is that, in addition to a general sensitivity to stimuli of various kinds, we find special sense organs developed in animals, that is, tissues which have become differentiated morphologically and physiologically solely for the reception of special classes of stimuli, *e.g.*, light, contact, vapours, &c. Thus we have the eye for the appreciation of the form, size and colour of external objects ; the ear for the appreciation of sounds; taste-bodies for distinguishing the flavours of various foodstuffs; tactile bodies in the skin and certain special structures at the ends of the nerves of external or internal organs for the appreciation of contact with bodies likely to produce pain or pleasure ; and the nose, the duty of whose sensitive inner surface it is to receive impressions from volatile substances. Why are such sense organs absent as a rule from plants? We say "as a rule," for the sense of touch is, at least in some plants, fairly well developed, but we have no evidence of the possession by plants of any of the other special sense organs (though attempts have been made to show that some plants at least do possess sense organs of a kind). Let us try and obtain an answer to this question.

FIG. 25. Cobæa

Self-preservation is obviously of paramount importance to every living organism. It must obtain food; it must avoid injury; it must acquire the requisite supplies of heat, air, moisture, and so on, to enable it to live healthily; these are the primary necessities of its existence.

Sense organs in plants.

The capacity for responding rapidly to contact with extraneous bodies is developed in the animal, in the first instance for the recognition of injurious surroundings and of the presence of food. Where response to contact is developed in plants it is, with few exceptions, connected only indirectly with the acquisition of food. More often it is associated with the attempt to obtain support, where the plant is unable by its own unaided efforts to stand erect, and is developed most prominently in tendrils, such as one finds in the pea, Cobæa (Fig. 25), passion-flower, and other climbing plants which possess such organs. In the case of some carnivorous plants, however, response to the stimulus of contact is intimately associated with nutrition as, *e.g.*, in the carnivorous plant Dionæa (Fig. 26), the two halves of whose leaf-blade close immediately on any insect that may happen to touch any one of the six sensitive hairs which arise from the upper surface of the leaf, or in the case of our own Sundew (Fig. 15), where contact of an insect with the sticky tentacles in the centre of the leaf brings about a slow infolding of all the peripheral tentacles over the trapped animal, and also a rapid secretion of digestive fluid from their glandular ends. In other plants still, such as the sensitive plant (Fig. 27), Mimosa, rapid movement, presumably for protection, takes place in the leaf when touched, and similar movements, due to other stimuli, are well known to occur in other forms, such as Oxalis, Lathyrus, &c.

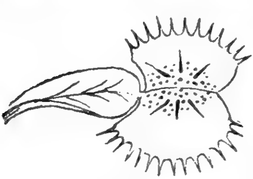


FIG. 26. Dionæa.

A little reflection will show us that the animal on detecting, by contact, an injurious object or an object fit for food, being motile, can at once move away from or towards the object as the case may be—while the plant, on the other hand, has no such power of movement. A sense of contact for this purpose is thus useless to it, for, being fixed, it could not benefit by its possession. The ingestion of organic

FIG. 27. Mimosa. A, before, B, after stimulation. ($\frac{1}{4}$ Natural size.)

food by the animal necessitates, on its part, power of movement or locomotion, so that it may seek for such food (p. 78); the plant, on the other hand, does not require to search for the raw materials, for these are brought to it by atmospheric currents, or lie round its roots in the soil. The animal is further liable to all sorts of injuries during its search for food—the plant is certainly almost equally liable to injury, but even though it recognised coming misfortune it could not escape from it. As a corollary we may note that the majority of non-motile animals, such as sea-anemones, corals, zoophytes, barnacles and such like, are aquatic and have their organic food brought to them by water currents. Non-green plants, again, though dependent on organic food materials, make up for the want of locomotory power by the production of enormous numbers of offspring, and distribute them far and wide on the chance of some few reaching an appropriate and favqurable habitat.

For the same reason the senses of smell, of hearing, and of sight are well developed in animals, both for the avoidance of injury and for the procuring of food in the first instance, whilst such senses would be useless to plants and are not developed. As for the sense of taste the raw materials absorbed by plants, such as carbon dioxide, water, and the salts of the soil, are absorbed irrespective of whether they are tasteless or otherwise, while the organic substances used as food by the animal, have every possible variety of flavour, and require to be discriminated by the organism.

Transmission of stimuli.

The stimulation or excitation of these varied sensory structures, be they differentiated and undifferentiated, is often followed by movements or indications of appreciation or otherwise, in regions, it may be, far removed from the point of application of the stimulus. Thus, for example, a touch applied to one of the segments of a Mimosa leaf is followed by movement not only of that segment, but also of all the segments in the vicinity. It follows from this that the stimulus must have been transmitted from the point of application to distant points. How is this accomplished? In the higher animal, as every one knows, transmission is effected by specialised processes from cells which are elongated very much in one direction, and known as nerves—but in plants the transference of the impulse is not so easily explained.

Microscopic research has shown that the cells in many plants are in communication with each other through their walls by very fine threads of protoplasm, so that there may be direct protoplasmic communication from one part of the plant to another. Indeed a recent investigator, Němec, has gone so far as to affirm the existence of special tracts in the cells themselves, along which impulses may be carried.

This general survey of the phenomena of sensitivity, so far as we have as yet carried it, has thus taught us one important principle, viz., that, in so far as animals and plants respond to stimuli from without, development of sensitivity proceeds along two divergent lines, the one corresponding to the needs of free organisms, the other corresponding to the needs of fixed organisms.

Fixed and free organisms.

Let us look a little more in detail in the first place at fixed organisms.

It will be at once obvious that to a fixed organism orientation is all-important, for the root must penetrate the soil, and the shoot must expand in the air. Now if a seedling be laid on its side, and its shoot and root in consequence be horizontal, how are these two parts to ascertain which is the way up and which the way down?

In the beginning of the last century Knight discovered that gravity acted as a stimulus to the plant, and that the root and shoot responded differently to this stimulus, so that the root, no matter what its original position, bent towards the soil and the shoot, no

Gravity.

matter what its original position, bent towards the sky. If some germinating peas be pinned to the rim of a vertically revolving wheel, so that their roots and shoots form all possible angles with the horizon, it will be found that both roots and shoots grow in the directions in which they have been originally placed, because, owing to the slow revolution of the wheel, the stimulus does not affect the same part continuously in the same direction. What stimulus is given during one half revolution would appear to be neutralised during the second half; at all events, even though the stimulus be appreciated there is no visible response so long as the wheel is revolving. Gravity has, we might say, been put on both sides of the equation and may, as the mathematician puts it, be ignored.

In botanical terminology the normal root is said to be geotropic, and the normal shoot a- or apo-geotropic. A very simple and instructive experiment is to take some moistened mustard seed and throw them against the inside of a damp empty flower-pot. The seeds will adhere to its surface, and will germinate *in situ*. The pot is then turned upside down over damp blotting-paper or wet sawdust, &c., the pot being at the same time covered over by a wet cloth. If the pot be examined after a couple of days, it will be found that all the young roots have grown downwards along the wet wall of the pot, and the shoots have grown upwards, but without touching the wall. If the pot be now placed in its normal position, so that the roots point upwards and the shoot downwards, and if the mouth of the pot be covered with a black cloth and be left for forty-eight hours, the roots and shoots will then be seen to have bent through an angle of 180° and regained their originally selected positions.

Let us now study another stimulus, that of light. Since light is of such transcendent importance to the plant it is manifestly of the highest advantage that the shoot should learn to grow towards the source of light, just as it is equally important that the root should learn to grow away from it. If some mustard seed be grown on damp moss on a window-sill we shall find that the shoots grow towards the window (heliotropism), while the roots, if exposed, grow away from it (apheliotropism). This is still better seen if the plants be grown in culture solutions. Now if other mustard seedlings be cultivated in the same way, but if they be placed during cultivation on a horizontally revolving disc, it will be seen that the roots and shoots obey the stimulus of gravity only, their shoots show no tendency to turn towards the light, and their roots show no inclination to turn away from it. **Light.**

Fig. 28. Heliotropic curvature of mustard seedlings.

Another illustration of the sensitivity of vegetable protoplasm to light has been given in the case of the movements of zoospores (p. 64).

Water is as important a factor in the life of the green plant as light, and it is therefore obvious that it is of the utmost value, to the root especially, that it should be sensitive to its presence; roots, as a

Water.

matter of fact, grow towards water. Hence the frequency with which drain-pipes are clogged up by the intruding roots of plants living in the vicinity. A very interesting and at the same time simple experiment serves to demonstrate the predominant effect of water as a stimulus over gravity. Remove the bottom from a cigar-box and replace it by one made of wide meshed wire netting, floor the inside with wet bog moss and plant in it some peas or other seeds (Fig. 29). In a few days the roots, in obedience to the stimulus of gravity, will have grown through the wire netting and into the air below. Finding, however, that the air is less moist than the moss above them, they change their direction of growth and bend back again into the box, thus showing that the hydrotropic stimulus is more vigorous and effective than the geotropic stimulus.

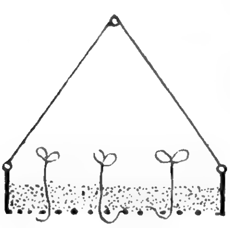


FIG. 29. Hydrotropism.

Let us briefly consider, in conclusion, the influence of some chemical stimuli on plants. One of the com-

Chemical stimuli.

monest weeds in our rivers and canals is an American aquatic plant, known as Elodea. If some of the young leaves of this plant be placed under the microscope it will be seen that the chloroplasts and other contents of the cells are in a continual state of movement. It is, of course, the protoplasm which moves, and in doing so carries with it the chloroplasts, and by watching these the rate of motion of the protoplasm may be, at all events approximately, measured. If such a leaf be exposed to ether vapour, the streaming gradually comes to a standstill, to be resumed when the ether vapour is removed, unless the exposure to the vapour has been too prolonged, under which circumstances the protoplasm is paralysed.

Again, if we examine some of the extremely minute organisms known as Bacteria, we find that, in the motile state, they are sensitive to the presence of oxygen gas, being attracted to it wherever it is produced. We have already seen that a green cell in sunlight and in the presence of carbon dioxide manufactures organic substances and evolves oxygen gas during the process. Let us place such a green cell, say, of a unicellular plant, in the centre of a cover-glass preparation in water (Fig. 30). Obviously, if exposed to light under the microscope, oxygen will be given off from it and will accumulate in the water in the immediate vicinity of the cell. If we introduce some motile Bacteria below the cover-glass they will aggregate round the green cell. If the preparation be darkened for a time and then examined, we shall find that most of the Bacteria have now betaken

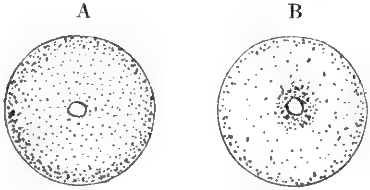


Fig. 30. Bacteria and green cell. A, exposed to light; B, in darkness. (After Engelmann.)

themselves to the margin of the cover-glass, since, near the edges, oxygen will have been absorbed by the water from the air. Engelmann has made use of this fact in a very ingenious manner to prove that the rays absorbed by chlorophyll are those chiefly concerned in the processes which result in photosynthesis with its accompanying evolution of oxygen. For if a filament of an alga be placed on the field of the microscope and illuminated from below by the solar spectrum, obviously, some cells will be affected

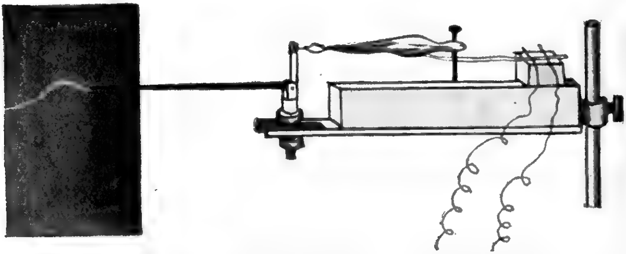


FIG. 31. Muscle-nerve preparation and recording drum. (After Waller.)

by red, some by orange, some by blue rays, and so on. Since the rays which are absorbed by chlorophyll, viz., the red and the violet, are believed to be those chiefly concerned in photosynthesis, the Bacteria will congregate near these regions, for there oxygen will be given off during photosynthesis.

The general conclusion we arrive at, then, is that plants as well as animals are sensitive to external stimuli, and that the protoplasm alone is the sensitive substance.

Sensitivity in animals. Perhaps we may most easily gain some elementary acquaintance with the general mechanism of sensitivity in animals by studying what is termed in physiology a muscle-nerve preparation (Fig. 31). It is well known that the tissues of the lower animals retain their vitality for some considerable time after death, and thus permit of the performance on them of certain simple physiological experiments which cannot conveniently be carried out on the living animal. One of the muscles of the hind leg of a frog is dissected off a recently killed animal and the nerve supplying it is also carefully exposed. If one end of the sinew attached to a muscle be now fixed in a rigid clamp, and the other free end be attached to a weight, we are able, by applying a stimulus to the nerve, to cause contraction in the muscle, thereby raising the weight. Moreover, if we attach to the weight a pointer, placed in such a way as to write on smoked paper covering a revolving drum, we are able to obtain a record of the amount of the muscular contraction in relation to the nature or intensity of the stimulus applied to the nerve. Let us suppose the nerve to be stimulated by an electric shock, we obtain a pronounced contraction on the part of the muscle, but the beginning of the contraction and the moment of application of the stimulus are not synchronous; a longer or shorter period elapses between the application of the stimulus and the response (Fig. 32). This period is known as the latent period, and during it various chemical and molecular rearrangements are no doubt taking place, both in the nerve, in carrying the message along, and in the muscle fibres, preliminary to their contraction. If the stimulus be

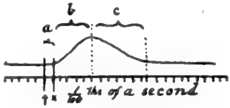


FIG. 32. Tracing of a simple muscular contraction.

repeated at very short intervals the muscle becomes at length rigid in the contracted condition; it is said to be in a state of tetanus (Fig. 33). Gradually, however, the muscle becomes less and less contracted as fatigue sets in, until, finally, it is unable to raise the weight at all, and in this condition it remains for some time. If the stimulus be reapplied after a short period of rest, the muscle is again able to raise the weight, but not so far as it did at first.

The nature of the stimulus applied may be of the most varied character; it may be a chemical reagent, an electric shock, or merely a tap from a pencil.

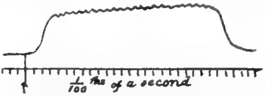


FIG. 33. Tracing of imperfect tetanus in muscle.

It is not difficult to see that the chief characteristic of the animal as contrasted with the plant in relation to sensitivity is what may be termed the centralisation of administration. The plant has, as we have seen, diffused sensitiveness to certain stimuli, but in the animal, not only is the perception of

Central nervous system. many of these stimuli localised, but one or more centres are developed to which these stimuli are transmitted; there they are analysed before a reaction takes place, which reaction is caused in turn by a stimulus generated in the centre and transmitted to the region of response. In the simplest condition the same cell that receives the stimulus also brings about the response, but in most multicellular organisms the element that receives the stimulus and the element that reacts are distinct, but put in communication with each other by means of a central element, so that the motive impulse to contract or secrete as it may be, is transmitted from the central element by an efferent nerve to the contractile or secretory cell (Fig. 34A).

In the higher types of animal life a fourth element is added, so that there are two central elements, one to receive the impulse from the sensory organ, and another connected with the former to transmit, by means of the efferent nerve, the impulse to the muscle, gland, or other body affected. When the response takes place without any consciousness being aroused, it is termed a reflex action. Usually, however, the two nerve centres are connected with a nerve cell complex forming a central nervous system, by whose means a definite and determinate co-ordination of the various parts of the organism is insured.. It is the development and elaboration of this central nervous system that furnishes the key-note to the history of the evolution of the animal line of life.

Nerves.

Reflex action.

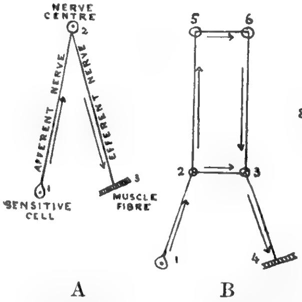


FIG. 34. Scheme of nervous system. A, simple reflex action; B, 1, 2, 3, 4, reflex action; 1, 2, 5, 6, 3, 4, conscious nervous response.

CHAPTER IX

MOTION AND LOCOMOTION. THE SKELETON

Motion and locomotion.

EVERY organism is capable of exhibiting motion in some part, even though such movement may be visible only with the aid of a microscope. Most animals, are capable of locomotion, or movement from place to place, while but few plants have that power. The power of movement possessed by the animal and the fixed condition of the plant forms a popular distinction between the two branches of the organic world, but although for the most part ignored as a characteristic difference by science, it is still worthy of close attention, since it is bound up with other differences which are fundamental.

We have said that most animals are capable of locomotion, and that this is necessary to their existence, since, without that power, it would be impossible for them to obtain organic food, which is only local in distribution. Fixed animals, such as zoophytes, sea-anemones, barnacles, &c., live in a medium, the sea, wherein organic food is distributed more uniformly and where currents of water bring the organic food to them, just as atmospheric currents bring the necessary carbon-dioxide to the plant. On the other hand, the vast majority of plants are fixed organisms, but the raw materials which they require for the purpose of constructing organic compounds are to be found everywhere; there is no need to move about in search of them. Locomotion among the higher plants when it does occur is purely physical, and dependent on the absorption and evaporation of water and the consequent bending and unbending, extension or shrinkage of parts of the organism, and not, as in the animal, on the movements of special contractile tissues. Further, locomotion in the higher plant is not associated with the problem of self-nutrition, but with the distribution of offspring. On the other hand, many of the lower plants have the power of locomotion, but these plants are aquatic and their powers of movement are as much associated with the problem of dispersal of progeny as with that of nutrition.

It has already been said that all plants and animals exhibit powers of motion in some degree. Even in the higher plants the protoplasm of the cells, at least in the young state, shows power of movement; the leaves of many plants are able to open and close, according to certain conditions; fruits and seeds, growing points, &c., show powers of movement associated with growth conditions. Illustrations of the power of movement in individual parts of the animal body, apart from locomotion of the whole organism, are too familiar to require citation.

Movements of protoplasm.

The types of movement that are exhibited by protoplasm itself are very varied in character. Apart from the circulation of protoplasm in cells, already referred to (p. 73) we have the ciliary movements of the cells lining various tubes, such as those of the respiratory organs, the cells covering the surfaces of gills, &c., and the amœboid movement of the leucocytes of the blood, of many gland cells, of the cells lining the alimentary canal of many of the lower animals, and, in the plant world, the ciliary movements of many lower Algæ and of many reproductive cells in higher forms, such as mosses and ferns, and the amœboid movements of the Slime Fungi, of the reproductive cells of many lower Fungi and of Algæ, &c.

Naturally, it is in the animal rather than in the plant world that we expect and find special organs for locomotion. These are most varied in character and comprise such types as the water-tube feet of starfish and their allies, the jointed appendages of insects, crabs, lobsters, spiders, &c., the contractile massive foot of the molluscs and the wings of all grades of birds, bats, &c., the fins of fish and the familiar limbs of mammals. Amongst these we recognise three types, those adapted to terrestrial, those adapted to aerial, and those adapted to aquatic conditions, with, occasionally, as in the birds, appendages both for locomotion on land or in water and for locomotion through the air.

Organs of locomotion.

The subject of motion and locomotion in organisms leads us naturally to the question of the skeleton or hard parts, and to that subject we must devote the rest of this chapter.

Skeleton.

The necessity for locomotion in search of food in the animal is associated with the condensation of the skeleton and the jointing of its various parts—whilst the uniform distribution of the skeleton in the plant is associated with its fixed habit. We shall see how this principle is exemplified and established in the course of our discussion of the skeleton.

Before discussing its composition let us, first of all, attempt to determine what functions the skeleton fulfils by considering simple cases from the animal world. Manifestly, it gives protection to soft parts. For example, the skull and vertebral column protect

Functions of the skeleton.

the central nervous system, while ribs give protection to the heart, lungs and other important organs. The exoskeleton of the turtle, armadillo, &c., protects the entire body, the shell of the snail and of the limpet and the integument of the beetle perform similar functions, as do also the scaly hide of reptiles, the hair of furry animals, &c. Similarly, in plants, cork is protective, and even plants which do not develop cork develop a thin corky cuticle which is protective in function, while others are provided with thorns, hairs, wax, resin, &c., which are the analogues of an exoskeleton.

Another function of the skeleton is to give rigidity to soft parts which require it. Thus the thigh, leg, arm and forearm bones give rigidity to these members, while their jointing at the same time permits freedom of movement; the skeleton framework of a leaf keeps its green substance expanded, and so on.

The skeleton of the animal, moreover, performs a special function in that type of organism, in that it gives points of attachment for muscles and enables the individual parts to be moved independently or collectively, and, at the same time, co-ordinately. On the other hand, the skeleton of the plant may perform a function which that of the animal does not perform, namely, circulation, or the conveyance of both crude and manufactured food materials from one part of the organism to another. Manifestly, it would be excessively inconvenient if the skeleton of the animal acted also as a circulatory organ, for circulation would be interrupted or impeded every time the skeleton was put in motion; in the plant, on the other hand, economy of tissue is effected by combining the function of circulation with that of giving rigidity in an unjointed and, in itself, immobile framework.

Chemical composition.

We may now turn our attention to the general nature of the material of which the skeleton is composed in the two types of organism. The material in the one case is mainly bone, in the other mainly wood, and we may consider these two substances from two points of view, (*a*) chemical composition, and (*b*) structure. First, as to chemical composition. If a piece of bone and a piece of wood be placed in a furnace and burned so far as they will burn, we find that, at the end of the operation, we still have a bone, though it has lost considerably in weight, whilst the outline of the piece of wood is entirely lost. Further, the ash left over after burning weighs only a small fraction of the original block. Chemical analysis, in fact, shows us that, whilst two-thirds or more of the dry bone is composed of mineral matter, not more than a twentieth of the dry weight of the wood is inorganic in charac-

FIG. 35. Wood of the Plane tree in tangential longitudinal section. (× 75.)

ter. Thus, one of the long bones of an ox, after being thoroughly dried, yields about 60 per cent. of calcium phosphate and about 10 per cent. of other inorganic salts, while the remaining 30 per cent. consists of combustible nitrogenous organic matter. On the other hand, a piece of perfectly dry fir wood yields on an average only about 2 per cent. of its weight of incombustible ash, consisting mainly of salts of calcium, potassium and sodium, while all the remainder is composed chiefly of compounds of carbon, hydrogen, oxygen and nitrogen.

Structure.

Again, as to structure, we find that wood consists of overlapping, spindle-shaped fibres (Fig. 35), while bone consists of concentric lamellæ surrounding central spaces containing nerves, blood-vessels, &c., the lamellæ being, so to speak, nailed together by fibres (Fig. 36).

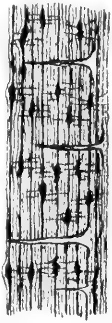


FIG. 36. Longitudinal section of bone. (×50.)

Taking these two series of facts into account, let us next inquire whether bone and wood form good building materials from an engineering point of view, and for that purpose let us contrast them with cast-iron and steel. Obviously, a good all-round building material should be able to withstand equally well a crushing force and a tearing force. From the following table it will be seen at once that a bar of cast-iron can withstand a crushing force extremely well, but that it is very liable to snap if subjected to a bending or tearing one. Steel, on the other hand, can withstand both tearing and crushing forces absolutely and relatively better than cast-iron, hence its constant use as a material for the construction of girders, rails, masts, columns, &c. The same table shows us that wood and bone are able to resist tearing and crushing forces about equally, but that wood is stronger than bone in its power of resisting a tearing force, while bone is stronger than wood in its power of resisting a crushing force. How important this point is we shall see later, when we come to consider the strains to which these skeletal substances are subjected in the plant and animal respectively.

Material.	Lbs. required to break a rod 1 sq. mm. in sectional area.	Lbs. required to crush a rod 1 sq. mm. in sectional area.	Relative values as building material.	
			Tearing.	Crushing.
Steel .	225	319	29	41
Cast-iron	28	160	4	22
Bone .	26	33	13·5	17
Oakwood	14	10·5	17·5	13

(*Note.*—The relative values are obtained by dividing the figures given in the first two columns by the specific gravity of the materials, viz., steel, 7·2; bone, 1·9; oak wood, ·9. The values given are approximate only. The table is adapted from Macalister, "Encyc. Brit." *Art.* Anatomy.)

Arrangement of skeletal material.

Bearing these fundamental data in mind, the next point of importance is to determine how we may best arrange a given amount of material, bone or wood, as the case may be, so as to combine economy of material and effectiveness to resist crushing or bending. Obviously the plant has to withstand more tearing than crushing. Thus, pressure of wind tends to bend the stem of a plant, that is, to tear it on the convex side and crush it on the concave side, and also to tear the roots out of the soil with a rectilinear strain. The long bones of the leg, owing to their being jointed together, are not subjected to extreme tearing forces, but have to withstand more crushing, since they support the weight of the body. Broad expansions, such as the leaves of a plant, have to resist rupture at their edges; the body of the animal, on the other hand, being much more compact than that of the plant, is not subject to such stresses. A simple engineering example will make the arrangement of skeletal material in the two cases obvious at once.

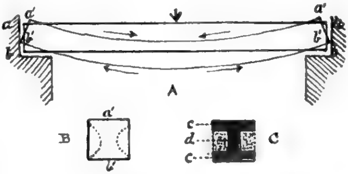


FIG. 37. Principle of the girder.

Principle of the girder.

Suppose that we rest a bar of wood or other elastic material on two supports as represented in Fig. 37, and place a heavy weight in the centre. If the weight be sufficiently heavy, the bar will be bent so that the under side becomes convex and the upper side concave. Careful measurement reveals the fact that the underside has increased in length, while the upper side has decreased; in other words, the underside is in a state of tension and the upper side in a state of compression. Manifestly, the layers immediately subjacent to these outermost layers will be slightly less extended and slightly less compressed, respectively, than they were before the weight was applied; a median region of the bar must, therefore, be neither extended nor compressed. If neither stretched nor compressed, that region is obviously doing nothing towards supporting the weight, and we may therefore cut it away very considerably, so long as we leave sufficient to keep the two outer regions at the same distance apart. Far less material than what we have available will be required for that purpose, so that we may hollow out the sides of the bar and leave a central region or "web," as it is technically termed, to keep the two "flanges" apart. The "girder" thus formed will be almost as strong as the solid bar, whilst its own weight will have been greatly decreased and material economised.

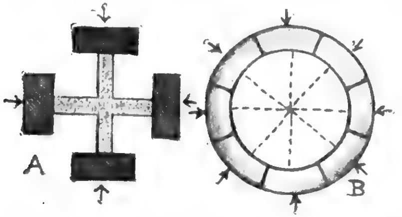


Fig. 38. Principle of the hollow column: A, crossed girders; B, hollow column.

In the illustrative case we have just considered we have assumed that the weight is pressing only in one of two directions (for manifestly, the beam might have to resist an upward as well as a downward pressure). Let us now, however, suppose the weight or pressure to affect the beam laterally as well as vertically. A girder structure must in that case be provided laterally also, and the two webs would cross each other at right angles. We thus get in cross section such an appearance as that seen at Fig. 38. Lastly, let us suppose the pressure to be exerted in any direction; we must then provide an infinite number of girders whose flanges must face every point of the compass. Under these circumstances, the flanges will obviously keep each other apart, and we may then get rid of the

Principle of the hollow column.

webs altogether. We thus reach the principle of the hollow column, and the hollow column, as every one knows, is one of the commonest structural devices adopted in engineering, in shipbuilding and architecture. If we examine the long bones of the body, we find that they are all hollow columns, combining the maximum of strength with the minimum weight of material (Fig. 39). The long bones are, it is true, in the embryonic state, solid, but are hollowed out by certain cells which have this special duty to perform.

Fig. 39. Longitudinal section of human thigh bone. (⅓ Natural size.)

In the case of the plant, as an examination of erect, and, at the same time, slender, stems shows, the supporting or skeletal tissue is laid down on the same principle. For example, the stem of such a plant as wheat is a hollow column, and in other plants, the special skeleton tissue is peripherally placed in flanges, kept apart and yet held together by more delicate central tissue. The varieties in the mode of deposition of the skeleton or mechanical tissue in such plants are extremely numerous as may be seen from the examples illustrated in Fig. 40. Even in forest trees it not infrequently happens that the central wood decays, and an old tree may be quite hollow in the centre and yet be quite able to support the superincumbent weight of branches and leaves.

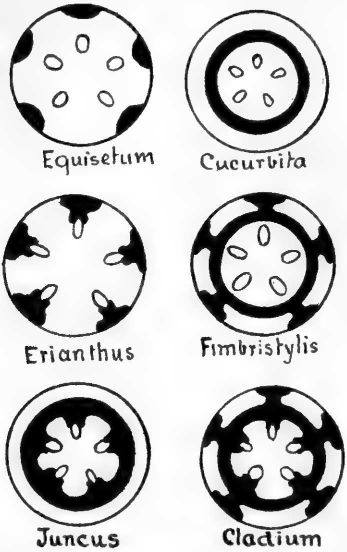


FIG. 40. Distribution of skeletal tissue in plant stems. (After Van Tieghem.)

Roots, on the other hand, have to withstand a rectilinear pull, and are not subjected to bending at all, and engineers tell us that the tissue required to resist such a strain should be centrally placed. This is precisely the arrangement adopted in the root (Fig. 41). Even when there is a central pith it may become hardened, or sclerotic, while the softer tissues are peripherally placed.

Principle of the arch.

We may now turn to the consideration of another engineering example—the arch or rafter. An excellent illustration is obtained from the human ankle (Fig. 42). In every roof (Fig. 43) where the weight to be supported is at all likely to bear too heavily on the walls, the "struts" which meet at the apex of the roof, and which would, at their free ends, tend to force the walls outwards are connected by a "tie beam." The struts are obviously in a

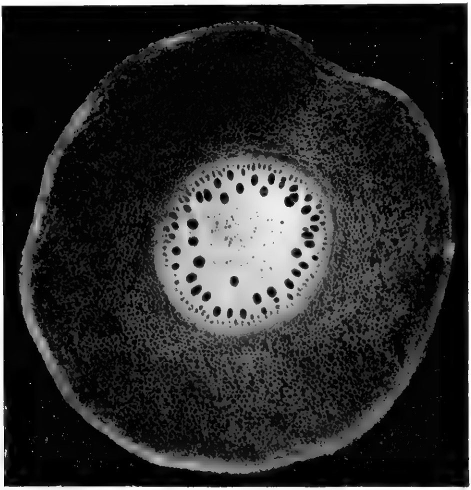


FIG. 41.—Transverse section of a root, showing aggregation of vascular and skeletal tissue in the centre. (× 50.)

state of compression and the tie beam in a state of tension. When these strains are equal, the rafter is a rigid system, and will then bear down vertically on the walls without exerting any tendency to force the walls outwards. Now the trunk of the body bears down through the long bones of the legs on the arch of the ankle. The ankle has, on the one side, the bones of the foot, on the other, the heel bone for its two struts, while the tie beam is the muscle

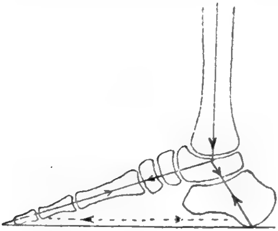


FIG. 42. Human ankle.

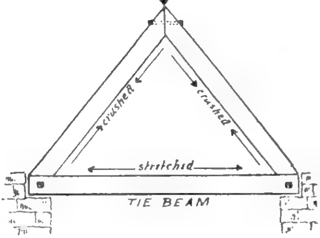


FIG. 43. Raf.er.

and sinew of the sole. Obviously, the tie beam must not in this case be permanently rigid, but capable of being made either rigid or flexible as need requires. In the plant, struts are frequently adopted by tall, top-heavy trees, the earth forming the tie beam.

FIG. 44. Crane showing lattice (girder) shaft and solid head.

The principle of the crane, again, is very well exemplified in the human thigh bone (Fig. 39). When the body is bent forward, the weight rests on the knuckle of the thigh bone, revolving in the socket of the hip bone, and is liable to "sheering." How is this avoided in a

Principle of the crane.

crane, where also the weight is supported on the end of a tapering shaft? A glance at Fig. 44 shows us that the material of the steel frame is arranged so as to support any such weight, and counteract the tendency to sheer off the head of the crane Similarly, if we examine the head of the femur, the bone substance will be found to be arranged on an exactly similar plan, as we see from a comparison of Figs. 44 and 39.

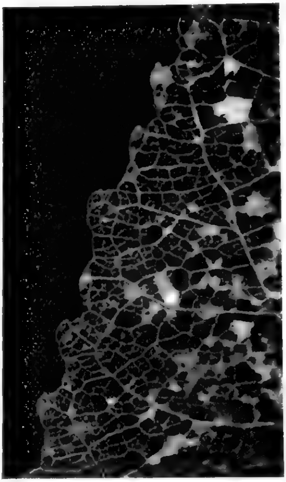


Fig. 45. Venation at the edge of a leaf.

Venation of leaves.

Lastly, the edges of flat structures, *e.g.*, leaves of plants, are often strengthened by strands of skeleton tissue and these strands are aided by the veins, which are usually arranged, in broad leaves at all events, in a series of successively smaller arches from the midrib outwards (Fig. 45). Large leaves which have no such strengthened margins are liable to be torn to ribbons by the wind, very much in the same way as a flag is frayed out unless protected by a marginal cord.

CHAPTER X

THE ADAPTATION OF ORGANISMS TO THEIR ENVIRONMENT

We may now look briefly at the general relations of organisms to their environment, how they adapt themselves to their surroundings, making the best of such as are favourable to their healthy existence and the multiplication of their offspring, and protecting themselves from such as are injurious to them or their progeny. Let us, first of all, look at plant life, and here, at the outset, we meet with differences once more dependent on the fact that the plant is a fixed organism while the animal is pre-eminently a motile one. Manifestly, we may expect the plant to show more adaptability than the animal, simply because the animal, in virtue of its locomotory powers, can remove itself from obnoxious influences, while the plant cannot escape, and must therefore adapt itself, temporarily or permanently, to its surroundings or succumb.

Before going into the consideration of specific examples, let us briefly summarise the principal external influences which affect plants.

Nature of the environment.

First, we have what may be termed mechanical influences of the environment, represented by amount of space, lateral or vertical pressures and tensions, and so on; then we have chemical influences, such as those of food, air, water, the nature of the medium in which the organism lives, &c.; thirdly, physical influences, which we may summarise under the heads of heat, light, and electricity; and, lastly, vital influences, the influences, that is to say, exerted by neighbours, parasites, and that most active of all vital agents, man. We may consider our organism, in short, as a central unit surrounded by an environment—everything not the plant—in part aiding, in part retarding the organism in its healthy development. The case is, however, not so simple as it looks, for not only may these various influences be all active at the same moment, but they act on and modify each other, and the modified influence may have an entirely different effect on the organism from that which it would have had if it had been unaltered by other conditions.

It will be useful at this point to quote a few examples from the profusion of literature on the subject of the influence of the environment on the organism.

Mechanical influences.

It has been shown by several experimenters that, when bred in confined spaces, the offspring of certain shrimps, &c., develop into dwarf forms, and that a definite relation exists between the size of molluscs and that of the vessel in which they are grown. The influence of changes in the pressure—lateral and vertical—of the environment, more especially on the form of aquatic plants, on the shape of corals, shells, sponges, trees, &c., has been the subject of research by many investigators, while the effect of pressures and tensions on cell form and planes of division has also occupied the attention of both botanists and zoologists.

Chemical influences.

Looking next at chemical influences, tadpoles and young fish, when well supplied with oxygen, develop more rapidly than under normal conditions; drought induces encystation and latent life in many lower organisms; dry air induces the formation of a thick cuticle and much skeletal tissue in many plants, while excess of moisture is accompanied by the formation of little cuticle and absence of strengthening tissue; the presence or absence of water has also a marked effect on the mode of development of some amphibious organisms (see also p. 98). The Axolotl of the Mexican lakes, for instance, is at one stage aquatic and provided with gills, but develops lungs, like a salamander, when subjected to dry conditions. The effect of artificially altering the salinity of water on the movements and forms of organisms inhabiting it have led to important conclusions on the origin of fresh-water from salt-water faunas. Indeed, the fluids of the body also have been shown to become altered by changed conditions of the medium, affecting, as it would appear, the character of the blood corpuscles, the amount of pigment developed, &c., while ciliated cells may be made to become amœboid and *vice versa* by varied changes in the medium. It has been found that certain chemicals can induce the unfertilised eggs of certain animals to segment, but the classic researches of the Hertwigs and of Loeb on the fertilisation and segmentation of the ovum under different conditions can only be referred to in this connection—space forbids their quotation in detail.

Pre-eminently favourable nutritive conditions have been found to induce ciliated lower forms to become amœboid or even to take on cell walls, and it is well known that asexual reproduction—by purely vegetative methods—is encouraged by such conditions, while vigorous pruning of shoot or root tends to the development of flowers and fruit. More than one authority claims to have shown that better nutrition tends to the excess of female offspring, while relative starvation tends to the formation of males. Indeed, the great physiologist, Claude Bernard, went so far as to say that the whole problem of evolution circled round the variations in the nutritive factors affecting plants and animals.

Apart from the changes in the rate of response of contractile organs immediately observable on alterations in temperature already referred to, it has been shown that the rate of multiplication of certain of the lowest animals is markedly increased by a rise in temperature, whilst cold, in addition to retarding movement, diminishes the rapidity of development and tends to induce the formation of dwarf and even larval forms, and to affect the sex of flowers. Similarly, light influences the formation of pigment in certain animals, *e.g.*, insects, and affects the colouration of birds' eggs, while in relation to plants, we have already quoted numerous instances of the importance of variations in light in relation to the distribution of chlorophyll, the anatomy and morphology of leaves, the movements of motile leaves and of free organisms. Light is also known to govern the mode of reproduction in certain Algæ, and, in excess, to act injuriously on Bacteria, while some botanists hold that deficiency in illumination favours the production of male as opposed to female cones in certain members of the pine family.

Physical influences.

The reaction of organisms of different types on each other may be demonstrated by endless examples. To quote only a few cases, we have the alteration in form in both constituents due to the constant association of Algæ and Fungi in the composite structures we term lichens, the remarkable cases of hypertrophy of vegetable tissue in fungal

Vital influences.

and insect galls, and the structural changes induced in some sponges by the constant living with them of certain polyps. The varied forms of flowers are now very generally looked upon as direct adaptations to visits of insects and that the manifold forms of domestic plants and animals have arisen as a result of conscious selection and cultivation by man is a fact too familiar to require proof. Evidence in abundance is forthcoming in Darwin's classic work on the subject ("Animals and Plants under Domestication") and in the extensive literature that has arisen since its publication.

Adaptation of plants to habitat.

The conditions of the environment are infinitely varied in different parts of the world—even, it may be, in the same district. In no two regions indeed are they exactly similar in all respects, and even in the same spot, the conditions are never the same for two moments in succession. Under these circumstances, it must be obvious that the organism, whether plant or animal, must be capable of keeping itself in equilibrium or accord with the ever-changing conditions. In certain regions some conditions of the environment are specially emphasised. Thus, in a desert region the absence of water is the principal factor to be considered, and unless the plant is adapted to live in such dry conditions it must obviously succumb. Again, aquatic plants are adapted to live either entirely or partially submerged. A general survey of the plant world enables us to distinguish certain types of structure specially adapted to special climatic conditions. Thus we have aquatic plants, desert plants, arctic and alpine plants, seacoast plants, swamp plants, &c., as well as plants adapted to peculiar modes of life, such as parasites, carnivorous plants, climbers, epiphytes, these latter being plants which grow on, but not at the expense of, other plants.

Adaptation of organs to special functions.

Then, again, we have adaptation of different types of organ to subserve special purposes or functions. For example, protection from destruction by animals is well exemplified in such

FIG. 46.—A, prickles; B, leaf thorns; C, branch thorns.

common plants as the rose, the hawthorn, and the holly. In each case the protection is afforded by sharp spines, but a little knowledge of morphological botany teaches us that the spines are of very different origin in each case (Fig. 46). In the hawthorn they are modified branches, in the holly they are extensions of the veins of leaves, in the rose they are merely hardened and sharpened emergencies from the surface layers of the stem or leaf-stalk, and have no connection with the internal vascular system. Once more, delicate-stemmed plants are able to maintain themselves in the erect position by holding on to their stronger neighbours. and so enjoy the maximum of air and light they would otherwise fail to obtain. This they do by means of a variety of structures, all of them performing the same function, but of the most diverse morphological value. Cobæa, for example, climbs by means of tendrils which are the terminal leaflets of branched leaves (Fig. 25). The grape also possesses tendrils which perform the same function, but, in this case, the tendrils are modified flower branches. The bramble climbs by means of prickles, which are, at the same time, protective, and the ivy by throwing out aerial roots which cling to walls, trees, &c.

FIG. 47. Ulex europæus: A, grown in moist air; B, grown in dry air ($\frac{1}{4}$ nat. size).

Experimental work in adaptation.

A considerable amount of experimental work has been carried out of recent years on several plants with the object of determining how far they may be made to adapt themselves to changed surroundings. Take, for example, the common gorse, familiar to every one by its bright yellow flowers, spiny green shoots and absence of genuine photosynthetic leaves. If a seedling gorse plant be examined, it will be found that it has no spines, but, on the other hand, possesses branches with small but quite recognisable leaves (Fig. 47). On cultivating such a seedling in a moist atmosphere, it develops into an adult without any such protective arrangements as one sees in

FIG. 48. An amphibious buttercup.

the adult grown under normal conditions. If, however, the conditions approximate to the normal, no more leaves are developed, and all further growth takes the form so familiar to us on our commons and moors. The white water buttercup, common in wet ditches, is another illustration in point. The lower leaves of this plant developed in the water are much divided into numerous fine linear segments, whilst those developed in the air are provided with three to five obovate or rounded lobes (Fig. 48). Under dry conditions all the leaves have the lobed form, but if entirely submerged all are filamentous. It must be understood, of course, that the one type of leaf cannot, after once being developed, be transformed into the other; but leaves subsequently produced will assume the aerial or aquatic form according to external conditions.

Mimetic resemblance.

The wonderful phenomena of mimetic resemblances seen between animals, between plants, and between plants and animals are well worthy of consideration in this connection, but space forbids us even to give instances, let alone consider any one of these in detail.

CHAPTER XI

REPRODUCTION

THE life of every organism has two aspects: the vegetative, or individual, aspect, and the reproductive, or tribal, aspect. In the one case all the energies of the organism are devoted to its own individual nourishment, protection, and so forth; in the other, certain organs come into play, previously in abeyance or up to that time non-existent, the activity of which, since they are, as a rule, incapable of nourishing themselves, immediately brings about a drain upon the vegetative organs. Further, among the higher forms, the offspring are, for a time at least, dependent on the parent for support, and this constitutes a further drain on its resources. Hence we see that tribal life must be antagonistic to individual life. Indeed it may be said, at least in general terms, that whatever conditions are favourable to vegetative development are against the interests of the reproductive processes, while the reproductive processes must of necessity react adversely on the vegetative system. Thus gardeners prune fruit trees when they wish them to bear fruit, or remove the flowers when they desire plentiful foliage. Keeping this fact in mind, let us inquire into the different modes of increase presented by plants and animals.

Antagonism of individual and tribal life.

As we have already seen in Chapter II (p. 8), at or before the completion of, or at some period in, the life cycle of the plant or animal, provision is

Asexual reproduction.

made for the continuance of the race, and this is attained in one or both of two ways, *i.e.*, by separation of a part of the body of the parent capable of giving rise directly to a new organism of the same type, in other words, by vegetative and "asexual reproduction," or by separation of a cell—an ovum or egg-cell—which is itself, save in exceptional cases, incapable of developing into a new organism without previous fusion with a corresponding cell—a sperm or fertilising cell—almost always in animals, and very generally in plants, derived from another individual. This latter method is termed "sexual reproduction." It is customary to speak of the sperm-producing parent as the male, and the ovum-producing parent as the female. The ovum, after fusion with the sperm, becomes the oosperm and develops into the embryo and, finally, into the adult.

Let us inquire first as to the theoretical origin of these two kinds of cells.

One of the first things we become acquainted with when we study the origin of cells is that they are capable of division. Why does a cell divide? A cell is a living unit; in it, during life, certain constructive changes are going on, tending to the accumulation of organic substances and of energy in the potential form and, at the same time, certain destructive changes, tending to the liberation of potential energy in the kinetic form, the decomposition of complex compounds, and the formation of simpler degradation products or excreta. We have seen already that the surface of the cell is the medium through which all nutritive substances must enter the cell, and it is equally obvious that from that same surface the waste products must be given off. If, in consequence of adequate nutrition, the cell

ell ivision.

grows, obviously the surface will increase synchronously with the volume, but not in the same ratio, for mathematicians tell us that, in a sphere, while the mass increases as the cube of the radius, the surface increases only as the square. Under these circumstances there will come a time when the mass must attain a size just such as may be adequately nourished by the possibilities of the surface as a means of entrance of food, and adequately purified by the possibility of getting rid of waste. A further increase in the volume is obviously impossible, since not only is there no surface available for the entrance of sufficient food, but the surface is also inadequate for the excretion of the waste. The cell must then either die or readjust the relation between surface and volume. If it divides into equal parts, its volume is at once halved and the surface area of each half is increased by the whole circular face exposed by the division (Fig. 49). For instance, in the spherical cells A and B, let us assume that the radii are two and three millimetres respectively. The volumes of these spheres may be calculated from the formula $\frac{4}{3} \pi r^3$, where r = radius and π = a number approximately estimated at $3\frac{1}{7}$. The volume of A will thus be $33\frac{11}{21}$ cubic millimetres. The surface of a sphere may be determined from the formula, $4 \pi r^2$, so that the extent of the surface of cell A amounts to $50\frac{2}{7}$ square millimetres. Similarly, the volume of cell B will be $113\frac{1}{7}$ cubic millimetres, and its area will be $113\frac{1}{7}$ square millimetres. Assuming for the sake of argument that an area of 1 square millimetre is sufficient for the

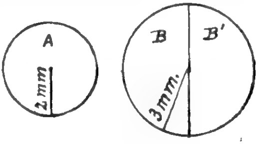


Fig. 49.

adequate nutrition and purification of 1 cubic millimetre of protoplasm, we see at once that the cell A has more than ample area for its nutritive and excretory needs, and may go on growing without detriment, while B has reached the maximum limit in this respect, and must be insufficiently nourished and accumulate waste products should it by any chance increase still further in volume. Let B, however, divide into hemispheres then each half will have a volume of $56\frac{4}{7}$ cubic millimetres, while the area of each will be $56\frac{4}{7}$ square millimetres + $28\frac{2}{7}$ square millimetres (the area of the circular face exposed), *i e.*, $84\frac{6}{7}$ square millimetres—more than re-establishing the balance on the side of area.

Ovum and sperm.

It is inconceivable, however, that the two new cells arising in this way should be precisely similar in all respects. Apart altogether from differences in the protoplasm, one or other will have an excess of waste products or of reserve products, and thus there arise differences between the daughter cells which result from division, both in minute structure and in activity. It is known that the accumulation of reserve nutritive bodies is accompanied by a tendency to sluggishness and non-motility in a cell, and hence there might arise a more massive and non-motile ovum, and a smaller and more active sperm. These cells are the characteristic reproductive cells of the female and the male respectively, both in the plant world and in the animal. It is, of course, not suggested that this is the way in which these reproductive cells arise in higher individuals, though it is possible that some such explanation might account for the original differentiation of cells of different sex.

Our next question must be, at what period in the life cycle of the organism are such cells formed?

Let us consider plants first. Some of them, as every one knows, last only, it may be, a few hours, a few days, or a few months. Others again, and these include all our higher plants, are annual, biennial or perennial. By annual we mean that the plant starts life as a seed in the beginning of the year, grows to maturity and forms flower, fruit and seed again in the same year, the parent dying off in late autumn or early winter. Biennials, on the other hand, start life from the seed, and in their first year of growth, devote all their energies to attaining full vegetative maturity, at the same time laying aside a surplus for propagative purposes, to be employed in the year following, when the flower and fruit are formed. Lastly, the perennial starts life in one year and may grow for several years before it reaches an age at which it is able to flower and fruit. Thereafter it does so, either every succeeding year or intermittently. These three conditions may be expressed diagrammatically as in Fig. 50.

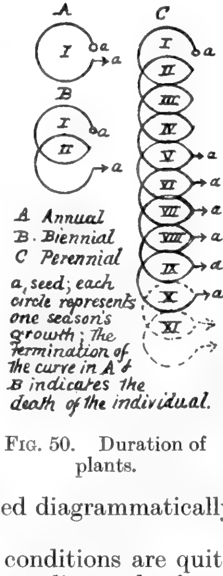


FIG. 50. Duration of plants.

In the case of the animal the conditions are quite similar. Some of the lower forms live only for a brief period, a few hours or days; but the majority of animals, including all the higher ones, live for several years, it may be for a hundred or more, although in no case as long as some of the highest plants, which, in many cases, measure their duration by centuries. During these periods, annually or more frequently in the year, or at intervals of two or more years, reproductive cells are formed and offspring are produced.

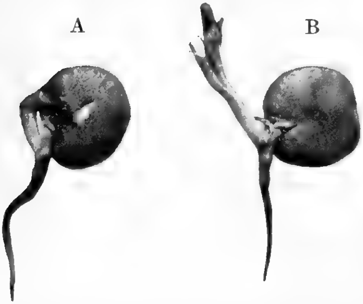


Fig. 51. Two stages in the germination of a bean. In A the radicle has developed and the plumule is on the point of escaping from the testa; in B the plumule is beginning to unfold. ($\times \frac{1}{2}$.)

In order that the offspring may have a chance in the struggle for existence it is manifest that they must not only be protected during the early stages of their existence, but also that some provision must be made for their proper nourishment during the embryonic period and until they are capable of feeding themselves. Both these necessities are provided for in a variety of ways.

Protection and nourishment of embryos.

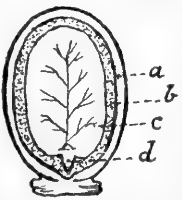


Fig. 52. Seed of Castor-oil: *a*, testa; *b*, food reserve; *c*, cotyledon; *d*, radicle.

The lower the rank of the organism the less provision is made for it in either respect. In the very lowest forms, indeed, no provision at all is made, and the offspring, newly born, are left to shift for themselves and take their chance among the favourable or unfavourable conditions of the environment. But higher up the scale, protection is either afforded by the parent, or the offspring itself has special protective adaptations. Further, the parent lays aside reserve stores in association with the embryo to start it in life.

One striking difference makes itself evident in the early stages of existence of higher plants and of higher animals respectively. The embryo animal is nourished by its parent and develops continuously from the moment of fertilisation of the ovum until the embryo becomes able to shift for itself, but in the case of the higher plant the conditions are somewhat different. The oosperm gradually develops into an embryo up to a certain stage and has, at the same time, reserve food stored in it or round it. Then ensues a period of rest, and in this condition it, along with its food supply and protective structures, is known as a seed. This resting stage, or seed-period, may last for several months or even years, after which

FIG. 53. Winged fruits of Maple.

the latent life of the embryo is awakened and, in the process of germination, it continues the development so long interrupted. During this resting period, again, the embryo is effectively protected. For example, the seed of the pea-plant comprises a protective shell or testa, enclosing a massive embryo, consisting of an embryonic shoot or plumule, an embryonic root or radicle, and two large swollen "seed-leaves" or cotyledons, filled with reserve proteids and carbohydrates (Fig. 51). During germination the insoluble reserves are, by the action of enzymes, transformed into soluble substances, and serve to nourish the plumule and radicle until the former has developed green leaves above ground, and the latter has obtained a firm hold on the soil and has developed branch roots and root-hairs for absorbing the necessary salts and water. In the case of the castor-oil seed (Fig. 52), the reserves — chiefly proteid and oil — are stored within the testa but outside the embryo, which latter appears as a minute nodular body

FIG. 54. Seeds of Poplar.

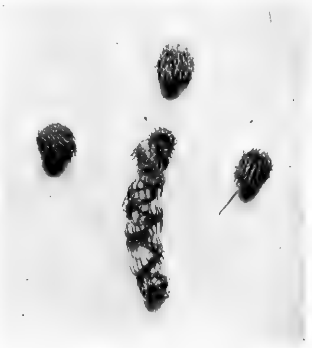


FIG. 55. Fruit of Medicago, closed and open.

with two large but delicate cotyledons, containing practically no reserves.

We have next to inquire what is the significance of this difference between the two types of organism? The explanation is again to be found in the fact that the animal is a motile and the plant a fixed organism; for it is during the hibernating period that the seed is distributed. Each parent may produce thousands of seeds, and manifestly it would never do to sow them in the immediate vicinity of the parent; there would be no room for them to take root, much less find nourishment. They must be dispersed, and it is manifest that there is more likelihood of their surviving if they be thoroughly protected and in a quiescent condition while dispersal is being effected, than if they be in an actively germinating condition.

Distribution of plants.

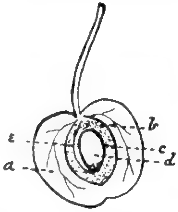


FIG. 56. Fruit of Cherry: *a*, succulent layer; *b*, hardened layer; *c*, testa; *d*, embryo.

The seed being, like its parent, non-locomotory, must be aided in dispersal, and the agents employed are, in the main, four, viz., wind, water, animals, and ejaculatory efforts on the part of the parent plant.

Illustrations.

Let us glance at an example of each of these modes of dispersal. In the case of wind it is obvious that the seeds must be light and buoyed up by something in the nature of a parachute. Thus we have the wings on the fruits of the maple and of the ash (Fig. 53), and the hairs on the seeds of cotton and of the willow (Fig. 54). It comes to the same thing, in the end, whether single-seeded fruits be dispersed or whether the fruit wall opens and the individual seeds be dispersed. Hence the "float" may be developed either from the wall of a single seeded fruit, as in Clematis, or from the wall of the seed itself, as in the willow. Obviously the same adaptations will be effective in relation to water dispersal, provided the protective arrangements are such as to shield the embryo from injury from water, be it fresh or salt.

Fig. 57. Fruit of Geranium before and after bursting.

Animals are by far the most effective agents in seed dispersal. Thus seeds and fruits may be provided with hooks or spines which stick to the fur or feathers, as in the case of the burdock, hedge-burr, medic, &c. (Fig. 55). Succulent fruits, on the other hand, appeal to the desire for food on the part of the animal. In some cases the fruit is removed from the plant and carried to a distance before being eaten. The seeds, then rejected, are thus sown far away, it may be, from their place of origin. In other cases the fruit is swallowed entire and passes through the intestine, but the embryos are protected from the action of the digestive juices of the animal's alimentary canal, either by the testa or by a hardening of the innermost layer of the fruit wall —as in the cherry (Fig. 56).

In other cases still, the plant itself arranges for the dispersal of its seeds, *e.g.*, by squirting them out, as in the "squirting cucumber," or by slinging them to a distance, as in the geranium (Fig. 57). In the former case the motive power is the elasticity of the fruit wall stretched to its utmost limit by the pressure exerted by the swollen contents of the ripe fruit; in the latter it is due to the drying and sudden rupture of part of the fruit-wall.

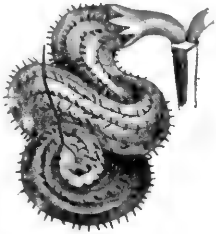


FIG. 58. Fruit of Scorpiurus. (After Taubert.)

In some cases it is believed that insectivorous birds are deluded into carrying off fruits or seeds on account of their likeness to insects, dropping them at some distance on discovering their mistake. Examples are seen in the castor-oil seed, the seeds of Jatropha, and the fruits of Scorpiurus (Fig. 58).

CHAPTER XII

THE STRUGGLE FOR EXISTENCE AND NATURAL SELECTION

No sketch of the principles of Biology, even though as brief as the present one, would be complete without a reference, however short, to the subject which forms the title of this chapter.

Types of organisms. Every day experience teaches us that both in the plant world and in the animal world there are many different types of organism, and that these may be arranged in a gradually ascending series from the most lowly unicellular types to the highest and most complicated forms, culminating in a daisy or a tree, on the one hand, and in man himself on the other. Under each type there are endless sub-types, and under these, again, yet other subordinate types. It becomes at once evident that some explanation of the relationships of these types to each other must be forthcoming if we are to believe in life on the globe as an organic unity. Round this question there has for long raged a vigorous controversy, some authorities holding that each type represented a distinct act of creation, others holding that types were not immutable, but that there existed a family relationship between them, if one had only the data necessary to construct a genealogical tree. Without entering in any detail into this controversy let us attempt to gain some insight into the fundamental premises which must underlie any theoretical explanations that may be advanced.

The first fact to which attention may be drawn is one not generally appreciated, viz., the enormous powers of increase possessed by organisms, if considered as living under ideally favourable conditions. A numerical example will bring this fact home to us.

Powers of increase of organisms.

Let us suppose that an organism, say a plant, can produce fifty seeds in one year. Let us suppose that all these are sown, and that all grow to adult life, each in turn producing fifty seeds in the second year; suppose that each of these fifty plants again produces fifty seeds, developing into seedlings in the following year, and so on. A simple arithmetical calculation will show us that in the tenth year, if every plant survived, we should have the prodigious number of 1953 millions of millions of plants then existing derived from the original one!

To take actual cases, shepherds' purse—one of our commonest weeds—is calculated to produce not fifty but 12,000 seeds annually. Burdock is believed to produce over 40,000, whilst purslane may give rise to 2,000,000! Our estimate of fifty, therefore, is immensely under the actual facts.

Man himself is calculated to be capable of doubling his numbers every twenty-five years. Few wild birds produce less than six young per annum. Let us suppose that each pair produces young four times in their lives. Each pair may therefore, if all live, give rise in fifteen years to many millions of birds like themselves, including the offspring produced in turn by these descendants of the original pair. A carrion fly can produce 20,000 larvæ, and each larva is mature in about five days. In three months, therefore, if all of them lived and produced eggs and larvæ in turn, the original carrion fly would have given rise to 100 millions of millions of carrion flies !

These figures are sufficiently startling when they are put down in black and white, but another and equally startling fact meets us at once when we study the subject more closely, namely, that this prodigious rate of increase is never maintained. It is perfectly obvious to every one that one plant in an incredibly short space of time would soon cover the globe to the exclusion of everything else. If every pair of birds produced in a few years 10,000,000 of birds, the sky would be dark with their wings. There must therefore be an enormous destruction of individuals, especially in the early stages of life, by various injurious agencies. Extreme cold or heat, damp, drought, disease, enemies, all play a part, and the net result is that, despite these enormous powers of increase, the number of individuals of each type, living from year to year, remains fairly constant.

Destruction of life.

Nothing, perhaps, brings this destruction of life more vividly home to us than to consider how many organisms, in the adult or in the embryonic condition, are destroyed in order that an average dinner may be provided for one human being (Arthur : "The Right to Live," 1897). Suppose that the dinner consists of tomato soup, fish, roast beef with potatoes and cauliflower, chicken, a rice pudding, together with the usual accompaniments of bread, cheese, and, say, a glass of wine. To produce the plate of tomato soup at least two tomatoes will be required, representing at least 200 possible seedlings. Then there will be one fish, one ox, one chicken, say three potatoes, representing the possibility of at least twelve plants, and one cauliflower. The bread will represent at least 500 grains of wheat, the rice pudding at least 1000 grains of rice, not to speak of a couple of eggs required as an ingredient. In addition we have, say, 100 seeds of mustard and ten fruits of pepper. Here, then, to start with, we have 1828 lives sacrificed. But to these we must add millions of yeast cells, required in the manufacture of the bread, millions of Bacteria required for the maturation of the cheese and wine, together with thousands of seeds of the vine, destroyed in the production of the wine. We need not pursue the illustration further, for when we begin to consider that not only is man slaying his thousands of lives at every meal, but that every herbivorous animal is slaughtering plants all day long, and every carnivorous one, animals, whenever it can get the chance, we need have no difficulty in understanding how it is that, notwithstanding its enormous powers of increase, no organism ever succeeds in entirely dominating the earth.

It will thus be seen that relatively only a few of each generation survive and propagate in turn. There must be a continuous and intense, though in most cases unconscious, struggle for existence taking place among organisms, and this struggle will be keenest amongst those most closely related, since obviously these forms will be desirous of the same location, the same environment, the same articles of food, and will endeavour to protect themselves from the same kind of enemy or vicissitude of climate. Again, the struggle will be keenest among the young, since every organism is most liable to injury in the young stages of development, that being the most critical period in its life-history. We must now ask ourselves what conditions determine which of the organisms shall survive and which shall succumb?

Struggle for existence.

Before we can answer this question we must look at two series of phenomena of fundamental importance, viz., those of heredity and those of variation.

It is a matter of common knowledge that an organism produces an organism liker to itself than to any other organism — an oak tree produces an acorn, which in turn produces an oak tree; a lobster produces an egg, which in turn becomes a lobster. The offspring inherits all the fundamental characteristics of its parent—it is hereditarily like its parent. But nevertheless no offspring resembles its parent in every particular; it occasionally shows features which recall characters of its grandparents, or even of some farther back ancestor, and it also presents individual idiosyncrasies of its own, which, so far as we can see, are not traceable to any ancestor. We are accustomed to say "as like as two peas"—we might just as well say "as unlike as two peas," for no two peas are exactly alike. There are differences in colour, in weight, in size, in form, in the number and shape of the cells of which they are composed, in the contents of these cells, and so on, and the plants arising from them are also different from each other in every detail, though we have no hesitation in identifying both as pea plants. No child is precisely like either parent—though it may show characters present in both; each has an individuality of its own. Some of these variations may be of such a kind as to lessen its chances of success in the struggle before it; some may be, on the other hand, entirely in its favour. It must be at once apparent that those individuals which possess any variation giving them a superiority, however little, over their fellows will, on the whole,

Variation and heredity.

be more likely to survive than those which have not the variation in question. They will in this way be "naturally selected from among the sum total of individuals of that generation," much in the same way as certain plants and animals are, artificially, *i.e.*, consciously, selected by man, on account of their possessing some feature of service to him or agreeing with his taste. **Natural selection.**

An illustration will make this subject clearer. Let A be an organism—say a plant—adapted to ordinary terrestrial conditions ; it will give rise, in any particular year, to, say, 100 seeds. These seeds will be scattered far and wide, but some may get eaten, some may fall on rock, some on water, and none of these will germinate. Let us suppose that ten get planted in situations which are, on the whole, suitable for their germination. Of these, *a*, let us say, germinates at the bottom of a moist ditch, while *b* germinates on fairly dry arable soil. Both develop into seedlings and thus start two new centres of colonisation for A. *a* gives rise in like manner to progeny, and let us assume that the variations shown by *a′*, one of *a*'s progeny, are such as to enable it to make a home satisfactorily under moister conditions than A or *a*, and that *b* also gives rise to progeny, one of which, *b′*, is better adapted to live under drier conditions than A or *b*. If these conditions are maintained for a series of generations, the aquatic characters of the *a′* series will become emphasised, just as the characters of the *b′* series will gradually become more and more suited to dry conditions. Manifestly, in the competition for space, the original *a* and *b* types are likely to die out and be replaced by the types *a′* and *b′* ; *b′* and *a′* have thus been naturally selected out of a series represented at the extremes by *a* on the one hand and *b* on the other. Either *a* or *b* indeed, may again develop characters which in some respects give it an advantage over the more constant descendants of A, whose territory it will therefore invade, and hence instead of having one type in a particular locality we may get two types divergent both from each other and from the original A.

In some such way as this it has appeared to many biologists to be possible to explain the endless varieties of related organisms that now cover the surface of the globe and that peopled it in past ages, whose descendants the former are. To Charles Darwin belongs the credit of having been the first to clearly expound the part played by natural selection in the evolution of new forms in his great classic, "The Origin of Species" (1859). To other biologists the theory of natural selection has appeared more or less inadequate, even granting the genealogical relationship of organisms, and many variations and modifications of Darwin's theory have been promulgated during the past half century. To one of these only can reference be made here.

One of the great objections offered to Darwin's theory has been that the evolution of new forms by natural selection would involve a quite stupendous period of time; and long, undoubtedly, as the earth has been inhabited by plants and animals, even these eons of time are considered inadequate for the evolution, by so slow a method, of the endless types of organism that are now in existence or have existed in past ages. *Natura non facit saltus*—Nature does not proceed by leaps—has been an axiom with most biologists since the days of Linnaeus, but during the last few years, chiefly due to the persevering energy of Professor De Vries of Amsterdam, we have come to believe that Nature does make leaps not infrequently and, it may be, even generally, if only there were a sufficiently large army of detectives available to catch her in the act. De Vries and others have found that some variations appear suddenly and spasmodically (mutations), and that these variations are constant, that is to say, reappear in the offspring generation after generation. Such variations have been termed "mutations," and it must be at once manifest that if mutations be at all frequent in Nature, and have been even more so in past ages, starting-points for new races of organisms may have arisen and may now be arising without the need for the long period of time postulated under the natural selection theory. Indeed, as a recent critic has put it, natural selection must have a significance quite different from that attributed to it by Darwin; for while, according to Darwin, the struggle for existence takes place between individuals, and new species arise by selection of those possessed of variations most likely to aid them in the combat, according to De Vries, fully developed species, produced by a sudden mutation, must come into conflict with those already in existence. One thing, however, is clear, that the last word has not yet been said on this, the problem *par excellence* of Biology.

Mutations

Science has been defined as the search for unity amid diversity, and even in the course of our brief study of the principles of the science of Biology we have seen this aphorism abundantly exemplified. Both plants and animals, as we have found, possess vitality, both are capable of self-nourishment, and this self-nourishment is effected in both types in fundamentally the same manner, viz., by the assimilation of organic compounds. Both are sensitive to stimuli, both multiply their kind. Both have the power of movement, although not in equal degree, and the skeletons of both are constructed in accordance with the same laws. Finally, we have seen that there is good evidence for believing that organisms are related to each other—in some cases, less, in other cases, more distantly—but that all of them may be regarded as terminal twigs of the infinitely branched trunks of the bifurcate tree of life. It must be left to other volumes of this series to connect the organic world with the inorganic, from which in the long run both obtain their nutriment, and by whose laws they also are governed.

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