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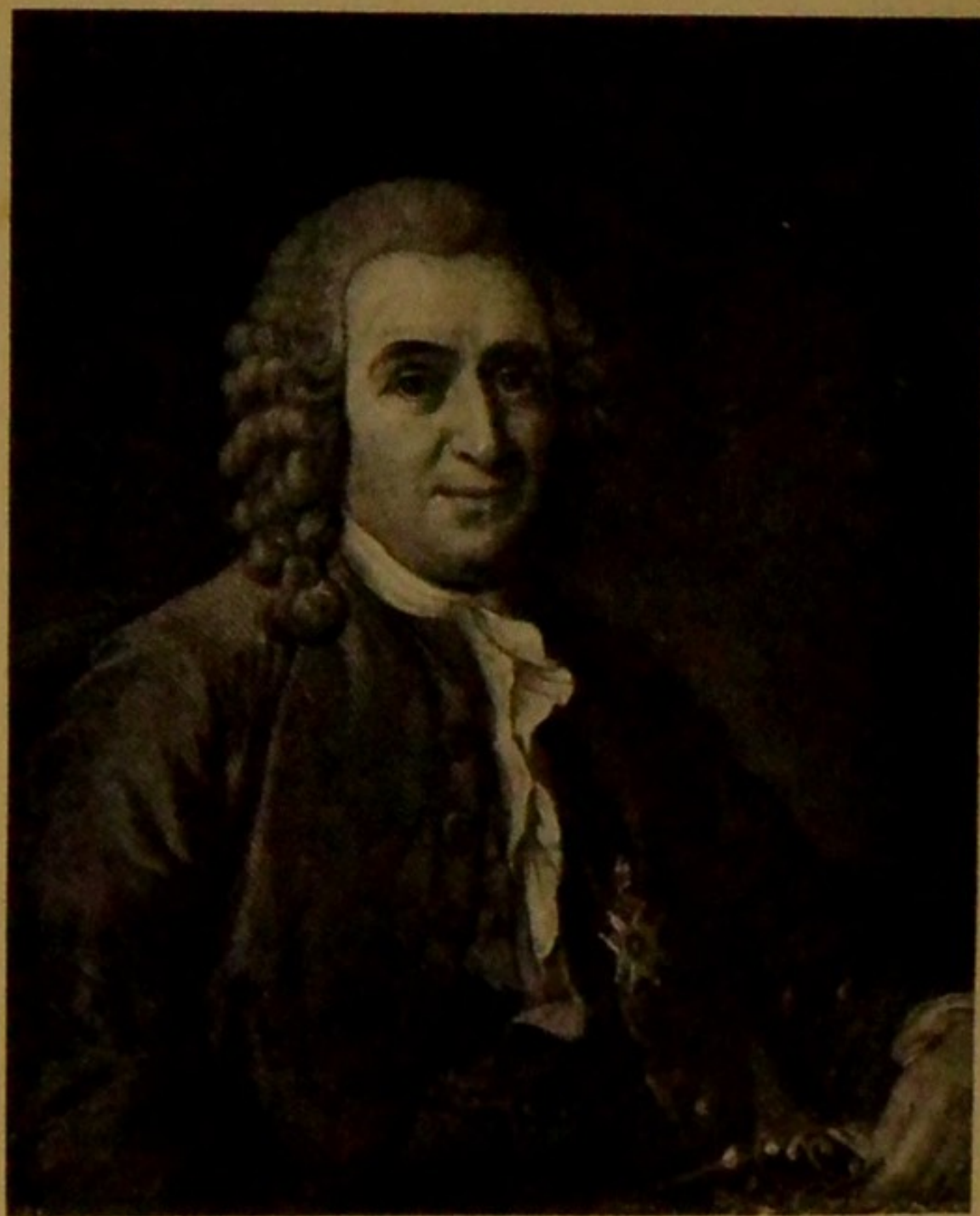
PLANT LIFE AND STRUCTURE

Translated from the German of

DR E. DENNERT

By

CLARA L. SKEAT



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PLANT-LIFE
AND
STRUCTURE



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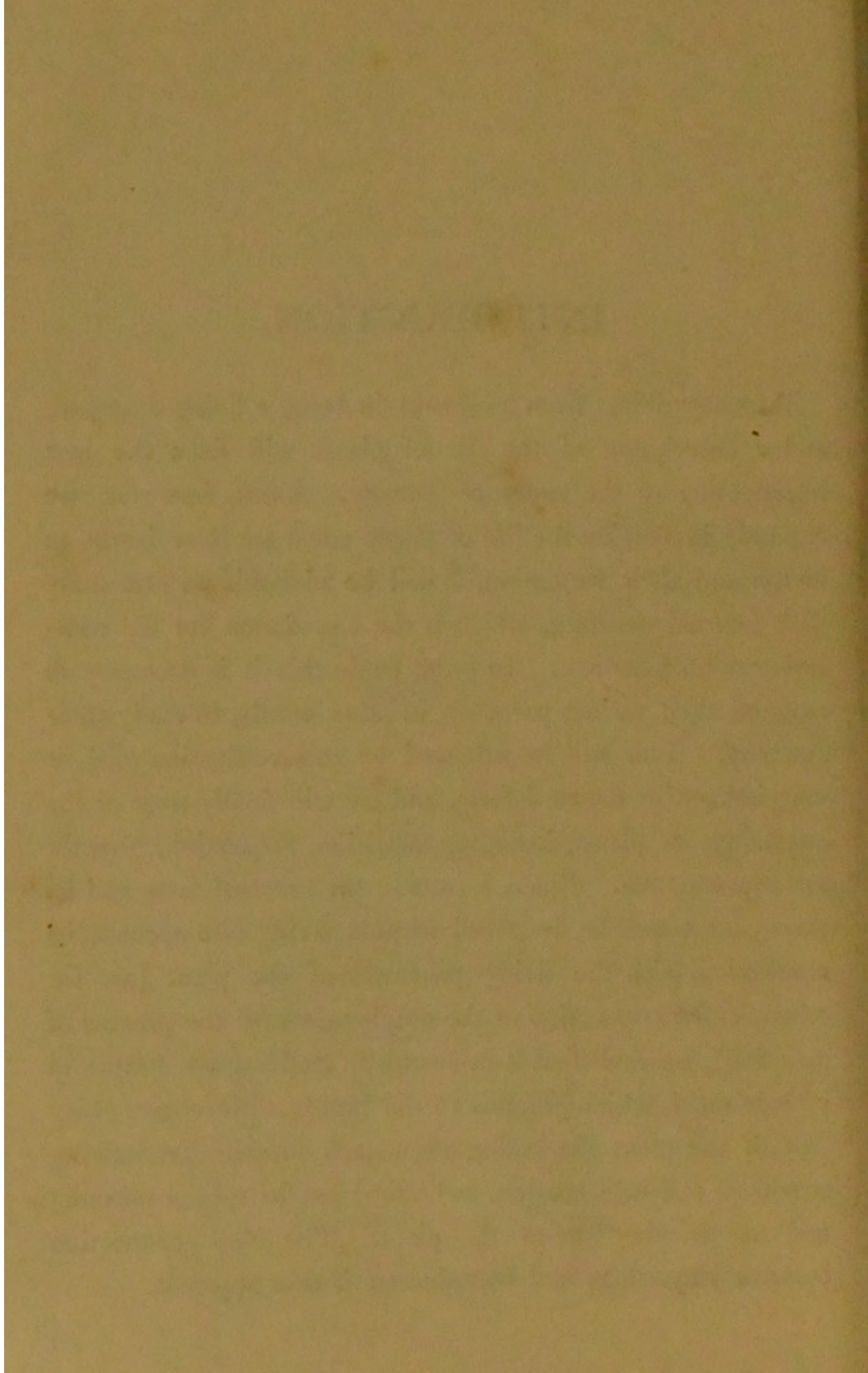
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INTRODUCTION.

A PLANT differs from a mineral in being a living organism, and a description of the life of plants will form the best introduction to the study of Botany. Since, however, we can only investigate the life of plants when we have learnt to understand their formation, it will be advisable to first study their internal structure, which is the foundation for the comprehension of the rest. In order to do this it is necessary to examine their various parts, or, in other words, to study their anatomy. This will be followed by an investigation of their morphology, or outward form, and we will finally treat of the physiology of plants, including nutrition, respiration, growth, and reproduction. Since, however, the external form and its parts cannot well be described without taking into account its connection with the living processes of the plant (as, for example, the connection of the cotyledons with the process of nutrition), we shall find it necessary in studying the former to include much which pertains to the latter. Moreover, every part of the plant (including even such insignificant-looking structures as stings, brushes, and hairs) has its special meaning and use in the life of the plant. The close connection between Physiology and Morphology is thus apparent.



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PLANT LIFE.

I. The Internal Structure of Plants.

1. *The cell as the fundamental unit.* Life may be described as the response of a living being to its environment. In order to accomplish this end, however, the living being requires various implements. These implements are called organs, and their possessors are called organisms.

Every organ has its special function, but in order that this may be fulfilled there must be a certain amount of division of labour in the organ itself. It must possess other organs of a secondary nature, and it is easy to understand that this division and specialisation of function is always increasing, and that a division and specialisation of the organs must necessarily keep pace with it. This finer structure can not, however, be seen without the microscope, which reveals a very delicate tissue, finer than any that could be made by human hands. This tissue consists of a number of little bladders lying close together, each having its own firm wall and its own contents. The little bladders are called cells, and as all organs are composed of them, we may rightly consider cells as the fundamental units of the plant.

2. *The structure of the cell.* The cell (Fig. 1) is therefore a little bladder, but whereas in a bladder the wall is the most important part, in the cell the contents only are essential, the wall being formed by them.

In young cells the contents are a slimy mass which completely fills the interior. The microscope shows little

granules, and a larger body called the nucleus floating about in this mass; the nucleus contains a nucleolus. In this

FIG. 1.

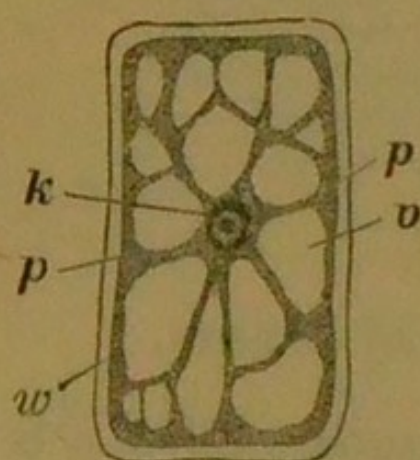


Diagram of a cell.

w, cell-wall; *p*, protoplasm;
k, nucleus; *v*, vacuole.

short description we have by no means exhausted the finer structure of this slimy mass and its nucleus. We will not, however, enter further into the subject, as investigations concerning it are not yet concluded.

The slimy mass is called protoplasm, and consists chemically of substances known as proteids, which are distinguished by containing a widely diffused element called nitrogen. Since we know that all the phenomena of life proceed from protoplasm, we are justified in describing it as the living principle of plants.

We must remark in passing, that among the lower plants there are some forms which are devoid of a cell-wall and cannot be described as cells. Hence it is apparent that the contents of the cell are more essential for its life than the wall. Although we may thus consider the cell as the fundamental unit of the tissue, a part of it only is really living. To this living part the term "energid" has lately been applied by J. von Sachs, as we shall see below.

The protoplasm of a single cell has received the name of "energid," since from it proceeds all the energy of life. For the constitution of the whole plant as an individual it is very important that the energids of the separate cells should not be entirely cut off from one another, but that they should stand in close connection with the neighbouring energids. This is accomplished by means of extremely fine threads of protoplasm, which from the first penetrate the minute pores of the cell membrane, and thus connect all the energids together. It is obvious that if any special cell is irritated, the stimulus can be carried to others by means of these threads.

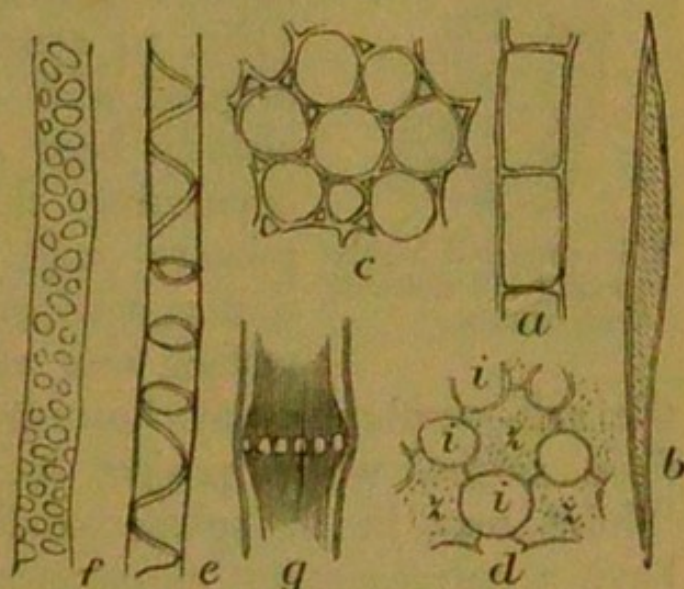
The living activity of the energids is shown by their

division. This can only take place in a cell which contains protoplasm, without which the cell may be considered as dead. We may further observe that in an uninjured cell the little granules of the protoplasm exhibit a streaming movement, which is also a sign of life. The division of the protoplasm, and even that of the whole cell, has been actually observed.

Cell-division begins in the nucleus, thus showing that it is rightly regarded as the central organ of the cell, *i. e.* of the energid. Both protoplasm and nucleus have a thread-like structure. When a cell begins to divide, the threads of the nucleus divide first, forming a "nuclear plate" in the middle; they then move in two groups to the poles, where they constitute two new nuclei. After this has been accomplished little particles of cellulose collect in the middle of the cell, and these finally unite to form a middle wall; the division of the cell is then complete. These processes are accompanied by the formation in the protoplasm of fine threads ("spindle-fibres") which connect the two new nuclei.

The cell-wall or membrane is firm and elastic; it possesses the peculiar property of all organic membranes, *i. e.* that of allowing fluids to pass through (osmosis). It consists of a substance which is chemically known as cellulose. By means of the energids the cell has the power of growth both in length and thickness. The result of growth in length is a fibre-like

FIG. 2.



Various forms of cells, highly magnified.

a, prismatic cells; *b*, fibrous cell; *c*, tissue composed of round cells with inter-cellular spaces; *d*, stellate cell (*x*) with large spaces (*i*), (spongy tissue); *e*, vessel showing spiral and annular thickening; *f*, dotted vessel; *g*, sieve-tube, showing the junction of two vessels, and a sieve-plate seen in section (the contents are shaded).

cell (Fig. 2, *b*); many other forms may also arise, as prismatic cells (Fig. 2, *a*), star-shaped cells (Fig. 2, *d*), etc. The cells may also present great variations in size. In the higher plants they are generally microscopic; there are, however, lower plants, consisting of a single cell (non-cellular plants), which under some circumstances grow very large, and which may show a well-marked differentiation in their form. The fact that the energids of these cells possess numerous nuclei shows that such unicellular plants really correspond to multi-cellular plants.

Growth in thickness proceeds from the interior of the cell. Concentric layers are often plainly seen in the thickened membrane. The layers are generally formed

FIG. 3.



Thickened cell, highly magnified; cell-wall with canals.

in such a manner that canal-like fissures (Fig. 3) arise, and these penetrate to the original wall of the young cell. It has already been stated that very fine canals connecting the cells are found in this primary wall. The canals usually join similar ones of adjacent cells and appear in surface view as dots. The thickenings of

the cell-membrane may, however, occur in such a way as to form ridges, which project into the interior of the cell. These may be of spiral, annular, or net-like form, and have a corresponding appearance when seen in surface view (Fig. 2, *e* and *f*).

The bordered pit is a special kind in which the canal is not of uniform width throughout, being wider towards the primary cell-wall, and narrower towards the opening, while at the same time a similar pit corresponds to it on the other side. The adjacent pits appear as a lens-shaped space which is divided in the middle by a wall. These bordered pits are valves; they are found, for example, in fibrous cells which are then known as "tracheides."

Growth in thickness produces at the same time changes in form and in substance, materials being stored in the cellulose, which lend it peculiar properties. The membrane, by storing

suberin, may either become corky with cutin, or woody with lignin. In the first case it shows great flexibility and is at the same time impermeable to water. Plants form cork in their cell-walls when these two qualities are needed. A cell-wall which becomes woody acquires excessive rigidity, and yet does not lose its power of allowing water to pass through; on the contrary, water then moves in it with great facility. Lastly, the cell-wall may become mucilaginous, as in the seeds of flax and quince.

As the cell-wall grows, and the cell itself increases in circumference, the protoplasm does not increase in proportion, and spaces necessarily arise. These spaces are called vacuoles; they are not, however, empty, but are filled with cell-sap, which enters from without. The cell-sap consists of water which contains some salts, and sometimes also sugar, organic acids, and colouring matter. The protoplasm is in this case vacuolated, forming a net-work; the nucleus is usually found more or less in the middle, and is supported by strands of protoplasm. The protoplasm at the edge of the vacuoles is firmer than the rest, and this has given rise to the theory that each has its own wall. If the vacuoles continue to increase, the protoplasm becomes merely a lining of the cell-wall, and carries the nucleus with it. A completely closed sac is thus formed, and this has been called the "primordial utricle."

The protoplasm and cell-sap are, however, not the only contents of the cell: the living protoplasm has the power of forming many other substances. Of these the most important is the green colouring matter or "chlorophyll," which imparts to the plant that green colour so pleasing to the eye. A closer examination under the microscope shows small protoplasmic bodies in the protoplasm of certain cells, especially in those of leaves. These bodies are called chloroplasts, and contain a green colouring matter which is insoluble in water, but will dissolve in alcohol.

Chlorophyll is an indispensable constituent of those plants which are capable of obtaining their food at first hand; it

usually supplies the plant with food in a manner which will be explained later when dealing with the nutrition of plants. The green colour is only formed when a plant is exposed to sunlight. Every one knows that plants which germinate in a cellar are pale and yellowish, but that they become green when placed in the light. The presence of iron is also necessary in order that the chloroplasts may become green.

The position of the chloroplasts in the interior of the cell is often influenced by the light. They lead in a certain respect an independent life, and they have even been observed to divide. In addition to the chlorophyll corpuscles, there are other bodies which are of special importance among the cell contents. These are the starch-grains, and must be considered as the product of the food taken in by the plant. They arise inside the chlorophyll corpuscles, or in special colourless granules, called "leucoplasts." The fact that they are in the form of corpuscles shows that they are insoluble in cell-sap, and therefore also in water. Starch-grains exhibit various forms in different plants. This renders it possible to detect adulterations in the various kinds of flour which consist of starch by examining them under the microscope. A stratification in the grains can usually be more or less plainly discerned. They are easily recognised when coloured blue with iodine. They are of great importance in the life of the plant, but at present we will only remark that they represent the most important constructive and reserve materials.

Among the other cell contents may be mentioned those colouring matters which are not green. In spite of their great and striking variety they may be divided into two groups: (i) those which are soluble in the cell sap, *i.e.* blue and red colours, and (ii) those which are insoluble, *i.e.* yellow colours. The latter are in the form of corpuscles, which are doubtless closely connected with chlorophyll grains, and are called "chromoplasts." The great variety of colours in the plant world is attained in a very simple manner, by combinations of the various colours and by special structural modifications. Tannin is a substance which is widely distributed in the plant

world. It is soluble, and can therefore only be shown by certain chemical reactions. In spite of extensive experiments we know little of its use, but it is certain that a kind of tannin is connected with a red or blue colour.

Besides the above-mentioned cell-contents, crystals of various salts occur. These may take the form of needles, double pyramids, and stars. Oxalate of lime needs special consideration in this connection; crystals of this salt are by-products, which, being poisonous, furnish a means of protection against the attacks of animals. Aleurone grains may lastly be mentioned. These are formed of proteid, and often contain roundish or crystal-like masses of proteid. They occur in the seeds of grasses and of *Ricinus*.

3. *Wood-vessels and sieve-tubes.* It may be stated as a principle that there is no part of the plant which does not consist of cells, or has not been originally derived from cells.

The body of the plant is traversed by tubes, which arise in the roots and terminate in the delicate veins of the leaves. These were also originally cells, but they have become tubes through the absorption of the transverse walls of perpendicularly adjacent cells. They are called "vessels," and form a system for conducting air and water. They can be recognised under the microscope by the fact that they possess peculiar thickenings on their walls, which project on the inner surface of the tubes, and are either spiral, ring-like, net-like, ladder-like or pitted; we can distinguish therefore between spiral, annular, reticulate, scalariform and dotted vessels. These thickenings obviously serve to stiffen the vessels (Fig. 2, *e* and *f*), thus giving them greater strength. The walls of the vessels are woody, and therefore allow water to pass up. As they no longer contain energids, the vessels may be considered as dead, but in spite of this they play an important part as conductors of air and water. The vessels and tracheides are connected by transitional forms.

Near the vessels of the wood there occur in plants others called "sieve-tubes." These are also tubes which are formed

from upright rows of adjacent cells, but in this case the transverse walls are not entirely absorbed, but are pierced with holes like a sieve. Similar sieve-plates are also found on the sides of the sieve-tubes. The walls consist of cellulose, and the protoplasmic contents, which are present at least as a thin layer round the wall, indicate that the sieve-tubes are still living. They serve for the conduction of nutritive material in the form of proteid (Fig. 2, *g*).

We may finally mention the laticiferous vessels, containing a milky juice which is characteristic of many plants. These vessels arise by the absorption of the transverse walls of rows of cells. There may also occur laticiferous spaces, consisting of single, branched cells of great length, which continue growing at the end, as in spurge.

4. **The tissues.** It has been already shown that the living activity of the cell consists in the fact that it is capable of division. Many of the lower plants remain always unicellular. If division takes place the two daughter-cells again separate. Among most plants this separation does not, however, occur, the two new cells remaining in connection with one another. These daughter-cells are capable of following the example of the mother-cell and of dividing again, while each time the dividing cells give up their own individuality, and form two new cells. Thus arises a community of cells, which is called a "tissue" (Fig. 2, *c* and *d*).

The character of the tissue will be obviously influenced by the direction in which the division and expansion of the cells takes place. If this occurs in a direction perpendicular to the long axis of the cell, there arises from this growth a thread-like tissue, only one cell wide. If the division takes place in two directions, a flat structure arises; and lastly, when the cells divide in three directions perpendicular to each other a cellular body is formed.

Plants are found corresponding to all these forms. Among unicellular plants we find, especially in the lower forms, those which represent a thread-like, flat or cubical tissue. Among the higher plants similar tissues occur, but the cubical form

then predominates. In classifying the various kinds of tissue in the higher plants, the structure of the separate cells is of importance, but if they are to be rightly understood their function must also be taken into consideration.

When the cells which compose the tissue are dice-shaped, prismatic, or globular, the tissue is said to be parenchymatous (parenchyma); when it consists, on the other hand, of long fibrous cells it is said to be prosenchymatous (prosenchyma). The former is of most use in taking up food, the latter in the conduction of water and mechanical strengthening. When in a parenchymatous tissue the corners only of the cells are thickened, it is called collenchyma, but if the whole wall is thickened (Fig. 3, sclerenchyma) it is called sclerenchyma.

The classification of tissues according to their function is of much greater importance. We must first consider whether the tissue is still capable of division, in which case it is called "meristem" (the most important being the meristem of the growing point, which is found at the tips of shoots and buds, and that of the cambium, by means of which the stems of trees increase in thickness). If the tissue has lost the power of division it is said to be "permanent." The permanent tissues may be distinguished as epidermal, fundamental and vascular, according to their position and form.

(a) *The epidermal tissue*, as the name implies, covers the whole of the young plant like a skin: in older plants it is found in the leaves only. The remaining tissue of the plant appears as a mass of cells (fundamental tissue) in which certain cord-like bodies (vascular tissue) are as it were imbedded.

The cells of the epidermis have no inter-cellular spaces; they contain no chlorophyll, and the outer layer of the external walls is corky (cuticularised); they are therefore elastic and impermeable to water. They are either hexagonal and elongated, as in green stems, or their walls are sinuous and fit into one another, as in broad leaves. They possess weak energids, colourless chromatophores, and contain much water; thus the plant is surrounded by the epidermis as

by a water mantle. The impermeability to water is often increased by a waxy deposit on the epidermis, as in peas; and incrustations of silicate and chalk sometimes occur. The epidermis of leaves serves also for the interchange of gases and for transpiration. On this account it possesses special contrivances called stomata. Two bean-shaped cells, or "guard-cells," containing chlorophyll, are placed opposite each other, and between them is a cleft, which closes or opens as the guard-cells approach or recede. Both movements are regulated by the plant itself; when the guard-cells are turgid they separate, when they are flaccid they approach one another, the movement being connected with the difference in form of the walls of the guard-cells.

Stomata are chiefly found on the lower surface of ordinary foliage leaves, on the upper surface of floating leaves, and in fewer numbers on herbaceous stems. Many plants possess special water-stomata which excrete water in the form of drops.

Hairs are epidermal structures; the simplest are formed by the outgrowth of the epidermal cells; when cells of a deeper layer take part in their formation, they are called emergences. Both are very varied in form, and serve as a protection against evaporation and the attacks of animals. Many hairs give rise to a secretion, as in glandular and stinging hairs.

(b) *The fundamental tissue* may show any of the above-named forms according to the function which it is destined to fulfil. Parenchymatous ground tissue is for the most part nutritive in function, and therefore often contains chlorophyll; it occurs in leaves and in bark. The pith of trees is also parenchymatous, but must be considered as dead since its cells contain no protoplasm. Sclerenchymatous and collenchymatous tissues occur in the bark, and tend to give it rigidity. Between the cells are often found pits and intercellular spaces (Fig. 2, c), which serve for ventilation. When the spaces are large, and the cells stellate, a spongy tissue is formed (Fig. 2, d). (See many water-plants.)

The ground tissue may also serve as a place to store up food, starch being often deposited in it as a reserve material. Waste materials as resin, gum, ethereal oils, and alkaloids may also accumulate in the ground tissue. These may have secondary uses.

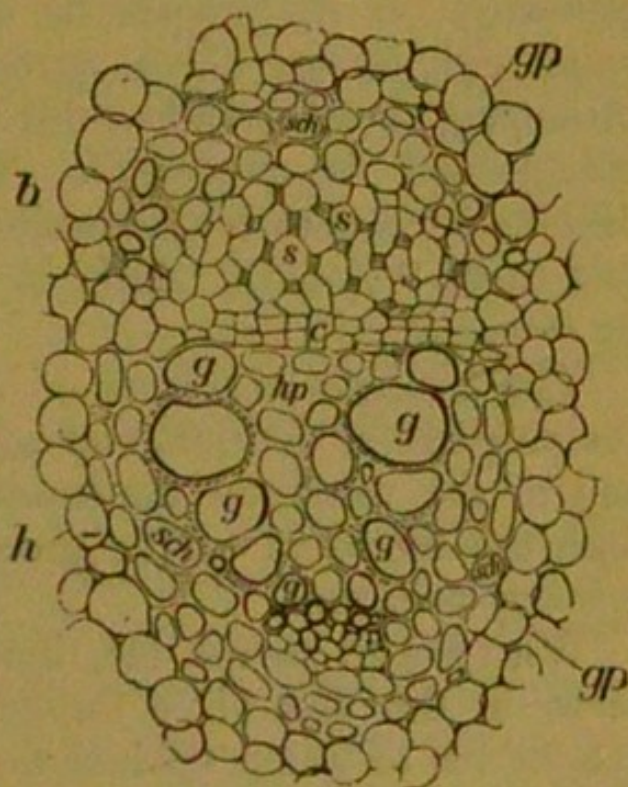
(c) *The vascular tissue* is represented by those cords which traverse the whole plant, being, as we have already said, embedded as it were in the ground tissue. They begin in the tips of the roots and end in the fine ramifications of the veins of the leaves. They form a conducting tissue, but have also other uses, which will be presently explained. They are a beautiful proof of the supreme wisdom of the methods of Nature, many functions being fulfilled by one set of organs.

The cords or strands (Fig. 4) contain vessels, and are therefore called vascular bundles. This is not, however, a good term, as the vessels are not the most important constituents, a better name being that of "conducting tissue." They consist, when in their most distinct form, of three parts: vessels, called also wood, sieve-tubes or bast, and cambium. The vascular bundle usually appears egg-shaped

in tranverse section, and these three parts are so arranged that the cambium occupies a narrow zone between the two other parts. The vascular bundle is generally so placed that the wood is in the centre, and the bast at the circumference.

The wood-vessels are so called from their most conspicuous

FIG. 4.



Ranunculus repens, creeping buttercup,
a vascular bundle highly magnified.

b, bast; *c*, cambium; *h*, wood; *s*, sieve-tubes; *g*, vessel; *hp*, wood prosenchyma; *sch*, sheath; *gp*, fundamental tissue.

elements, the vessels. The inner vessels are smaller than the outer, and an examination of the longitudinal section shows that these inner small vessels are spiral and annular. The outer vascular bundles possess only dotted vessels. Between the vessels lie parenchymatous cells and wood-fibres, the latter often constituting the greater part of the wood.

In the bast are found sieve-tubes (without nuclei), and close to these are parenchymatous cells, called companion-cells (with nuclei). This part of the vascular bundle is generally formed of thin-walled unligified cells, and occupies a smaller space than the wood. The bast is often protected on the outside by a group of fibres, which may unite with similar fibres surrounding the wood, and form a protecting sheath. When this surrounds the whole bundle its enlargement is prevented. The cambium then becomes differentiated into a thin-walled tissue. Such a bundle is said to be "closed," while in the former case it is said to be "open."

The cambium is a layer of very delicate cells which have the property of division, and add to the bast on the outside, and to the wood on the inside. It is connected directly with the meristem of the growing-point, and is therefore a primary meristem.

With regard to the function of the vascular bundles they serve in the first place for conduction; the wood for the conduction of water, the bast for the conduction of albuminous matter. At the same time the vascular bundles serve a mechanical purpose and keep the plant upright by means of their cells and fibres; they accordingly form girders, which in their whole disposition as well as in the arrangement of their cells conform to the laws of mechanics.

5. Growth in thickness. Single vascular bundles, as those described above, are found in weak annual stems, in the stems of Monocotyledons, and in leaves. It must, however, be borne in mind that the arrangement becomes less simple when the stem in the course of its life increases in thickness, as in most Dicotyledons. In this case the growth proceeds from

the bundle, and from that special part of it which is called the cambium.

The delicate cells of the cambium retain the power of division; they form as it were a perennial spring of youth, by means of which the plant can be continually renewed. At the same time a strange thing occurs. It is apparent that growth in thickness would be irregular if the cambium were only present in separate bundles. In order to prevent this a closed ring soon arises, this being formed by means of the division of those parenchymatous cells of the ground tissue which lie between the patches of cambium. The new cells thus formed are added to the cambium.

The cambium ring which has arisen in this manner continues to produce vessels, fibres and parenchyma on the inside, and sieve-tubes, fibres and parenchyma on the outside. The former form a close thick cylinder of tissue, usually known as wood; the latter, on the contrary, form only outside the original vascular bundles. The bast fibres, however, are connected together in firm strands, and on account of this property are used for purposes of tying and similar uses.

In the Coniferæ the secondary wood consists only of tracheïdes, while in shady trees (as in those of our orchards and woods) it has a very complicated structure, producing tracheïdes, fibres, parenchymatous cells and many transitional forms in addition to true vessels. By this means a great variety arises among the different kinds, so that the wood is characteristic of the species. The vessels and tracheïdes serve for the conduction of air and water. Starch is often stored in the parenchymatous and fibrous parts in the winter.

FIG. 5.

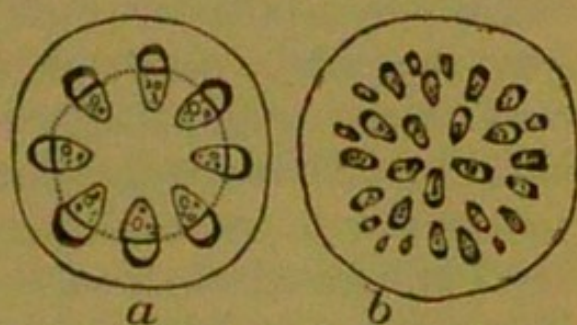


Diagram showing the arrangement of the vascular bundles (in transverse section) in a Dicotyledon, as crowfoot (Fig. 5, *a*), and a Monocotyledon, as sedge or grass (Fig. 5, *b*).

In *a*, the bundles are arranged in a circle, and the cambium arises along the dotted line when growth in thickness begins. In *b*, the bundles are seen to be scattered.

The woody tissue must not be regarded as a perfectly compact cylinder. It is, on the contrary, traversed by plates of cells which run in perpendicular rays from the inside to the outside, so that in transverse section they appear as narrow rays, but in radial section (*i. e.* a section taken in the direction of the radius) they are seen as plates of cells. They are called pith rays because they in some cases radiate outwards from the pith or central part of the ground tissue: this is the case in the original spaces between neighbouring vascular bundles. There are, however, other pith rays, which are shorter and do not reach the pith; these are said to be "secondary" in contradistinction to the others which are "primary." The food-material formed in the leaves passes into the pith rays, and starch is often stored in them.

The activity of the cambium depends naturally on outward circumstances. If the means of nutrition are unfavourable, the living activity which is shown by the division of the cambium is lessened. In our latitudes, however, the period of growth is not continuous, but is interrupted by the approach of the colder season. The withered leaves then fall from the bough, and the tree stretches its bare branches mournfully towards the sky. Even in the interior of the tree the flow of life is checked, as if a deep winter sleep held all the cells under its numbing influence; the division of the cambium is completely stopped, and no increase in thickness can therefore take place. We know, however, that winter does not come suddenly after a warm summer day. He slowly seizes his sceptre, and by means of his milder fore-runner, autumn, he accustoms nature to his own harsher sway. In consequence, the activity of the tree in the course of the autumn gradually ceases, and the divisions of the cambium become less and less. At the same time the cells formed from it become thicker-walled and narrower, and the number of vessels is smaller. The result is that the autumn wood appears closer than that formed earlier in the year. When after the winter rest, a fresh period of growth sets in, awakened by the milder breezes, then the living sap begins

once more to move in the plant, and division takes place in the cells of the cambium with renewed energy. In consequence of this a tissue arises, called the "spring wood," which is of an entirely different character. It has wide thin-walled cells, and is richer in vessels, and is thus of a much looser texture than the "autumn wood."

If we imagine this process repeated year after year, we can understand that when seen in transverse section the wood appears to be composed of concentric rings, a sharp demarcation appearing between the open spring wood and the firm close wood of the previous autumn. These are the well-known "annual rings." The fruitfulness and mode of growth of each year may be inferred from their formation and thickness. Since a ring is added to the wood every year, the age of the tree may be reckoned from the number of annual rings. Growth is not so regular in the region of the bast, especially when the bast fibres arise in a circle. In any case the age of the tree cannot be told by an examination of this part.

As the tree increases every year in thickness, the outer sheath must necessarily undergo a change. The epidermis is formed of corky and elastic cells, and these are able at first to yield to the pressure exercised on them from within; but this condition cannot long continue, and when the bounds of the elasticity of the epidermis are overstepped, the cells are ruptured. The plant must then in some way prevent the stream of sap from finding an outlet at the side.

Before such a catastrophe can take place there arises a layer of meristematic cells, either in the epidermis itself or in the cells which lie beneath it. Thus a complete sheath of close-lying cells is formed in the stem. Although these cells are for the most part rather thin-walled, yet on account of the cuticularisation of their walls they exhibit considerable extensibility, and at the same time prevent the evaporation of water. If this substitution for the epidermis is to be permanent, it must be constantly renewed, and this is effected by means of a special cambium in the bark of the tree. From this

cambium new cork cells are given off on the outside, at the same rate at which the outer cells perish or become ruptured by the increase of the tree in thickness. The sheath of tissue thus formed is called cork, and is of varying size. In the oak the thickness of the layer of cork renders it possible to remove it and use it in various ways, for which its elasticity and impermeability to water render it valuable.

The supplementary cork cambium may arise either in the epidermis itself, or in the deeper layers of the bark. This may lead to a formation of a special kind. If the cork originates in the deeper layers it will cut off all the tissues outside it. The cork prevents water from being brought to these tissues, the natural result being that they slowly perish. The outer layers of tissue (bark) become dried up and gradually fall off with the outer cork. We may distinguish between two chief kinds of bark, scale-bark and ring-bark. The former can be easily seen in pear-trees and pines. In these, small portions of the bark are cut off by the cork and set free in the form of scales. The ring-bark, seen in cherry-trees and birches, is formed, on the contrary, by a closed cork layer which completely surrounds the tree. In consequence of the increase in thickness this layer cracks and comes off, thus making room for a deeper layer of cork.

6. Waste products. Beside the elements in the plant body which we have mentioned above, there are others of minor importance. These are called waste products, and are substances excreted by the plant because they are valueless as regards its further growth. The waste products are usually gums, resins, and ethereal oils. They are by-products of metabolism,¹ but in spite of this have some subordinate function. They thus show the wonderful way in which every part of the plant has its use, while the interdependence of the various parts proves that all is guided by Supreme Wisdom, and is not merely due to chance. Many

¹ By metabolism is meant those "active chemical processes which are inseparably associated with the vital activity of the protoplasm."
(*"Vines," Physiology of Plants*, p. 4.)

If these substances, especially in leaves, seeds, and fruits, are resinous and strong-smelling, and protect the parts in which they are found from being devoured by animals. Others, as certain ethereal oils, serve, on the other hand, to attract animals in order to induce them to scatter the seeds or fruits.

The large masses of resin, which flow from wounds in firs and pines, keep out the air, and thus enable the wounds to heal more effectually. The balsams which cover buds, as in the horse-chestnut, protect the young leaves from animals, and from excessive transpiration. The sticky material on the stems of the viscous Catch-fly acts as a lime-twigg, and catches unwelcome guests before they can enter the flower.

These substances are found stored up in the epidermal, fundamental, or vascular tissue. We may here also include latex, which consists of a milky liquid often containing starch-grains or sugar, and sometimes also resins and gums. It is found in ramifying vessels which either form a network as in *Scorzonera*, or consist of branched cells as in spurge. Resins, gums and tannin are often found in long, thin-walled, overlapping cells, which lie chiefly in the ground tissue. It often happens that between the cells arise intercellular spaces, formed by the separation of the cell-walls, and containing gum and resin. At the same time the passage may be lined by special cells which secrete these waste products, partly producing them at the same time by changes in their own cell-walls.

7. *The life of the tissues.* A great division of labour is seen in the various tissues. One kind serves for nutrition, another for conduction, and a third for storage. One retains water in the plant, and regulates evaporation, another gives it the necessary rigidity. Each thus has its special work. We have already seen that the tissues have the power of growth. This is shown by the increase of the stem in thickness, by the formation of cork, and the cutting off of new cells at the growing point.

The life of the tissues naturally depends on the life of the

energids of their cells. It follows therefore that as the cell without energids is dead, a tissue composed of such cells is dead also. Even dead tissues, however, may have a special use. Many indeed, as bark, and often also pith, are thrown off or re-absorbed. Others, as, for example, the heart-wood of trees, tend to increase rigidity and keep the tree upright.

8. *Structure of leaves and roots.* The stem and root, being both axial organs, are radial in structure; the leaf, on the contrary, is bilateral, and shows a distinction between the upper and lower side. The fully-formed leaf is flat, and consists chiefly of ground tissue. It is covered on both sides by an epidermis, the structure of which has already been described. In the ground tissue of the leaf lies a rich network of vascular bundles, called in this case veins or nerves. These names are both objectionable, as the strands bear very little resemblance to the veins of animals, and none at all to nerves. They are simple vascular bundles, and are incapable of growth in thickness, though often possessing considerable mechanical strength.

The chief strands are specially strong, and serve for the conduction of food, and for the support of the leaf (like the ribs of an umbrella). The finer strands serve, on the other hand, for conduction only, and form a very close network, in order that they may be quite near the places from which material is to be removed. The food-material is found in the remaining ground tissue, which consists of a more or less loose parenchyma, the cells of which contain a large amount of chlorophyll. Two layers can usually be distinguished in the leaf tissue. Under the upper epidermis lie perpendicularly arranged cells (palisade parenchyma). Several palisade cells come into contact with certain somewhat funnel-shaped collecting cells, and these again unite with the loose spongy parenchyma in which are large intercellular spaces. Below this tissue is the lower epidermis with its stomata. The palisade cells are primarily assimilating organs; their elongated shape, perpendicular to the leaf-surface, retards the entrance of the rays of light to the least

possible extent, this being important for the process of assimilation.

This outline sketch of the structure of the leaf will be seen to leave scope for many deviations. Great differences in the external forms of leaves are always connected with variations in the internal structure.

The root, being an axial organ, resembles the shoot rather than the leaf in anatomical structure, although it at the same time exhibits fundamental differences. In the first place the vascular bundles, at least in thin roots, lie in the centre of the ground tissue, leaving no pith; secondly, the vessels and sieve-tubes are not disposed on the same radii, but lie on different radii so that two neighbouring groups of wood-vessels are separated by a group of sieve-tubes. In addition, the first-formed narrow and thick-walled vessels of the primary wood lie to the outside, while the larger vessels of the secondary wood are inside. The number of these groups of protoxylem varies in different roots. The third peculiarity of the root consists in the fact that the central vascular cylinder is surrounded by a simple sheath of thin-walled cells called the pericycle, outside which is the endodermis or bundle-sheath. The latter is often formed of thick-walled cells, by means of which the axial cylinder is made watertight from the outside. The whole of this centrally situated cylinder may be surrounded by a thick layer of cortex. Outside lies the epidermis, which, however, contains no stomata, as these would be useless below the surface of the earth.

The roots are capable of growth in thickness, but since the wood and bast are not arranged in the same way as in the stem, this must necessarily be accompanied by a difference in the method of growth. Division takes place in the cells lying inside the bast and outside the wood. A cambium is thus formed, which has at first a wavy outline, and gives rise to bast on the outside and wood on the inside. The cambium gradually becomes more and more circular, and at last the difference between the stem and the root can scarcely be distinguished. In many cultivated roots, on the

other hand, the thickening does not depend on the formation of wood, but on the increase of the parenchyma, which undergoes great enlargement, and serves for the reception of a great quantity of cell sap, as in turnips, carrots, and beetroots.

If we inquire into the reason of the difference in anatomical structure between the stem and root, we find it lies primarily in the mechanical work performed by each. It is a law of mechanics, that in contrivances which are destined to possess rigidity, the parts on which the work depends are exposed to the greatest stress, and are placed in the periphery, while the strength of the central part is of less importance. On the other hand, in contrivances which are constructed to withstand tension, the mechanical elements are concentrated in the axial portion. Therefore, as may easily be seen, the stem which stands upright must be constructed with a view to resist bending, and for this reason the cells which are mechanically important form a hollow cylinder. On the other hand, the roots which are firmly fixed in the ground are constructed to resist tension, and for this purpose they possess an axial cylinder of great mechanical strength. In the same way, aerial parts of plants, which have to resist a strong pull from below, need a centripetal arrangement of their mechanical cells. This is seen in the stems of erect fruits.

II. The External Organs of Plants.

1. *The work done by the plant and the method of doing it.* The two chief aims of the living plant are the preservation of its own life and of that of the species. All work achieved by plants tends to one or the other of these ends. We may well speak of "work," for the busy life of plants is often such that it might put to shame the work done by many of us. We may take the cherry seedling as an example of this. In the hard stone of a cherry there is a little kernel or seed, from which may spring a cherry tree. If we wish to free the seed from its voluntary prison, we must use a great amount of force. Our fingers have not strength enough to do such simple work as opening a cherry stone, and we shall have to use our teeth. Perhaps even they may not avail, and we are driven to seek some external aid, such as a heavy hammer, in which case our efforts are crowned with success. Let us now, however, examine the small embryo in the seed. Does it dare to measure its puny might against our vaunted strength? Lay it in the earth; expose it to the gentle influences of moisture and spring breezes: how easily it bursts its prison walls, and comes forth triumphantly like a hero! It is now clear that work has been accomplished. Important work is also done when the plant unfolds its leaves in spring, when it takes up water by its roots and carbon dioxide from the air, and works them up into starch. In order to do work, however, implements are needed, and these are found in the organs. If we wish to accomplish any work, or even merely to understand it, we must be thoroughly acquainted with the implements which are necessary for its performance. We will therefore give a rapid survey of the external organs

of plants, at the same time constantly referring to the part they play in their life. In other words, we will seek to understand the use of each organ, and this can only be rightly done when it is considered in the living state.

Before going any further we must correct one error which is likely to occur. The chief interest to an inquirer into the secrets of nature lies in discovering "causality," that is, the reason of various natural phenomena. He will also inquire into the cause which has determined the peculiar characteristics which each plant has acquired in the course of its development. The question of the function of an organ is quite distinct. To take a well-known example: we know that the function of cork is to prevent the evaporation of water from the older stems of plants, but this fact does not explain the origin of cork. We must keep this point quite clear in our minds, especially as people at the present time are often contented with a teleological method of explanation, and believe that it also indicates the cause.

It is not advisable to classify the organs of plants according to their functions, as we are able to do in the case of animals, since they have not a uniform character, as may be seen in the latter. A plant organ serves, however, for several purposes at the same time, to a much greater extent than is the case with animals, and must in consequence be treated of more from a physiological point of view. It is preferable, therefore, to found our classification of plant organs on a purely morphological basis.

A good principle for classification would be to distinguish axial organs from their appendages, but since it is more usual to speak of the root and stem, we will also follow this method. The stem itself is said to be vegetative, when it serves for purposes of nutrition, or sexual, when it serves for propagation. The most important appendages of the stem are the leaves; we may therefore speak of the root, stem, and leaves as the three principal organs.

We have already shown that there is no marked distinction between organs in relation to their function; it is also clear

that any organ can, under certain circumstances, be diverted to quite other uses. Such an effect is always brought about by special external conditions. In any case we can discover in every organ a form which is in the closest relationship with its surroundings. This we may designate as the typical form. If the organ, however, has, through any external influence, forsaken its proper function in order to perform another, we say that it has undergone "metamorphosis." Such an organ has not necessarily become less active. If diminution of activity should, however, occur, the organ is spoken of as a "reduced" form. Finally, it is still to be shown that plants are mounting by an ascending scale towards perfection, and that we can therefore recognise both lower and higher degrees of perfection in the different organs. As we now consider ourselves justified in accepting the law of development throughout the whole organised world, we conceive all lower forms to be "rudimentary."

A typical leaf possesses a flat thin blade and a stalk, the former having green leaf tissue and numerous strands of vascular bundles. A leaf of this structure serves both for purposes of nutrition and of transpiration. Circumstances may, however, arise, in consequence of which these functions may be checked without the plant becoming less highly organised. The leaves may in this case be either partially or entirely used for other purposes; thus leaves which have become metamorphosed into tendrils, may serve to hold a weak stem upright. As an example of deterioration in mode of life, we may take a plant which abandons the position of independence, which rests on its power of obtaining nutrition from water and carbon dioxide, and slavishly associates itself with another plant, living on the produce of its work; in other words, it becomes a "parasite." Parasites become more and more accustomed to a *dolce far niente*, and this is always accompanied in nature by a deterioration of the whole organism. Such parasites lose the chlorophyll, which is so valuable to other plants, their leaves also dwindle and become more or less represented by small scales, which we cannot designate by the name of

leaves. We speak of these as reduced forms. The leaves of the lower plants, which are of very simple structure, because they have only small and simple services to perform for their humble possessors, are said to be "rudimentary." Mosses are plants of this kind, the leaves being one cell thick.

From these examples we may conclude, that there are often many difficulties in determining the true use of an organ by the study of its adult form. The study of the history of development is of great assistance to us in this respect. Organs, like plants, arise from small beginnings. If we therefore follow the development of any organ, we may arrive at important conclusions, which cannot be drawn from the adult form. Since therefore the history of development contributes largely to the comprehension of morphology, we will introduce the latter subject by a general survey of the former.

2. *The development of the organs.* The whole plant, even in the case of the mightiest oak tree, arises from a single minute cell. By frequent divisions a cellular body is produced, and from this again, by the outgrowth of special parts, the rudiments of the first organs. These organs similarly develop further by the repeated division of their cells, and by the growth caused thereby, the adult form being gradually acquired. In the development of such an organ the growth is usually completed by elongation and expansion alone. This is not only the case at the first germination of the seedling, but it also occurs when new parts arise in the adult plant. Under normal conditions, new parts are formed either at the tip of the plant and of its side branches, or in the axils of the leaves. These growths are called "buds," especially when, owing to some interruption in the vegetative period, their activity is quiescent for a time, and reasserts itself at the commencement of a new period. On the other hand, the plant grows more or less continuously at the tips of the shoots and roots.

The extreme tip of the bud, the so-called growing-point, is a rounded mass of delicate cells, which are meristematic or capable of division, and in which life is more active than in

any other part of the plant. Here arise the new lateral organs of the axis, of which the first are the leaves. These are small cellular protuberances, which fold over the growing point and protect it. The leaves which are the furthest from the tip are the most advanced in development. The oldest leaves, aided by various other contrivances, serve very efficaciously for the protection of the buds. It is obvious that these need protection, since in them is centred the whole hope of the plant.

The end of the axis which grows down into the soil, that is to say, the tip of the root, has an essentially different structure. It needs special protection, as it bores its way into the ground between the particles of soil. The growing-point is covered by a sheath, called the root-cap, which fits on the tip like a thimble on the finger. The cells of the root-cap are also renewed by the growing-point. Another essential difference consists in the fact that the lateral organs of the root are not formed from protuberances of superficially placed cells and cell-masses. Lateral roots are present, but these are not of superficial origin. They arise in the interior, on the outside of the vascular cylinder, and are therefore obliged to bore their way through the more or less thick cortex of the root.

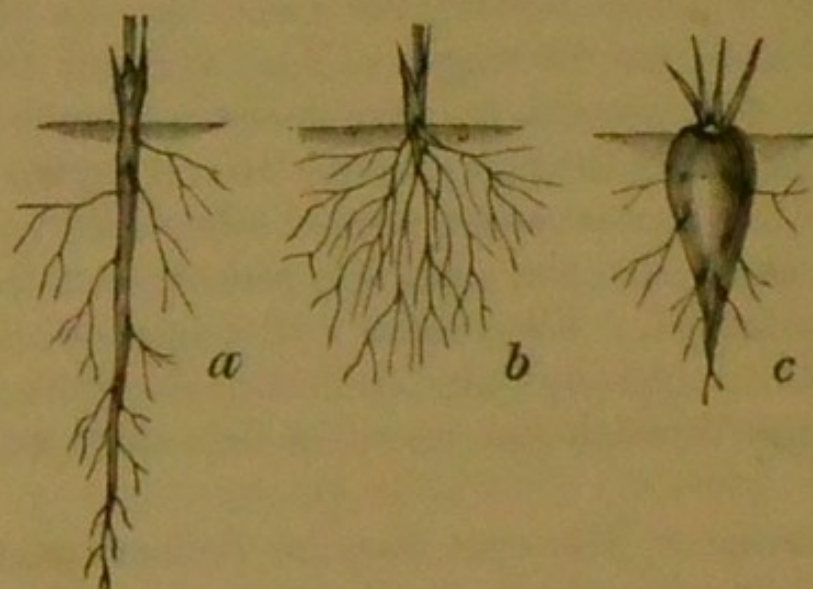
3. *The root.* The root may be defined as that organ, or system of organs, which grows down into the substratum (in most cases the soil). It serves not only to keep the rest of the plant firm, but also to take up part of the nourishment in the form of water, and salts dissolved in it.

Even in the seed we can distinguish the small radicle, which on germination grows and becomes the root. It possesses the singular property of growing vertically downward in the direction of the force of gravity. It soon begins to give rise to lateral roots, which possess the same property, but which grow down in a rather more slanting direction, thus gradually forming in the soil a rich network of roots. Roots are produced in accordance with the needs of the plant; the larger and heavier the plant, the greater the work which the roots must

perform in order to hold it firmly in the ground in opposition to various forces, as for example that of the wind. In plants which have woody aerial shoots we generally find that lignification takes place in the subterranean parts of the strongest roots. The use of such roots consists entirely in holding the plant firmly in the substratum, and in the taking up of water. Many plants attain this object by sending down into the ground a strong main root, called the tap-root. In this case there is no great development of lateral roots. An example of this is the carrot.

Other plants, on the contrary, have a smaller main root, and in order to supply its place they send out strong lateral

FIG. 6.



Various shapes of roots.

a, tap-root; *b*, fibrous root; *c*, succulent root.

roots on every side, and are held by these, as the mast of a ship is held by ropes. The tap-root may be very thick and succulent (as in the cultivated carrot, Fig. 6, *c*).

It often occurs that the radicle of the seedling leaves off growing; in this case there is of course no tap-root, and tufts of lateral roots grow out in its place, and do the work of the main root. Such roots are said to be fibrous, and are found in grasses (Fig. 6, *b*).

Another use of roots is to suck up water from the soil. For this purpose they are provided with root-hairs, which are

long unicellular structures, and are outgrowths of the epidermis. The root-hairs penetrate into the ground, and in order that they may be able to take up moisture more easily, they are very closely connected with the particles of soil. Young roots are on this account covered with a coating of earth, which adheres to the root-hairs. The root-hairs are not found all over the root, but only in a special region behind the growing-point. As the root tip advances in growth, new root-hairs arise on it, and the old ones die off from behind. By this means the absorptive region is always being pushed further into the ground, and is thus brought into contact with fresh particles of soil and enabled to obtain the greatest possible amount of moisture. The number of leaves depends on that of the root-hairs. The more the foliage leaves give off water by transpiration, the greater provision must be made for absorbing water. Thus a quantity of water must be taken in, corresponding to the carbon di-oxide absorbed, in order that both may be used for purposes of nutrition.

The above remarks are closely connected with that property of roots which is known as geotropism, or turning towards the earth. The main root has a tendency to grow vertically down into the soil, and this makes it possible for the roots to penetrate into the substratum. This property has been referred to stimuli of various kinds. The force of gravity draws the root downwards, light drives it away, and moisture has even more influence than either. These stimuli have a rather different effect on the lateral roots, since these do not grow vertically downward, but at an angle with the main root.

The typical root does not undergo any very great metamorphosis. We can imagine that this is more likely to occur when a change takes place in the environment. Many plants possess aerial roots, the chief use of which is to support the plant, either by holding it very close to the surface against which it is growing, as in ivy, or by growing down into the soil from a great height, and on reaching it, serving as props, as in the screw-pine and mangrove. Other aerial roots grow, contrary to custom, up into the air instead of down into the

ground. These serve as respiratory organs, and take in air for the plant. This remarkable property is found in certain mangroves. The lateral roots of many palms have a protective function, being transformed into thorns.

The most remarkable plants, however, are those in which the roots undertake the work of leaves, being ligulate and smooth, containing chlorophyll, and being capable in consequence of carrying on true nutrition.

Water plants often exhibit great metamorphosis in the root. In this case the whole root-system can naturally be simplified; in many cases it is limited to a single root only, as in the well-known Duckweed. In a plant called *Jussieua*, some of the roots are transformed into swimming organs; they produce a spongy tissue containing a great deal of air, which makes the plant lighter, and raises it in the water.

The reduced roots of parasites have the same double use as those of independent plants, but they exhibit an entirely different form, being brought into contact with a substratum of a different nature. They are usually short sucker-like processes, which penetrate into the body of the host, from which they suck the juices, while they serve at the same time to hold the plant firm. This may be plainly seen in the well-known mistletoe by a close examination of the part which joins the host. In other parasites the roots are still further reduced; they may even be represented by a sucker-like disc alone. Such absorptive organs are called "haustoria."

The lower plants have also simple rudimentary roots, which are usually root-hairs springing immediately from the epidermis, but which correspond entirely both in design and function to the roots of the higher plants; these may be seen in mosses and lichens. It may occur, as in some Fungi, that the richly branching root system of the higher plants is exactly imitated by a single cell.

4. **The Stem.** By the term stem we understand that part of the plant which is raised above the substratum, and which bears leaves and flowers. It is usual to consider the axis, leaves, and flowers separately.

The function of the typical axis is seen in its internal structure. Since the axis bears lateral organs, it endeavours to hold itself and its appendages upright. It must therefore be constructed so as to fulfil the mechanical laws of rigidity and flexibility.

(a) *Mechanical structure of the axis.* It is well known that the object of an architect is to make the most of the least possible material. The same plan is carried out in the plant. The cells, which are employed for the construction of the mechanical scaffolding, are the bast fibres, woody fibres and collenchyma. In architecture a beam is made strong enough to resist curvature by strengthening the edge, the part inside having little mechanical importance. A beam of this kind, including both the strengthened periphery and the intervening portion, is called a girder. Such supports occur also in the stems of plants, and since the plant must resist bending on all sides, the supports of the stem must also be arranged all round the edge, *i. e.* in a circle. A girder is formed in the stem by every pair of strands of bast-fibres which lie diametrically opposite to each other, as seen in the transverse section. The connecting part is formed by the other parts of the vascular bundle and by the ground tissue. Thus, for example, in Fig. 5, *a*, each opposite pair of bundles constitutes a single girder. In many cases these single supports, which are placed in a circle, are also mechanically strengthened, either by bundles of isolated bast fibres or by collenchyma. In other cases they cohere laterally, forming a cylindrical tube. Even then strengthening bands may arise directly connecting the cylindrical tube of bast with the epidermis.

A third kind of arrangement occurs when the separate vascular bundles form single girders, being strengthened on each side; this is found chiefly in Monocotyledons. Several circles of concentric girders may be present. In some Monocotyledons the stem is strengthened by a ring of thick-walled fibrous cells beneath the epidermis. We must guard ourselves, however, from considering the structure we have

described as a purely mechanical contrivance. If the epidermis is removed from an upright herbaceous plant, it loses its elasticity to a considerable extent, and if it is dug up in an uninjured condition, and allowed to lie for even a short time exposed to the air, it is said to wither, *i. e.* it loses its elasticity, and its tissues become flaccid. Thence we may conclude that elasticity is the product of several factors; in addition to the internal structure of the axis of the shoot, there is a certain tension exercised by the elastic epidermis, and by the cells which are in a turgid condition.

In this account we have only considered one of the duties which the stem has to fulfil, *i. e.* that of keeping the plant upright. Another function is to provide a passage by which nutritive salts may be taken up and constructive materials carried down. The vascular bundles are of special use in this respect. As we have already seen they contain various cells and vessels which serve for the conduction of watery and albuminous substances.

(b) Development of the axis according to the duration of life. In a young plant the stem is always herbaceous. Short-lived plants retain this character, and it is also found in those in which the aërial parts die off at the close of the vegetative period. In those plants which have a longer duration of life, the axis becomes lignified, in order to be able to withstand the winter. This lignification is connected with the anatomical changes which we have described above, and becomes manifest externally by the formation of cork and bark.

It is usual to distinguish plants as herbs, shrubs and trees, according to the nature of the stem. Plants are called annuals, when their life only lasts during one vegetative period; biennials, when the root and part of the stem survives the winter, and the plant dies at the end of the second year. By perennial plants, we understand those in which the subterranean parts survive the winter, while the aërial herbaceous part sometimes dies down. If the aërial parts survive the winter, they are generally lignified, and the plants are said to be

woody. If they keep their leaves during the winter, they are evergreens; if they lose them in autumn, they are said to be deciduous.

(c) *Branching of the axis.* The points on the stem at which leaves are borne, are more or less thickened, and are called nodes. Certain vascular bundles branch off into the leaves, in order to place them in connection with the conducting channels in the stem. The stem is divided by the nodes into sections, which are called internodes. In addition to the terminal bud, growth also takes place in the stem in the axils of the leaves. At these points arise buds which develop later into branches, and these produce lateral axes of a higher order, by means of which branching is brought about.

Normal lateral shoots are always confined to the axils of leaves. There are, however, adventitious shoots, which may appear at any part of the plant, as on the stems of poplars and willows which have had their shoots cut off. The superabundance of strength still present in the stem impels it to renew itself by some method; since, however, the place where shoots would naturally be formed, *i. e.* the axils of the leaves, are no longer present, they take any way they can find. Such adventitious shoots also arise from buds which are said to be dormant (see page 33). The buds which are formed on the leaves of begonias are adventitious shoots. Other examples are seen in the reproductive shoots which arise on the roots of dandelion and tansy when the aerial parts are destroyed.

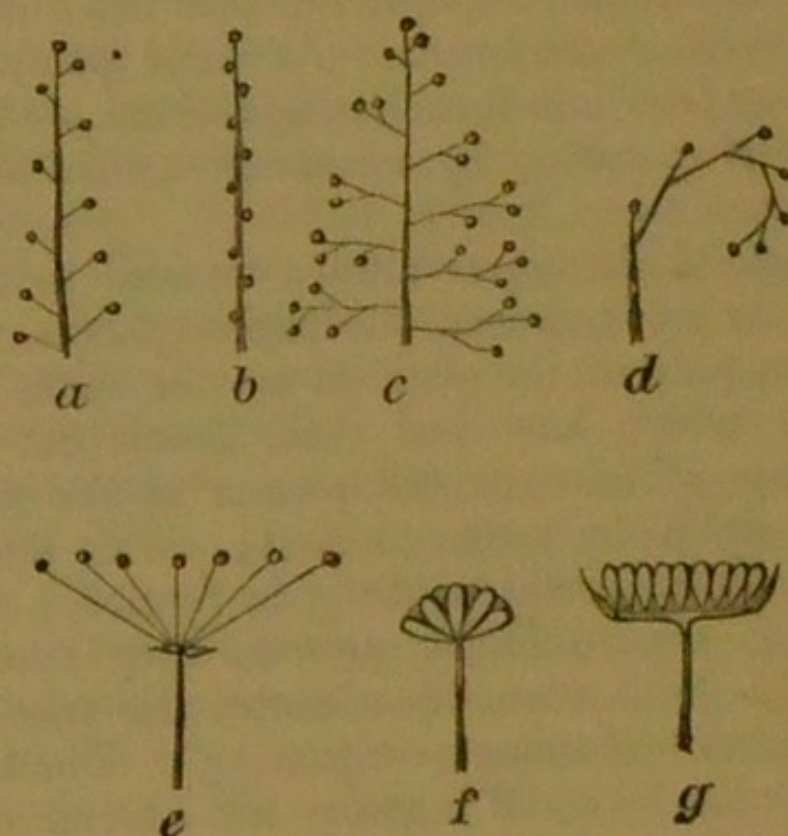
There are many varieties of branching, but we can only give the general outlines of the laws which govern it. The first question of which we must treat is that of the relationship of the development of the main and lateral axes.

In this respect a fundamental difference rests on the fact that the growth of the main axis is either discontinued at the tip, so that lateral axes take its place, or it continues to grow leaving the lateral axes behind. In the first case the branching is dichotomous, or forked, in the second, monopodial. A

monopodium is said to be botryose when in each case the lateral axes are less developed than the main axis, so that the latter can always be recognised; on the other hand, it is said to be cymose, when the side shoots outstrip the main axis in their development.

The various methods of branching are shown with special clearness and variety in the axis of the flowering shoot or inflorescence (Fig. 7). A botryose inflorescence is called a

FIG. 7.



Diagrams of inflorescences.

a, raceme; *b*, spike; *c*, panicle; *d*, helicoid cyme; *e*, umbel; *f g*, capitulum.

raceme when the lateral axes bear flowers without further branching, as in mignonette, or a panicle, when the lateral axes are branched. When the main axis is elongated, and the flowers are sessile, it is called a spike, as in plantain. If a botryose inflorescence has sessile flowers on a *short* axis it is called a capitulum, as in camomile; on the other hand, when the flowers are stalked it is called an umbel, as in carrot. There are also many varieties of panicles.

In cymose branching of the floral axis the difference lies

mainly in the number of lateral flowers below the terminal flower which represents the main shoot. If there is only one, a pseudaxis is formed. When the lateral branches develop on one side only of the pseudaxis, the inflorescence is said to be helicoid, as in *Hemerocallis*; when the lateral branches are developed alternately on opposite sides, it is said to be scorpioid, as in forget-me-not. If several similar side shoots are present we cannot speak of a pseudaxis. When the side shoots are few in number and equal in length, the inflorescence is called a cymose umbel, as in spurge; if there are only two lateral shoots it is a dichasium, as in pink.

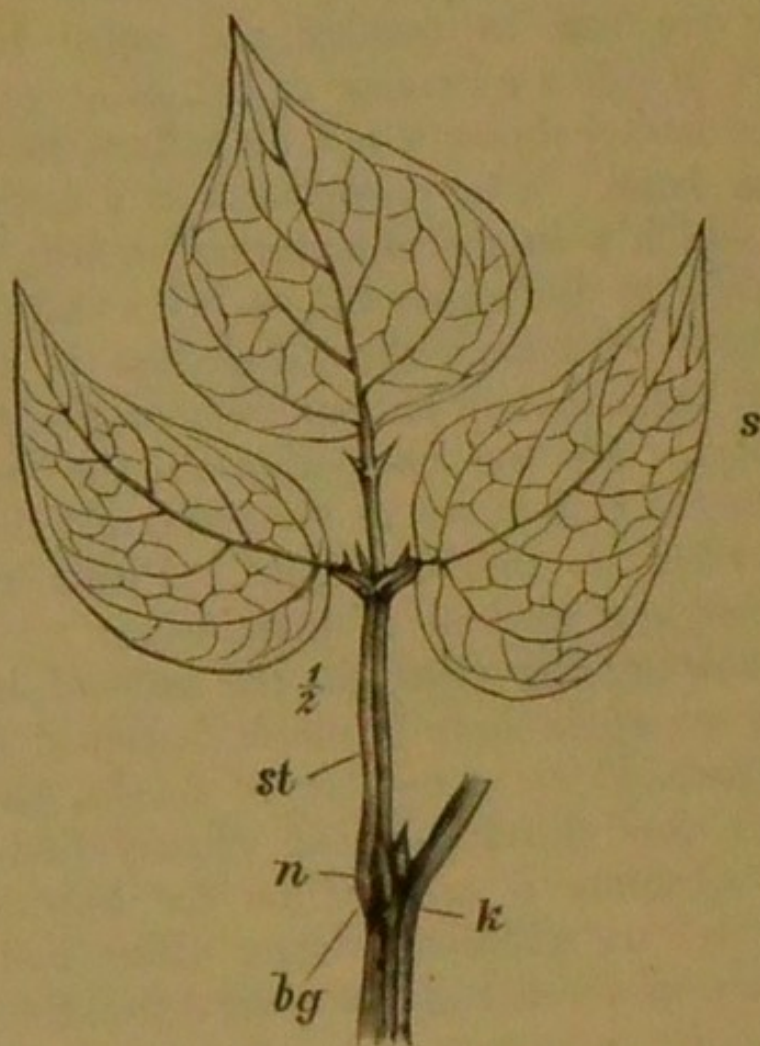
(d) **The bud.** The young stem of a seedling is a very short axis, which is in direct continuation with the radicle at one end, while at the other end it bears two special leaves, the cotyledons. Between the cotyledons is a minute bud, the so-called plumule. The first stem of the plant is called the hypocotyl. By the elongation of the hypocotyl the young seedling is pushed out of the testa, and the first pair of leaves is carried up into the light. Plants exhibit many differences in their method of germination.

Young stems are also found in the buds of lateral shoots. In this case we again have a much shortened axis, but the latter is surrounded by a number of leaves, the inner ones of which are less developed and closely folded together. The whole structure is encased on the outside by special leaves, of which we will speak later. The buds are organs for the renewal of the life of the plant after the interruption of the vegetative period, which may be caused either by drought in deserts and steppes, or by a cold season, as in our latitudes. Buds are therefore characteristic of certain climates.

Two other kinds of buds may here be mentioned, namely, (1) the bulbils or gemmæ of many plants, which separate from the parent plant, and form new ones, and (2) the so-called "dormant" buds. The latter, like other normal buds, arise in the axils of leaves; they disappear, however, before they are able to develop, the bark of the tree growing over them.

They always preserve their capacity for growth, and if the top of the tree in question is removed, together with all the normally-formed buds, the dormant buds break out from their place of concealment, and strive to preserve the life of the tree. The shoots which spring from dormant buds may easily be mistaken for adventitious shoots.

FIG. 8.



Leaf of *Phaseolus multiflorus*, or scarlet runner ($\times \frac{1}{2}$).

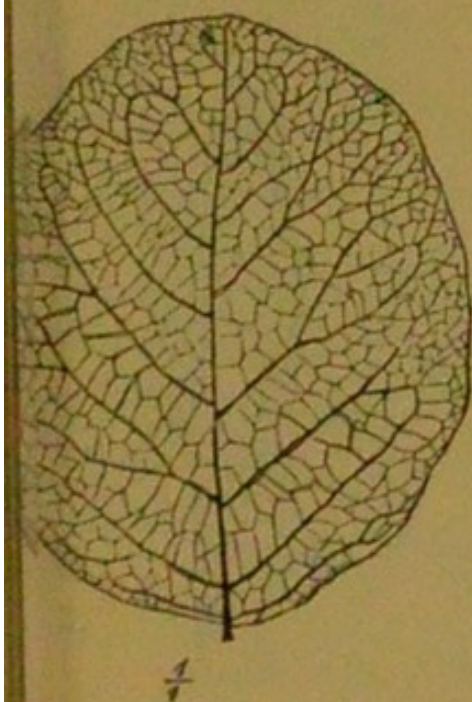
s, blade (with three leaflets); *st*, leaf-stalk; *bg*, leaf-base; *n*, stipules; *k*, node of the stem.

5. The leaf. (a) *The parts of the leaf.* The leaf is the most essential organ borne by the stem, since it serves for nutrition, and thus for the preservation of the individual, this being always the main object in the justifiable egoism of nature. The importance of the leaf in this respect is shown by its anatomical structure, which is specially

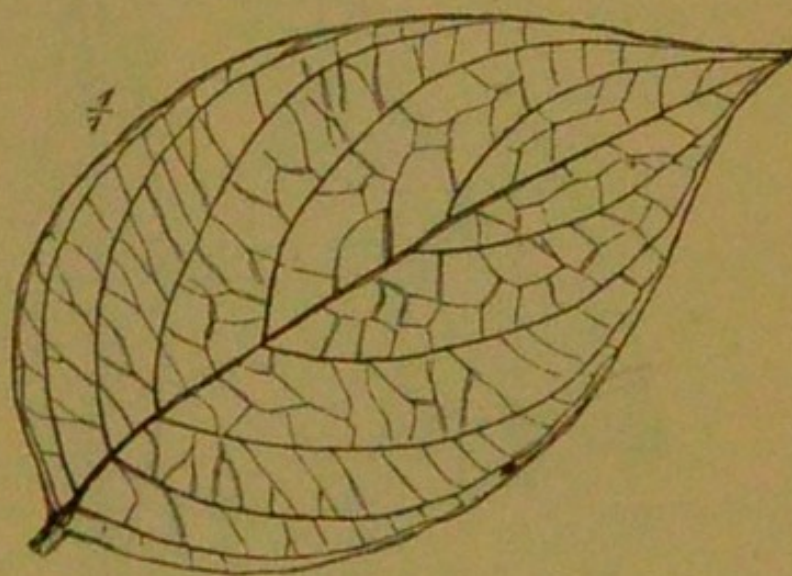
adapted for nutritive purposes, as may be seen in the description already given. A leaf shows externally three different parts—the leaf-base, *i. e.* the part which attaches it to the stem, the petiole or leaf-stalk, and the lamina or blade. The lamina may be prolonged down the petiole, when the latter is said to be winged. If the whole leaf-base becomes broad, so as to embrace the stem, it is described as sheathing; the sheath serves as a covering for the buds, or for the protection and

FIG. 9.

FIG. 10.



of *Symphoricarpos racemosus*,
snowberry.



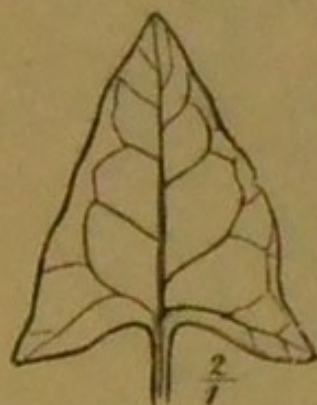
Leaf of *Viburnum spec.*, guelder-
rose.

strengthening of a weak stem, as in grasses. Outgrowths from the leaf-base are called stipules. These may attain a large size, as in pansy and pea, and may even supply the place of the blade. They may sometimes serve to protect the bud, and fall off when it unfolds, or they may be entirely absent.

The use of the petiole or leaf-stalk is to bear the blade, and place it in a favourable position as regards light and air; its development depends therefore entirely on circumstances. It is short, when the leaf can obtain sufficient light and air without it, and long, when the plant lives in a dense confusion

of vegetation, so that every leaf must exert itself to obtain its own rights. A great variety is seen in the transverse section of different leaves. If the leaf has a furrow on the upper surface, this acts in a certain sense as a gutter, and carries the rain from the blade to the stem, down which it passes to the ground. This work of the leaf-stalk is assisted by the presence of grooves on the stem, lines of hairs, wing-like projections, and ridges.

FIG. 11.



Leaf of *Atriplex latifolia*, orache.

FIG. 12.



Leaf of *Nerium oleander*.

FIG. 13.



Leaf of *Convallaria majalis*, lily of the valley.

The lamina or blade consists of a flat green tissue, traversed by a rich network of vascular bundles (see p. 38). Its shape is very various. We speak of leaves being round (Fig. 9), ovate or egg-shaped (Fig. 14), elliptical (Fig. 10), cordate or heart-shaped (Fig. 15), reniform or kidney-shaped, sagittate or arrow-shaped, hastate or spear-shaped, triangular (Fig. 11), lanceolate (Fig. 12), and linear.

The blade is seldom simple and undivided, it has usually a few indentations at the edge. If both the teeth and notches are pointed, the margin is said to be saw-like or "serrate,"

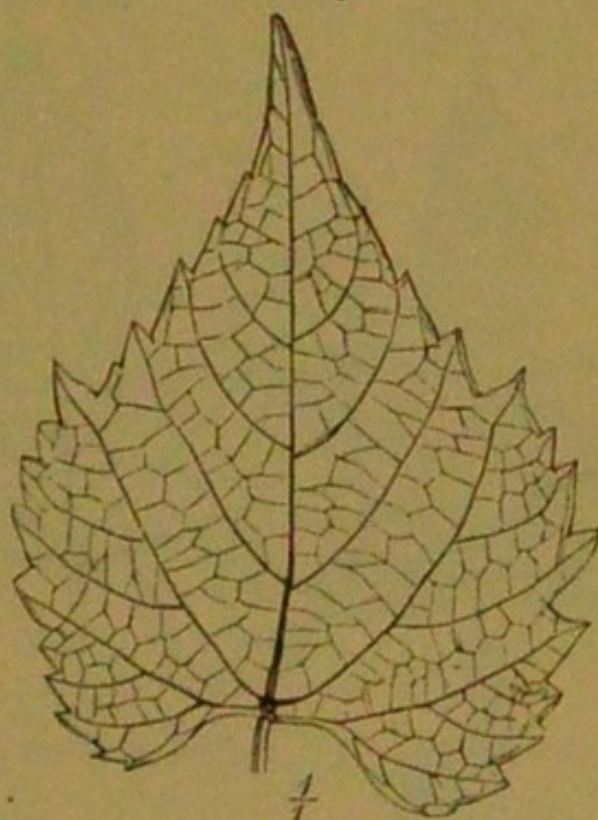
as in rose (Figs. 18 and 15); if the teeth are pointed, and the notches rounded, the leaf is said to be toothed or "dentate," as in dandelion and in *Cyclanthera pedata* (Fig. 17); if the teeth are rounded, and the notches pointed, it is said to be notched or "crenate," as in ground-ivy (Fig. 14); lastly, when both teeth and notches are rounded, it is said to be wavy or "sinuous," as in oak. If the indentations are deeper, the whole leaf is said to be

FIG. 14.



Leaf of *Napeta glechoma*,
or ground-ivy.

FIG. 15.



Leaf of *Vitis vulpina*.

lobed (Fig. 16), or dissected (Fig. 17), according as the indentations are smaller or larger.

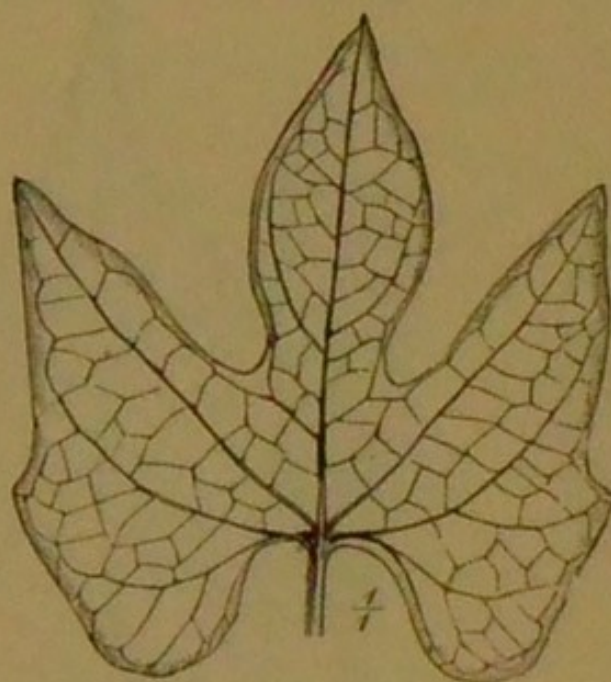
The lobes either radiate from one point like the fingers of a hand, when the leaf is said to be palmate (Fig. 17, the special kind of division represented in this case is called pedate); or they lie laterally on each side of a main axis, like the barbs on the shaft of a feather, when the shape is said to be pinnate.

If the indentations go further, so as to form independent segments, the leaf is said to be compound, and the two kinds,

palmate and pinnate, can again be distinguished. This construction may be repeated several times, so that leaves may be twice or thrice pinnate, etc.

We might make inquiries as to the meaning of these differences in the forms of leaves. This, however, is a point which is not clearly understood. A simple leaf is much exposed to being torn by mechanical forces, as wind, hail, and rain, especially when it is insufficiently protected. We might almost

FIG. 16.

Leaf of *Mina lobata*.

be tempted to say of a compound leaf, that Nature has in this case specially provided a natural tearing of the leaf, in order to prevent the casual tearing by some external force.

(b) **The veins of leaves** have a twofold use. They constitute, in the first place, the necessary conducting channels for the leaf, and form also a firm framework, which keeps the blade spread out, so that it is exposed to the light. The stronger strands are of special service in this respect; but between these is found an extremely fine network of delicate veins, which can often only be distinguished when the leaf is held up to the light. These finer veins traverse the nutritive tissue, and provide the shortest possible route for the passage

of the constructive material from every part to the principal channels of communication in the plant.

The arrangement of the veins again shows the greatest variety. The chief types correspond with those of leaf-division. We might say with greater correctness, that the division of the leaf is based upon the venation. The leaf has either one principal strand, as in snowberry (Fig. 9), or several, as in lily of the valley (Fig. 13). If the leaf is traversed by one principal strand, or midrib, bearing lateral

FIG. 17.

Leaf of *Cyclanthera pedata*.

FIG. 18.

Leaf of *Rosa canina*.
st, stem; n, stipules.

branches, it is said to be pinnately veined (Fig. 9), but if the lateral veins spring from the same point as the midrib, so that they become rather widely separated towards the margin, the leaf is said to be palmately veined (Figs. 16, 17). A good example of the first is seen in the guelder-rose, of the second, in the maple. In both types we can again distinguish four different forms, according to the course of the lateral veins. If these veins pass to the edge of the leaf in a network of fine strands, the venation is said to be

reticulate, as in snowberry (Fig. 9); if they end, on the other hand, in the teeth or indentations of the margin, they are said to be marginal and free, as in *Vitis* (Fig. 15); if they bend round towards the apex, they are said to be arched, as in guelder-rose (Fig. 10); if after bending round they unite with the next vein above, they are said to be looped, as in cherry and orache (Fig. 11).

The presence of several main strands is characteristic of the leaves of Monocotyledons, as grass, lily, and lily of the valley (Fig. 13), and of some Dicotyledons, as plantain. According to the course of the veins we can easily distinguish between apical, curved, and parallel venation.

The study of venation belongs to that province which is specially suitable for the elementary student, to whom it usually affords much pleasure. The leaves may be simply pressed, photographed, or printed from Nature. We might mention also the preparation of skeleton leaves by rubbing them with a brush (the leaves should first be steeped for some time in water and then dried). To take a photograph, the leaf is laid upon ordinary sensitised paper, fastened in a printing frame, and placed in the sun until the image of the leaf comes out rather darker than is necessary. The paper is then toned and fixed in a combined toning and fixing bath, and, lastly, washed and dried. The method of printing from Nature consists in laying the leaf with its lower surface on some finely rubbed oil-paint, and then using it as a stereotype plate, and pressing it on to white paper.

The importance of venation in scientific botany becomes evident, when we consider that the veins of leaves are very constant in their arrangement. Thus, from the impressions of the leaves of plants which flourished in the earlier ages of the earth's history, we can draw conclusions as to the systematic position of the plants in question.

(c) *The arrangement of the leaves* on the shoot axis is either spiral or bilateral. In the first case, by connecting the nodes from which the leaves spring, we obtain a continuous spiral round the stem; in the second case, the

leaves arise in such a way that we can distinguish between the posterior and anterior sides of the axis. These two forms we find, moreover, in the structure of other living organisms. The flower of the white water-lily has a spiral arrangement, but the leaf is bilateral, having an upper and a lower surface, as well as a right and left side. The bilateral arrangement of leaves on the axis is specially seen in plants which creep along the ground. The spiral arrangement of leaves has led to the drawing up of a law (Schimper and Braun) which is more or less firmly established. The lateral difference between the points of insertion of two adjacent leaves, the so-called divergence, is a fraction of the circumference of the axis, and this fraction is constant. Hence the leaves occur on the stem in vertical series, or orthostichies. The number of leaves which occur between two leaves following one another in the same vertical series is also always a definite one. The absolute value of such laws is now, however, questioned. Be it as it may, the position of the leaves is in any case of definite use to the plant.

The regular arrangement of the leaves prevents them from interfering with one another, each being able to get the necessary amount of air and light. This may be proved by examining the leaf-arrangement on any branch.

(d) *The stages in the metamorphosis of the leaf.* If we glance at the successive forms of leaves, which occur both during the life of a single individual, and also in the adult plant when considered from below upwards, we find a regular sequence of forms, as follows—

(1) Seed-leaves or cotyledons; (2) scale-leaves; (3) foliage-leaves; (4) bracts; (5) floral leaves.

The first leaves produced by the plant are called seed-leaves or cotyledons. There is only one seed-leaf in Monocotyledons, and two in Dicotyledons; a larger number is found in the Coniferæ only. The cotyledons are either thick and fleshy, as in bean, or thin and leaf-like, as in beech. When the seedling leaves the husk, and shoots up from the ground, the cotyledons either remain behind in the earth

(pea), or come above the surface (bean). They generally differ in shape from the foliage leaf (the petiole being almost always absent); in some cases, however, they resemble it. Although they are simple in structure, they are at the same time of great importance.

The young seedling, like a nestling, is at first very helpless; it possesses no green leaves, and is not in a condition to gain its own living. It is therefore supplied with food which will support it until its foliage-leaves are sufficiently developed for it to be able to obtain nourishment for itself. This is the use of the thick fleshy seed-leaves, since these contain in their cellular tissues a rich store of starch, from which the seedling can draw its supplies. Thence it comes that seeds, like peas and beans, afford us a valuable food-material. When the cotyledons more nearly resemble foliage-leaves, they spring up out of the earth, become green, and carry on the work of nutrition until the true foliage-leaves take their place (beech). In other plants the seed contains a special nutritive tissue (endosperm). The seed-leaves in this case often have a widely different function, and act as absorbent organs for the starch (grasses and palms).

The scale-leaves are either found on subterranean stems (see p. 46), or they occur at the base of a new aërial shoot, when they have the form of simple scales, and serve to protect the bud. At the same time they are clearly connected with the ordinary foliage-leaves, as is seen by a study of their development. A rudimentary or primordial leaf soon separates into the leaf-base, and a part which we may call the upper leaf; from the former arise the stipules, and from the latter the blade. If a petiole be present, it becomes interposed later, by intercalary growth between the upper leaf and the leaf-base. The general plan of a scale-leaf is exactly similar to that of a foliage-leaf. The difference which arises later is caused by the fact, that the growth of the upper leaf is checked, and the leaf-base only develops, and forms a scale-leaf. This is shown by the frequent occurrence of small reduced leaf-blades at the apex of fully formed scale-leaves; these blades

may under certain circumstances be induced to develop further.

The shape of the foliage-leaves has been already described. Their development may vary very much in a single plant. The leaves which first succeed the cotyledons do not always assume the form which is typical of the adult plant; this being specially the case in plants with compound leaves. These leaves (primary leaves) are usually simple at first, and only gradually attain the typical form. Two forms of leaves are sometimes found in the same plant (heterophylly). Some species of Eucalyptus have at first square branches bearing opposite oval leaves, which are placed horizontally; later on they have round branches, on which are borne alternate needle-shaped leaves, which are placed vertically on edge. Water plants also afford a good example of heterophylly. Thus the water-crowfoot has submerged leaves which are finely divided, and floating leaves, which, with their very slightly lobed blades, lie upon the surface of the water.

As the foliage-leaves approach the tip of the stem, they often decline both in size and general development, and gradually pass into the bracts. These are similar to the scale-leaves, both being checked in their development. They occur as small, insignificant, scale-like leaves close to the flowers, and their use is difficult to understand. On the other hand, they may undergo special changes and become large and brightly coloured, supplementing the work of the flower.

On account of the differences in the functions of these floral leaves they will be specially described later.

We may conclude from what has been said above that the forms of leaves undergo variation from below upwards, and this may be expressed by the term "metamorphosis." This word must naturally be understood in another sense than that which it has when used in connection with animals, as in the Amphibia or insects. In the case of leaves it is not one and the same form which undergoes transformation.

6. *The various forms of shoots.* The character of the stem depends essentially on the form of the leaf. We

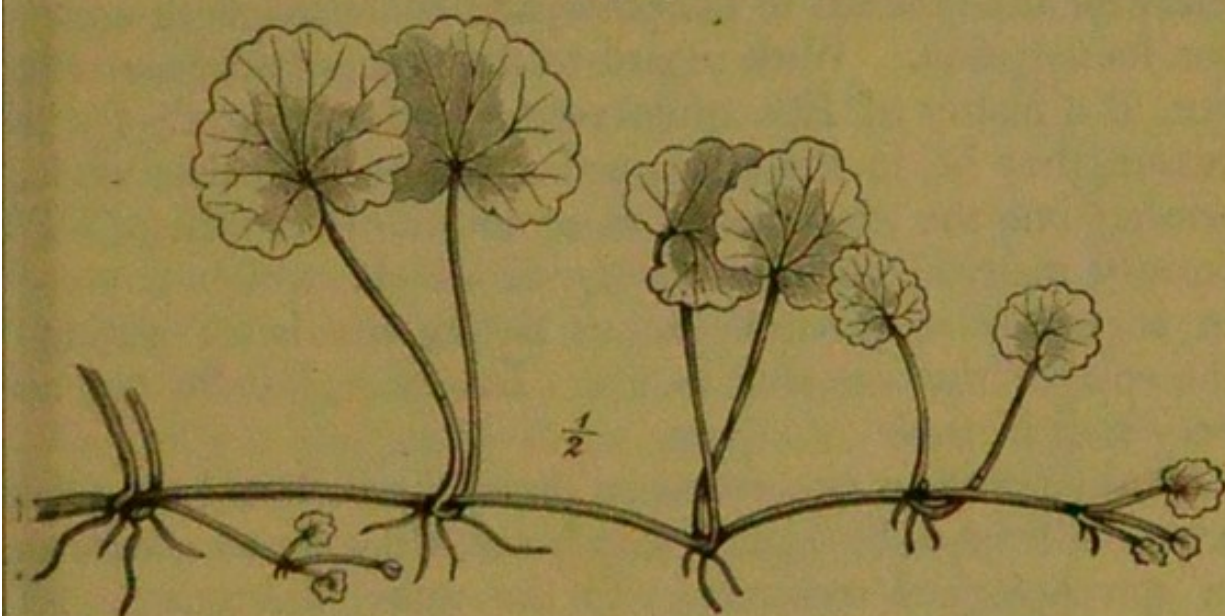
will therefore now discuss the different varieties of shoots, since we have already learnt something of the axis and its appendages.

(a) **Normal forms of shoots.** The response of the normal shoot with regard to geotropism, is exactly opposite to that of the root, *i.e.* it does not grow vertically down into the earth, but away from it. This property, which has the effect of carrying the leaves and flowers up into the light and air, is aided by the mechanical structure of the axis. If the axis is not capable in itself of holding the shoot upright, it must either seek some support or relinquish the attempt, and this naturally depends on the nature of the surroundings. If a plant which is growing in the close entanglement of a hedge, or the underwood, did not strive to attain an upright position it would be doomed to destruction. Other plants would deprive it of so much light and air, that it would not be able to obtain sufficient for its own support. If, on the other hand, the plant is not surrounded by taller plants, and the light and air can have free access to it, the upright position is no longer necessary. We therefore see, in open sandy wastes, roadsides, and similar places, a number of small plants flourishing, although they are quite close to the ground. It is worthy of remark, that the same species of plant is able to change its habit in accordance with its surroundings.

Creeping stems may attain special importance. There are plants which bear lateral shoots with long thin axes. These creep a long way over the ground, and are chiefly distinguished from the main axis by bearing only small scale-leaves. After a time a young plant with normal leaves develops from the terminal bud; it bears roots, and finally becomes independent. Such a shoot is called a "runner"; it is obviously a reproductive shoot and serves for the purpose of propagation. The young plant is pushed a long way off the mother plant, by means of the long thin shoot. It is in this way brought into contact with fresh soil, and the shoots do not interfere with each other's growth. The plant

thus possesses a power of movement, which must be of great advantage to it. This habit is chiefly seen when the seeds do not ripen to perfection, as in plants growing in hedges, and on banks, and walls. The latter stretch their runners over the stones, and the young plants find cracks full of soil in which they can take root. As examples of such plants we might name creeping cinquefoil, strawberry, creeping bugle, etc. Many plants possess subterranean reproductive shoots, as grasses, sedges, and shave-grass.

FIG. 19



Glechoma hederacea, ground-ivy. Runner, taking root at the nodes. (Half.)

A very common form of shoot is the rootstock or rhizome (lily of the valley). We understand by this, a shoot which has lost its power of negative geotropism, or which is compelled by geotropism of a different kind to avoid light and air, and grow horizontally under the surface of the soil. When the aerial parts of a plant die down in autumn, the rhizome survives the winter. It is grey, white, or brown in colour, and is provided with pale scale leaves. If the rhizome is to give rise to new shoots in the spring, it is necessary that buds should be present, and since the young shoot which develops from the bud is at first incapable of self-nutrition, the rhizome must in itself contain reserve food-material. As the rhizome is always growing at the tip, and forming new

shoots, the latter are brought into contact with fresh portions of soil, as in the case of runners. The plant thus continues to find a sufficient quantity of nutritive salts.

(b) *Metamorphosed shoots.* Many shoots undergo a change both in structure and function, and this change is usually designated as metamorphosis.

Among the perennial organs of shrubs we may include two other forms of shoots, namely, tubers and bulbs, and these must both possess three definite qualities. They must be so constructed that they can withstand frost; they must possess buds for the renewal of the plant, and contain reserve material for its nutrition. With regard to the first point, these organs are, as a matter of fact, often very sensitive to frost; for this reason they lie in the earth, and are protected by it, while in winter-time the snow serves as an additional covering. The reserve material consists chiefly of starch, which is present in an extensive parenchymatous tissue, the latter arising at the cost of the vascular tissue. Tubers and bulbs are also very rich in water.

Although these two forms of shoot, the bulb and the tuber, are alike from a biological standpoint, they are very different in morphological structure. In the tuber, the axis is very much developed, while the leaves are reduced; in the bulb, on the other hand, the axis is reduced, while the leaves become thick and succulent. The potato may be given as an example of a typical and well-known tuber. It exhibits lumps of an irregular, roundish shape, which consist of a white substance (parenchymatous tissue) containing starch and water, and covered by a brown rind. The potato tuber has pit-like marks, in which are little buds in the axils of minute scales; these marks are commonly called "eyes." The scales are the leaves; they, as well as the buds, are a proof that the tuber is really a shoot. The onion is a good example of a bulb. It consists of a broad but much shortened axis, forming a sort of plate, from which spring the leaves; the latter are present in great numbers, the inner ones being much thickened. The outer ones are thinner and more

scaly, and, as in the case of the scales of the tuber, must be considered as scale-leaves.

The phenomenon of succulence leads to a special kind of metamorphosis in the shoot. Plants living in districts which are subject to continuous or temporary drought must possess contrivances to prevent dessication. This danger does not arise from want of water, but from excessively rapid transpiration. The plant protects itself against want of water by providing places for its storage, which consist of considerable quantities of large-celled parenchymatous tissue. This is always accompanied by a thickening of the organ in question, which is then said to be succulent. The organs of transpiration are the leaves. If it is necessary for the plant to protect itself from loss of water, it is necessary that the formation of leaves should be reduced, either by the diminution of the leaf-surface, or by the presence of fewer stomata.

There are also many plants in which the leaf-surface is reduced, without any provision being made for water-storage. An example of this is asparagus, in which the leaves are small scales, while the branches are thin and needle-like (Fig. 20).

Water is stored either in the axis or in the leaves. The enlarged succulent shoots present a very varied appearance. If the axis is much thickened, the leaves are generally smaller, and may even disappear entirely; if the leaves are thickened, the axis is generally reduced in size.

To the first type of succulent plants belong the wonderful members of the cactus family found in the American desert- and steppe-flora (Fig. 21).

There is an extraordinary variety in the formation of the shoot in cacti; they may form high columns and candelabra,

FIG. 20.

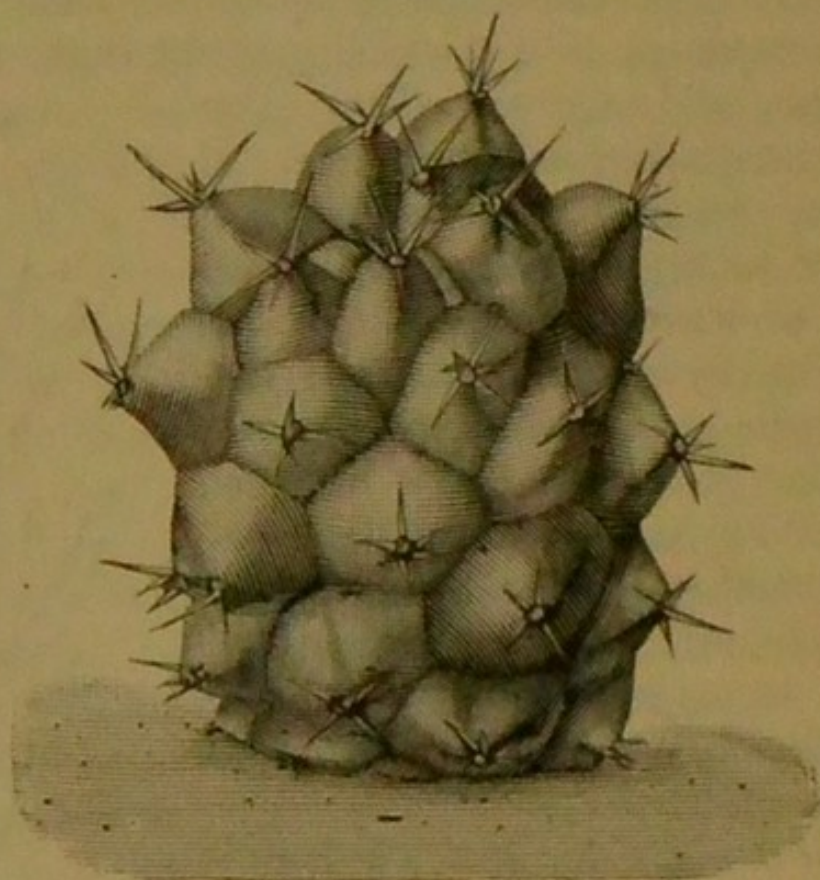


Asparagus officinalis.
Branched stem.

b, scale-leaves; *z*, branches
in the axils of the
leaves. (Life-size.)

or they may be flat, round, barrel-shaped, or covered with protuberances. They are often provided with prickles, which frequently attain a considerable size. These offer a threatening aspect to the beholder, and act as a defence to the plant. Cacti grow in deserts and steppes, and hide in their tissues a store of water; they would therefore be exposed to the attacks of thirsty animals, which are, however, kept off by the prickles. Such thickened shoots are almost

FIG. 21.



Mammillaria centricirrha; cactus with thickened axis and reduced leaves.
(Life-size.)

always green, and, therefore, take the place of the aborted leaves in carrying on the work of nutrition.

This leads us to another form of metamorphosis in the shoot. If the leaves are reduced, it is possible that the plant may be unable to obtain sufficient nourishment. We find, then, the strange device of the shoot itself, not only performing the functions of a leaf, but even becoming leaf-like in form. This is seen in many cacti, as, for example, the prickly pear, in which leaf-like shoots grow out of one another.

We must not fall into the common error of mistaking the shoots for leaves.

Leaf-like shoots are often called cladodia. Plants possessing them are found in dry and sandy districts even in our latitudes. There are, for instance, species of *Genista*, in which the leaves are undeveloped, and the stem undergoes a leaf-like expansion. Another example is seen in the little duck-weed, which covers the broad surface of stagnant water with its bright green. The whole shoot consists in this case of a leaf-like structure, and is usually regarded, incorrectly, as a leaf; it consists of single or branching cladodia.

In the second kind of succulent plants, the leaves undergo greater development, and store up water. A few forms of this kind occur in the order *Crassulaceæ*, e.g. *Sedum* and houseleek. In these the stem is generally stunted, as in the American agaves, which are well protected by the defensive prickles at the tip and edge of the leaves.

Some shoots undergo special metamorphosis for the sake of protecting the plant; these are called thorns. In thorns leaf-formation is also suppressed, the leaves being either absent or very minute; the tip of the shoot soon ceases to grow, and the tissue of the whole structure becomes lignified. Thorns are seen in the hawthorn (Fig. 22) and the sloe. In *tragacanth*, the petioles of fallen leaves become hard and thorny, while in many cases stipules, or even whole leaves, are changed into thorns (*Berberis*).

Those protective organs of plants, which are called prickles, are not formed from shoots, but are appendages or outgrowths. They are found either on the axis or on the leaves. They are not connected with the internal tissues, and are only external structures, which can be easily removed. The protective organs

FIG. 22.



Crataegus oxyacantha, hawthorn; thorn formed from a metamorphosed shoot. (Life-size.)

of the rose are not thorns, as the proverb tells us, but prickles.

We must finally consider a group of metamorphosed shoots, called climbing shoots. We have already seen that the shoot is not always capable of standing upright. When such plants grow in open places, they simply lie upon the ground, and are yet able to obtain sufficient light and air. The case is different, however, when they grow in the close entanglement of a hedge, a wood, or even of a field, for then a fight for light and air naturally arises. We can see this varied behaviour in the same plant when it grows either in or at the edge of a corn-field. The convolvulus is a small plant with a weak stem, and is almost invariably found in corn-fields. By the side of the road, or at the edge of the corn-field, it finds sufficient light, air, and space; the shoots then simply lie on the ground, and creep along. If we look, however, at plants which are growing in the corn, we see that in this case they use the stalks near them as a support, in order to raise themselves up into the light.

The supports used by climbing plants may be either dead or living; they may climb by upright palings, by the stems of neighbouring plants, by the trunks of trees, by walls and rocks, or by anything which is supplied for the purpose. The plant serving as a support would be unharmed by the climber if it were not that it is often prevented from increasing in thickness. This after a time kills the plant.

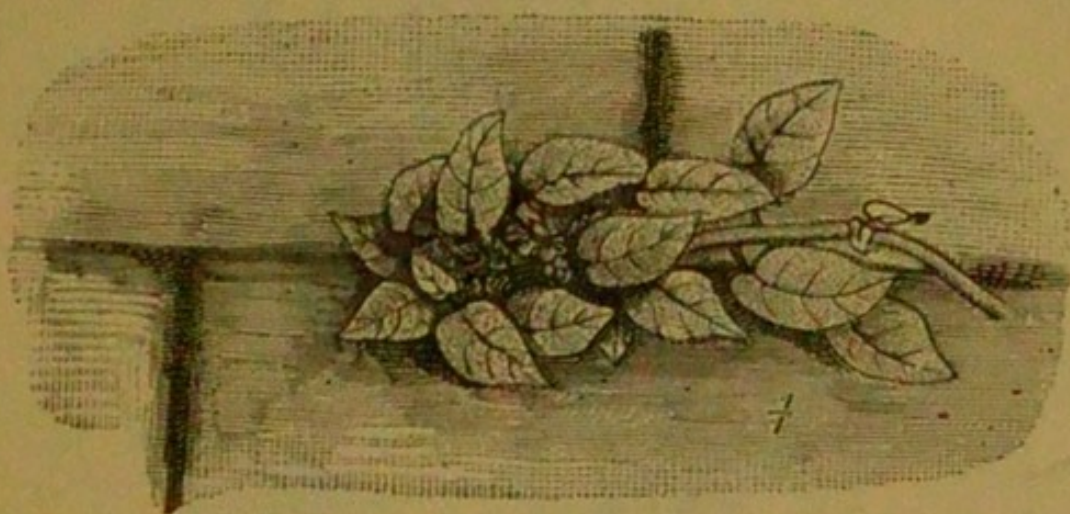
Different organs may be used by the plant for the purpose of climbing. The stem has the power of twining round a support. The growing tip of such "twining plants" has a tendency to curl in a spiral; it thus seeks, as it were, for a support, and if it finds one, curls round it, twining in most cases to the left, but in some to the right. If the stem finds no support the tip often curls of itself; but as it cannot grow without such aid, development ultimately stops. The bean twines to the left, and the hop to the right.

In other cases the shoots possess aerial roots, with which they cling to the surface, which is usually more or less rough.

Weak shoots often make use of epidermal hairs, hooks, and prickles, with which to cling firmly to other plants (cleavers, and wall-pellitory, Fig. 23).

The case is less simple when the whole or part of the shoot is metamorphosed into a special organ, as in tendrill-climbers. A tendril is a thin, thread-like organ, which, like a twining stem, is capable of curling round a support. In some cases entire side-shoots become thin tendrils, these being often also branched (vine and white bryony, Fig. 24).

FIG. 23.



Parietaria diffusa, wall-pellitory. Shoot, clinging to the wall by means of hairs.

The tips of the tendrils either twine, or have adhesive discs. The duty of attaching the shoot to a support may be undertaken by the leaf-stalk (*Tropæolum*). Sometimes the leaf, or part of it (as in stipules), is turned into tendrils. This occurs chiefly in compound leaves, the work being then divided, so that some leaflets serve for nutrition, while others at the tip of the leaf serve to support the plant (pea).

The leaves may also perform the function of roots. This occurs in many water-plants, which possess no true roots. Thus we find a remarkable division of labour in the water-lily, *Salvinia* (belonging to the *Hydropterideæ*), in which some of the leaves carry on the work of nutrition, while others are modified as floating organs. The leaves are made to float by the formation of a tissue which contains

air-chambers, and which is on that account specifically lighter than water. The remaining leaves are finely divided, submerged, root-like organs.

A very attractive form of leaf-metamorphosis is seen in the "insectivorous plants," in which the leaves are adapted for catching insects. The simplest example is offered by our native sun-dew (*Drosera*), which grows in bogs and

FIG. 24.



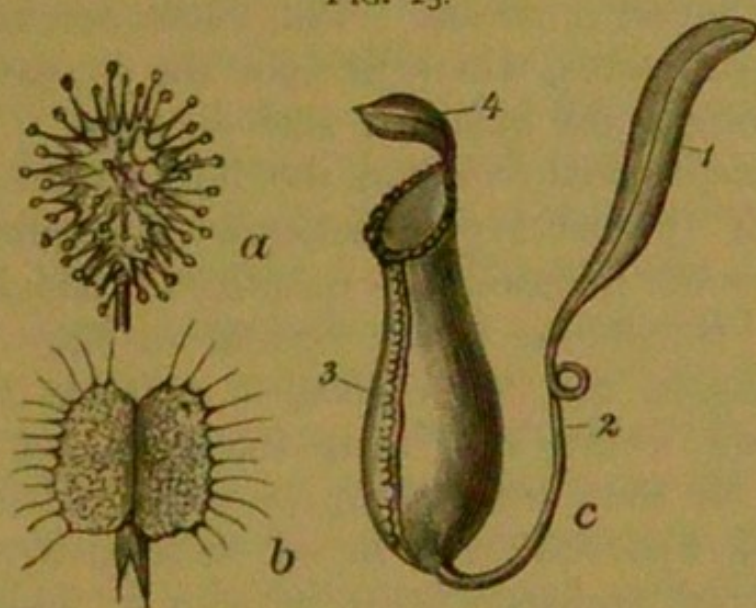
Bryonia dioica, white bryony. Shoot, with tendrils. (Half.)

swampy ground. It has round petiolate leaves, which are covered with long club-shaped glandular hairs, bearing at their tips a viscid secretion (Fig. 25, *a*). The touch of a small body, as an insect, on the leaf, causes a greater discharge of the sticky secretion; at the same time the hairs curve over the insect, holding it firmly, while it is suffocated by the closing of the apertures of the tracheæ by the sticky liquid. It is a remarkable fact, that although inorganic bodies, as sand, promote the increase of the glandular secretion, they do not cause any movement of the hairs. The dead insect is now digested by the leaf of the plant, all

nutritive parts are dissolved, and nothing remains but the indigestible chitinous parts, which finally fall off. As in other insectivorous plants, the digestion of animal food is merely supplementary to normal nutrition, which goes on at the same time.

Drosophyllum, a plant growing in sandy places in the Mediterranean region (Morocco, Portugal), has narrow linear leaves which are covered with sticky glandular hairs. Small insects remain hanging on the hairs, which are used as fly-traps. The Venus' fly-trap (*Dionæa*) of North America

FIG. 25.



Leaves of insectivorous plants.

a, *Drosera*, natural size; *b*, *Dionæa*, reduced; *c*, *Nepenthes*.
1. leaf-like petiole; 2. tendril; 3. pitcher; 4. lid, reduced.

possesses metamorphosed leaf-stalks, which carry on regular nutrition in the place of leaves, and a blade which is capable of closing together down the middle line, and which bears teeth at the edge, and red glandular hairs upon its surface. The two halves of the blade close suddenly if touched, the teeth interlock at the edges, and the entrapped insect is doomed to death.

A second group of insectivorous plants possesses leaves with bladders, which serve as a trap for animals. The rootless bladder-wort (*Utricularia*), which is found in our inland waters, has leaves which are blown out like small retorts; at

the entrance is an elastic lid, which is like a valve, and yields only to pressure from the outside. The opening is also surrounded by bristles, so that the whole structure recalls the small Crustacean, *Daphne*, which abounds in our pools and ditches. The interior of the bladder is lined by absorptive cells. If small creatures enter the bladder, it is impossible for them to escape alive; they are either suffocated or starved, and when they decay, their remains are absorbed by the plant in a way which is not yet thoroughly understood.

The pitcher-plants, belonging to the genera *Sarracenia* and *Nepenthes*, deserve special mention. *Sarracenia* is a marsh-plant of North-east America. The leaves develop as strange pitcher-like structures, which lie upon the ground, and curve upwards, having at the mouth a shell-like lid. The pitcher possesses a longitudinal flap, and the lid secretes honey; the inner wall of the pitcher is smooth. The funnel-shaped mouth catches the rain-water, a quantity of which collects in the pitcher. Small insects are enticed in large numbers to ascend the flap to the honey-glands; on their arrival there they fall down inside, and being unable to get out of the pitcher, they are soon drowned in the water. It may be that their death is hastened by a liquid secreted by the pitcher. The number of animals caught in such a pitcher is often very great. Some pitcher-plants seem to display a cunning which is almost revolting; some even secrete honey on the flap which runs up the side of the pitcher, others have bright colours, as well as honey-glands, on the lid, and thus, with all the means at their disposal, they entice the unhappy insects to sure destruction.

The arrangements for catching insects are the same in *Nepenthes* as in *Sarracenia*. These plants, which belong to the tropical vegetation of the marshes of the primeval forest, often climb up the trees like lianes. The leaf shows a vast capacity for work, being at the same time the organ for nutrition, climbing, and capturing insects. The lower part (petiole) is leaf-like, then follows a tendril (the second part of the leaf-stalk), then a pitcher (which is also considered

very many to be yet another part of the leaf-stalk), and lastly a leaf-like lid (the blade). On the pitcher are found treacherous path-finders and gay colours, which entice con-
 sidering insects. The latter are fed with honey even on the very border of the assassin's den, but after this farewell revel they generally slip upon the smooth edge, and are hurled, like lost souls, down into the abyss.

(c) **Reduced shoots.** Parasites afford a good example of reduction in organs. Among them occur some of the few cases in which we can speak of extensive and permanent variation, caused by a changed mode of life. This is not to be wondered at, for the assumption of a parasitic habit signifies the perversion of the nature of the plant. A plant is only distinguished from an animal by the fact that it is capable of independent nutrition from inorganic material; the abandonment of this method of nutrition must of necessity be connected with an important modification of organisation.

Many different stages occur in the parasitic mode of life. There are parasites in which the usual method of plant nutrition is still to a great extent retained, but which incline towards parasitism, although they show scarcely any reduction of the axis and leaves. Since such parasites take from their hosts only water and some salts, the reduction affects the roots alone. Examples of this are the Mistletoe, mentioned above, and the Yellow Rattle, both of these being plants in which the parasitic nature is not easily recognised.

To a second group belongs Dodder (*Cuscuta*), a plant which twines round other plants (flax, hemp, stinging-nettles, clover), and which possesses no roots of its own. It adheres to its host instead by means of aerial roots, which are metamorphosed into sucking-organs, and absorb the useful juices; it does, however, most harm by strangling its host, especially when it is present in great quantities.

In Dodder the reduction of the leaf-surface has taken place very thoroughly; the leaves are only small scales, and the whole plant is not green, but of a reddish-yellow colour. This occurs still more in many orchids, and to an even

greater extent in *Monotropa* and *Orobanche*, which, in consequence of the nature of the method of nutrition, caused by the absence of green colour, have undergone complete metamorphosis, and adapted themselves to a parasitic mode of life. These plants are, however, not always murderers and robbers. Many of them live on the mould and humus of the soil of the forest; others, on the other hand, adhere by their roots to the roots of other plants, and suck up from them their living juices.

In many tropical parasites the body is a more or less shapeless mass, bearing small scales in the place of leaves. It is either sunk in the body of the host or supported on it, and consists almost entirely of a large flower. It is worthy of note that the flowers of these parasites are not reduced; some of them even have the largest flowers in existence, as the *Rafflesia Arnoldi*. The flowers of this plant resemble large cabbages when in bud, and when opened they have a diameter of one metre; at the same time they possess a very unpleasant odour, resembling that of putrefaction. These extraordinary flowers were discovered in Sumatra in the year 1818; but no one has succeeded in finding them anywhere else.

(d) ***Rudimentary shoots.*** The forms of shoots described above occur in the higher plants, which are usually designated as the seed-bearing plants, or *Phanerogams*. Among the seedless plants (*Cryptogams*) are found a whole series of shoots showing a progressive order of development.

When the plant-body consists of a single cell, as in many *Algæ* and *Fungi*, it may be considered as a shoot of the simplest form. No division of labour takes place in this case; all the work is done by the whole cell. Special growth may however take place in the cell, even in the lowest forms of unicellular plants, the two ends of the cell becoming differentiated during the progress of development. The lower end may attach itself to the substratum, and may from the physiological standpoint be regarded as a root; the upper end may be green and grow upwards, corresponding to

the aërial shoot of the higher plants. Such a case is found both among the Algæ and the Fungi (Mucor).

The next step in the development of the shoot is the formation of a single flat layer of cells, which may be either a simple body displaying no division of labour, or may on the other hand be much more highly differentiated. The shoot considered apart from the sexual organs, which even in this stage play an important part, only shows a very slight advance in its form, seen chiefly in the structure of the appendages, *i.e.* the leaves. These first appear in the highest Algæ (Characeæ); but are absent in the Fungi, in which they are not required.

The next stage is found in mosses, and is distinguished by the differentiation of the shoot into the axis and leaf. The leaves are sometimes represented only by scales as in the liverworts. Since, however, the plant is impressed with the necessity of possessing the means of nutrition, the axis takes the characteristic form of a flat shoot, or cladode, in which the leaves occur as scales on the under surface. In the higher mosses the axis becomes more stem-like, and possesses leaves of the simplest kind. Vascular bundles are lacking in these small plants. This is owing to the absence of true roots, the place of which is supplied by root hairs.

In the next stage, represented by the ferns, the axis and leaf undergo considerable further development both with regard to their anatomy and morphology. Thus even in the cryptogams we meet with forms which serve different physiological ends.

The shoots of Phanerogams are still more highly developed; their varieties have, however, been already sufficiently explained.

7. Hairlike structures. We will now briefly consider those forms which are simple epidermal outgrowths, and are generally called hairs.

These may occur on all the organs of plants. In roots only one kind is found, namely root-hairs. These arise on the

outside of the growing root as single cells, and serve to take up water from the soil.

The hairs which are found on the shoot and leaves are, on the contrary, very various; they may be either simple tubercles, or long or short threads; sometimes they are thickened at the tip like a club, in other cases they are branched or stellate. They cover the leaf in one case with rough hairs, or in another with a thick woolly blanket, thus protecting the plant from desiccation and excessive radiation. They may be dry scales (ferns), sticky hairs, protecting the bud-scales of trees from insects and damp by means of their gummy secretion (horse-chestnut), glandular hairs, stinging hairs, capturing hairs, or the digestive hairs of insectivorous plants.

Prickles may be included under the term emergences, or epidermal structures in whose formation deeper layers of tissue take part, but into which vascular bundles do not enter. They are therefore easily separated from the organ which bears them, and by this means are readily distinguished from thorns. It will be readily understood that they serve to protect the plant from the attacks of animals.

8. *The flowering shoot.* All these shoots serve for the purpose of nutrition, and in a subordinate manner for protecting the plant, holding it firm, and catching insects; they are thus of use for the preservation of the individual. These selfish aims are not, however, the only ones which govern the plant world. We find as a secondary object one which must be quite indifferent to the plant as an individual, *i. e.* the preservation of the species, the giving rise to a new generation, which, after the plant itself has perished, shall occupy its place in life. This is known as reproduction.

In order to fulfil this purpose the plant-body forms special shoots, called flowers.

The flowering shoot is either found at the tip of the vegetative shoot and its lateral branches, or it forms special shoots from buds which arise in the leaf axils, and which can be recognised at a very early stage of development. There

is great diversity in the number of the flowers. Some plants are content with only a single flower, others have more, while others again produce a great quantity, in which the number is in inverse proportion to the size. It often happens that a whole shoot-system with many axillary branches serves the purpose of reproduction; this is called an inflorescence. In order to increase the available space for flowers, extensive branching often occurs. The chief kinds of inflorescence have been already mentioned. The leaves on the shoots of the inflorescence are smaller, and of simpler form than the foliage leaves, and have been already described under the name of bracts (Fig. 29).

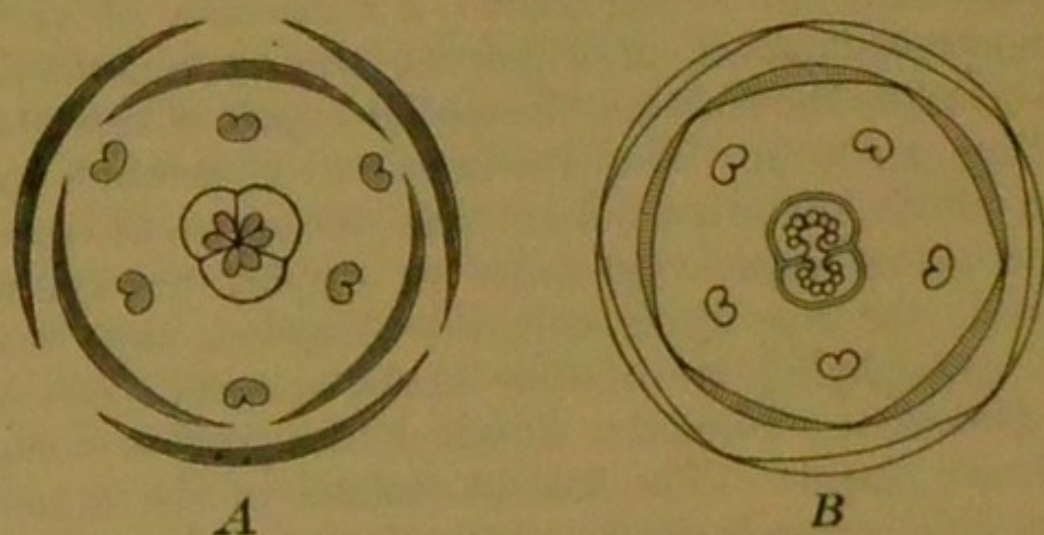
(a) *General structure of the flower.* The flowering-shoot or flower shows a succession of variously metamorphosed leaves, of which the outer are protective in function, while the inner are the special organs of reproduction (see Figs. 27-30). The protective part or perianth consists of two whorls, the calyx and corolla; the organs of reproduction or sexual organs (in order to employ a term which is suitable for the whole vegetable kingdom they may be called sporophylls) are of two kinds, stamens (male) and pistil (female). The parts of which the pistil is composed are termed carpels. The leaf-like nature of the organs can only be clearly seen in the two outer whorls; it is not apparent in the other floral leaves. A metamorphosis of the leaf occurs also in the stamens and pistil—or, as they might be better termed from their nature, staminal and carpellary leaves. This is shown both by the history of their development, and by the reappearance of ancestral features. It may occur that the stamens and pistil are wholly or partially leaf-like in form, as in double flowers, which from this cause have lost their power of producing seeds.

From the above we gather that the staminal and carpellary leaves are the essential parts of the flower; the perianth is inessential, and may be absent. If it is present with all the other organs, the flower is said to be complete (Fig. 27); if it is absent, the flower is naked. It may occur that either

only one whorl of the perianth is present (the calyx or the corolla, Fig. 29); or the whorls may be both alike. In either of these cases it is called a perigone. In Fig. 30 the calyx, which is clearly present, is petaloid and coloured. When stamens and carpels are both present the flower is said to be hermaphrodite (Fig. 27). If, however, only one of the two sets of organs is present the flower is di-clinous or unisexual, being male, if it possesses stamens, and female, if it possesses carpels. If both are absent the flower is useless for purposes of reproduction, and can only play a part in assisting other flowers, as we shall hear later.

Fixed rules can be observed in the arrangement of the

FIG. 26.



Diagrams. A. Tulipa, pentacyclic, trimerous flower.
B. Solanum, tetracyclic, pentamerous flower.

parts of the flower. The representation of the flower in horizontal section is called a floral diagram (Fig. 26), and gives a very good idea of its general arrangement. The parts of the flower may be either in whorls (cyclic) or spiral (acyclic). The latter type is rare, but an example occurs in the cones of the order Coniferæ. In the cyclic flowers the number of whorls must be carefully noted, since it often happens that one kind of floral organ is in several whorls. This is especially the case with stamens. We speak therefore of flowers having one or many whorls. The number of leaves in a whorl is also important. The

leaves may be from two to an indefinite number, and the flower is accordingly either di-, tri-, tetra-, pentamerous, etc.

As regards the position of the whorls with reference to each other we find two varieties; in one case the members of the following whorl are placed between those of the preceding whorl, *i. e.* they are alternate, in the other case the members of the following whorl are placed in front of those of the preceding whorl, *i. e.* they are opposite. The following are a few examples: *Solanum* (Fig. 26, *b*) has a flower in four whorls (tetracyclic), and every whorl consists of five members (pentamerous); in the order *Cruciferae* (as cabbage) the flowers are in six whorls, and the whorls vary in the number of their members (the calyx in two whorls, each consisting of two sepals, the corolla in one whorl of four petals, the stamens in two whorls, the outer consisting of two stamens and the inner of four, the pistil in one whorl of two carpels). Flowers of the order *Liliaceae* (*Tulipa*, Fig. 26, *a*) are five-whorled (pentacyclic), each whorl having three members (trimerous).

The arrangements we have just mentioned are not, however, always so obvious as it might appear. Reductions may take place in the different parts, which are then said to be abortive. If the parts entirely disappear we must seek for explanation in the history of the development of the flower. On the other hand, division or reduplication may take place in any whorl, as in the inner staminal whorl of the *Cruciferae*, which has become tetramerous by branching. Lastly, decohesion may take place between the adjacent members of a whorl, and thus the regular relations of the numbers may be disturbed.

The increase in the number of petals of double flowers rarely arises by the interpolation of fresh petals. The redoubling is generally due to one of two other causes: the division of the originally simple members into many, or the transformation of stamens and carpels into petals, this revealing at the same time their leaf-like nature.

The way in which the petals are folded in the bud is

called *æstivation*; it is *valvate*, when the petals touch by their edges, *imbricate*, when they over-lap one another. We will not enter into details on this subject, or on that of the insertion of the flower, by which we understand the way in which the different members of each whorl are attached to those of the preceding whorl. The history of the development of the flower can not here be explained. It must suffice to say that the growing-point of the flowering shoot ceases to grow as soon as it has given rise to cellular protuberances from which the floral organs are developed. In this it resembles the vegetative shoot.

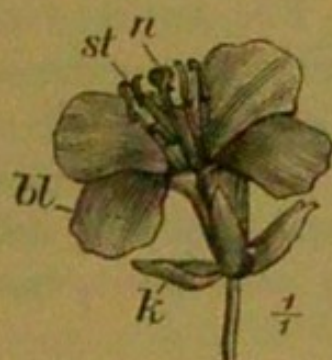
The flower may be either regular or irregular in structure. Flowers are said to be regular when the members of all the whorls have a similar structure, and are radially arranged on the axis (*forget-me-not*); they are said to be symmetrical when the flower can be divided into two similar and equal halves (*Mimulus*, Fig. 30, *Pea* and *Dead-nettle*). Dissimilarity may be shown by difference in colour and position, but chiefly by variation in size. The origin of the symmetrical formation of flowers is a disputed point.

(*b*) ***Special structure of the floral organs.*** (*a*) ***The axis.*** The axis of the flowering shoot is called the receptacle; it generally consists of whorls of leaves with very much shortened internodes. The leaves are typically in the order mentioned above: calyx, corolla, stamens and pistil, the latter occupying the tip or centre of the flower. It sometimes occurs, however, that the internodes between two different whorls of floral leaves are elongated, so that a whorl is raised up as if on a stalk (*Caryophyllaceæ*). Glands having a honey-like secretion may be formed on the axis between the whorls; if the gland is a ring-shaped wall it is called a disc (*Labiataæ*). The axis may also become enlarged and form a flat disc, on which the whorls are more or less separated. If we now imagine that on this disc-like receptacle a growth takes place between the stamens and pistil, so that the calyx, corolla and stamens are raised up as if on a wall, we see that it results in the formation of a

cup-like structure. In the interior of the cup is the pistil, the remaining organs being on the margin of the receptacle (Rosaceæ, as rose). In the third and last case the inner surface of the cup-like axis adheres to the carpels, so that the other floral organs appear to be placed above the ovary (Umbelliferæ). This is called the insertion of the flower. In the first case the perianth is below the ovary or hypogynous (Figs. 27 and 28), and the pistil superior; in the second case the perianth is round the ovary or perigynous, and the pistil half-superior; and in the third case the perianth is above the ovary or epigynous, and the pistil inferior.

(β) *The perianth.* Flowers which have no special perianth are said to be naked (ash, willow). The perianth,

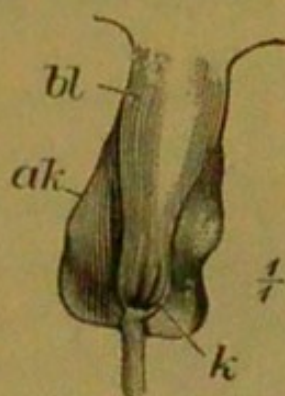
FIG. 27.



Diplolaxis tenuifolia, hermaphrodite complete flower.

k, calyx; *bl*, petals; *st*, stamens; *n*, stigma of the pistil.

FIG. 28.



Thunbergia alata, lower part of the flower.

ak, epicalyx; *k*, calyx; *bl*, tube of the corolla.

when present, may be either simple, when all the members are alike, in which case it is called the perigone (Fig. 29); or we may be able to distinguish two distinct whorls, which are called the calyx and corolla (Fig. 27). In all three varieties the members may be either united (Figs. 28 and 30), or free (Figs. 27 and 29); in the first case the number of leaves is shown by the teeth or divisions at the edge. The expression "united" does not indicate the cohesion of originally simple leaf-like structures, since a perianth of this sort generally arises as a circular ring.

The typical calyx and corolla are distinguished chiefly by their external features. The calyx is green and leaf-like, rarely coloured (Fig. 30), the sepals usually having a wide base, and being undivided (sometimes divided in roses). Its protective function is exercised chiefly when the flower is young, *i. e.* it shields the internal parts from cold and wet. For this reason the calyx often only possesses a transitory importance, and may fall off soon after the flower opens (poppy). If it persists it acquires later a secondary function, and helps to disperse the fruit by providing it with a flying organ. The most striking example of such a calyx is shown by some of the *Compositæ*. Many plants of this order possess a very small hair-like calyx, which develops later when the fruit ripens into a feathery parachute-like crown, called the pappus (dandelion, *Gnaphalium*, Figs.



Begonia spec., pistillate flower.

v, bract; *st*, pedicel; *fr*, ovary; *bl*, perigone; *n*, pistil.

32 and 48). The terms which are used in describing the gamosepalous (sepals united) calyx are self-explanatory (tubular, campanulate, funnel-shaped, cup-shaped, globular, inflated). The calyx may also be symmetrical in form.

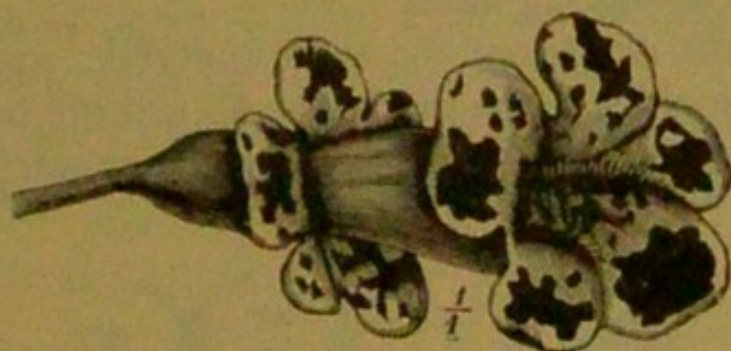
The corolla is, on the other hand, usually brightly coloured and delicate in texture; it may be clawed and fringed (Pink). The bright colour is due to blue or red colouring matter in solution or to yellow corpuscles; other peculiarities, as a velvet-like surface, may be present. Regular polypetalous corollas (petals separate) are found in the *Cruciferae*, *Caryophyllaceae* and *Rosaceae*; the *Papilionaceae* have a symmetrical polypetalous corolla, the

Campanulaceae a regular gamopetalous corolla (petals united), and the *Labiatae* a symmetrical gamopetalous corolla.

In the order *Compositae* the two last-mentioned forms

are found in one inflorescence (Figs. 31 and 32), the tubular florets being regular, the ligulate florets symmetrical. For the rest we may use the same terms as those employed for

FIG. 30.

*Mimulus luteus*. Flower with petaloid calyx.

the calyx. The development of the perigone may be of a similar character; it is either sepaloid (green) or petaloid (coloured).

It is obvious that the corolla is only protective in function to a very small extent. There are cases in which the corolla or the perigone closes at night, and protects the more internal parts from cold. The petals are, however, usually very delicate, and are spread widely open, this position being connected with an important biological fact. Many insects, especially the Hymenoptera (bees, bumble-bees), play an important part in the fertilisation of plants. The plant is dependent on them, and therefore seeks to attract them; it offers them the honey which it secretes in the flower, and the super-abundant pollen. It entices them by the gay colours of the corolla, and by pleasant odours. The large petals are noticed by the insects from afar, and provide them with a convenient landing-stage.

FIG. 31.

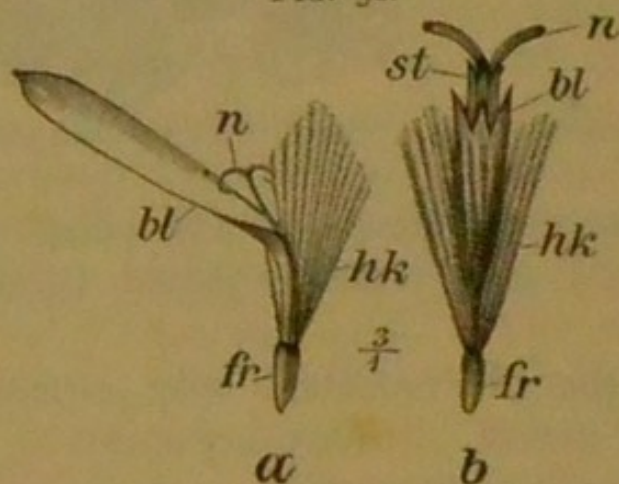
*Solidago virgaurea*, golden rod. Flower-head.

We often find a wonderful division of labour in this process. In many inflorescences, as in the capitulum, the peripheral flowers are larger than the others, and serve both as a means of attraction and as a landing-stage. As regards

any other purpose they are useless, since they have become barren by the loss of the stamens and carpels (chrysanthemum, cornflower, golden-rod, Fig. 31, and flea-bane, Fig. 32). In other cases the corolla often offers the insect an easy entrance, as in the Labiatae.

The corolla may now and then undertake some other duty, of which the chief is the secretion and storage of honey. For this purpose many corollas have a spur-like prolongation (orchis,

FIG. 32.

*Pulicaria dysenterica*, flea-bane.

a, pistillate ligulate floret of the ray; *b*, hermaphrodite tubular floret of the disc; *fr*, inferior ovary; *hk*, feathery pappus; *bl*, corolla; *st*, staminal tube; *n*, stigma. (Enlarged.)

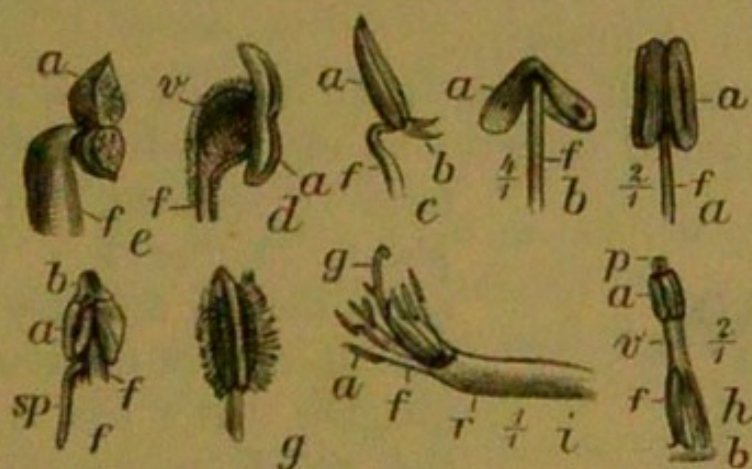
violet); or the whole petal may be converted into a nectary or honey receptacle (hellebore).

Other foliar organs perform or at least supplement the functions of the perianth. Some plants possess a structure called an epicalyx (Thunbergia, Fig. 28, Malvaceae, Rosaceae): this consists of bracts, which are situated very near to the calyx, and thus resemble the leaves of the flower. In other cases, bracts of the inflorescence may be included in the apparatus for the attraction of insects. The perianth sometimes bears stipules which in the narcissus form the corona.

(γ) **The stamens.** The stamens or male sporophylls are included under the term "androeceum." The number of stamens varies, but the regularity of the variation enabled Linnæus to found upon it his artificial system of classification. The stalk of the stamen is distinguished, under the name of

the filament, from the upper globular part which is known as the anther. The filament is inessential and may be absent; it is, however, usually present in order to raise the anther to the right position. The anther consists of two halves, each of which is again divided by a furrow into two parts. This corresponds with the internal structure. On making a transverse section through an anther we see four cells, the so-called pollen-sacs (microsporangia). In the ripe stamen

FIG. 33.



Various forms of stamens.

Salpiglossis, typical anther; *b*, *Petunia hybrida*, with diverging anthers; *c*, *Calluna vulgaris*, with tail-like appendages on the anthers; *d*, *Maurandia*, with vertical anthers and thickening (*v*) at the tip of the filament; *e*, with anthers which are attached vertically at the attenuated tip of the filament; *f*, *Viola tricolor*, with lengthened filament (*a*) and spur-like appendage (*sp*); *g*, *Thunbergia alata*, with knob-like hairs; *h*, *Lobelia erinus*, united filaments, (*b*) floral axis, (*v*) united part of the filaments, (*f*) free part, (*p*) pollen; *i*, *Lupin*, with lower part (*r*) of the filaments united; in all nine figures *f* indicates the filament and *a* the anther.

These cells are filled with a fine dust, or pollen (microspores), which consists of small single cells. The pollen grains vary in form in different flowers; the outer surface being marked with knobs, warts, or prickles, etc. The cell wall is double, consisting of the intine and extine. The two pollen sacs are united by the connective.

In all these different arrangements the variations follow fixed rules, so that they can be used for systematic classification.

It occasionally happens that the stamens are barren, *i.e.* they produce no pollen. In this case they may either shrivel

up and become entirely reduced, or they may persist and assume another form and function, as for example that of "staminodes," which are often of a glandular nature.

The stamens may be free, or they may cohere in several bundles (see the Linnæan classification). In the *Compositæ* (Fig. 32, *b*) the anthers unite so as to form a tube, but the filaments are free. The anther may even cohere with some part of the pistil (orchids).

When the pollen ripens the pollen sacs open by means of certain thickened cells, situated beneath the epidermis; these cells contract on drying.

(δ) **The pistil.** The pistil consists of a separate carpel or of many united carpels; all the carpels are included in the term "gynæcium." The metamorphosis of the leaf can be more easily seen in the case of the pistil than in that of the stamens. If we imagine that a leaf is folded along the midrib so that the edges meet, and that these grow together (at the edge or ventral suture) so as to form a cavity, we shall have an example of the simplest form of pistil. Three parts can be distinguished in the fully-developed pistil, the ovary, style, and stigma.

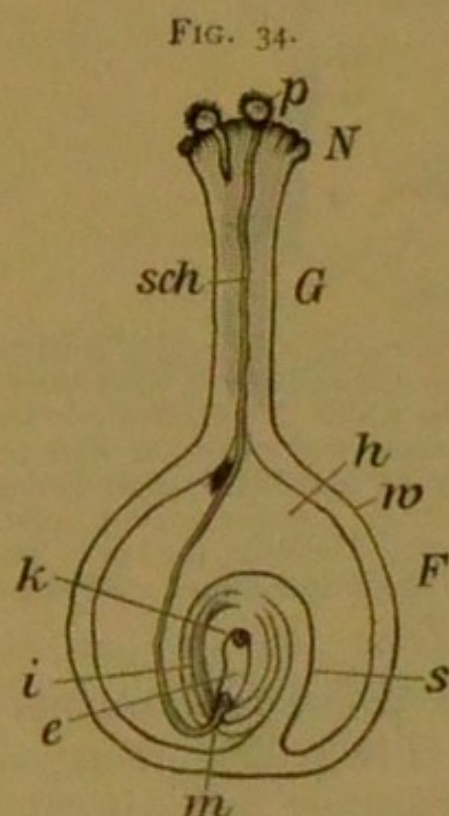


Diagram of typical pistil.

F, ovary; *G*, style; *N*, stigma; *w*, wall of the ovary; *h*, interior of the same; *s*, ovule; *i*, integument; *m*, micropyle; *k*, nucellus; *e*, embryo-sac; *sch*, pollen-tube; *p*, pollen grain.

The pistil may be compared to a bottle, the lower part of which would correspond to the ovary, the neck to the style, and the cork to the stigma. The leaf-like nature of the pistil is most clearly seen in the *Papilionaceæ* (pea). Plants have usually several carpels, which either remain free (as in the

Ranunculaceæ, for example, anemone), or cohere, either by the ovaries alone, or also by the style and stigma. The

fusion is sometimes no longer recognisable, the carpels forming a one- or many-celled structure. This may occur either superior or inferior ovaries.

In the ovary is a special part called the placenta, which bears the most important part of the pistil, *i.e.* the ovules (macrosporangia). In simple pistils the ventral suture is the placenta, but in compound pistils a different arrangement is found. In the lily, the placentation is axillary (on the margins of the carpels which meet in the centre of the ovary), and in the poppy, parietal (on the wall of the ovary). In the central placentation (*Primula*) the ovules are situated on an axis which stands freely in the centre of the ovary. Finally it may happen that only a single ovule is present, and that it is attached to the base of the ovary (*Polygonum*).

The ovule is the structure from which the seed arises. The stalk, if present, is called the funicle; the point at which the ovule is joined to the stalk or to the placenta is called the hilum (plainly seen in the pea). The principal part of the ovule is the nucellus, which possesses one or two coats (integuments), having at one point a very small opening, the micropyle. At an early stage a large cell appears in the nucellus; this is the embryo sac (macrospore), and at the end nearest the micropyle are seen three cells, of which the innermost is the egg-cell. The position of the ovule is either straight, when the hilum and micropyle are opposite one another (orthotropous), or turned (anatropous) when the mutual positions of the hilum and micropyle are the same, but the whole ovule is bent towards the hilum, and coheres with the funicle. Lastly, we speak of a curved ovule (campylotropous), when it is bent in such a way that the hilum and micropyle are not opposite one another, but side by side.

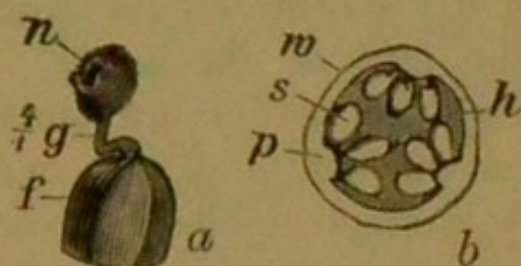
The question of the morphological signification of the ovule is still much disputed, since it is not clear whether it represents a bud or a leaf; it appears however that the latter view is more correct.

The second part of the pistil is called the style, and

contains a canal filled for the most part with a spongy tissue; the style may be absent, or if present it may be branched or divided (Fig 37). It shows great variation both as regards length and thickness.

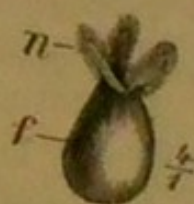
The third part or stigma is more essential. It may be either knob-like and simple, or divided into two or more parts according to the number of the carpels (Figs. 35-38).

FIG. 35.

*Viola tricolor*, pansy, pistil.

a, side view; *b*, transverse section; *f*, ovary; *g*, style; *n*, knob-like hollow stigma; *w*, wall of the ovary; *h*, cavity of the ovary; *p*, placenta; *s*, ovule.

FIG. 36.

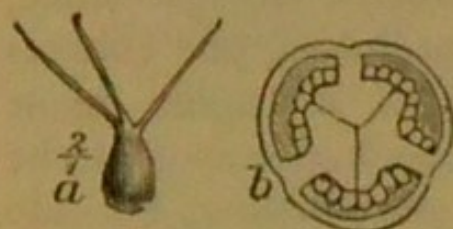
*Cardiospermum halicacabum*, ovary with sessile stigma.

f, ovary; *n*, trifid, fleshy, hairy stigma.

It is usually covered with protuberances, and is also sticky and slimy, in order that the pollen grains may adhere to it. It may possess an apparatus for collecting pollen, being either brush-like, cup-shaped, or umbrella-shaped (Fig. 38, *c*, *e*, *b*).

Fertilisation is effected by means of the stamens and pistil. Part of the contents of the pollen grain unite with the egg-cell.

FIG. 37.

*Hypericum perforatum*, St. John's wort; pistil, *a*, side view; *b*, transverse section.

The pollen grain is usually brought to the stigma by the agency of insects (hence the honey and attractive apparatus), and is anchored to it by means of the irregularities on its surface, and on that of the stigma. The secretion of the stigma acts as a stimulus on the pollen grain, and the latter gives rise to a

tube which penetrates the tissues of the style, and finally reaches the egg-cell.

The process we have described above takes place in

the Angiosperms (plants in which the seed is contained in closed seed-vessel). In the Gymnosperms (plants with naked seed), the carpels do not form a closed case, but remain open, leaf-like and scaly. They may be seen in the well-known cones of pines and firs.

9. **The fruit.** The result of fertilisation is the formation of the fruit and seed. The fruit is the product of the ovary, and the seed arises from the ovule.

The changes which take place on fertilisation are, however, of so profound a nature that they often involve other parts of the flower. Thus even bracts may form the husk of the

FIG. 38.



Various forms of style and stigma.

a, *Convolvulus*, simple knob-like stigma with pollen grains; *b*, *Salpiglossis*, with a style which is enlarged at the top; *c*, *Lobelia erinus*, with brush-like hairs (*b*) below the stigma; *d*, *Begonia*, with curled stigma; *e*, *Thunbergia alata*, style with cup for collecting pollen; *f*, *Valeriana officinalis*, with tripartite stigma; *g*, *Scirpus*, bifid stigma, with prickly surface; *h*, *Sarothamnus scoparius*, spirally-rolled style with collecting brushes at the tip; in *a*, *b*, and *c*, *g* indicates the style and *n* the stigma.

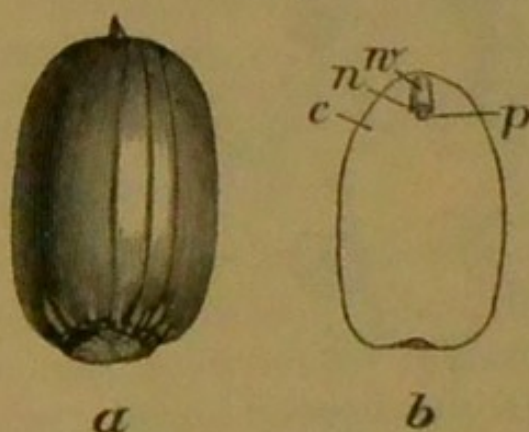
fruit (cupule of Cupuliferæ: oak, beech, hazel). When the floral receptacle is stimulated to growth a false fruit is formed, as will be described later.

The greatest metamorphosis takes place in the ovary. After fertilisation the style and stigma have performed their functions, and generally wither. In some cases, the style develops into a flying organ (some of the Caryophyllaceæ), in the wild geranium it forms a boring apparatus (see p. 76).

The number of fruits naturally depends on the number of ovaries. In true fruits the part which contains the seed

consists of the wall of the ovary, and this has usually three layers. Fruits may be classified according to the nature of these layers. We can distinguish between true fruits and false fruits; the former consisting of the ovary only, and the latter of other parts of the flower in addition to the ovary. True fruits are said to be succulent when the wall is juicy, and dry when the wall is scaly, leathery, or woody. Dry fruits may be either indehiscent, dehiscent, or schizocarps. In the indehiscent fruits the seed-vessel only splits on germination; to these belong the caryopsis (fruit of grass), in which the seed-vessel adheres to the seed, the nut (as in oak, Fig. 39, and hazel-nut), in which the pericarp is very

FIG. 39.

*Quercus*, oak, fruit, a nut.

a, side view; *b*, longitudinal section; *c*, cotyledon, the embryo lies at the top; *w*, radicle; *p*, plumule; *n*, scar left by the second cotyledon.

FIG. 40.

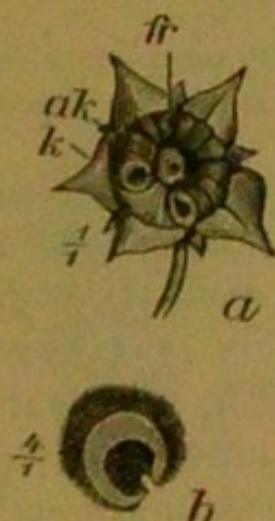
*Diplotaxis tenuifolia*, rocket, siliqua.

hard, and the samara (maple), in which the pericarp has a wing-like extension. Dehiscent fruits allow the seed to escape when ripe; this is done either by splitting open at some point, or by means of special apertures. If the fruit dehisces along the ventral suture it is called a follicle (pæony); if it dehisces along both sutures and has no partition, it is called a legume (Papilionaceæ, as pea); if it has a false partition (formed by the growth of the placenta), it is called a siliqua (Fig. 40, Cruciferæ, as rocket). In all other cases we speak simply of a capsule; this may open

py teeth (corn-cockle), or by pores (poppy), or by a lid (scarlet pimpernel). The schizocarp (Figs. 41-42) divides when ripe into several parts, each of which forms a one-seeded indehiscent fruit (Umbelliferæ). The fruit is often jointed for this purpose (siliqua of wild radish).

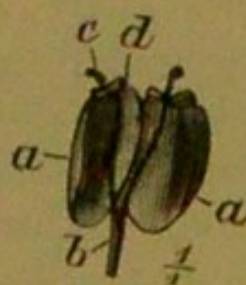
Succulent fruits are generally indehiscent; some cucumbers, however, explode when ripe at the slightest touch, and as they do so shoot out their seeds to a great distance. The commonest kinds of succulent fruits are the drupe or stone-fruit, and the berry. In the former, the inner layer of the wall of the ovary (endocarp) becomes hard and stony, while the two

FIG. 41.

*Malva rotundifolia*, mallow.

aa, calyx with schizocarp; *b*, single indehiscent fruit; *ak*, epicalyx; *k*, calyx; *fr*, fruit.

FIG. 42.

*Heracleum sphondylium*, hog-weed, schizocarp.

a, the two fruits (mericarps), *b*, the stalk of the two fruits; *c*, style; *d*, disc.

outer layers remain soft (peach, Fig. 43, and cherry); a drupe only contains one seed. The berry has several seeds, and the endocarp is not stony (currant, bilberry, nightshade, Fig. 44).

When other parts of the flower beside the ovary take part in the formation of the fruit, the latter is called a false fruit, as we have already stated. Thus, for example, in the strawberry there is a fleshy floral axis, on which grow the small true fruits. In the fig, the fruit is formed of the whole

inflorescence, the axis of which is fleshy. In the apple the cup-like fleshy axis adheres to the ovaries.

By an "aggregate fruit" we understand one like the

FIG. 43.



Persica vulgaris, peach, drupe.

FIG. 44.



Solanum nigrum, berry.

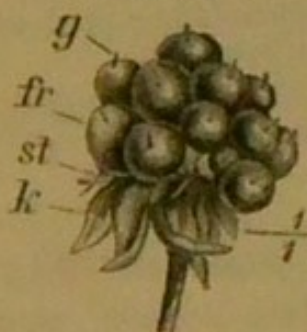
a, side view; *b*, longitudinal section.

blackberry (Fig. 45), in which the separate ovaries are small drupes or drupels, situated on the cone-shaped axis.

The biological importance of the fruit is evident. It protects the growing seed, and when it is ripe, assists in its distribution. The first object is attained by the great strength of the wall or pericarp. It is often additionally provided

with prickles and thorns, which defend it against the attacks of animals (thorn-apple). The fruits may be further protected by the bitter, sour, or otherwise unpleasant nature of the succulent part (walnut, unripe cherries). In indehiscent fruits the hard woody shell effectually keeps out the cold and wet during the winter. The fruit also assists in the distribution of the seeds. If the seeds were scattered close to the mother plant, it is obvious that

FIG. 45.



Rubus fruticosus, blackberry, aggregate fruit.
k, calyx; *st*, withered stamens; *fr*, fruits; *g*, styles.

during the process of germination and growth they would stand in each other's way. Each would tend to monopolise the soil, air, and light, and all would probably remain weak and

badly developed. It is therefore most important for the preservation of the species, that the seeds should settle as far as possible from the parent plant.

The contrivances in fruits and seeds for effecting this result, offer an attractive picture in the book of nature. The plant often assists itself in bringing about this result. This is always the case in dehiscent fruits, especially in the sling-fruits, in which the seeds are shot out by various mechanical contrivances. A beautiful and well-known example is seen in the balsam or touch-me-not (*Impatiens*). There is a special tissue in the fruit which shrinks as it dries, causing the walls to curl up in such a manner that the seed is shot far away. Another noteworthy example is that of the *Centaurea* (Figs.

FIG. 46.



Centaurea scabiosa, greater knapweed, with closed bracts.

hk, involucre of bracts; *bl*, remains of the flowers (the fruits are inside).

FIG. 47.



The same with open bracts. The bracts are widely spread, and the fruits have been scattered; in the middle is seen the pitted receptacle.

46, 47); in this case, the involucre of bracts which surrounds the inflorescence opens in dry weather, and the fruits which it contains are scattered. In other cases plants make use of the wind or animals. The seeds are often so light that a gust of wind will blow them out of the capsule, especially when the seed possesses a flying apparatus, of which there are many different kinds.

The flying apparatus may be a wing-like structure (maple) or a parachute (cupule of hornbeam, feathery pappus of

Compositæ, Fig. 48). These are for the most part developments of the ovary, bracts, or perianth; in clematis the seed vessel is carried by means of the feathery style.

It is often the case that animals are the means of transport for the fruits, and in this again two varieties may be distinguished. The dispersal may be of an entirely mechanical nature, the fruits possessing diverse kinds of prickles, brushes

FIG. 48.



Sonchus oleraceus, sow-thistle, the hair-like calyx, or pappus, forms a flying organ.

or barbs, with which they fasten themselves to the fur of passing animals, often even boring into their flesh (grasses, galium, agrimony, Fig. 49). These fruits are often also sticky, and adhere to animals by this means. Some fruits, on the other hand, attract animals by offering them a tempting bait. This occurs in those succulent fruits which contain sugar and aromatic substances, as well as a watery liquid, in their

juicy ovaries, thus providing a food which is suitable even for human beings. Such fruits are often carried by animals to some distance, the juicy part is then devoured and the hard part is left. When small, the whole fruit is often eaten. The seeds pass uninjured through the alimentary canal, being protected by their hard coat, which is capable of resisting the action of the solvent juices in the stomach and intestines.

We may lastly mention those fruits which are provided with an apparatus for boring their way into the ground. For this purpose many possess simple prickles with barbed hooks. Thus *Trapa* or water-chestnut anchors itself to the slimy soil. Other plants possess a long brush which is hygroscopic (sensitive to dampness in the air); this brush elongates when damp and curls up when dry, and gradually works its way into the soil (*Erodium*).

10. **The seed.** The fertilised ovule forms the seed. It consists of a seed coat (testa) which arises from the integuments, and an embryo, which is produced from the

egg-cell in the embryo sac; in addition, a nutritive tissue is often found close to the embryo; this is called the endosperm or albumen.

FIG. 49.



Agrimonia Eupatoria, agrimony;
fruit with barbed
hooks.

The embryo is naturally the most important part of the seed. It consists of one, two, or several seed-leaves (cotyledons), the plumule or young stem, and the radicle or young root. The whole structure is the result of the fertilisation of the egg-cell, which undergoes repeated division, and thus forms a minute but complex plant. All the parts of the young plant can be recognised in the embryo.

The testa adapts itself in its formation to the part for which it is destined. If the fruit has a strong indehiscent shell, the seed-coat is not unnecessarily tough, but thin and membranous, as in the acorn and walnut. In dehiscent and succulent fruits, on the other hand, the embryo after leaving the fruit needs further protection, and this is provided by a firm and leathery (bean), or stony skin (grape). A special peculiarity is seen in the seeds of flax and of some other plants, in which the outer cells become mucilaginous when wetted. Not only the fruits, but the seeds themselves, may possess flying organs; these are seen in the pine in the form of wing-like appendages, and in the willows and willow-herb as tufts of hairs. The seed may even provide food for birds, in which connection we may mention the arillus or fleshy mantle, which grows up from below and surrounds the seed (yew, nutmeg).

The presence or absence of endosperm is used as a means of classification; but it has also a special physiological significance. The cotyledons are usually rich in reserve materials (the most important being starch), and these serve to nourish the young plant. In other cases the place of the cotyledons is taken by endosperm. This endosperm is a parenchymatous tissue, which contains protoplasm, oil or starch, and fills up all the space between the embryo and the testa. It usually

arises from the embryo sac; more rarely other cells of the nucellus take part in its formation.

The embryo lies either inside or outside the endosperm. It may be either straight or curved. The nature and use of its parts have been already explained.

III. The Life of the Plant.

PLANTS may be said to be anchored to the soil; they cling to the earth with their roots, while their stems bearing the leaves and flowers, seek the light and air. If a plant is allowed to develop without being disturbed, it is seen to spring from a very small beginning; it grows as if tended by an unseen hand, becomes gradually more and more an independent organism, and finally bears flowers and seeds, from which arise organisms of the same species.

The life of the plant shows thus two essential processes, these being growth and development on the one hand, and reproduction on the other. These processes depend entirely on the proper nutrition of the plant.

1. **Nutrition.** The nutrition of plants (exclusive of parasites), differs essentially from the corresponding process in animals. It is distinguished by the fact that inorganic materials are changed into substances resembling those of which the plant body is composed. This process is known as assimilation. Both the method of nutrition, and the means by which it is effected, are entirely different in plants and animals.

(a) **The constituents of plant food.** From our point of view, a plant is most moderate in its demands; it is contented if the air supply it with carbon dioxide, and the soil with water. The rain-water which percolates through the earth, takes up from it many soluble salts, which are thus absorbed by the plant. The materials we have mentioned constitute the whole of the bill of fare. If we examine more closely into the substances which are necessary for the nutrition of the plant, we find that they are those chemical

elements of which the body of the plant is composed. Since the chemical constitution varies in different plants, and is in fact peculiar to each kind, we must assume *à priori* that there must be a corresponding difference in the food absorbed from the soil. All plants need equally water and carbon dioxide; they vary, however, in the kind and quantity of the salts taken up in solution.

The principal chemical elements of which plants consist are carbon, hydrogen, oxygen, and nitrogen; we may add to these sulphur and phosphorus, and a few metals, potassium, calcium, magnesium and iron; silicon is also of frequent occurrence. The part played by these elements in the plant is not yet quite certain; in any case, all are necessary with the exception of silicon, which is not of great importance.

These substances are not taken up by plants in the condition of elements, but as compounds, in chemical combination with other elements. The method by which the first three are obtained is quite clear; carbon dioxide consists of carbon and oxygen, water of hydrogen and oxygen. Nitrogen is widely spread in the form of a salt called nitre; it is also a constituent of the air, which consists of four parts of nitrogen to one of oxygen. Experiments prove that the nitrogen of the air can only be taken up by plants belonging to the order Leguminosæ. The metals we have mentioned are taken up by plants in the form of salts, especially as nitrates, sulphates, and phosphates.

We can show by means of water-cultures, that these salts, with water and the carbon dioxide of the air, form the necessary food of plants. The following experiment may be made. Place some maize, peas or beans to sprout in clear damp sawdust; when their roots have sufficiently developed, *i. e.* when they have attained a length of from 3 to 4 cm., clean them carefully, and transfer them to a cylinder containing a food solution, putting the root of the plant through a

¹ A centimetre is a little more than a third (0·39) of an inch. A litre is $1\frac{3}{4}$ of an imperial pint, or 35 ozs.

ble bored in the cork. The solution is prepared by dissolving the following salts in a litre of distilled water :—

Potassium nitrate,	1 gm.
Calcium sulphate,	$\frac{1}{2}$ "
Magnesium sulphate,	$\frac{1}{2}$ "
Calcium phosphate,	$\frac{1}{2}$ "

It is as well to cover the cylinder with pasteboard or black paper, in order that no Algæ may grow on the glass; if it is then placed in the sunlight the plant will thrive very well, and after a time will acquire yellowish leaves. A slight addition of a solution containing any salt of iron causes the leaves to assume their normal colour.

Some plants differ from others in the substances which they need. If the soil does not contain the salts required the plant will not thrive; this fact explains to a great extent the distribution of plants. For example, some need salt, and flourish best on the seashore, or in the neighbourhood of salt-licks.

(b) *The organs and process of nutrition, and the absorption of food.* The method by which plants take up nourishment must at first appear puzzling to the student, for they possess no openings corresponding to the mouths of animals. We must examine into the nature of the organs which the plant extends into the air, or sends down into the damp earth. These organs are the leaves and roots, and in them are found the means by which food is taken up. The leaves, as we have already seen, possess minute openings or stomata, through which air and carbon dioxide enter the leaf. At the tips of the roots there are very delicate cells, known to us already as root-hairs, which, without possessing any opening, are capable of absorbing water from the soil. It is a remarkable fact that this process goes on even when the soil appears to us perfectly dry. These fine hairs are in the closest connection with the particles of soil; this is illustrated by the fact that the roots of a young plant pulled up out of the ground, appear as if covered by a

mantle of earth. According to the laws of diffusion water containing salts in solution is capable of penetrating through an animal or vegetable membrane.

Water is taken up by the roots alone, but it is also needed in the leaves and growing points, which are high up on the plant and exposed to the light. The conduction of water therefore becomes a question of great importance. The channels for the passage of water and other substances are supplied by the vascular bundles, the woody cell-walls of which possess the peculiar property of allowing water to pass quickly up them. The remaining tissues are also of use in conducting water, but not to such an extent as the woody cells. The question of the tissue concerned in the conduction of water is not yet fully understood, but the above explanation is the one most usually given. The second question, *i. e.* the force by which water is raised in the plant, is also not definitely solved. It has been ascribed to capillary force, but although the small vessels certainly act as capillary tubes, the water passes to a greater extent up the walls. We know that root-hairs suck up water with such force that it is driven upwards, and will exude if a cut is made in the stem. This phenomenon is spoken of as bleeding (vine), and the force which causes it is called root-pressure. The upward movement of water in the stem is not, however, fully explained by root-pressure, since this force is not capable of raising it to so great a height. The movement seems rather to be the result of many forces working together.

Transpiration, or the giving off of watery vapour, is another process closely connected with that of the conduction of water. Leaves are continually transpiring from their upper surfaces. This may easily be observed if a leafy plant is placed with its leaves touching the glass of a window which is colder on the outside. The result of transpiration is that the solutions of the various salts in the plant-cells become more concentrated. Since there is an endeavour among the neighbouring cells to restore equilibrium in the degree of concentration in their cell-sap, it follows that a movement

of water must take place from cell to cell, and this finally induces the absorption of water by the roots of the plant. A condition of complete equilibrium is never attained, as water is continually being given off by transpiration. It may nevertheless be considered one of the chief causes of the upward movement of water in the plant.

We have observed that in the ground parenchyma of the leaf two different kinds of tissue can be recognised, palisade and spongy parenchyma. The palisade parenchyma is the tissue by which food is taken in, the spongy parenchyma is a transpiration tissue, containing a system of air passages, and placed in close connection with the respiratory cavities or spaces below the stomata. The latter do not lie above the palisade parenchyma, but on the side adjoining the spongy parenchyma. After this explanation the mechanism will be easily understood. If the intercellular spaces of the spongy parenchyma are filled with watery vapour, it passes out through the open stomata; the stomata close, on the other hand, if there is no superfluity of watery vapour. Thus transpiration and root-pressure aid each other in promoting the ascending stream of water containing salts in solution. At certain times root-pressure must alone suffice to induce the movement; this is the case in Spring, when there are present no transpiring organs in the shape of leaves. At such a time the stream of sap is known to be especially strong. The water taken up by the plant is partly nutritive and partly water of constitution, but to a much greater extent it is the means of carrying the salts which the plant must necessarily take out of the ground. These salts could not otherwise be obtained in sufficient quantities.

Many other phenomena of great interest are closely connected with transpiration. It has, for example, been shown in this account of the internal structure of plants, that the path of the upward stream of water is laterally protected. This is effected either by the cuticularisation of the outer epidermis, by cork cells, by a covering of wax, or by the position of the guard-cells of the stomata in a deep hollow. A very interest-

ing subject of study is to be found in the methods for guarding against excessive transpiration. A few examples will enable us to realise this. We might mention the hairy covering of many leaves, especially of plants living in dry localities, as steppes and deserts. Another example is that of succulent or fleshy plants, in which are seen beautiful arrangements for the storage of water, and for the prevention of excessive transpiration. In the switch-plants, a remarkable reduction of leaf surface is seen in the green, switch-like twigs, assimilation being carried on by the stem itself, as in broom and *Spartium Scoparium*.

The position of the leaves with regard to transpiration also affords an interesting study. In some plants the leaves place themselves parallel to the rays of light, thus preventing excessive transpiration; this may be carried so far that the leaves change their position from time to time, according to the needs of the plant.

The process of the absorption of water containing salts in solution has been already explained; it only remains now to speak of the methods by which other elements, especially nitrogen and carbon, are taken up. Nitrogen is taken into the plant chiefly in the form of nitrates dissolved in water. It appears strange that free nitrogen is rejected by plants, although it is present in considerable quantity in the air. It has been known for some time that leguminous plants will prosper on a soil which is free from nitrates. It is only of late years that it has been observed that this obvious capacity for using the atmospheric nitrogen, has its foundation in a strange partnership between bacteria and these plants. Leguminous plants have little tubercles on their roots, and these are filled with a parenchymatous tissue which contains innumerable bacteria. It is now assumed that these creatures in some way absorb nitrogen from the air.

The carbon which is needed by plants is obtained only from the air, in which it is present in a small proportion in the form of carbon dioxide, the quantity being continually increased by the breath of animals.

If we wish to inquire still further into the process of nutrition in plants, the following experiment will be very instructive. When a water-plant is placed in water containing carbon dioxide, and exposed to the sun, little bubbles of gas are seen to rise from the plant, especially if the stem be cut. (On a closer inspection, these bubbles are found to consist of oxygen. By a suitable experiment the same fact may be observed in land plants. Plants therefore take in carbon dioxide and give off oxygen.

From many experiments which have been made, it follows that this process is only possible in green plants, and that in others, like mushrooms, carbon is obtained in a different way.

Assimilation cannot therefore be carried on without chlorophyll, but chlorophyll alone is not sufficient. In order to make assimilation possible, the aid of a more powerful factor is needed, *i. e.* light. Numerous observations point to the fact that light exercises a great influence on assimilation, so that a plant which is deprived of it becomes sickly, and finally dies. Light influences both the formation and the activity of chlorophyll. If plants are allowed to grow in a cellar they remain yellowish, and form long thin shoots. In this condition they are said to be "etiolated."

The question of the method by which assimilation is carried on in the cell is also of great importance. It is not yet fully understood, but we know that the process consists in the decomposition of carbon dioxide and water, oxygen being given off at the same time. It is more difficult to discover the next stage. We only know that starch is one of the first products of assimilation, as the microscope reveals small starch-grains in the chlorophyll corpuscles. Starch may also be recognised by a simple experiment; it has the property of turning blue when touched with a solution of iodine. A leaf which is still growing should be partly covered with tinfoil, and after a few hours plucked from the stalk. It should be placed first in boiling water and then in hot alcohol. These two liquids will dissolve many substances, especially chloro

phyll, so that it becomes colourless; the starch, however, remains undissolved. The leaf should now be laid in a solution of iodine; it then becomes blue in the places which were not covered with the tinfoil, showing that starch has been formed in the parts exposed to the light, but not in the covered parts.

With regard to the question of the use of salts in the nutrition of the plant, it is found that the salts of iron are necessary for the formation of chlorophyll, and that salts of potassium and magnesium play a part in the formation of proteids. Sulphates, phosphates and nitrates convey sulphur, phosphorus and nitrogen into the plant, these being also needed for the formation of proteids. The use of potassium is not very clear; apparently it is of service to combine with the poisonous oxalic acid evolved during assimilation, forming crystals of calcium oxalate. This being poisonous to animals, the plant is provided with a protection against them.

(c) **Metabolism.** Even if starch be not the first product formed in the assimilating cells, it may yet be regarded as the basis of almost all the other substances found in plants. The most important are sugar and cellulose, which with starch are known as "carbohydrates." Since these substances have the same, or rather, a similar chemical composition to starch, it is easy to understand that they may arise from it. There is a similar connection between the various fatty compounds, while the albuminous substances or proteids also resemble one another. Of these proteids asparagin is an important constituent. The three groups, carbohydrates, fats and albuminous substances, suffice for the formation of all the organs of the plant, as is shown by their presence in places where reserve materials are stored. The products of assimilation pass into the parts of the plant where active growth is taking place, and chiefly to the growing points and to the fruit where they are stored. Later in the year, however, less fresh tissue is formed, with the result that as the activity of assimilation continues, substances arise which cannot at once be utilised; these collect in various receptacles as "reserve material."

The substances thus stored remain in a passive condition, and are often insoluble in the cell sap. When the time comes for them to be converted into constructive material and it is necessary for them to pass to growing parts, they must undergo transformation into an active condition. This change is brought about by means of ferments, small quantities of which are able to convert large quantities of reserve material. Diastase, the ferment which changes starch into sugar in germinating barley, is one of the most important. Among the ferments which have the power of dissolving albumen we must include those which effect the digestion of organic food in insectivorous plants. Since the insoluble reserve materials may be either carbohydrates, fats or proteids, there must be three different kinds of ferments, according to the kind of reserve material which is to be dissolved.

The sieve tubes form the channels along which the proteids are conveyed, while the carbohydrates pass along the bast parenchyma. It is obvious that the force which induces the movement emanates from places where active growth is going on, and where much material is being used.

The methods by which various other substances are formed from the first products of assimilation, are still obscure. These substances may be glucosides, vegetable acids, alkaloids and ethereal oils.

The important processes we have just discussed form the foundation for the whole of plant-life, and may be included under the term "metabolism."

It must be borne in mind that assimilation can only take place in those plants which contain chlorophyll. In the widespread groups of parasites and saprophytes, and to some extent in insectivorous plants, chlorophyll may be partially or entirely absent. In the former case assimilation is carried on to a certain extent in addition to the other means of nutrition which they possess. In the latter case the plant does not obtain the necessary carbon or nitrogen in the form of salts, but by absorbing organic materials from its surroundings, whether from putrefying or living organisms.

(d) *Respiration.* The above account has not yet exhausted all the processes of plant nutrition. For the maintenance of the living movements in plants a certain stimulus is necessary, and this is obtained from a process which, though of less importance than in animals, is still also a necessity for plants. This is known as respiration, by which is understood the taking in of oxygen, and the giving out of carbon dioxide. It is thus exactly the opposite to assimilation. While the latter is a process of reduction, in which oxygen is set free, the former is a process of combustion or oxidation. The oxygen taken in burns part of the organic matter (chiefly carbohydrates) in the tissues of the plant. At the same time, carbon dioxide is formed and is breathed out by the plant as it is by animals.

The significance of this process is clear; combustion is always connected with a diminution of matter. This entails, however, a disturbance of the internal chemical equilibrium of the plant. The endeavour to restore this equilibrium is a stimulus for the formation of fresh organic material, and is thus a powerful factor in the life of the plant. If respiration does not take place, assimilation ceases, and the plant gradually dies.

Since respiration and assimilation are exactly opposite processes, it is obvious that there must be also a difference in the conditions under which they occur. As a matter of fact respiration is most easily detected in the dark, although it goes on even more actively in the light. In daylight assimilation takes place to such an extent that growth is more active than combustion, and respiration is obscured. On the other hand, tissues which contain no chlorophyll, as flowers, buds, and germinating seeds, carry on respiration without assimilation. The respiration of parasites, etc., needs special consideration, as it completely corresponds from a physiological standpoint with that of animals.

It is a matter of daily experience that every case of combustion is connected with an evolution of heat. In the combustion of organic matter in the bodies of animals it is well

known that heat is set free; it is, however, less easily perceived in plants. The heat which is generated is quickly transmitted to the water contained in the tissues, and the large surface of the plant body offers many opportunities for the loss of heat by radiation. Nevertheless, by means of suitable experiments, an evolution of heat may be proved in parts of plants which are actively breathing; this is specially well shown in germinating seeds and opening flower-buds. The degree of heat evolved is generally low, but in the spadix of the Italian arum a temperature of from 40° to 44° Celsius has been observed, which even exceeds that of human blood. We must mention in this connection the strange phenomenon shown by many Alpine plants at the border of snow-fields, as, for example, *Soldanella*. These plants bore a hole through the snow by means of their flowers, the heat evolved by the developing flower-buds bringing the snow to melting-point.

In conclusion, we may add that the phosphorescent light shown by many fungi may be ascribed to respiration, light being evolved instead of heat. In the case of phosphorescent wood the light is not given out by the wood itself, but by the fungi which flourish in its tissues.

2. Growth. Growth is the immediate result of nutrition. The store of constructive material produced by excessive assimilation does not only compensate for that part of the plant-body which is consumed in the process of respiration; a large quantity remains over, and this, especially in the period of active growth, is used for the formation of fresh tissue. Thus an increase in size and change of form is brought about; this is called growth.

Every increase in the size of the body of the plant cannot, however, be designated as growth; this name is only applied when the change is permanent. Many dried plants, as *Algæ*, swell up when placed in water. It is obvious that this change is not due to growth, as if the water is allowed to dry up the plant will shrink like a sponge, and assume its original shape and size.

Growth naturally depends largely on nutrition; it is

affected also by light and warmth, as well as by gravitation and other mechanical forces. New organs arise at the growing-points, and after remaining quiescent for a time in the embryonic condition, they elongate in order to attain their final form and size, while at the same time internal changes occur. This process is continually repeated in the growing axes, until the end of the vegetative period causes it to cease. The embryonic stage of growth is distinguished by the continuous formation of new cells, through the division of the cells of the growing-point. There is not, however, any visible increase in size. The second stage, *i.e.* that of elongation, is chiefly distinguished by the growth in length of the existing cells and therefore that of the whole organ; in the third stage, the cells undergo further internal development. This is seen in the thickening of the cell wall, and in other ways. In the growing stem, these three stages pass gradually into one another. It is in the second stage that true growth takes place.

In most cases growth is closely connected with cell-division, but it is doubtful if this is the primary cause. It obviously depends on the direction of the cell-divisions. If these take place only in one direction, the product is a thread-like organ; if in two directions, a flat surface arises, and if in three directions the result is a cubical body. All these conditions occur, both in the whole plant (*Algæ* and *Fungi*) as well as in separate organs; in the higher plants, the third occurs the most frequently. The cell-divisions at the growing-point follow certain definite laws.

In cell-division it is a general law that the new walls should be perpendicular to the old ones; thus the growing-point always assumes a peculiar form, having lines which are parallel to the surface (*periclinal* lines), and others which are perpendicular to it (*anticlinal* lines).

The question of the influence of internal and external forces on the form of the growing plant is of paramount importance.

It must be borne in mind that there are internal forces

unknown to us which co-operate with external forces in the processes of growth. These external forces operate on all plants in the same way, but with different effects; the differences must be therefore due to the special peculiarities of plants. It is owing to internal forces in the plant that the roots arise on the part directed downward, and the shoots on the part directed upward. The same result is sometimes attained by two different forces. The force of gravity causes the roots to turn downward, and the shoots and leaves to grow upward; further, we know that light has the same tendency, roots forming on the side turned away from the light, and shoots and leaves on the side exposed to the light. If a plant creeps on the ground, as is specially the case in low plants, as mosses, roots arise on the lower surface and leaves on the upper surface. Since both the forces of gravitation and of light have this effect (as may be demonstrated by special experiments), the differences which thus arise must be traced back to internal causes, which are not yet understood.

It is important to form an idea of the relationship between the internal and external causes of growth. The peculiar cause of so many specific kinds of growth is supplied by the internal constitution of the energids of the protoplasm, which must in consequence be specifically different. The external causes of growth are really stimuli, which either set in motion (*e.g.* nutrition, water, warmth), or regulate (*e.g.* gravity, light) the processes on which the life of the plant depends. This may be illustrated by an example. A bud only grows and unfolds when the energids in the cells of its young leaves and growing-point are still living, and when some external agency awakes it from its dormant condition. This is effected by the heat rays of the sun in spring, and by the renewed movement of the food materials. The direction of the reviving growth is regulated by the force of gravitation and light; for example, the young leaves spread out towards the sun.

We must now refer to the promotion of growth by means of external stimuli. It is obvious that the plant is influenced

by its food materials, and that it cannot live without them. It also possesses a power of selection with regard to them, and this we must trace back to the specific constitution of the energids.

The force of gravity produces the following results on the growing organs of the plant (which need not be in the embryonic condition): the root grows in the direction of the force, and is said to be positively geotropic; the stem grows in the opposite direction, and is said to be negatively geotropic. If a shoot which is undergoing elongation is placed in a horizontal position, it curves upwards. (This of course cannot occur if the cells are already lignified.) As an increase of water in the cells of the lower or convex side of the shoot can be proved, this fact has been connected with the cause of the curvature. It is found that the nodes of the haulms of grasses preserve their geotropic properties for a long time. If an adult grass-haulm is placed horizontally, it begins to curve at the nodes; the side turned towards the ground elongates, and the upper side becomes shorter, it is therefore possible for the grass to regain its upright position. A proof of the connection between the force of gravity and growth is afforded by the following experiment. If seeds are allowed to germinate on the revolving wheel of a centrifugal machine, the roots will grow outwards towards the rim of the wheel, and the shoots inwards towards the axle.

The effect of light on the parts of a plant which are undergoing elongation is plainly shown in the well-known experiment of growing plants in the dark. The shoots become very long and thin, the blades of the leaves, on the other hand, become much smaller, and the formation of chlorophyll is stopped, with the result that assimilation cannot take place. Plants grown in the dark are said to be "etiolated."

The experiment shows that light retards growth, while the absence of light promotes growth in length. Shoots which are exposed to the light on one side only, exhibit the same peculiarity. The shaded side undergoes rapid elongation, while the side exposed to the light grows more slowly; the

shoot thus curves towards the light. This is known as positive heliotropism. Negative heliotropism also occurs; it is seen in many tendrils (as those of the vine) which curve towards the shaded side.

The growth of plants is also influenced by warmth. Growth ceases within certain limits of temperature which are peculiar to each plant. This is seen in the cessation of activity in the plant-world at the return of the cold season. Within these limits the energy of growth rises to a certain point, and then decreases again as the temperature is raised, until it reaches a point at which all growth is stopped. These points are called the minimum, optimum, and maximum of the energy of growth. Water has an important influence on growth. The cells of the growing-point are filled with protoplasm; the larger the cells become in the second or elongating region, the more water they contain. The water is attracted by organic acids and salts of potassium; it filters through the cell-wall, but is retained by the primordial utricle, and thus the walls tend to become stretched. This condition of the cell is known as "turgidity." The stretching of the cell-wall, which is due to turgidity, is one of the most important causes of the elongation of an organ.

The extension of the tissues is the result of the changes induced by growth, turgidity and imbibition. If a cell has taken up much water, so that its wall becomes turgid, the shoot will be mechanically strengthened. The pith shows marked turgidity; all the internal tissues possess it to a greater extent than the external. For example, if a split flower-stalk of dandelion is laid in water, it will become strongly curved, because the inner surface elongates owing to turgidity. Imbibition is one of the most remarkable properties of the epidermis. By it is understood the capacity for taking up molecules of water between the molecules of the epidermis, thus often causing the latter to swell with great force. An example of this is a swelling seed. Even dead cells have the power of imbibition, as may be seen by soaking a piece of dry wood in water.

The tendency of the pith is to elongate, while the wood and bark contract; they thus counteract one another. Elongation increases as the internodes become older, and then ceases. We may mention as a cause of elongation, that the pith grows more quickly than the cortex and wood. The result of imbibition taking place more quickly in the pith is that it displays a greater amount of turgidity. A cross-strain is thus produced. If the cortex is removed from the wood, it cannot be replaced so as to completely surround it. The wood also has a tendency to stretch but is prevented by the opposite tension of the cortex. It is obvious that growth in thickness combines with turgidity and imbibition to bring about this result. The delicate cells of the cambium are not influenced, as might be supposed, by the pressure from within and without. This is due to the turgid condition which is characteristic of these cells.

3. *Movements in response to stimulus.* Life is the result of equilibrium between an organ and its surroundings. The surroundings operate on the organism in the form of certain stimuli, and the organism responds in a definite way. This response usually takes the form of movement, although every movement must not be regarded as a response to stimulus. Many plants, as Algæ, lichens, or the well-known rose of Jericho, when dried and placed in water, undergo a change in volume owing to imbibition of water, and in consequence of this movement takes place. This is a purely physical phenomenon, being a mechanical movement and not a response to stimulus. On the other hand, we saw that in a seedling the forces of gravity, light and moisture, exercise so powerful a stimulus, that the root grows downward and the stem upward. The only explanation which can be given of the varied kinds of response to the same stimulus is that life plays a special part in this case; no explanation is offered by physical laws. It is therefore unreasonable to maintain that the phenomena of life can have a mechanical explanation. If the idea of a vital force, that is, a special power operating in the organism, is relinquished,

we do not by that means get any nearer to an understanding of the phenomena of life. Indeed a recent investigator, Kerner, declares that he does "not hesitate again to designate as vital force this natural agency, not to be identified with any other, whose peculiar effects we call life."

Protoplasm is the basis of life; in fact, all movements in response to stimulus arise either directly or indirectly from it. Dead cells, *i. e.* those which are devoid of protoplasm, do not respond to stimulus, although free protoplasm shows such movements. This can be observed in the lower Algæ and Fungi, in swarm spores, and also in the living cells of higher plants. The movements of protoplasm sometimes take place by means of fine filaments. Some swarm-spores of Algæ and Fungi possess thread-like organs, called flagella or cilia, the lashing movement of which causes them to move hither and thither. On the other hand, the movements of the protoplasm may be amœboid. The lower Fungi at certain stages of their life resemble the Amœbæ, which are the lowest of the Rhizopoda. They possess the power of putting out pseudopodia, or portions of protoplasm, after which the rest of the protoplasm flows. The streaming movement in the energids contained in the cells has already been mentioned.

Movements can occur either in growing organs, or in those which have ceased to grow. If some external cause can be observed in the movements of growing organs, these movements are said to be in response to a stimulus, if this is not the case they are spoken of as movements of nutation.

We will treat first of the former, and will refer to what we have already said concerning geotropism and heliotropism, the phenomena depending on which are movements in response to stimuli. This point will be made clearer by the following experiment. If a bean is allowed to germinate in quicksilver the root grows downward, the irritability and force of the protoplasm being so great that the root is enabled to overcome the strong opposition offered by the quicksilver.

There are many drooping plants, and plants growing on walls (as the ivy-leaved toad flax), which are too weak to

keep upright; their shoots do not obey the stimulus of the force of gravity which would raise them, and they grow towards the earth. If any twining plant, as the bean, is compelled to grow downward, the elongating portion will curve upward. A heliotropic phenomenon is displayed at the same time, the leaves turning upward, and exposing their upper surfaces to the light. An important example of this kind of movement is seen in twining plants. It is obvious that this is also a case of growth, but the peculiarity is that the zone of greatest growth lies always to the outside and progresses spirally, giving a spiral direction to the whole shoot. If a twining plant is exposed to a continual slow rotation on a clinostat it will lose its capacity for twining. Twining takes place upward along an upright support, thence it follows that the force of gravity is a stimulus, and that the twining depends on a special kind of geotropism.

Heliotropism causes leaves to assume a special position; if possible, they turn their upper assimilating surface towards the light. At the same time they endeavour to protect themselves by their position from the direct rays of the sun. In every tree and bush, as for example in the hazel, it can easily be seen that the twigs of horizontal growth, as well as the upright ones, possess horizontally placed leaves. Wall-plants often display a beautiful leaf-mosaic, formed by leaves lying close to one another, but without mutual interference (as in wall pellitory, Fig. 23). Many fruits, on the other hand, turn away from the light.

Among the stimuli which induce movement we may include contact and rubbing: this is shown in twining plants (see p. 51). The tips of these plants, as well as the young tendrils, make circular nutations (see p. 97), and when a tendril has found a support, whether it be vertical, sloping, or horizontal, it twines itself round it, enfolding it in many coils; at the same time the part of the tendril behind the point of contact also curls up into a spiral, proving that the stimulus is transmitted. Warmth, water, and chemical substances may also act as stimuli and induce movement.

A second group of movements due to growth includes those of nutation, that is to say, curvatures which may be traced back to an unequal growth of the upper and lower surfaces of an organ, and in which no special external stimulus can be detected. In this case the capability of movement ceases with growth. A similar process takes place, showing, however, periodical repetition, when a leaf raises itself, one of its surfaces growing more quickly in the day than in the night,

FIG. 50.



Colchicum autumnale, Autumn crocus.
Open flower (in daytime).

FIG. 51.



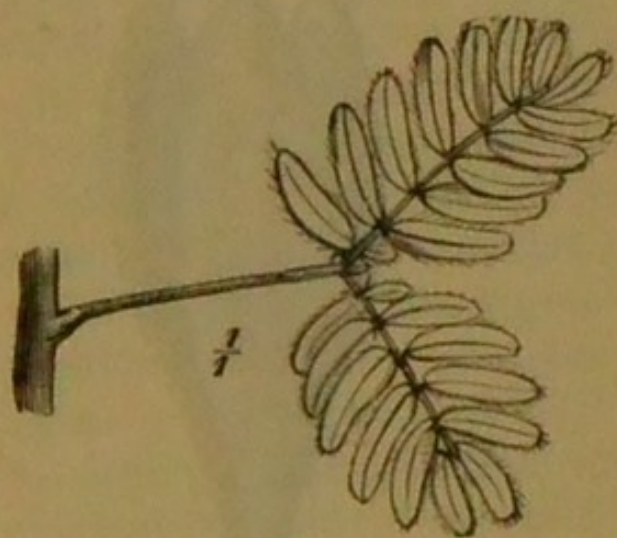
The same with closed flower
(at night).

or *vice versa*; the leaves of flax move upward at night, because growth is more rapid in the lower surface; in some species of *Polygonum*, they move downward because the upper surface grows more quickly at night. A similar case is that of many flowers which open by day and close at night, or the reverse. The autumn crocus is an example of the former, and the evening primrose of the latter. This is often due to variations in the light, as is the case in the tulip and scarlet Pimpernel.

In opposition to the movements mentioned above, those which are due to variation do not cease with the elongation of the organ, but are repeated on the application of a certain

fresh stimulus. To these belong the movements of the sensitive plant *Mimosa pudica*, the leaflets of which sink down if shaken; many stamens are similarly sensitive to touch (Compositæ, an example of which is Sweet Sultan). The movement is due to loss of turgidity in the cells of a mass of parenchymatous tissue (the pulvinus), which is always present at the base of the petiole, the water passing into other cells or intercellular spaces. Movements of variation are often the

FIG. 52.



Mimosa pudica, sensitive plant.
Open leaf (resting position).

FIG. 53.



The same, leaf closed
(after stimulation).

response of the plant to stimuli due to light or temperature; thus the leaves of the sensitive plant close together in the dark, like the leaves of the wood-sorrel and many of the Leguminosæ (clover and vetch). This is called a sleep-movement (day and night position), and it is traced back to the tension due to turgidity in the cells of the pulvinus.

The above-mentioned movements due to stimuli may be interfered with if the external stimulus be too strong. The over-stimulated organ loses for a time the power of movement, and remains in a condition of rigidity. This may be due to cold, heat, darkness or drought.

4. **Reproduction.** (a) *Various methods of reproduction.* The processes described hitherto have the pre-

servation of the individual as their chief object. This is not, however, the only aim in life : if every individual does not do its utmost for the preservation of the species, all life on the earth would cease at the death of the existing organisms. The process of reproduction is therefore of greater importance than any other in the life of the plant.

We will first consider certain phenomena which belong rather to propagation than to true reproduction. Plants have a means of propagation not possessed by animals. An animal has a much more united body than a plant ; its organs are to a certain extent ruled by reason, and are under the influence of a central organ, the nervous system. A plant, on the contrary, preserves a greater amount of independence in its organs ; this is shown above all in the fact that parts of plants are capable of detaching themselves and forming new individuals (vegetative reproduction). It is well known that a plant can be increased by layers, slips, etc. If a shoot is removed from a plant and placed in the earth, it will form an independent plant ; the lower end produces roots, while the upper end continues to grow as a shoot ; a new plant is thus formed. Many plants, as Begonias, can even reproduce themselves from a part of the leaf.

Propagation by means of runners, tubers, bulbs and bulbils belongs to the same category. The processes of budding and grafting are entirely different ; in this case there is no increase in the number of plants, their object being artificial improvement alone. Vegetative reproduction often takes place in plants when sexual reproduction is for some reason impossible. Many plants are propagated in this way only, especially the lower Algæ and Fungi (bacteria).

Reproduction in the stricter sense of the word is a sexual process, that is to say, the new plant arises as the product of the union of two cells (gametes). This process is not similar throughout the whole of the vegetable kingdom ; it reaches a higher stage of perfection, as plants become more highly developed. We will consider the various stages. The simplest case is one in which plants form two similar

cells the contents of which unite, as in many Algæ and Fungi. If, on the other hand, a difference between the cells can be observed, they are distinguished as male and female, and the process of their union is called fertilisation. The most striking difference between the two cells is, that the female or egg-cell is motionless, and the male cell is motile. Cases occur in which the male cell is non-motile, as in the Fungus, which causes the potato disease, and in the Floridææ or red sea-weeds. The stage of resting egg-cells and motile male cells is found in the mosses and ferns. In these the egg-cell is contained in a simple, more or less flask-shaped body called the "archegonium," while the male cells or "antherozoids" are found in club-shaped "antheridia." The antherozoids are filamentous cells with lashes or cilia, which they are able to move when on a damp substratum. Since the plants which bear these organs are always very small, the antherozoids are easily able to reach the archegonium in this way.

The cell formed by the union of two similar cells is called a "zygospore," and this cell has the power of giving rise to a new plant. In the case of an egg-cell which is fertilised by an antherozoid, the resulting spore is called an "oospore." In mosses the product of fertilisation is an urn-shaped body or "sporogonium," in which the spores arise. By "spores" we understand single reproductive bodies consisting of a single cell, which are capable of germinating and giving rise to a new individual. In the vascular Cryptogams the young plant is formed from the fertilised egg-cell which is borne on the prothallus. The spores arise later asexually in sporangia on the leaves. In many cryptogamic plants there are two kinds of spores (micro- and macrospores), which are contained in two kinds of sporangia (micro- and macrosporangia).

We have already sufficiently discussed the functions of the various parts of flowers in the higher plants or Phanerogams. In order, however, to understand the connection between them and the lower plants, we must observe, that the Phanerogams, like the higher vascular Cryptogams, possess macrospores and

microspores, namely, the embryo sacs and pollen grains. In the vascular Cryptogams prothalli arise from these spores, and these bear the special sexual organs, the egg-cells and antherozoids. In the Phanerogams the formation of the prothalli is much reduced. Even in this case there arises in the pollen grain a portion which represents the antherozoid, while the embryo sac contains an egg-cell. In both groups of plants the process of fertilisation consists in the fusion of the corresponding sexual organs, and the result of fertilisation is the rapid growth of the egg-cell. In the vascular Cryptogams the new plant is the immediate product of fertilisation, but in the Phanerogams the formation of the seed takes place first. The seed contains a miniature plant, which passes through a resting stage before it begins to grow. In both groups the asexual spores arise later on the adult plant on specially formed organs.

In the Phanerogams the process of fertilisation is brought about in a special way, called pollination.

(b) **Pollination.** A pollen grain is a non-motile male spore. A special apparatus is often needed to convey the pollen to the stigma. In hermaphrodite flowers self-fertilisation is comparatively rare, the pollen being generally prevented from falling on the stigma of the same flower. Cross-fertilisation has the advantage of ensuring a stronger progeny. If the stamens and carpels are on different plants, or even on different flowers, cross-fertilisation is obviously certain.

There are a great number of contrivances for ensuring cross-fertilisation in hermaphrodite flowers. The following cases may be taken as examples. The stamens and carpels are often ripe at different times, so that the stigma is not capable of being fertilised when the pollen leaves the anthers. This is called dichogamy (cf. *Aristolochia*, plantain, rue, etc.). The stamens and carpels are often in such a position, that any direct communication between them seems to be quite impossible, or they vary so much in length, that some external help is necessary before fertilisation can take place.

It is now known that cross-fertilisation is not so absolute a law as was formerly supposed. In many cases, self-fertilisation is known to occur, and is often specially provided for when the flower has waited for cross-fertilisation in vain.

The transference of the pollen may be effected either by the wind or by insects. If the pollen is very light, and is present in large quantities, a puff of wind is sufficient to carry a cloud of pollen dust to the carpellary flowers. Such wind-fertilised flowers occur in our monœcious and diœcious trees, the oak, beech and hazel being examples of the former, and the poplar of the latter. Insect-fertilised plants have a wider distribution. In the tropics the pollen is sometimes carried by humming-birds.

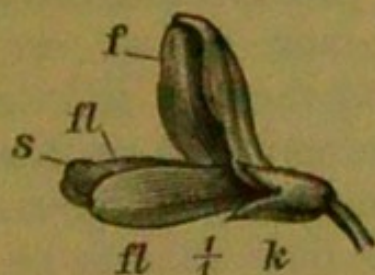
We have already seen that insects search flowers for honey and pollen, and that they are attracted for this purpose both by bright colours and a pleasant scent. Honey is eagerly sought for by insects. Since, however, some would not be able to fertilise the flower successfully, the plant is obliged to protect its sweet treasure from thieves and unbidden guests. This is often accomplished by the nature of the corolla, which is usually of such a shape as to render the honey inaccessible; the snapdragon, for example, has a sort of trap-door arrangement. In other cases, the flower is so constructed that it can only be fertilised by special insects, the relations of the length and arrangement of the various parts being such that only a proboscis of a certain length is able to reach the honey. The flower is always so constructed that the pollen shall be deposited on that part of an insect's body which will afterwards touch the stigma of another flower. The methods of pollination are almost as various as the forms of flowers.

The principal insects which carry pollen from plant to plant are butterflies, bees and humble-bees. If the flower is designed to attract butterflies, it has a long corolla-tube, corresponding with the proboscis of the insect; from the top of the tube the stamens and pistil project, as in honeysuckle. Flowers in which fertilisation is effected by night moths are generally

of a pale shining colour, and have a scent which becomes more powerful in the evening.

A good arrangement for cross-fertilisation is seen in the violet. In this case the pistil has a style which is thin and bent at the base (Fig. 35, *a*); the lower stamens (Fig. 33, *f*) possess a special spur which secretes honey, while the connective has a membranous prolongation at the top. All five stamens stand round the pistil, and the membranous parts touch one another so as to form a hollow chamber. The

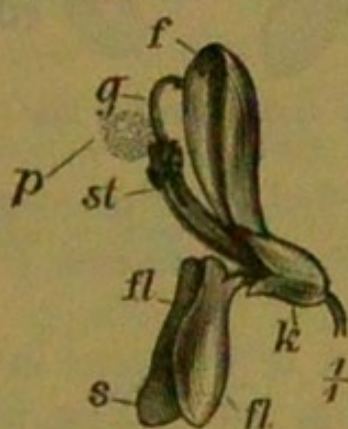
FIG. 54.



Genista tinctoria, or greenweed, papilionaceous flower, ready for pollination.

k, calyx; *f*, standard; *fl*, wings; *s*, keel.

FIG. 55.



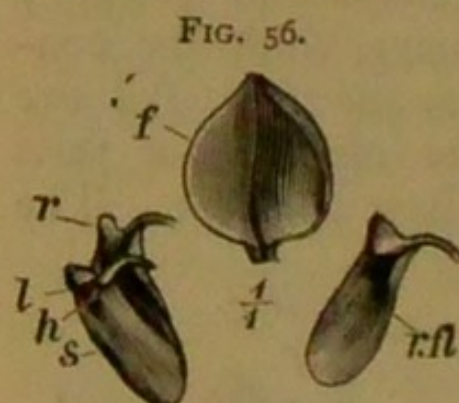
The same, after pollination; the wings and keel are depressed, the stamens (*st*) and the pistil (*g*) are directed upwards; *p*, cloud of pollen dust which is thus set free.

flower is on a long stalk and hangs down, so that the dry pollen falls when ripe into this chamber. If a bee should now visit the violet flower in order to obtain honey, it must necessarily bend back the pistil, this being facilitated by the thin and curved style; the pollen then falls upon its head, and is rubbed off on the stigma of the next flower which it visits.

Another noteworthy example is seen in papilionaceous flowers (see Figs. 54—56). The back petal stands upright, and is called the standard; this serves to attract insects from afar. The two lateral petals are called the wings, and in front of these are two petals which are almost united, and which form the keel (Fig. 56, *s*). The wings of both sides

have a protuberance which fits closely against another protuberance on the keel, the four petals being thus held closely together.

When in this position the petals are in a state of tension ; and are easily displaced if any pressure



The same, showing the various parts.

f, standard ; *rfl*, right wing ; *s*, keel ; *l*, left half ; *r*, right half ; *h*, protuberance.

is exerted on the protuberances on the wings, with the result that all four petals spring downwards. The keel contains the ten stamens, the lower part of the filaments cohering to form a single tube round the pistil, the style of which is curled like a feather. The anthers dehisce early and their pollen lies in the keel. If an insect now presses on the wings, these and the keel fall down, and the stamens spring up, so that the

pollen is projected in a cloud out of the keel, as represented in Fig. 55. The pollen at the same time adheres to the under surface of the insect's body, and when it visits another flower with projecting stigma some pollen must necessarily be deposited upon it.

(c) **Fertilisation.** The two cells which effect fertilisation are not placed in immediate connection by the deposition of the pollen on the stigma of the pistil. Fertilisation is preceded by another process. This consists in the germination of the pollen grain on the damp stigma, a tube being sent down through the tissue of the style to the ovary (Fig. 34). The pollen tube penetrates to the ovule, and grows through the micropyle to the egg-cell. Now begins the real act of fertilisation. After penetrating the integuments of the ovule, the generative cell of the pollen tube (containing a nucleus) enters the egg-cell and unites with it.

The egg-cell contains no nuclein, but the nucleus of the pollen tube is richly provided with this substance. By the process of fertilisation the egg-cell becomes in a certain sense complete, and energetic cell-division is at once set up. A

cell-body called the seedling is finally formed, and this bears the parts described above, the cotyledons, plumule and radicle.

While growth is taking place in the seed, another change, due to the stimulus imparted by the act of fertilisation, is set up in the wall of the seed-vessel. The result is the formation of the fruit, and this often includes other parts of the flower, especially the floral axis.

(d) *Care of plants for their posterity.* Self-love is not the only mainspring of the life of nature, as has been so often maintained; there are various processes in nature which bear witness to a law of love and mutual assistance, and of these the care of posterity takes the first place.

It seems almost unreasonable to look for such cases in the plant-world, and yet they are here very evident. It may suffice to point out one of these, *i. e.* that the plant not only extends its protection to the seed, during the period preceding germination, but also provides for its disposal in places which are suitable for its growth.

If the seed is destined to pass through a long resting period before germination, it is protected against the weather by a hard husk or ovary, as in the nut and cherry stone. The seed is protected in the same way if it be destined to pass through the alimentary canal of an animal, as in the currant and bilberry.

We have already seen that a favourable place is found for the germination of fruits or seeds, either by means of a flying apparatus, or by employing the agency of animals. Animals often carry the fruits clinging to their fur by means of hairs or hooks; in other cases they seek out the fruits for food.

CONCLUSION

If the reader has patiently followed me to the close of this little book, I have still a question to ask him and a request to make.

What do you think of all you have heard of the life of nature?

Can it be true, as is asserted by many, that purely mechanical laws rule in stone, beast and plant, and in your brain as you meditate on my question? Let the whole process of the life of a plant pass in review in your mind. Is it a lifeless machine which is wound up and then runs down, a musical box, which plays its tune? Do we live in a mechanical world, or is there a special law of life which governs you as it does the daisy by your footpath?

Do you hesitate to answer, or have you any presentiment of an eternal wisdom which rules this wonderful world, not by means of laws which are purely mechanical, but which are full of insight and design?

Which of these two ideas leaves the greater problem unsolved?

If you, dear reader, have till now followed me with some sympathy in this account of the life of plants, I have still a request to make, and this shall be my reward for acting as your guide. When you put down this book do not lay aside the study of plants, but look for yourself in the great book of Nature, where all that you have read here is written with far greater clearness and force than lies within the power of my feeble pen!

Jede Pflanze verkündet dir nun die ew'gen Gesetze,
Jede Blume, sie spricht lauter und lauter mit dir.
Aber entzifferst du hier der Gottheit heilige Lettern:
Ueberall siehst du sie dann, auch im veränderten Zug.

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