CHAPTER I

THE LIVING PLANT

Living and non-living matter. Since biology is the science of living organisms, it is appropriate that a biological text-book such as this should indicate in the first place the characteristics which define living organisms, and since it deals with plant biology, it should also give some of the distinctions between animals and plants, and a general statement of the position of plants in the organic life of the world. These subjects will be the basis of Chapter I.

The distinction between living and dead matter is a less simple matter than appears at first sight; we agree that a crystal of sodium chloride is dead, and an active human being is living, but the criteria on which the distinction is based remain undefined, and certain border-line cases are hard to resolve. Thus the muscles of the leg of a frog can be dissected out of the animal, and may be kept in Ringer's solution for some days still capable of normal contractile movements when electrically stimulated. The frog as a unit may be dead, but are we still entitled to regard the leg muscles themselves as dead? We can only approach such a question by examination of the distinctive characters of living and dead things.

The capability of movement is possibly the most obvious character of living things, but although evident in animals, the ability in plants is reduced to little more than growth movements far too slow to be seen by eye; movements of at least equal magnitude seem to be involved in the flow of rivers, convection currents, tides and so forth. Thus as an absolute and simple criterion, movement is eliminated.

It may be suggested that living things *grow*, but this in itself is an insufficient standard, for salt crystals, recognisably non-living, will grow when placed in supersaturated solutions. Nevertheless organic growth has certain qualities not found in crystal growth. Thus the organism takes into its body diverse chemical matter and *assimilates* it, that is builds it up into its own living material, protoplasm, so that this definite substance is always increasing by the intake of substances unlike itself, substances on other grounds regarded as dead. This growth, unlike crystal growth, is not indefinite but seems always directed to a definite end; when the organism reaches a certain adult size, it *reproduces* and gives rise to new individuals like the parent one but smaller. The apparent direction of the activities of the organism to this end seems a valid distinction between living and dead matter. Another such concerns *response to stimuli*. The response of a man to a pinprick by rapid movement can be paralleled by the slower response of plant stems in a dark room turning towards a lighted window, but the excised frog muscle still responsive to stimulus makes one question the fundamental, if not the general value of the criterion. The distinction between living and dead matter is most strikingly evident in the phenomenon of death, which marks a sharp cessation of all the activities we most commonly associate with living things. Such considerations as these convince us of the practicability of separating living and dead things for general purposes, but it is questionable whether such distinctions can be fundamental.

The claim of plants to be considered, equally with animals, as living organisms, must be evident from this brief discussion, but in Chapter IV a more detailed account of the various plant activities will be found, such as to leave no doubt that plants really do come into this category.

The uses of plants. The use of plants to the world at large is a matter which can only be properly estimated after a full knowledge has been obtained of the complex activities and complex interrelations of plant and animal life on the globe, but some points may be made now to be supplemented by others given in the later sections of this chapter and this book.

Plants form the basis of life on the globe because they possess the power of building up organic food, in large quantities, out of inorganic food. They thus supply food for all the animals living in the world and needing organic matter as food. Similarly they are the chief source of fuel in the world, whether coal, peat, lignite, wood or oil. They afford a ready though not the only source of vitamines, and since they include the bacteria and fungi, they must be considered as responsible for plant and animal diseases, for various fermentations and putrefactive actions which break down dead organic matter and animal excretions, which might otherwise, by their accumulation, put an end to animal life on the earth. Further extension and application of such uses will be found throughout several of the ensuing chapters of the book.

Plants and animals. There is little real difficulty in distinguishing between plants and animals; the highest types on each side are readily recognisable. Animals move about freely and plants do not, plants are commonly much branched and animals compact, and of the two groups, plants alone are predominantly green. These are perhaps the most striking differences and those most evident in a superficial comparison between two such organisms as a man and an oak tree. Yet to these differences of movement, shape and colour must be added differences in the mode of nutrition, of cellular structure and growth. The most fundamental differences of all lie in the nutrition, and to this all the other differences may be easily related. The nutrition of the green plant depends on the possession of *chlorophyll*, a complex mixture of green and yellow pigments borne on the surface of small protein bodies, called *chloroplasts*, which are found in immense numbers in every green leaf and which, in some form or other, are present in all green plants. These bodies, when exposed to light, are able by absorbing the radiant energy to convert carbon dioxide into simple organic material such as sugar. This is the process known as *photosynthesis*. Supplies of carbon dioxide constantly diffuse from the air towards these places where it is being used up, and so the green parts of a plant are able to synthesise large amounts of sugar which form the starting point of the synthesis of all the complex organic material of the plant body itself. The plant nutrition also involves the intake of mineral substances in solution from the soil, their combination with the substances produced in photosynthesis, and the synthesis of both into still more complex organic material. Thus the plant food is inorganic, and the plant synthesises organic material from it. Such a function is quite lacking in the animal world, and it is upon this difference that all the chief distinctions between animals and plants eventually rest. The possession of chlorophyll is the key to *autotrophic* existence, that is nourishment by a system which is quite independent of other organisms. Because they have chlorophyll, the plants could readily live alone in the world, but the animals could not exist without the plant life which constitutes their food supply. As the animal eats solid food so it must have a mouth or gullet, a digestive region in which this food is rendered suitable for utilisation by the body, and excretory mechanisms by which residue can be disposed of. None of these exists in the plant, but the green colour of the plant indicates its photosynthetic powers, and the branched and spreading form of leaves and branches is significant as offering an extremely large surface for the absorption of inorganic substances present in great dilution in the soil or in the air. The widely spread leaves are significant also as an efficient means of absorbing light.

Since the animal cannot make organic material it must live on organic food made by plants, and to seek its plant food it must be able to move about. Thus its powers of locomotion and its compact form are seen to be implicit in its mode of nutrition. The differences between plants and animals in cellular structure and in localisation of growth will be dealt with later, and they too will be found to be very obviously related to the nutritional processes.

From this it will be clear that the safest single criterion for distinguishing a plant from an animal will be the possession of the chlorophyll pigment. All the other distinctions are vague and exceptions can be found to them.

Thus there are fixed animals such as sea-anemones and sponges. There are branched animals such as the corals and compact plants such as the cacti. Finally there are, in the sea, in river water and in rain water, simple organisms hard to classify either as plants or as animals. According to the theory of evolution all species of living organism have developed by a process of gradual change from a few simple original types, and there exist to-day a few simple organisms probably much like these ancient types. For example, there are tiny green unicellular organisms which absorb their food in liquid form but which are also motile like a true animal. Somewhere in ancient history, the main separations have been made from types like these into animal and plant lines of evolution. Indeed such separation may have occurred repeatedly, but in any case from such a point the organic world has diverged into the holozoic and the holophytic classes—that is, those classes entirely animal, and those entirely plant-like in their nutrition—the holozoic, dependent and the holophytic, independent.

The comparisons outlined so far between plants and animals, though sufficiently striking, can be supplemented by a view at a different angle, of the relation to each other forced upon them by their different modes of life. And in this case the dependence of the human race itself upon the plant world may be more fully recognised. This view involves a consideration of the energy relationships of animals and plants. In both animals and plants, by the process of *respiration*, compounds of high energy content are oxidised to compounds of lower energy content, and the energy set free produces heat and movement and maintains the various activities of the life of the organism. Perhaps the greatest simplification of this idea is to say that the following equation represents the respiration process in both plant and animal cells.

$$\underset{\text{(glucose)}}{C_6H_{12}O_6} + \underset{\text{(oxygen)}}{6O_2} \longrightarrow \underset{\text{(carbon dioxide)}}{6CO_2} + \underset{\text{(water)}}{6H_2O} + 677 \text{ kg. calories}^1.$$

This process going on in all living cells supplies energy for growth and movement and maintenance. If such a consumption of organic material of high energy content is constantly going on by both plants and animals it might be expected that shortly all such organic matter in the world would be consumed, and so indeed it would, save for the fact that plants can synthesise this organic material, by means of the chlorophyll in the cells of the leaves. This

[1] 1 kg. calorie, i.e. 1 kilogram calorie, is the amount of heat required to raise the temperature of 1 kilogram of water through 1° C. The equation indicates that 180 grams of glucose (1 gram molecule) on complete oxidation liberates 677 kg. calories.

can be empirically stated as the reverse of the former equation:

$$6CO_2 + 6H_2O + 677 \text{ kg. calories} \rightarrow C_6H_{12}O_6 + 6O_2.$$

As a result of this process of *photosynthesis* or *carbon-assimilation*, carbohydrates are produced by the plant which have a greater energy content than the equivalent carbon dioxide from which they are formed.

This plant process is the chief process by means of which new energy is fixed on the planet. The winds and river-flow are due to sun energy, and the tides are lunar, but all our common fuels such as coal, peat, petrol and wood burn with energy derived from sunlight, by photosynthesis. George Stephenson is said to have explained enthusiastically that it was sunlight stored millions of years in coal which enabled his locomotive engines to pull their trains along.

Thus the supply of fuel which is oxidised to give power and heat depends closely on photosynthesis, but the direct use of plant products as fuel is less important than the other slower process of respiration which, as we have said, is also an oxidation process going on slowly, but continually and essentially, in all plant and animal life. In this also the energy release is the essential part of the reaction, and only by the photosynthesis of plants are supplies of high energy organic material produced.

In plants both photosynthesis and respiration go on, and the former predominates, so that not only can a plant produce all the organic material which it can respire, but it has an overplus which is stored in various ways, for example in roots, stems, leaves, cell-walls, seeds, etc.

It is by consuming plants that animals acquire the energised products for their respiration, or by eating animals which have previously eaten plants. The energy produced may result in movement or in heat or it may be used to synthesise living material of even greater energy content. Thus one animal is effective food for another, but no animal has the capacity for utilising inorganic substances and radiant solar energy on a large scale and thereby becoming independent. For as it is, all life is dependent upon green plants and this is the deeper meaning of the phrase "all flesh is grass." Even man is bound by the same ties, though the progress of research may in time alter this. Should photosynthesis, the utilisation of solar energy in the formation of sugar from carbon dioxide, ever become possible *in vitro*, we may envisage an age of food and fuel and power as cheap as the town water supply. That day is not yet, but the not too visionary picture will shew the unrealised significance of photosynthesis and the plant world to mankind.

Cellular structure of plants. Plants and animals are made of protoplasm and its products. Whilst protoplasm itself is the fundamental living matter of the organism the great bulk of a complex plant body is made up of the non-living substances secreted as a kind of skeleton by the protoplasm. The protoplasm is split up into more or less separate units called cells and each of these secretes a cell-wall round it. This wall behaves as a sort of external skeleton—an exoskeleton, like that of a crab or lobster—and upon it devolve practically all the mechanical functions of the living plant. This theory of the cellular composition of plants and animals was propounded by Schleiden and Schwann in 1831 and now appears almost as a self-evident fact.

Each cell has a "nucleus," and in a young state each cell is capable of division and extension almost indefinitely, but all the same, a multicellular plant is much more than a collection of living units in a common skin. The protoplasm of each living cell extends through tiny perforations in the walls into the neighbouring cells so that there is complete protoplasmic continuity from end to end of the plant. The demonstration of this fact made a great change in the general conception of plant structure and plant physiology. For instance, this discovery provided some path along which might pass the conduction of stimuli from cell to cell of the plant, a process recognisable in plants just as in animals despite the absence of any definite nervous system. These very fine filaments of protoplasm explained, or rather their presence agreed readily with, the behaviour of the plant as a single organism, rather than as a complex colony of micro-organisms.

The plant cell is commonly a box-like body about $\frac{1}{20}$ of a millimetre long. The protoplasm lines the inside as a colloidal layer. The wall itself is largely cellulose and may in some cases be observed to be laid down in layers from the inside by the protoplasm. The space inside the protoplasm is called the vacuole and contains "cell-sap," a fluid which is a dilute solution of organic and inorganic substances, mostly useful as material or secreted as products of the cell's activities. The outer layer of the protoplasm, next to the cell-wall and next to the vacuole, forms a structure which from its physico-chemical characteristics is of the greatest importance to the life of the cell. It cannot be distinguished as a separate layer under the microscope.

The protoplasmic layer contains the *nucleus*, the most complex unit in the plant cell, and as in the animal cell, a body of the utmost significance in the reproduction and multiplication of the cell. The nucleus can be identified as a definite, almost spherical, granular body (Fig. 1). Other smaller structures called plastids occur in the protoplasm and they may be coloured green by the presence of a surface layer of chlorophyll, in which case they are called chloroplasts. They are generally ovoid or lens-shaped masses of protoplasm. In the layer of chlorophyll on the surface of these plastids, photosynthesis takes place, and the absorption of carbon dioxide, the formation of carbohydrates and the giving out of oxygen involved in this process.

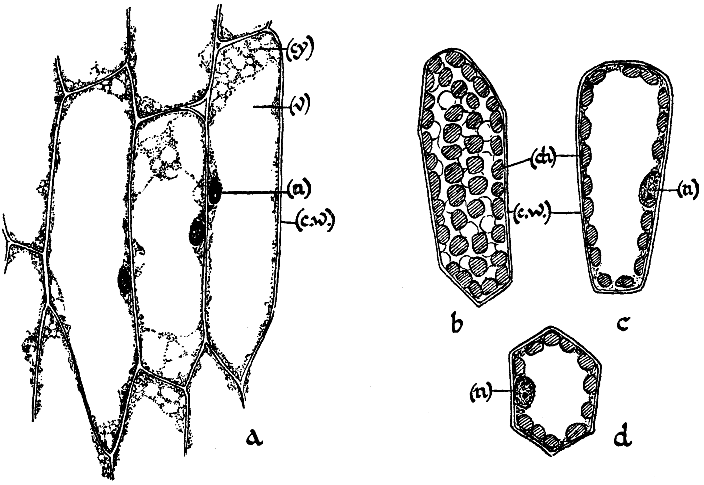

Fig. 1. Living cells. *a*, cells from the skin of the fleshy leaves of the Onion bulb; they have thin cellulose walls (*c.w.*), lined with a thin layer of cytoplasm (*cy*), which contains the ovoid nucleus (*n*). The greatest part of the interior of the cell is occupied by the vacuole (*v*) containing cell-sap. *b*, *c*, *d*, green photosynthetic cells from the Iris leaf containing abundant chloroplasts (*ch*). *b*, cell seen in side-view shewing chloroplasts on all the walls; *c*, cell in longitudinal section shewing the nucleus (*n*) and chloroplasts in the cytoplasm lining the cellulose wall (*c.w.*); *d*, the same cell seen in transverse section.

The small size of the plastids gives an enormous surface area for the bulk of plastid material, so great that the chloroplast surface in a big leaf of a castor oil plant would be over a hundred square yards. The chlorophyll can be extracted from the surface of these bodies but will not then photosynthesise. The plastids may be colourless, as in tubers for instance, and then they are called leucoplasts. They serve, in such cases, as centres of starch formation.

Not all the plant body is made up of living plant cells