SENIOR BOTANY

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PREFACE.

In preparing this book I have used material from *Plant Biology, Life Histories of Common Plants,* and *Botany for Matriculation.* From these three works this volume differs, apart from condensation in some places and omission in others —processes necessary to make the book more suitable for the use of students preparing for the Senior Local Examinations of the Universities of Oxford and Cambridge—in the preparation of a chapter on climbing, parasitic, and saprophytic plants, and especially in the great expansion of the chapter dealing with the Ecology of Plants. This important and interesting subject receives here, indeed, more adequate treatment than in any other work on Elementary Botany with which I am acquainted.

The essence of good teaching in Elementary Botany is to bring the student into the closest personal contact with the fundamental facts of the science. Accordingly I have inserted a large number of experiments, but as some teachers may find that the time which their classes can devote to the subject does not allow them to work through all the experiments here given, those experiments which are of fundamental importance and would in themselves form a fair first course in Practical Elementary Botany are indicated with an asterisk. So far as possible, however, the sections dealing with germination and with the examination of typical plants, the latter being given chiefly in Chapters IX. to XVI., should be carefully worked through.

In the chapters on the Natural Orders some paragraphs have been enclosed in square brackets. This is to indicate that the plants described are not found growing wild in Britain, but are commonly cultivated in gardens, shrubberies, or plantations.

For the loan of certain illustration-blocks I am indebted to the courtesy and kindness of Messrs. Baird and Tatlock, Cross Street, Hatton Garden, London, E.C.; the Council of the Linnean Society; Dr. T. W. Woodhead; Dr. W. G. Smith; and my colleague Mr. E. R. Marle, B.Sc.

Mr. W. B. Clive has prepared an excellent set of microscopical preparations (*Plant Biology Set of Micro. Slides,* price 25*s.*), which will be found to answer admirably for use with this book; the set is accompanied by a descriptive booklet.

I shall be very glad to receive suggestions and criticisms from teachers and others who use this book.

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NOTE ON SECOND EDITION.

The only important change in this Edition is the insertion of a new Appendix dealing with Soils. This contains an elementary account of the physical and chemical characters of the principal types of soil, especially in relation to vegetation.

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CHAPTER I.

INTRODUCTION.—THE BROAD BEAN PLANT.

1. Seed Plants.—In this book we shall study only the higher plants, which produce flowers and seeds and are therefore called the Flowering Plants or Seed Plants, to distinguish them from the lower plants which do not produce seeds—Ferns, Mosses, Fungi, Seaweeds, etc.

Most Seed Plants agree in certain general features of form and structure, though showing endless differences in details.

2. Practical Work.—Get all the seeds, plants, and other materials mentioned in the directions for practical work and carry out the directions faithfully, making observations and experiments for yourself and keeping a careful record of your work written in your own words and illustrated by your own drawings from actual objects.

3. Sketches Required.—It is of the utmost importance that, besides keeping a written record of all your observations and experiments, you should make careful drawings of all specimens you examine. Use a note-book of unruled paper (not too thin); if you write your notes in the same book, keep notes and sketches on separate pages; make your sketches large (natural size or, in most cases, enlarged) and clear (no shading, no superfluous or meaningless marks or lines, and no "inking-in" afterwards). Measure the specimens you are going to draw, record the measurements, and if enlargement is necessary in order to show details clearly, draw to a definite scale and note how many times your sketch is magnified ($\times$ 2, $\times$ 3, etc.). All the parts shown should be labelled; do not write the names inside the drawing, but at the end of a line drawn to the part named. Write below each drawing the name of the plant, the part of the plant, the aspect represented, etc.

4. Hints on Lens Work.—So much can be done with a lens, especially if a microscope is not available, that some hints on lens work may be useful. The best kind of lens is the "aplanatic" or "platyscopic," which gives a flat field of vision without distortion of the edges; but a cheap triple folding-lens will do. It is easy to make a simple stand to carry the lens, and to allow of both hands being used in dissecting the specimen examined. The lens can be fixed to a cork which slides up and down a vertical rod, *e.g.* a knitting-needle or hat-pin, inserted into a wooden base. Another useful plan is to get a piece of thick glass, about 9 by 4 ins.; to one side of it paste two pieces of thick paper, each 3 by 4 ins., one black, the other white (or a single piece, 6 by 4 ins., with one half painted black). Keep the papered side downwards, placing on the upper side the objects to be examined with the lens; move them along so as to see their appearance against the opaque white and black surfaces, and also against the light through the clear part of the plate. See Ch. III.

5. The Parts of the Plant.—If we examine a number of common Seed Plants, we find that in most cases it is easy to recognise two sharply distinguished parts—the **root,** which grows downwards into the soil, and the **shoot,** which grows upwards into the air.

Select for your first studies a few plants whose shoot is **erect** (not burrowing in the soil, or creeping, or climbing) and **herbaceous** (not hard and woody), and find out in what respects these plants agree.

6. *Materials for Study.*—Pull up, or dig up, specimens of the following common plants: Broad Bean, Chickweed, Groundsel, Red Dead-Nettle, Poppy, Candytuft, Charlock.

Examine each plant thoroughly, after washing off any soil that may cling to the root, making notes and sketches of your observations. The Broad Bean is given fully in this chapter as a type, and the other plants should be carefully compared with it at every point.

7. The Broad Bean Plant.—A good way in which to begin work on plant-life is to raise plants from seed. The chief reason why the Broad Bean has been chosen for our first studies is that its seeds are easily germinated at any time of year, yielding in a short time vigorous young plants which serve admirably for practical work on plant structure and plant physiology. Flowering and fruiting plants can be obtained throughout the summer months; in winter one must, of course, use seedlings raised indoors.

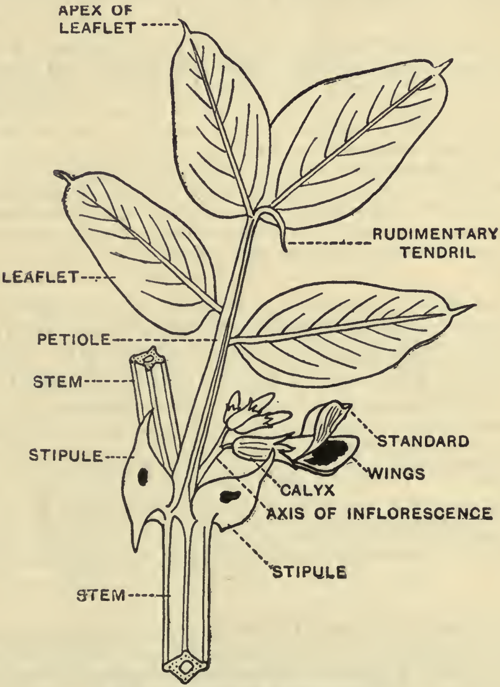

Fig. 1.—Part of a Broad Bean Plant

The Broad Bean (*Vicia faba*) is distinguished from other "Bean-plants" (French or Kidney Bean, Scarlet Runner) by its erect mode of growth, its square stem, its leaves with large stipules and from four to seven oval leaflets, its white flowers with a black blotch on each lateral petal (Fig. 1).

The Broad Bean is commonly cultivated for its large edible seeds, and (like most cultivated plants) shows several varieties (Longpod, Mazagan, etc.), differing in such details as shape and size of pod and seed and in times of flowering. A common and distinct variety is the Field or Horse Bean, of which the seeds are used chiefly for feeding horses, the "straw" for stabling purposes; its seeds are much smaller and less flattened than those of the typical Windsor Broad Bean.

Dig up an entire Broad Bean plant in the garden (or the very similar Horse Bean grown in the fields), and free the root from the soil that clings to it by shaking it to and fro in a pailful of water and afterwards washing under a stream of water from a tap. Set the plant in a basin of clean water, so as to allow the branching root to spread out, as well as to prevent its drying up.

If complete flowering and fruiting Broad Bean plants cannot be obtained at once, begin by studying the seed and its germination (Art. 31 and rest of this chapter; Ch. II.). Make successive sowings in the garden, also in pots and boxes, so as to get abundant material, in the form of seedlings, to start work with.

8. The Root consists of a main downward-growing axis (continuous with the upward-growing axis or stem), from which arise branches that spread out from it. Are these first branches horizontal or not? Do they all make the same angle with the main root? These first branches give rise in their turn to finer branches; in what directions do *these* grow in the soil, and how many times may the process of branching be repeated? Compare the different directions of growth taken by the main axis and by the successive sets of branches. Do these differences help the root to come into contact with as much soil-space as possible in the most economical way?

9. Rootlets.—Are the first branches scattered irregularly over the surface of the main root? To make out their arrangement, cut out a straight piece of main root, about 6 ins. long, cut off the branches about half an inch from their origin, and look along the piece from end to end. Sketch the piece, showing the rows of branches arranged along the axis. This arrangement can easily be made out in seedlings. In the Broad Bean the side-roots are usually in 5 rows on the main root; in the Scarlet Runner and the French Bean there are usually 4 rows, arranged with great regularity on the main root.

Examine closely the place where a branch (rootlet) leaves the parent-root. Is the surface smooth and continuous, or is there anything visible that suggests the way in which the branch arose from the parent-root? What further information is gained by cutting across the parent-root at this point with a sharp knife or a razor, and examining with a lens the cut surface? In what region of the main root are the branches shortest and thinnest? Look for young branches just emerging from the parent-root; in what direction do they grow at first?

10. Root-Tip.—Note the gradual tapering of the main axis and of the rootlets towards their free ends, and the softness and whiteness of the latter as compared with the older parts. Cut off the ends of some of the rootlets, about an inch behind the extreme tip, place them in a drop of water on a glass slide, and examine them with the lens; try holding the slide (1) against the light, (2) over a white surface, (3) over a black surface.

11. Root-Hairs.—Look for very fine threads, which will be found behind the root-tip, if the latter has not been damaged. These are the root-hairs, to which small particles of soil may still be sticking. Root-hairs are more easily seen in seedlings. They previously existed on the older parts of the root, but they disappear as the root grows, while new hairs are continually being formed just behind the growing extremity of the rootlet.

12. Root-Cap.—At the end of each rootlet, note the more transparent conical mass at the extreme tip, separated from the denser main body of the rootlet by a curved outline. This conical mass is the root-cap; it is thickest at the tip and extends a little distance at the sides, fitting over the end of the rootlet like a thimble on a finger.

Root-hairs and root-cap can be more easily examined in a seedling; they are often damaged in removing the mature plant from the soil.

13. Root-Nodules.—Note, here and there on the main root and the rootlets, little wart-like swellings, varying in size and shape. These swellings (nodules or tubercles) are characteristic of the roots of Beans, Peas, Clover, and allied plants. See Art. 240.

14. Hard and Soft Tissues of Root.—Cut the main root and the branches at several points, transversely and longitudinally, and note the hard central part surrounded by the soft outer tissue. Scrape the latter off, all round a piece of root, to see the hard central cylinder. Is the hardness of this central tissue due to the presence of woody substance, as in old roots as well as stems of trees? It is easy to find out. Get some aniline chloride (about $1\frac{1}{2}$d. per ounce), dissolve in a little alcohol, and add water to make a 10 per cent. solution. Dip a wooden match into the solution: does the match turn bright yellow when withdrawn? If the colour does not appear quickly, add a few drops of hydrochloric acid to the solution. This solution affords a ready test for woody substance (*lignin*). Place some on your sections of the root, and notice which parts turn yellow.

15. The Shoot.—The whole of the upper part of the bean-plant, above the ground, may be called the *shoot*, as distinguished from the root, which grows in the soil. In passing from the downward-growing axis or root to the upward-growing axis or stem, what changes do you notice in (*a*) shape of axis, (*b*) colour of axis, (*c*) nature of appendages carried by the axis? Note the four flat sides of the stem, and its green colour, often tinged with red. We saw that the root consists of a main cylindrical axis which is covered at the tip by a root-cap and which bears as appendages (*a*) root-hairs, (*b*) root-nodules, (*c*) rootlets which repeat the form of the main axis and bear the same appendages. What are the appendages of the shoot-axis (stem)?

(*a*) Some of these consist of a stalk which is grooved on its upper surface, carries a number of thin flat outgrowths on either side, and (usually) ends in a slender prolongation. (*b*) Other appendages of the stem consist of a four-sided stalk which carries appendages like (*a*), and which therefore repeats the form of the main stem itself and may be called a **branch** of the stem, just as a rootlet is a branch of the root. In many plants, *e.g.* Wallflower, the first kind of stem-appendage consists of an undivided thin flat piece; such an appendage is called a *simple leaf*. The corresponding appendage of the Bean is also a leaf, but here the leaf is *compound*, its thin flat portion being divided into several pieces, the **leaflets**.

16. Air-Spaces in Shoot.—You have noticed a central cavity in some of the cross-sections. How far does this cavity extend in the stem, and is it continuous? Find out by slitting up the whole stem from top to bottom. Does it run out into the branches and the leaves? What does it contain in the uninjured living stem? Nearly fill a large basin with hot water (just boiled), and notice what happens when you place in it (*a*) a piece of stem only, with the cut ends previously well plugged with plasticine, (*b*) a whole plant.

The results of these simple experiments show that the whole shoot contains air-spaces and that these communicate with the atmosphere by openings scattered over the surface. From the number of bubbles seen to escape, the leaves evidently have far more air-openings than the stem. Which side of a leaflet, upper or lower, seems to have most openings? These air-openings are called *stomates*.

17. Hard and Soft Tissues of Stem.—Cut slices across the stem at several places, starting with the uppermost (youngest) parts and working downwards. Arrange the slices in order on your glass plate, cover with a little water, and examine with the lens. Note that the young parts are solid and soft, while the older parts are hollow and hard. Note the hard tissue lying within the soft green outer tissue. In young parts the hard tissue consists of separate strings (bundles) forming a ring of whitish points in cross-section; note the extra bundles lying outside of the ring, occupying two of the four projecting corners (there is a small bundle in each of the corners alternating with these two, but they are harder to see). In older parts the bundles are joined in a continuous hollow cylinder or tube (a complete ring in cross-section), but the extra bundles lie outside of this in the same positions as in the young parts.

Now run the water off and place on the sections a little aniline chloride, noting the result. Cut the stem longitudinally into strips and note the bundles, which will be easier to follow if the strips are placed in potash solution (made by dissolving a stick of caustic potash in water) for a short time. Scrape the soft outer tissue from a piece of stem and notice the hardness of the bundles, especially in the older parts.

18. The Leaf.—Each leaf consists of an axis (leaf-stalk) which bears right and left a number of thin flat outgrowths. The two lowest of these lie on each side at the base of the leaf-stalk, close to the stem; they are called **stipules** to distinguish them from the leaflets carried higher up on the stalk. The leaflets are rather variable in number, but we usually find a pair close together, right and left, near the top of the stalk, and from two to four spaced out on the stalk below these. Note the difference in shape between the leaflets (oval) and the stipules (triangular, like one lateral half of a spear-head); what other differences do they show? Notice the slender outgrowth into which the leaf-stalk is (usually) prolonged above the leaflets (Fig. 1).

Do any of the leaves in your plants bear a leaflet in place of this outgrowth, and do you find any leaves ending in structures intermediate between these two extremes? Note that the leaf-stalk comes off at one of the ridges of the stem, the stipules being against its two adjacent flat sides.

19. Arrangement of Leaves.—Follow the ridges along the stem, and find out in how many rows the leaves are arranged. Do leaves come off at all four ridges? Do the ridges run straight up and down the stem, or is there any twisting? Compare the leaf-arrangement in the Broad Bean with that observed in other plants which have square stems—*e.g.* White or Red Dead-nettle, Mint, Figwort, Coleus—and note any differences.

20. The Leaflet.—Notice the chief vein (midrib), which runs through the leaflet from the base to the tip. What do you notice at the tip? Note the branch-veins arising on each side from the midrib, the finer veins arising from these, and the delicate net-like arrangement of the still finer veins (hold the leaflet against the light). What differences do you notice between the upper and lower surfaces of the leaflet? Notice that the chief veins appear as grooves on one surface (which?) and as projections on the other.

Hold the leaflet, with the lower surface towards you, between the thumb and forefinger of each hand, and, starting from a point on one edge, tear the leaflet across. Notice the thin colourless skin which can be torn off in this way, and the green inner tissue which is exposed; small specks of the green tissue remain attached to the skin, unless the tearing is done very carefully (try it several times, starting at different points on the edge of the leaflet). Now try to tear off the upper skin in the same way, and notice that it also is colourless, though a good deal of the green tissue always comes away with it. The leaflet therefore consists of a thin colourless skin covering its upper and lower surfaces, and a thick middle green tissue which is denser towards the upper surface and looser towards the lower surface (how is this inferred from your tearing experiments?) and which contains the veins.

21. "Bloom" on Leaf-surface.—Dip a leaflet into water and notice, on lifting it out, that the water runs off the surface very quickly, leaving it dry. Lay a leaflet on the table and place a drop of water on either surface in turn: notice in both cases that the water forms a globule instead of spreading over the surface. This shows that the leaf is not easily wetted by water, and suggests that the surface is covered by some substance like wax. This waxy substance is similar to that which forms the "bloom" on Grapes, Plums, etc., so that one might say the Broad Bean leaflet is covered with "bloom," which prevents water from wetting it and reaching the inner tissue. Try to remove the bloom by rubbing the leaflet gently (1) with a dry cloth, (2) with a cloth dipped into warm water; water placed on the leaflet will then wet the surface and spread over it.

22. The Stipules.—How does a stipule differ from a leaflet in shape, colour, and texture? Has it any veins (hold it against the light)? Notice the patch near the centre of the stipule: at first it is bright red or violet in colour, later it becomes brown or black. On which surface of the stipule is this patch most easily seen? This patch consists of minute glandular hairs, very closely crowded together on the lower surface of the stipule. A similar patch of glands occurs on the stipule in the Common Vetch of fields (*Vicia sativa*), the nearest ally of the Broad Bean among British plants; its functions are doubtful.

23. The Leaf-Stalk (Petiole).—Note the groove on the upper surface, making the leaf-stalk gutter-shaped. What does this comparison with a gutter suggest as to the use of the groove in wet weather? Test the matter by a simple experiment with a watering-pot, or watch a plant during a shower of rain.

What about the narrow prolonged tip at the end of the leaf-stalk? The nearest relatives of the Broad Bean are the Vetches and Peas, which differ from our type in being weak-stemmed climbing plants, the upper leaflets of their leaves being modified into slender organs (tendrils) which coil around supports. Get any of these (*e.g.* Sweet Peas) and compare their leaves with that of the Broad Bean. What light does the comparison throw on the nature of this part of the Broad Bean leaf? A special organ used for climbing is called a *tendril.* Make out with the lens the structure of the leaf-stalk. How are the bundles arranged? Is there a central air-channel, and is it continuous with the air-channel of the stem, or the branch, that bears the leaf?

24. Branches and Buds.—You will have noticed that each branch of the stem arises just above the base of a leaf, and that as a rule they become shorter towards the upper end of the stem. Pull off the young leaves at the end of the stem or of a branch, to see the small young branches (*buds*), one above the base of each leaf. These buds are called *axillary*, the space between the leaf-base and the part of the stem above it being called the *axil* of the leaf. At the very end of the main stem and of each branch there is a *terminal bud.* A bud is simply a young shoot, consisting of a short axis (stem) bearing young leaves which are closely crowded together and overlap the growing apex of the axis. Later on, the stem part of the bud grows in length and the leaves become spaced out on it, as well as growing larger.

The points on the stem where leaves come off are called *nodes*, the parts between the nodes being called *internodes*; but these names, though useful in describing plants, are often associated with a false conception of the shoot as being made up of "joints," each consisting of an internode and a node bearing one or more leaves. The node is merely a place where a leaf stands on the stem, and where the bundles of the stem divide and join with those of the leaf and also with each other, causing a swelling.

25. The Flowers of the Broad Bean are arranged in small clusters, each cluster arising in the axil of a leaf, and each flower is attached by a short stalk to the axis of the cluster, which occupies the same position on the shoot as an ordinary branch. The cluster or flower-bearing branch is called an *inflorescence*. Turn down or pull off the leaf just below an inflorescence, and examine the latter closely. This special kind of inflorescence, with the individual flowers stalked and spaced out on the axis, is called a *raceme*; the youngest flowers are nearest the top.

If Broad Bean flowers are not available, use those of Sweet Pea, or Gorse, or some other plant of the Bean Family.

In dissecting flowers use a sharp penknife (a pair of fine scissors will also be useful), a pair of forceps for seizing the parts of the flower, and a lens.

Note the parts of a single flower (Figs. 2, 3), starting from the outside :—

26. The Calyx, a greenish or colourless cup, with its free edge produced into five pointed lobes. Note the veins which start from the bottom of the cup, one running up the middle of each lobe, others between the lobes.

27. The Corolla (Fig. 2), consisting apparently of four pieces, a large upper piece (*standard*), two smaller side pieces (*wings*), and a lower boat-shaped piece (*keel*). Note the way in which the standard is folded below over the wings, which in turn enfold the keel. The standard is on the upper (posterior) side of the flower, *i.e.* the side towards the axis of the inflorescence; note the position of each of the calyx-lobes with reference to the axis, the odd one being the lowest.

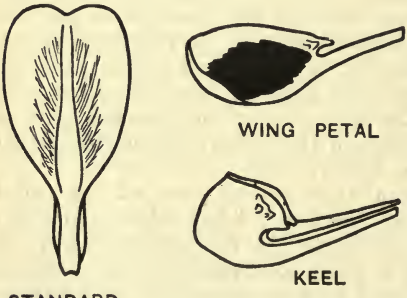

Fig. 2.—Corolla of Broad Bean.

Open the calyx by cutting or tearing it between the two upper lobes, to see the exact shape and position of each of the four parts of the corolla. Remove the standard and sketch it (front surface and side view); note its broad upper part, marked by coloured streaks, and the narrow lower part by which it is attached to the *receptacle* (*i.e.* the expanded upper end of the flower-stalk, to which all the parts of the flowers are attached). In each wing note the narrow stalk, and the broad oval portion which has a large blackish spot. Gently pull each wing outwards, and note that it clings to the outer surface of the keel: can it be pulled off without tearing anything? Note the way in which the wing on each side is locked with the keel; at this place the wing and the keel show a series of folds, the corrugated surfaces fitting together.

Remove and sketch one of the wings, both from the inner side and the outer side. In removing the standard and the wings, note that these pieces (*petals*) alternate in position with the calyx-lobes, *i.e.* the insertion of each of these three petals is just inside the space between two of the calyx-lobes. Now examine the keel, and note that it is carried on two separate stalks; detach these at their bases and pull them apart, when the keel will split along its sharp lower edge into two pieces. The corolla, then, consists in reality of five petals, the two lowest being attached to each other to form the keel, and the five petals alternate in position with the five *sepals* (calyx-lobes).

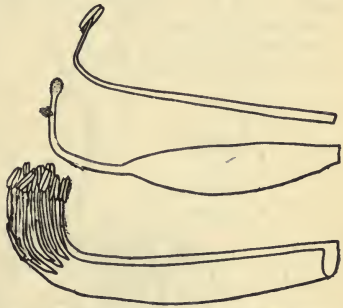

Fig. 3.—Stamens and Pistil of Broad Bean.

28. The Stamens (Fig. 3).—On opening up the keel you will see a number of small oval bodies (*anthers*), each carried at the end of a thin stalk (*filament*). How many anthers are there? If you see any stalks bare at the end, try another flower (a young unopened flower is best). Trace the stalks down, and notice that most of them are joined below to a thin colourless plate which is folded longitudinally. Does this folded plate form a complete tube or is it open? Where is the opening, and how is it covered over? Are any of the filaments free from the folded plate? Each anther, with its filament, constitutes a *stamen*, but only the uppermost stamen is free right down to the flower-axis; the others arise from the "stamen-trough." The upper parts of all the stamens bend sharply upwards, to suit the shape of the keel, in which they are enclosed; there is a narrow opening along the upper side of the keel, above the free stamen.

Examine an anther with the lens, noting the two lobes divided by a longitudinal groove, and each showing a less marked groove; the anther consists of four *pollen-sacs* lying side by side. This can only be seen in a young flower; in an older one the anther will have opened by two slits, one at each side, allowing the yellow dust-like *pollen* to escape. Sketch the ten stamens, with the "stamen-trough" as seen from the side; then cut round the base of the trough, remove it, and sketch it spread out.

29. The Pistil (Fig. 3), the innermost part of the flower, is now seen. It consists of a long green lower part with flattened sides, and a tapering free end produced into a slender outgrowth (*style*), which bends upwards and bears a tuft of hairs on the lower side of the bend, just below the tip. Examine these parts carefully, and sketch the whole pistil in side view. The lower part of the pistil resembles a small bean-pod, and for the present we may call it the "young pod." Is it hollow, and does it contain anything answering to the seeds found in the bean-pod? Cut it across, and open it up, to see what we may at present call the "young seeds." To which side (upper or lower) of the cavity are they attached?

Make and sketch a longitudinal section of the entire flower corresponding to that shown in Fig. 4.

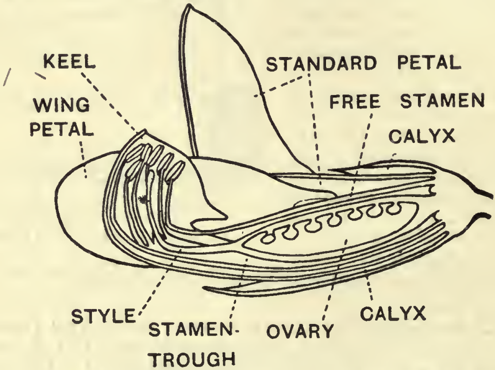

Fig. 4.—Longitudinal Section of Broad Bean Flower.

30. The Fruit.—You should watch some flowers from day to day, or compare different flowers on the same plant, and note any changes that occur as they grow older. What becomes of the calyx, corolla, stamens, style, young pod? What parts of the flower (*a*) wither, (*b*) persist, (*c*) grow larger? Watch the growth of the fruit (pod), opening up pods of different ages, to see what changes have occurred. How does the pod change in texture and in colour as it grows older and larger? How does the ripe pod open to let the ripe seeds out?

Do any changes occur in the rest of the plant (leaves, etc.) while the pods are ripening? What happens if you leave the plant undisturbed in the ground after the pods have ripened? What parts of the fruiting Bean-plant remain alive during the winter? What will next year's plants be produced from?

31. The Seed.—Examine some pods containing seeds, also get a supply of dry seeds (Windsor Broad Bean, about 6d. per quart). Notice the black (or brown) mark on the thicker end of the seed (Fig. 5). How was this mark on the loose seed produced? How does the seed become loose, and what does it break from when the pod opens? This mark may be called the *scar* of the *seed-stalk*. In what respects do dry seeds differ from fresh seeds?

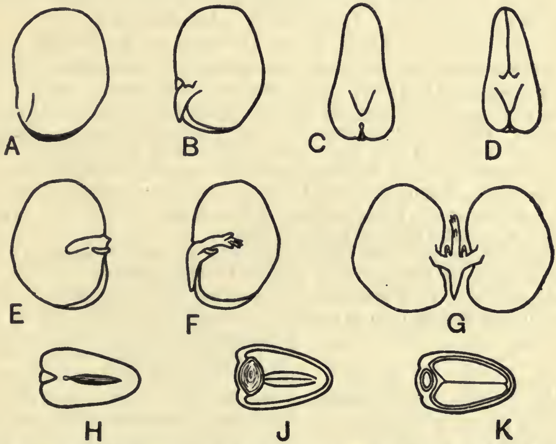

Fig. 5.—Seed of Broad Bean. A, C, and H are views of the entire seed; B, D, E, F, and G are views of the embryo (seed-coat removed); J and K, seed cut across (in J the cotyledons and radicle are removed, to show the radicle-pocket).

Put the dry seeds into water, and notice that in a few days they have swelled and become smooth and rounded, like the fresh seeds. Fill a wooden box, at least a foot deep, with moist sawdust, bog moss, or soil, and plant seeds about half an inch below the surface. See Chapter II. for details of germination. In the young green shoot that comes above the soil notice the forms of the earliest leaves.

32. Seed-coat.—Examine from time to time some dry seeds which have been placed in water, and notice that at first the surface becomes thrown into folds. Cut across the seed, and note that these folds are produced by a *coat* which encloses the contents of the seed. Evidently the coat at first absorbs water and swells more rapidly than the contents; this loosens the coat and makes it much easier to remove in a seed that has been soaked in water for a day or two. The wrinkling of the seed-coat is very marked in French Bean and Scarlet Runner.

33. Micropyle.—How does the water enter the seed? Is there any opening in the coat? The folds seen in the soaking seed usually appear first around the *edge* of the seed; this suggests that the water enters somewhere on the edge. Do you recall how we found out that various parts of the bean-plant contained air, which communicates with the atmosphere by openings on the surface of stem and leaves? Perhaps the seed as it lost water took in air, as a piece of wood does in drying. Drop some dry seeds into water that has just been boiled, and notice the stream of bubbles given off. Where do the air-bubbles escape? Wipe this end of the seed dry, in some seeds that have soaked for a few days, and look for the opening; squeeze the seed and see whether water oozes out. This opening is the *micropyle.*

34. Seed-lobes, etc.—Remove the coat from a soaked seed, starting at the end opposite the scar. Note the two large whitish *seed-lobes* or *cotyledons,* whose flat or slightly concave inner sides are pressed against each other. When you have stripped off the upper part of the coat, pull off the rest of it (the part covering the scar end) entire, like a cup. Note the smooth tapering body projecting from between the cotyledons and pointing towards the end of the scar where the micropyle is; also note the little pocket on the inner surface of the seed-coat, into which the projecting body fits.

Now pull apart the seed-lobes, and remove one by breaking across the short stalk by which it is joined to the thickest part of the projecting body. This brings to view a curved body lying between the seed-lobes, fitting into a groove on the flat inner surface of each lobe, and forming a continuous line with the projecting body. Has it, like the latter, an even surface, or does it bear any outgrowths? Examine it carefully with the lens, and try to turn back the outgrowths with a pin, without tearing them, so as to make out the positions of the outer ones.

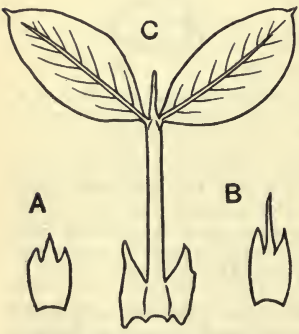

Fig. 6.—Earliest foliage-leaves of Broad Bean seedling.

35. The Seedling (Figs. 5, 6).—The first leaf above ground consists of a single piece with its margin cut by shallow notches into three lobes; the second leaf is divided deeply into three lobes, the middle lobe long and narrow, the lateral lobes broad and triangular. Then come several leaves, each consisting of two stipules and a short stalk which bears a pair of oval leaflets (note their folded appearance at first) and is prolonged into a rudimentary tendril. After several leaves like this we get leaves of the mature type, in which the stalk is lengthened below the terminal pair of leaflets, and carries two, three, or four additional leaflets. Have these early leaves, like the later ones, buds in their axils? In the first two leaves that appear on the young stem the three lobes evidently represent the two stipules and the rudimentary tendril.

36. Seedling compared with Seed.—Carefully pull up a seedling without injuring the root, and compare the latter with the root of the mature plant. Trace the young root upwards and the young shoot downwards, and notice the torn seed-coat and the cotyledons. In the axil of each cotyledon there is usually a bud. The cotyledons are therefore *leaves*, though differing from ordinary leaves (foliage-leaves) in many respects. They are often called the "seed-leaves."

The young plant, or seedling, has evidently grown from the whole of the seed-contents (*i.e.* everything inside the seed-coat), for we have seen that even the cotyledons are leaves, having buds in their axils. The cotyledons are the first leaves of the young plant, which is called the *embryo* while still inside the seed. The embryo consists of an axis which bears the two cotyledons at about the middle, and which ends in a root[1] (covered by a root-cap) at one extremity and a bud[2] (bearing young foliage-leaves) at the other.

37. Seedling compared with Mature Plant.—We have noted the simple form of the earliest leaves as compared with the older ones. The cotyledons are opposite each other and are attached to the same point on the axis, but the early foliage-leaves show the same arrangement (alternate, in two opposite rows) as in the mature plant. The root of the seedling shows the same general appearance and structure as that of the mature plant, into which it grows, later on forming the characteristic nodules.

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[1] The root of the embryo is termed the **radicle**.

[2] The shoot-bud of the embryo is called the **plumule.**

If you were unable to get mature Broad Bean plants when you began work, you will find it very easy to raise the plants from seed in pots of soil indoors or in the garden. Some plants should also be raised in "culture solution" (Art. 143).

We have seen that the use, purpose, or function of the flowers is to produce the ripe seeds. Later on we shall study the functions of the leaves, stems, and roots. At present, however, we shall take up the germination of the seed, for this will lead us at once to make experiments—the only way in which we can gain any real insight into the life of plants.

CHAPTER II.

SEEDS AND SEEDLINGS.

38. The Germination of the Seed.—We have seen that the Broad Bean seed contains a young plant and is covered by a seed-coat; that the young plant consists of an axis which bears at one end (radicle end) a root-cap, at the other end (plumule end) some young foliage-leaves, and at the middle a pair of large seed-leaves; that when the dry seed is placed in water it swells up; that when the soaked seed is planted in moist sawdust or soil the seed-coat breaks open; that the radicle end of the young plant's axis grows down into the sawdust or soil and forms the root, and the plumule end grows upwards into the air and forms the shoot, while the seed-leaves remain in their original position; that the young shoot keeps for a time the hooked form which it has while inside the seed-coat, but gradually straightens out as it grows upwards; and that the young plant or seedling which arises in this way gradually grows into a mature plant.

The changes that occur, from the time the dry seed is placed in water until the young plant establishes itself, are all included in the term *germination*. The young plant in the dry seed is alive but dormant, and the germination of the seed is simply the awakening of the young plant to active life and growth.

Broad Bean seeds (and those of most other plants) germinate best when sown within a year of their ripening; the longer seeds are kept the fewer will germinate and the feebler will be the growth of the resulting plants. Broad Bean seeds will sometimes germinate after being kept for six years. In other plants the seeds may remain alive for a longer time, but the embryo, though dormant, is *living* and therefore gradually losing substance by respiration, besides losing water to the dry air around it.

39. Hints on Fitting up Apparatus.—As you will be constantly called upon during the course to accurately fit flasks, etc., with corks bored with one or more holes, and bend glass tubing to various angles, you had better master these simple operations at once.

(*a*) **Fit a Flask of Medium Size with a Cork.**—Select a cork a little too large ; wrap it in a piece of paper and, using gentle pressure with your foot, roll it to and fro upon the ground. This softens the cork, and the risk of breaking the neck of the flask is lessened. If still too large, file down the cork equally all round.

(*b*) **Bore a Cork Lengthwise and Fit a Glass Tube tightly into the Hole made.**—Select a cork-borer (Fig. 8) slightly less in diameter than that of the tube to be fitted into the cork. The cork-borer is a brass tube about 5 ins. long sharpened at one end. At the other are two small holes opposite each other ; through these the accompanying iron rod may be thrust to serve as a handle. The borers are generally put up in sets of three or more. Place the cork against the edge of your bench, as shown in Fig. 7. Press the borer gently into the narrower end of the cork and work it alternately round to right and left. The borer must be sharp to make a clean cut, and the tube must fit tightly.

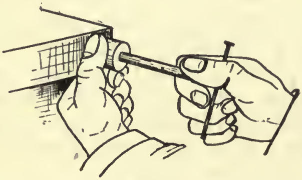

Fig. 7.

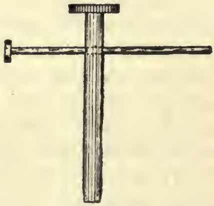

Fig. 8.

Now take the cork prepared in (*a*) and bore two parallel holes in it similar in position to those in the wash-bottle (Fig. 11).

(*c*) **Cut some Glass Tubing about $\frac{1}{4}$ in. in Diameter into Lengths 4 to 6 inches.**—Lay the tube flat on the bench and with a sharp triangular file make a scratch across it where required, the pressure used being regulated by the thickness of the tube. Now hold the tube in both hands, with the scratch away from the body and the tips of the thumbs touching each other just opposite the scratch. Break the tube by bending it, giving a pull at the same time. Round off the sharp ends by fusing them in the Bunsen flame.

(*d*) **Bend some pieces of Glass Tubing to form Right Angles.**—Use an ordinary spreading gas flame lowered until it is about 2 ins. across. Place the tube over the flame for a few seconds, and gradually bring it down into the hottest part, as shown in Fig. 9. Turn the tube round and round till it softens, then allow one end to fall until it makes the required angle. The bend should be round and smooth ; the Bunsen flame is apt to give buckled bends (Fig. 10).

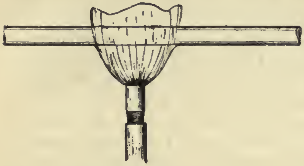

Fig. 9.

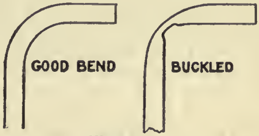

Fig. 10.

(*e*) **Bend some Tubing twice at Right Angles so as to form Three Sides of a Rectangle.**—When laid down all three sides must touch the bench.

(*f*) **Make two Nozzles.**—Hold a piece of tubing by both ends; soften the middle, and pull the ends slightly apart. Cut the tube through and round off the ends.

(*g*) **Complete the Wash-bottle.**—Bend suitable pieces of tubing to form angles equal to those seen in the wash-bottle in Fig. 11. Push them through the cork prepared in (*b*), and attach a nozzle by means of an inch or so of rubber tube.

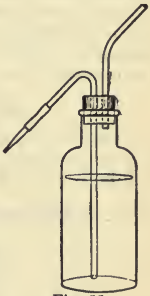

Fig. 11.

40. Experiments.—In making experiments, sketch the apparatus used. Make notes of the materials experimented with (name of plant or part of plant, number, condition, stage of growth, etc.); the duration of the experiment, date, time of day; the external conditions (temperature, light-intensity, humidity, barometer-reading, etc.); the precautions which seem necessary, and the sources of error which may spoil the results.

Always make "control" or "check" experiments, using the same form of apparatus, set up at the same time, but with one or other of the conditions different, *e.g.* in darkness instead of light; with the plants omitted; with killed instead of living plants; with plants in different stages of growth. Also make "repeat" experiments, using different plants under similar conditions or the same plants at different times of year or day, etc.

If your experiments do not succeed, try again; if they give discordant results, try to account for these and to think out a method for a repeat experiment under different conditions, with special precautions, or for making a new experiment altogether. In drawing conclusions, try to distinguish between probability and actual proof.

For various experiments with plants you will need (1) a rough balance for large weights, and (2) a finer balance for smaller weights. For the first, cooking-scales with weights from 7 lbs. to $\frac{1}{4}$ oz., or a cheap spring-balance, will suffice. If you have not a small balance, get a cheap pair of apothecaries' scales (about 4s.) and suspend them from a ┐-shaped wooden frame fixed to a board below. If you get a single gramme-weight and the fractions, you can make duplicate gramme-weights from sheet-lead.

The **metric system** of weights should be used. The unit of length in this system is the metre, a platinum rod kept in Paris and originally supposed to be a tenth-millionth part of the distance from the North Pole to the Equator. The metre is multiplied and divided by 10 for the higher and lower measures of length; the Greek prefixes *deca-*, *hecto-*, and *kilo-* represent 10, 100, and 1000, and the Latin prefixes *deci-*, *centi-*, and *milli-* represent ·1, ·01, and ·001. The same prefixes are used in the other measures. The unit of volume is the cubic decimetre, or **litre**, but the cubic centimetre (*i.e.* the millilitre), usually written "c.c.," is often used for volumes less than a litre (1000 c.cs.). The weight of 1 c.c. of distilled water at 4° C. is the unit of weight, the **gramme**, with multiples and subdivisions as before.

Place an inch-rule graduated to tenths or eighths and a centimetre-rule graduated to millimetres edge to edge, and find how many centimetres are equal to a foot. If the scales are accurate, you should get the number 30·5.

Metric Equivalents (Approximate).

1 inch = 2·5 centimetres.	1 centimetre = $\frac{2}{5}$ inch.
1 ounce (avoir.) = 28 grammes.	1 gramme = 15 grains.
1 fluid ounce = 28 c.cs.	100 c.cs. = $3\frac{1}{2}$ fluid ounces.

41. Germination Jars.—Into a large wide-mouthed glass jar put

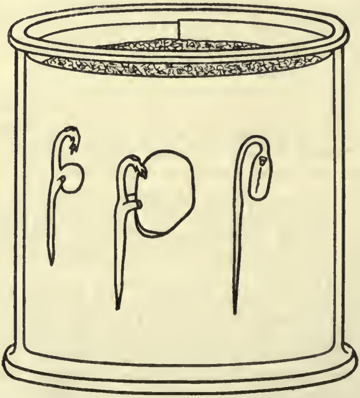

Fig. 12.—Germination Jar. The seeds (Pea, Broad Bean, Sunflower) have had the seed-coat and one Cotyledon removed.

a rolled-up piece of blotting-paper, then fill up the jar with sawdust, keeping the paper pressed against the glass. Place seeds in different positions between paper and glass (Fig. 12), and pour in water enough to moisten sawdust and paper. Fit up a few of these jars, because later on you will have seeds of several kinds to germinate. Sphagnum (bog-moss) is better than sawdust; it is easier and cleaner to use, and it retains water better. Tumblers or lamp-glasses may be used instead of large glass jars.

42. Glass-sided Boxes.—Get two oblong wooden boxes (depth should be at least a foot for the long roots of Bean seedlings).

(*a*) Remove one of the longer sides and replace it by a vertical sheet of glass; at each end of the box fasten a strip of wood on each side of the glass, or simply knock tacks in to keep the glass side in position.

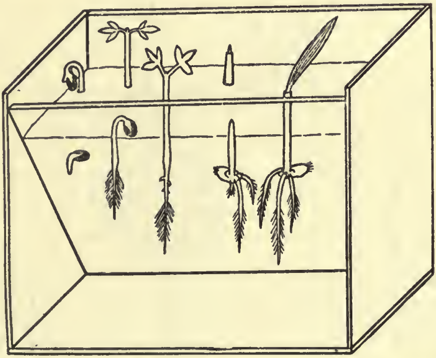

Fig. 13.—Glass-sided Germination Box, with Seedlings of Cress and Wheat.

(*b*) Make a similar box, but fix the glass side so that it slopes downwards and inwards (Fig. 13). Fill the boxes with moist sawdust and place the seeds close to the glass.

43. Early Stages of Germination.—How do the young root and the young shoot emerge from the seed-coat? Which is the first to appear on the outside? Notice the V-shaped split in the coat along the edge of the root-pocket, caused by the root swelling up and raising the outer wall of the pocket as a triangular flap (does the apex of the triangle reach as far as the opening[1] in the seed-coat or not?). The stalk of each cotyledon grows in length, pushing the cotyledons apart and allowing the curved shoot to grow out between them. What is the advantage to the young plant in the fact that the root emerges before the young shoot? What advantage is there in the hooked form of the young shoot?

Make Sketches (in this case twice the natural size will be large enough) of (1) entire seed from the scar end; (2) same from the front, *i.e.* thicker edge, showing the pore and the bulge caused by the root; (3) same in side view; (4) side view showing the triangular flap being

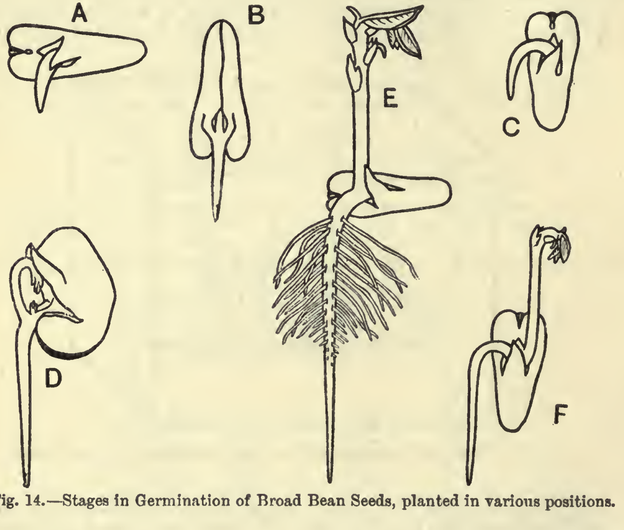

Fig. 14.—Stages in Germination of Broad Bean Seeds, planted in various positions.

pushed off by the growing root; (5) front view showing the same; (6) side and (7) front views of embryo after removing seed-coat; (8) scar-end portion of empty seed-coat, showing the pocket into which the root fits; (9) side and (10) front views of embryo with one seed-leaf broken

[1] The erroneous statement that the radicle grows out through the micropyle in germination is often made in books. This opening in the seed-coat doubtless helps the swelling radicle to split the coat, since it forms a weak spot, but a glance at a Broad Bean seedling shows that the coat splits along the edge of the radicle-pocket, the line of weakness, and that the split does not reach as far as the micropyle.

off; (11) section through whole (soaked) seed, to show pocket with root fitting into it (cut between seed-leaves). Also sketch various stages in germination of seeds planted in different positions and at different depths in your jars and boxes. See Fig. 14.

44. What things are needed to make the seed germinate?—What have been the surroundings of the seeds whose germination you have been studying? Write down these things as they occur to you. The seeds were steeped in **water,** placed in **soil** (or sawdust), exposed to **light** and **air,** and supplied with a certain amount of **warmth.** Now, which of these things are absolutely essential for germination?

* Can you devise a simple experiment to show that a seed can germinate in the air, without any soil or sawdust for the root to grow into? In what condition would the air have to be kept during the experiment? Get a wide-mouthed glass jar and pour into it enough water to cover the bottom to a depth of an inch or so. Then stick a long pin through a soaked Broad Bean seed and fix it into a cork (or a piece of wood to cover the mouth of the jar), inverting the latter so as to bring the seed into the jar (Fig. 15). The seed will germinate in the moist air. Keep this simple piece of apparatus for later experiments.

Will a seed germinate if kept dry? Place some dry seeds in dry sawdust and others in moist sawdust (an inch below the surface); compare the results after a week or two.

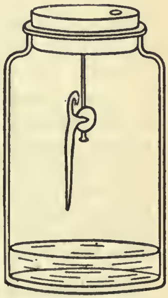

Fig. 15.

45. How to dry Seeds, Seedlings, etc.—Are the "dry" seeds sold by the seedsman quite dry, or do they contain any water at all? Into a dry test-tube (warm the tube all over to make sure it is quite dry) put a "dry" seed and heat gently over a Bunsen or spirit-lamp. Notice the drops of water which condense in the colder upper part of the tube. Weigh about 20 "dry" seeds, and dry them thoroughly without scorching or charring them at all. This is best done by placing the seeds for a few hours in an oven, or by means of a sand-bath or a water-bath. Then compare the weight of the thoroughly dried pieces and find out the percentage weight of water which the "dry" seeds originally contained (usually about 10 per

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* Throughout this book asterisks are used to indicate a course of experiments which are of fundamental importance.

cent.). This amount of water, though not sufficient to allow of germination taking place, is evidently necessary for the seed to remain alive and capable of germinating. The weight found after thorough drying, without charring, is called the **dry-weight** of the seed or seedling.

* To dry seeds, seedlings, leaves, etc., without charring them, use a slow oven, a water-bath, or a sand-bath over a small flame. A simple sand-bath consists of a shallow tin or pan filled with sand, supported on a tripod and heated below as usual, the seeds being placed in a smaller tin or a saucer resting on the sand.

46. Absorption of Water by Seeds.—In the absorption or imbibition of water by dry seeds we have an interesting subject for investigation. Imbibition is due to the attraction of the particles (molecules) of the two substances for each other, which partly overcomes the cohesion of the molecules of the imbibing substance, making them separate so that the substance swells. It makes the tissues more porous by separating the molecules and is thus an important aid to osmosis (Art. 51)—the process which controls the diffusion of liquids through membranes. Imbibition is increased by warmth and by the presence of dilute acids and alkalis, but is diminished by that of salts. The work done in imbibition is shown by the force exerted by swelling seeds or wood, and by the fact that heat is given off.

(*a*) Keep some "dry" seeds in a drying-oven or drying-bath until they show no further loss in weight, and then find out whether they swell up in water and whether they germinate. The results will show that killed seeds still have the property of absorbing water.

* (*b*) When a dry seed is placed in water, how much does it absorb, and what proportion do the volume and weight of the absorbed water bear to the volume of the dry seed? Weigh twenty dry Beans; pour water into a graduated vessel until it reaches the 150 c.c. mark, then drop in the beans, and shake the vessel to get rid of any air present; the rise in level gives the volume of the Beans. Take them out and place them in moist sawdust for two days, then wipe them dry, weigh them, and find their volume as before. If you have no graduated vessels, use a glass jar with a strip of paper, marked into inches or centimetres, gummed on the outside of the jar. Beans absorb about 130 per cent. of their own dry weight of water.

* (*c*) The swelling of seeds by imbibition of water can be easily demonstrated to a class. Put about 30 grammes of dry Peas and an equal

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* See footnote on p. 23.

amount of water into a narrow cylindrical glass jar. Cover the Peas with a cork; smear the edges of the cork so that it can slide inside the jar, and pass a thermometer through a hole bored in its centre. Weigh the cork down with lumps of lead or a number of weights and mark its position by gumming a strip of paper on the outside of the jar. Fit up a "control" experiment in which a cork with a thermometer hangs into a jar containing some water but no seeds. Note the rise of the cork as the Peas swell and push it up, and compare the temperatures, at the beginning and end of the experiment, in the jar containing the Peas and that containing water (or that of the surrounding air).

(*d*) Does imbibition cause rise of temperature in dead substances as well as in seeds? Put some powdered starch into a tumbler, to form a layer about an inch deep, put an equal amount of water into another tumbler, and set a thermometer into each. When the two temperatures are equal, pour the water over the starch, stir with the thermometer, and note the rise in temperature (how many degrees?).

* (*e*) If a small wooden box (*e.g.* a cigar-box with the lid fastened down by tacks) is filled with dried Peas and then immersed in water, it will burst as the Peas absorb water and swell. Try this experiment. A large mass of swelling Peas may lift a weight of more than 100 lbs.

(*f*) The force exerted by swelling seeds can also be shown by filling an ordinary narrow-necked bottle with Peas, and placing it under water in a basin; the bottle should be left uncorked, and some rubber bands should be put round it to prevent the shattered glass from being thrown out. Another method is to fill with dry Peas an empty rabbit-skull and let it lie in water; the bones will be torn apart along the seams (sutures) where they join each other.

* (*g*) How is the absorption of water by seeds affected by temperature? Weigh about 30 grammes of dry Beans or Peas, place them in a beaker of water at 35° C., set the beaker on a sand bath with a thermometer in the water, and keep the temperature steady at 35° C. for two hours. At the same time place an equal weight of seeds in cool water, with a thermometer; first let the water stand for a time till it acquires the temperature of the room. At the end of two hours, wipe dry both lots of seeds and compare the increase in weight in each case. The seeds that have been kept in water at 35° C. will have absorbed from two to three times as much as those kept in the cool water.

* (*h*) Weigh about 30 grammes of dry Peas and place them in a 10 per cent. solution of salt in a beaker or tumbler. At the same time put a similar weight of Peas in distilled water (or tap water). Compare the weights of the two lots of seeds after two hours, wiping them dry before weighing. Which lot has increased most in weight?

47. Where does Water enter the Seed?—When dry Beans or Peas are placed in boiling water, air escapes from the micropyle. When a dry seed is placed in water or moist sawdust or soil, does the water enter solely by the micropyle, or does any enter through the seed-coat?

* (*a*) In a box of moist sand, which must be kept moist by adding water every day, plant three rows of Beans, those in the first row with the scar end downwards, those in the second with the scar end upwards, those in the third laid flat with the scar at one side. Press them into the sand so that each seed is half buried, and compare the germination of the seeds in the three rows.

* (*b*) Could water enter by the scar if the micropyle itself were sealed up? Seal the micropyle in some dry seeds (weigh before and after sealing) with sealing-wax, plasticine, rubber solution (or tyre-mending cement); put the sealed seeds in water along with some unsealed dry seeds which have also been weighed. Wipe dry and weigh the sealed and unsealed seeds at intervals, to find out which lot is absorbing water most rapidly and which most slowly. When unsealed seeds have absorbed the maximum amount of water (about 120 per cent. for Broad Bean), seeds with sealed micropyle that have been in water for the same length of time will have absorbed only about 60 per cent.

48. How does Water enter the Seed?—If you put some dry Broad Bean seeds into a jar, fill the jar up with water, and let it stand open for a few days you will notice that the seeds swell up but do not germinate (the radicle may burst through the seed-coat), and a scum forms on the surface of the water, which after a time becomes cloudy and ill-smelling. The scum, cloudiness, and bad smell are due to the growth of "germs," or *bacteria*, which have evidently entered from the air, though some may have been present in the water (unless it was boiled for some time) or on the seeds (unless they were washed with formalin or other substance that kills germs). Bacteria can only grow in the presence of organic matter; hence the seeds have not merely absorbed water, but have also lost some organic matter, which has passed into the water around them. This loss occurs even when the micropyle is sealed up with sealing-wax, rubber-cement, etc.

49. Capillarity and Osmosis in Seeds.—Water enters the seed partly by way of the pore (micropyle) and partly through the seed-coat. The micropyle is a canal leading into the cavity of the seed, which draws water in by *capillarity*.

The water passes round the edge of the cotyledons, into the space between them, and into the radicle-pocket. Water also enters by *osmosis* through the seed-coat, and at the same time part of the solid matter contained in the young plant passes out, in solution, into the water. This substance which escapes from the seed is largely cane-sugar in the case of the Broad Bean. When the cargo of a wheat-carrying ship becomes damaged by water on a voyage, the weight of the Wheat when dried again is found to have suffered considerable loss by sugar passing out into the water. We shall see later how the Bean seed and Wheat grain come to contain sugar after soaking in water and beginning to germinate.

50. Capillarity.—The free surface of water (and other liquids) behaves much as though it were covered by an elastic membrane (surface film). It is this **surface tension** that draws the raindrop into the form of a sphere as it falls through the air, and that causes water to form into spheres on a dusty floor or on the leaves of many plants (or on any surface which is not wettable by water). The cause of surface tension is the attraction of the particles (molecules) of water for each other. This attraction extends throughout the liquid, but only the molecules at the surface show its influence, because it is only these that are not pulled evenly in all directions by water-molecules on every side.

When open glass tubes, having a very small bore, are held vertically in a liquid, there is always a difference between the level of the liquid inside the tube and that of the liquid outside. If a glass tube of this kind be placed in water, the level of the water in the tube will be above that of the water outside, and the surface of the water in the tube will be concave. In the case of mercury, the level inside will be below that outside, and the surface will be convex. The finer the tube, the more marked will the result be. The liquid only ascends when it is capable of wetting the sides of the tube.

Hence we have two kinds of capillary action—in one the liquid wets the tube, ascends, and has a concave surface, in the other it does not wet the tube, descends, and has a convex surface. We need only deal with the capillary ascent of water, which is of importance in plant-life. If the tube (supposed circular in cross section) is 1 in. in diameter, the water rises 0·054 in.; if 0·1 in. in diameter, the water rises 0·54 in., and so on. In a tube 0·001 in. in diameter the water rises 54 ins.

This capillary action is closely connected with the surface tension of the water, and it is therefore natural that the total lifting force which supports the column of water should be proportional to the circumference of the tube. The circumferences of tubes increase in the same proportion as their diameters (circumference of a circle $= 3{\cdot}14 \times$ diameter), hence a tube 0·1 in. in diameter will lift above the water-level ten times as much water as a tube 0·01 in. in diameter.

But the area of the water-column increases as the *squares* of the diameters of the tubes (area of a circle = ·785 × square of diameter), hence the wider tube will only lift its column one-tenth as high as the narrower one, its load being then ten times as great.

Fine tubes that show this phenomenon well are called *capillary* (*i.e.* hair-like) *tubes*, and the phenomenon is known as *capillarity*. The "soaking up" of ink by blotting-paper is an example of capillary attraction, the fibres of the blotting-paper being really minute tubes, whose substance is "wetted" by the ink, so that the level of the liquid rises considerably in the tubes. Other cases are the "sucking up" of water by a lump of sugar, the rising of the melted wax in the wick of a burning candle or of oil in a lamp-wick, and the diffusion of water through soil

51. Osmosis.—When raisins are placed in water, they swell up just as dry seeds do. On the other hand, if grapes are placed in a strong solution of sugar, they shrink. The swelling of the dried seeds or raisins and the shrinking of the fresh grapes are due to *osmotic pressure*.

If we place in a vessel of water a bladder filled with a strong solution of a substance having an "attraction" for water, *e.g.* sugar, a *large* amount of the water will diffuse (pass by osmosis) into the bladder (*endosmosis*), while a *small* amount of the solution will diffuse out (*exosmosis*). The weaker solution diffuses faster, and this continues until the same concentration is acquired, when it is equally rapid in both directions, and hence apparently ceases. Meanwhile pressure is set up inside the bladder, owing to rapid endosmosis.

* **52. Thistle-tube Experiments.**—(*a*) Get a thistle-tube ("thistle-funnel," with 18-inch tube, 3d. or 4d.), and prepare a strong (about 10 per cent.) solution of sugar, colouring it by adding red ink if the experiment is to be shown in a class. Get a butcher to clean, inflate, and dry a sheep's bladder for you; cut out a piece large enough to tie over the wide mouth of the tube, and soak it in water.

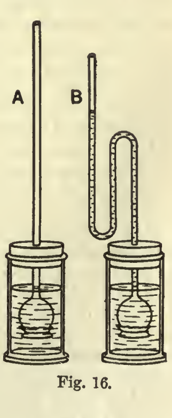

Fig. 16.

Plug the narrow end with a bit of plasticine, pour into the wide end enough solution to fill the head and an inch or so of the narrow part, tie over the mouth the piece of bladder, invert the funnel, and remove the plug of plasticine. Then fix the "funnel," head downwards, into the cork of a wide-mouthed glass jar containing water, so that the coloured sugar solution in the tube is level with the water (Fig. 16A). Observe the rise of the liquid in the tube of the funnel, also show that a little of the sugar solution diffuses into the water, by evaporating the liquid in the dish to dryness, when a small residue of sugar will remain. If the sugar solution used is strong enough, the presence of sugar in the water outside of the thistle-funnel may be detected by tasting.

(*b*) Repeat the experiment, using common salt (about 20 per cent.) instead of sugar in the bulb and distilled water instead of tap water in the jar. From time to time take a little water out of the jar, put it in a test-tube, and add a drop of silver nitrate; a white precipitate shows the presence of salt in the water.

When the liquid stops rising in the tube take the thistle-funnel out, replace the water in the jar with a very strong solution of salt, put the bulb in again, and note that the liquid now falls in the tube (why?).

53. Osmotic Pressure.—Careful experiments with suitable membranes have shown that the osmotic pressure set up by a 1 per cent. solution of saltpetre is enough to support a column of water over 100 feet high, *i.e.* equal to a pressure of 3½ atmospheres, or more than 50 lbs. per square inch. Some idea of osmotic pressure may be obtained by using apparatus fitted up like that shown in Fig. 16B (a thistle-tube like this costs about 6d.). The pressure can be measured by pouring mercury into the bent tube, so that at first the mercury is at the same level in the two limbs of the tube, and noting the extent to which the mercury is pushed down in one limb and rises in the other. The cork should be split so as to fix the tube in it (this is not shown in Fig. 16A, but the use of the cork is merely to hold the tube in position).

The pressure set up by endosmosis has an important application in connection with root-absorption and other processes in plant-life.

54. Properties of Water.—Since water is absolutely essential in connexion with the germination of seeds, and other processes in plant life, you should study, in books on Chemistry and Physics, the various chemical and physical properties of water. Get clear ideas on the following topics, and as far as possible make experiments for yourself, unless you have already gained a thorough practical knowledge of the subject.

The three states in which water exists, the impurities of natural water; filtration, solution, evaporation, distillation, condensation; the gases dissolved in natural water; the thermometer; alcohol, mercury, maximum and minimum, and black-bulb thermometers; change of state; freezing and boiling points; expansion of water when heated from 4° C. to 100° C., and its expansion when cooled from 4° C. (the temperature of maximum density of water) to 0° C.; conduction and convection of heat; specific heat; latent heat; unit of heat; composition of water, as shown by analysis and by synthesis; properties of hydrogen and of oxygen.

55. Is Air required for Germination?—The seeds in your germination jars and boxes are exposed more or less freely to air. It is very easy to find out whether air is essential for germination, by depriving the seeds of air, or by confining seeds in closed vessels containing different quantities of air and comparing the results.

Take four glass jars, all of the same size, and provided with well-fitting corks (Fig. 17). Fill these jars to different heights with moist sand, marking each jar into five equal parts, and putting into the first jar enough sand to reach the lowest mark; into the second, sand up to the next mark; and so on. The fourth jar will thus contain four

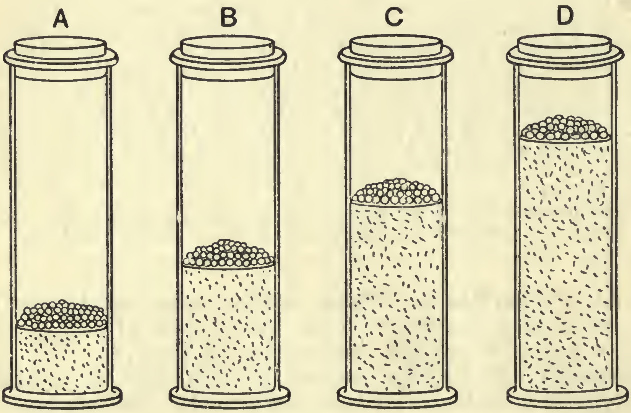

Fig. 17.

times as much sand, and therefore only a quarter as much air, as the first. Into each jar now place six soaked Beans (or twenty Peas), cork tightly, and seal with plasticine and vaseline. In which jar do the seeds germinate best? Do the results suggest that germinating seeds cause some change in the air, that they use the air up?

After three or four days, carefully remove the cork from one of the jars and lower a lighted taper or match into it: note what happens. Open another of the jars, and dip into it a glass rod which has been dipped into clear lime-water (or baryta-water, made by shaking up some barium hydrate with water and filtering).

56. Respiration of Germinating Seeds.—These experiments show that germinating seeds absorb oxygen and give out carbon dioxide, so that a germinating seed changes the air around it in the same way that an animal does by its breathing. Since the same change is produced by burning in air a candle (which contains carbon) or a piece of charcoal (which is practically pure carbon), we see that the respiration or breathing of a germinating seed, or of an animal, is simply a process of oxidation, a slow burning of carbon. Hence the seed must contain carbon in some form; we shall return to this point later. Meanwhile, here are some further experiments on the respiration of germinating seeds.

* (a) Get a wide-mouthed jar with a tightly fitting cork; bend a glass tube twice at right angles, so that the two parallel legs will be of about equal length, and through a hole in the cork push one of the legs until

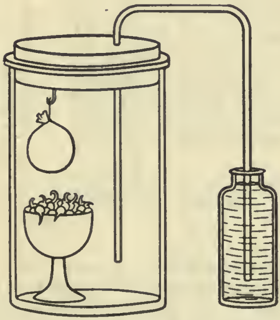

Fig. 18.

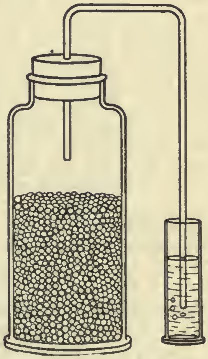

Fig. 19.

it nearly reaches the bottom of the jar (when corked). Fill a small muslin bag with soaked Peas, mixed with bits of soaked Sphagnum or clippings of wet sponge, and hang the bag to the lower side of the cork by means of a bent pin. Put a bit of sponge soaked in caustic potash solution[1] in a small wide-necked bottle or an egg-cup and lower it into the jar (Fig. 18). Smear the top of the cork and the rim of the jar with plasticine. Put the outside tube in a tumbler or open bottle

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[1] This solution rapidly absorbs any carbon dioxide in its neighbourhood, but the carbonate of potash formed is *soluble.*

of water coloured with red ink; keep the apparatus in a fairly warm place, and note any visible result.

After a day or two, when you find that no more water seems to be collecting at the bottom of the jar, raise the cork and insert a lighted taper. Now write out an exact account of what has happened during this experiment. What changes in the air have been wrought by the germinating seeds? Why does the water pass over through the bent tube from the vessel outside into the jar?

* (*b*) In the last experiment the carbon dioxide produced by the germinating seeds was absorbed by the caustic potash solution in the sponge. Omit the latter this time; half-fill the jar (Fig. 19) with soaked Peas or Beans, and fix the bent tube so that the end of one limb is above the level of the seeds, while the outer limb dips into a bottle containing lime-water or baryta-water. Set the apparatus in a warm place, and notice the bubbles of carbon dioxide which are given off, and which cause a white precipitate.

* (*c*) Take three U-tubes and three narrow jars (or test-tubes a little wider than the U-tubes). Place in one arm of each U-tube (Fig. 20) six soaked seeds (Peas or Wheat), then invert the U-tube after inserting a cork, with a wad of soaked cotton-wool to keep the seeds moist. Half-fill the jars or test-tubes with (1) water, (2) strong caustic potash solution, (3) strong solution of pyrogallol in caustic potash, and place the open ends of the U-tubes in the test-tubes. If you have no suitable narrow jars, support the test-tubes in a stand.

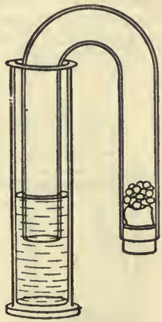

Fig. 20.

Notice that in (3) the solution soon rises in the inverted U-tube (how far does it rise, and why?) and the seeds germinate very little (why?); in (2) the solution rises, more slowly, and to the same extent (why?), and the seeds germinate well; in (1) the water hardly rises at all, though germination occurs as in (2). What has happened in each case? In (2) the seeds absorb oxygen from the air and give out carbon dioxide, which is absorbed by the potash solution, and the latter therefore rises slowly in the U-tube for about a fifth of its length; in (3) the potash and pyrogallol solution absorb the oxygen of the air in the U-tube. Why does the water not rise in (1)?

57. Intra-molecular Respiration.—In the foregoing experiments it is clear that normal germination does not occur unless the seed is supplied with air containing oxygen. In some cases, however, a slight amount of growth occurs even when the seeds are deprived of oxygen, and sometimes a good deal of carbon dioxide is given off under such conditions, as is shown by the following experiments.

* (*a*) Soak some Peas in water for a day, so that their coats can be removed without damaging the embryo (the coats are removed so as to avoid introducing air with the seeds). Fill a test-tube with mercury and invert it in a dish of mercury; then pass six peeled Peas under the open end of the tube, when they will float up to the closed end. In a day or so the test-tube is half full of gas: what is this gas, and how has it been produced? With a bent tube pass a little water under the test-tube, so that it will float up to the surface of the mercury, then pass up a small piece of potash; the potash solution thus formed absorbs the gas, and the mercury rises again to its original position.

This production of carbon dioxide, in the absence of free oxygen, is called "intra-molecular respiration"; apparently in some way the substance of the embryo is decomposed in this process, and besides carbon dioxide, alcohol and other products are formed. This process is very marked in Peas and Beans. In all cases it is a process of destruction, without healthy growth taking place.

* (*b*) Another method, good for demonstration to a class, is to use the "Torricellian vacuum." Pass a few peeled Peas into the vacuum at the top of a 33-inch tube filled with, and inverted over, mercury. The "vacuum" at the top of the tube contains mercury vapour, but no air. Test, after a day or two, with caustic potash as in the preceding experiment. Note the height of the column (1) after the Peas are passed up, (2) after the column is depressed by the carbon dioxide formed, and (3) after the absorption of this gas by the caustic potash. In each case note also the reading of the barometer at the time (why?).

In each case, as a control experiment, use Peas which have been killed by boiling in water: is carbon dioxide produced by killed seeds?

58. Heat produced by Respiration.—From the foregoing experiments it is clear that respiration is a process of oxidation, just as burning is, and this suggests that it may be accompanied by the giving out of heat. Do germinating seeds give out heat?

(*a*) Fit three tumblers or jars with a cork or a cardboard cover, with a hole in the centre through which a thermometer is passed. First compare the readings of the three thermometers by placing them together in water at different temperatures. Half-fill one jar with soaked seeds (Peas, Beans, Wheat, or Barley answer well); the second with seeds that have been killed by boiling (add some corrosive sublimate to the water to prevent growth of Moulds or Bacteria); the third with moist sawdust (as a control). Place the three jars, with thermometers inserted to equal depth in each, in a box, and put dry sawdust between and around them; cover the whole with a bell-jar or a dry cloth, and compare readings of thermometers at the start of the experiment and then at intervals of a few hours. A rise of 2° C. or more may be observed.

(*b*) Instead of jars or tumblers use three test-tubes, each with a bored cork for the thermometer; place the tubes horizontally in a cardboard box, with thermometer-stems projecting through holes, and pack round and between the tubes with dry cotton-wool.

59. Influence of Depth of Sowing on Germination.—In the lower as compared with the upper layers of the soil we find, as might be expected, less air, less circulation of air, and more water. How does the depth at which a seed is placed in the soil affect its germination?

* Plant seeds in your glass-sided box at different depths. Put the seeds close to the glass, and (unless the glass has been fixed in with putty so as to be air-tight) put them near the middle of the glass. If the seed is buried too deeply it does not get enough air for healthy germination, and it is apt to be attacked by moulds.

60. The Atmosphere.—As the life-processes of plants depend upon a supply of air, and are greatly influenced by changes in it, the properties and composition of air must be thoroughly understood by the student of plant life. Study this subject, as far as possible, by experimental methods, and consult books on Chemistry, Physics, and Physiography on the following points:—

The weight of air; pressure of the atmosphere; Torricelli's experiment; barometers; variations in air-pressure, and their connexion with weather changes; effects of pressure and temperature on volume of air; wind; gaseous diffusion; diffusion of gases through small openings (*e.g.* porous pots); composition of the atmosphere; preparation and properties of oxygen; nitrogen, nitric acid, nitrates; action of oxygen on metals and non-metals; acids, alkalis, salts, oxides; the differences between a compound, an element, and a mixture; how air is changed by the burning of a candle; the presence of carbon dioxide and of water vapour in air; humidity; hygrometry; dew, rain, snow; cooling caused by evaporation; conditions favourable to evaporation.

61. Warmth required for Germination.—When the temperature of the soil falls to 0° C. nearly all life-processes become dormant, and for most cultivated plants these processes do not begin until a temperature above 5° C. has been reached. There is for all plants a certain range of temperature within which germination is most rapid and which ensures the highest percentage of plants from the seeds sown. The temperature below which germination does not occur is called the *minimum*, that above which there is no germination is the *maximum*, while the most favourable temperature is the *optimum*; these might be called respectively the *lowest*, *highest*, and *best* temperatures for germination. In general, the temperatures at which the seeds of most cultivated plants (excluding, of course, hot-house plants) grow *best* in our climate lie between 18° C. and 35° C., with an average about 24° C.

Wheat and mustard begin to germinate at 4° or 5° C., Scarlet Runner and Maize at 8° or 9° C., Vegetable Marrow (Pumpkin) at 13° C., and Cucumber at 16° C. Here are the approximate optimum temperatures for germination of some common plants: Barley, Pea, Sweet Pea, Phlox, 18° C.; Cabbage, Carrot, Lettuce, Oats, Stock, Petunia, 21° C.; Rye, Beet, 24° C.; Clovers, Tomato, Mignonette, Pansy, 27° C.

(*a*) Place some soaked seeds in a glass jar and cover them with moist sawdust; plunge the jar into a box containing pieces of ice, which must be renewed as they melt. The ice will last longer if the box containing it is set into a larger box, and the space between the two boxes is packed with dry sawdust (why?).

(*b*) Another method is to use two boxes as in the preceding, but to place in the smaller box a single box of ice, with dry sawdust below and around it; place the seeds directly on the ice and cover them with dry sawdust, which will be kept moist by the melting ice.

* (*c*) In winter and spring the minimum temperature for germination should be determined for as many seeds as possible. Into a large flower-pot or seed-pan put some bits of broken earthenware at bottom, and fill up the rest of the pot with sifted soil. Plant in the pot a few seeds of different kinds, and bury the bulb of a thermometer at the depth of the seeds, tying the thermometer stem to a stick thrust into the soil. Sink the pot up to its rim in the soil of a garden bed and record the temperature each day, looking for any signs of germination. After two or three weeks bring the plants indoors; keep the soil moist; make notes of your observations. Other pots should be kept in different parts of the house or school, in addition to those kept outside. Such experiments will show that warmth hastens germination, while cold retards it.

62. Is Light required for Germination?—This question is very easy to answer by experiment.

(*a*) Place in a dark cupboard or cellar some jars or boxes containing seeds planted in moist sawdust. Compare with seeds of the same kind, planted and watered in the same way, but set in the light.

(*b*) A better plan is to keep the two sets of seedlings close together; exclude the light from one lot by covering the jar or small pot in which the seeds are planted by inverting over it a large flower-pot or putting it into a tin or wooden box with a few holes for ventilation. Compare the rate of growth of the two sets of seedlings from day to day, and note any other differences between them. See Art. 128.

63. Conditions necessary for Germination.—If you have carefully carried out the simple experiments on germination for which directions have been given, you will know what conditions are essential for germination of a seed which contains a live but dormant plantlet. **Water, oxygen,** and sufficient **heat** are the three essentials for the awakening of the young plant from its sleep. We shall see later that for the continued healthy growth of the plant other things are necessary, without which the seedling after a time dies.

64. Growth in Light and in Darkness.—If you have carefully performed the simple experiments mentioned in Arts. 56 and 57, you will see on reflection that the germinating seed must lose carbon in its respiration. To measure this loss we must, of course, dry the seeds and seedlings before weighing them. Does this loss occur both in light and in darkness?

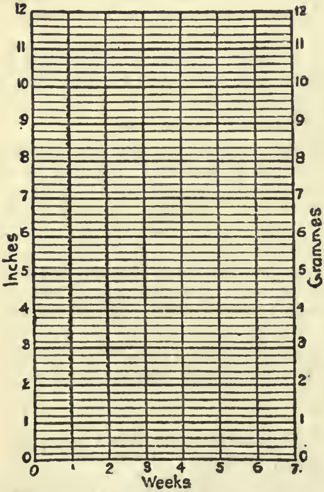

Fig. 21.—Chart on which to plot the Curves of Height and Weight.

* (*a*) Take about forty Beans as nearly alike in size and weight as possible; select four of them as samples, and find their weight after thoroughly drying them on a water- or sand-bath or in a slow oven. Take the dry weight of a seed, found in this way, as the average. Sow half of the seeds in sifted garden soil in a box which is kept in darkness, the other half in a box kept in full light; water both lots about equally.

At the end of each week measure and record the average height of the shoot in each lot of seedlings; remove three seedlings from each box, wash the roots in running water (do not leave any in the soil or lose them in any way), and dry them thoroughly without charring any part. When quite dry and brittle, weigh each lot and obtain the average weight of the solid matter in each plant. Get a piece of squared paper, as in Fig. 21 (spaces *representing* inches need not, of course, *be* inches). As the weekly observations proceed, trace two lines across the sheet, one (a continuous line) to show the weight, the other (a dotted line) the height of the seedlings grown in light; draw two other lines in red ink to show the weight, and height, of the seedlings grown in darkness.

* (*b*) Another method is to use Wheat grains, and grow them with the roots in water. From some Wheat count out thirty-six good sound grains, and divide them into batches of a dozen each; see that the weight of each batch is as nearly as possible the same. Dry one batch (A) and record the dry weight. Tie a piece of muslin over a tumbler or bowl filled with water, and put a batch (B) of seeds on the surface of the muslin, which should be kept wet. Another plan is to use a piece of flannel, stab twelve holes in it, and in each hole place a seed. Keep the tumbler in a warm, dark place, and renew the water every second or third day. Plant the third batch (C) as in (B), and keep both at about the same temperature, but when the young shoots appear, expose (C) to the light. When the shoots have grown several inches, carefully remove the seedlings from (B) and (C), noting the difference in colour between the two sets. Dry them thoroughly, without charring even the finest rootlet, and then weigh each lot and compare the weights of (A), (B), and (C).

65. The Bean Seed contains Food.—The results of these experiments will show that **a seedling kept in darkness loses in dry weight,** so that, apart from water, **it actually weighs less than the seed itself did**, and eventually it dies. It is obvious that this loss must be largely due to respiration, and that it is chiefly a loss of carbon in the form of carbon dioxide. The seed must, therefore, contain a store of carbon in some form, and it is at the expense of this stored carbon that the darkened seedling respires and grows. On the other hand, seedlings grown in the light increase in dry weight, and are therefore able not only to repair the loss due to respiration, but also to add to their dry weight in some way.

To repair the waste due to respiration and to provide material and energy for growth, the young plant in a seed requires a store of food upon which it can draw during the early stages of germination. Where and in what form is this food stored, how is it made use of, and how does it compare with the store of food placed at the disposal of young animals—*e.g.* in eggs and in milk? From their size and thickness, and the fact that they are used as human food, it is easy to infer that the cotyledons of Beans or Peas are storehouses of reserve food-stuffs.

In addition to carbon the Bean seed contains nitrogenous substances and also some mineral matter (ash ingredients). The Bean seed contains all the chief kinds of human food —water, mineral salts, proteids, starch, and oil (scanty).

* (*a*) Place a piece of Bean cotyledon on the end of a long needle (a needle mounted in a piece of wood like a penholder is best for purposes like this), and hold it over the flame of a spirit-lamp; notice that it turns black in a few seconds. Rub the charred mass on white paper; it leaves a black mark of charcoal (carbon). Continue to heat the piece for some minutes, and note that it burns to ash.

* (*b*) Heat some dry Beans or Peas in a test-tube fitted with a bent tube passing through a bored cork, and dip the free end of the tube into lime-water or baryta-water. Notice the white precipitate produced by the carbon dioxide set free.

* (*c*) Crush, or cut up into small bits, some Beans or Peas, mix them with three or four times the quantity of soda-lime, and heat the mixture in a test-tube. Fumes of ammonia are given off, proving the presence of *nitrogen.*

To make soda-lime, mix two parts of quicklime with one of solid caustic soda and one of charcoal; moisten with water, mix into a paste, dry thoroughly, and keep the powdered mixture in a corked jar.

66. Carbohydrates.—Starch and **sugar** both exist abundantly in plants, and are called carbohydrates, because on analysis the proportion by weight of hydrogen to oxygen found united with the carbon is always the same as exists in water—viz. 1 : 8. Starch is insoluble in cold water, but is easily converted, by various processes, into sugar, which is soluble. Other carbohydrates are **cellulose, gum, inulin, dextrin, glycogen.**

* (*a*) Heat some dry laundry starch in a test-tube. Note the condensation of water in the upper part of the tube. This proves the presence of *hydrogen* and *oxygen* in starch (since water is composed of these elements). Note also that the starch soon begins to *blacken,* proving that it contains *carbon,* and at the same time dirty white fumes are evolved, having a pungent odour somewhat resembling that of burnt sugar. Apply a light to the mouth of the test-tube —the fumes are *inflammable*; introduce a piece of moist blue litmus paper into it—the litmus becomes red, showing that the fumes are

acid. Introduce a glass rod, on the end of which is a drop of lime-water, into the test-tube. The lime-water becomes milky, showing that *carbon dioxide* is one of the products of decomposition of starch. This confirms the presence of carbon in starch (since carbon dioxide is a compound of carbon and oxygen). When all the volatile matter has been driven off, a black glistening residue of *charcoal* remains.

* (*b*) Shake a very little starch in a test-tube of cold water and boil well; add a few drops of iodine solution : a blue colour is formed. Boil the blue solution, and the blue colour disappears, to return on cooling.

* (*c*) Boil a little starch with dilute sulphuric acid, and test a few drops of the solution from time to time for (1) starch, and (2) sugar. The reactions of starch are gradually lost, and those of sugar appear instead.

* (*d*) Examine specimens of cane, grape, fruit, and milk sugars. (1) Taste them : they are all sweet. (2) Boil with a solution of caustic potash : cane sugar does not colour the solution, but the others turn it brown. (3) Add a little Rochelle salt (sodium potassium tartrate), then excess of caustic potash, and finally some copper sulphate solution.[1] [The object of the Rochelle salt is to prevent the precipitation of cupric hydroxide by the action of potash on copper sulphate.] Boil : cane sugar only precipitates red cuprous oxide on long boiling, but the others give a precipitate at once. (4) Add a solution of silver nitrate to which excess of ammonia has been added, and warm : the cane sugar only reduces the silver after long boiling ; the others do so very soon.

(*e*) Boil some cane sugar with dilute sulphuric acid for ten minutes, and test with Fehling's solution, etc. : it now gives the same reactions as the other sugars.

These properties of possessing a sweet taste and of turning caustic potash brown and reducing copper sulphate and silver nitrate, either at once or after previous boiling with dilute acids, are characteristic of the sugars.

67. Proteids, or nitrogenous food-stuffs, composed of carbon, hydrogen, oxygen, nitrogen, sulphur, and in some cases phosphorus, occur in both vegetable and animal tissue, though only plants can build them up from their elements. They form the living substance (protoplasm) found in cells of plants and animals ; in decaying they give off offensive smells. **Albumin** occurs in white of egg, **myosin** in lean meat, **gluten** in flour, **casein** in milk and cheese, **legumin** in Peas and Beans. See books on Human Physiology.

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[1] This is called **Fehling's test.** Dissolve 35 grammes of copper sulphate in 200 c.cs. of water to make solution A. To make solution B (to be kept in a separate bottle) dissolve 70 grammes of Rochelle salt in 200 c.cs. of 10 per cent. caustic potash solution. Use equal volumes of solution A, solution B, and water.

68. Wheaten Flour, made from the grains (seeds) of Wheat, makes very convenient material to examine and test for starch and proteids.

* (*a*) Take a tablespoonful of wheaten flour and enclose it in a piece of muslin. Hold it under a tap of gently running water and work the flour about by constant squeezing. Catch the whitened water as it flows away from the flour. In a little time the water passes off clear. Keep working it for a little longer time, then open the muslin and discover a mass of sticky material : this is gluten. Let the muddy water settle, then pour off the liquid and keep the sediment. The sediment is starch ; it forms a large proportion of the flour.

* (*b*) Put a small bit of gluten on the end of a mounted needle, and hold it over the flame of a spirit-lamp ; it burns, then turns black. Rub the charred mass on white paper ; it leaves a mark of charcoal (carbon).

* (*c*) Mix a little of the gluten with soda-lime, place the mixture in a test-tube, and heat by means of a spirit-lamp. As the gluten decomposes, ammoniacal fumes are given off, thus proving the presence of nitrogen in the gluten.

(*d*) Put a little of the gluten into a test-tube containing a weak solution of caustic potash. Shake well : the gluten dissolves.

(*e*) Put another bit of gluten into a small quantity of strong nitric acid in a test-tube or watch-glass. Heat. Note the yellow coloration, which deepens to orange if ammonia solution be gradually added. Add the ammonia solution very cautiously with a glass tube, as the action between the acid and the ammonia is a violent one.

(*f*) Place a little of the sticky gluten in a test-tube and warm it. Notice that the heat causes it to solidify.

* (*g*) Take a little of the milky liquid from the basin. The milkiness is due to starch granules. Boil it : this makes it go clear. Cool the clear liquid, and add a few drops of solution of iodine. A deep blue colour proves the presence of starch. Note that the blue colour disappears on heating ; does it reappear on cooling ?

69. Oils.—Many plants store up food in the form of oil. Oils are compounds made up of carbon, hydrogen, and oxygen, the oxygen present being insufficient to combine with all the hydrogen and form water. Chemically they are compounds of "fatty" acids with glycerine. Most vegetable oils are obtained from seeds, *e.g. mustard*, *sunflower*, *linseed*, *castor oil*.

Oily seeds usually contain little or no starch, and *vice versâ*.

* Remove the coats from dry seeds of Sunflower, Cress, Mustard, Castor Oil ; fold the seeds in blotting-paper and crush between two flat stones and note the greasy stain produced, which dissolves in ether or alcohol.

The young plant in a "Brazil nut" is very rich in oil, as can be seen on cutting the "nut" across, after removing the shell: the oil is made very evident if the knife be heated.

70. Digestion of Reserve Food.—The foods stored up in seeds for the use of the young plants must be insoluble in water, and not able to diffuse through membranes (cell-walls): why? The reserve food in the Bean cotyledons must, however, when the seed germinates, travel from cell to cell through the cell-walls in order to reach the places where it is needed (radicle and plumule), and in order to do this the food must be changed into soluble and diffusible substances. The food stored in a seed must, in fact, be *digested* before it can be used by the young root and shoot, and the process of digestion in a plant is essentially the same as in an animal. Find out all you can, from books on Physiology, about the digestion of starch, proteids, and fats. In the germinating seed, just as in an animal, starch is converted into sugar, proteids into peptones, oils into fatty acids and glycerine (which are further changed into sugars, etc.).

The conversion of the insoluble reserve foods into soluble foods is brought about by the action of *ferments*, corresponding to those secreted by the digestive glands of an animal's alimentary canal. Starch is changed into sugar by the ferment *diastase*, similar to the "ptyalin" of saliva and the "amylopsin" of pancreatic juice; proteids into peptones by *trypsin* (also contained in the pancreatic juice of animals); oils into glycerine and fatty acids by *lipase* (corresponding to the "steapsin" of pancreatic juice).

71. How long does the Seed's Food last?—We shall see later that green plants get their food from two main sources, air and soil. The young plant in a seed has a store of food for its early growth, a store which is sometimes very scanty and sometimes (as in Bean and Pea) very abundant. We know that tap-water and even rain-water are not pure, but contain dissolved substances, while soil-water or river-water will be much richer in dissolved matter. In order to find out how long the stored food lasts, we should therefore use *distilled* water, so that we know exactly what the roots have had at their disposal; we may use well-washed sand and water it with distilled water.

Bean and Pea seedlings exposed to light, with their roots in distilled water, grow for several months and may even produce flowers, though they are small and weakly as compared with seedlings grown in soil or in a culture solution. Small seedlings, with scanty food-stores—*e.g.* Mustard—live only a few weeks when exposed to light and supplied with distilled water, and for a shorter time when kept in darkness.

* (*a*) Deprive Beans and Peas of one or both cotyledons, and observe the result. Remove the cotyledons, in different cases, (1) just after the seed has been soaked, (2) after the root has grown 2 ins. long, (3) after the plumule has grown 2 ins. long.

* (*b*) Grow various seeds in jars containing distilled water, fixing them either into holes in muslin or flannel, or into split or bored corks; fill up the water as required, but always use *distilled* water. Keep some of them in darkness, expose others to the light, and compare their growth and their increase or decrease in dry weight. Another method is to let the roots grow into sand that has been washed thoroughly with tap-water and then with distilled water, using the latter for watering.

72. How is Food transported?—The foods produced by the action of ferments are soluble, and therefore able to travel to the places where they are needed, to supply material and energy for the growth of the young root and shoot. It is easy to trace the passage of the digested foods, especially in the case of sugar, because whenever the sugar accumulates some of it is usually changed back temporarily to starch.

* In seedlings of Bean, Pea, and other plants you are growing, note that the root and shoot of the ungerminated seed as a rule contain no starch, but that after germination has begun starch appears in the young root and shoot; cut these parts longitudinally, and apply iodine solution to the cut surfaces.

73. Energy furnished by Foods.—The amount of energy supplied by a food may be found by measuring the heat produced by burning it, and it is therefore called the *fuel value.* The fuel value of carbohydrates and proteids is about the same, that of fats is more than twice as great. In plants, as in animals, the energy is obtained from the food by oxidation (= burning), and carbon is the principal substance burned, setting free carbon dioxide. Burning 1 gramme of carbon sets free enough energy to raise 8 kilograms (= about 2 gallons) of water from 0° to 1° C., and about

2 litres (about 2 quarts) of carbon dioxide are given off. If all this energy were used in mechanical work, it would suffice to raise 3,400 kilograms through 1 metre (*i.e.* to raise more than 3 tons a yard high). The energy is used up by the plant in the form of heat and of chemical work, in addition to mechanical work.

74. Emergence of Seedlings from the Soil.—You will have noticed the way in which the plumule of the Bean protects the young leaves from injury by bending backwards at the tip as it pushes its way upwards. Seedlings can grow through hard and stiff soil, and in doing this the plumule must exert considerable force. The shoot of a Broad Bean seedling can push upwards with a force of over a pound, and since its diameter behind the hooked part is about one-eighth of an inch, the force exerted = 80 lbs. per square inch. From the fact that the cotyledons of a Broad Bean of average size contain about a gramme of carbon, the seedling can get a large amount of energy by using the stored food.

* (*a*) Plant some Beans about 3 ins. deep in moist soil or sawdust in a flower-pot, and pack stiff clayey soil (or plasticine) firmly above them. Watch them to see whether they emerge at the sides or whether they push the whole mass of clay upwards.

75. Other Seeds and Seedlings.—We have still many experiments to make in our investigation of plant physiology, and for a large number of these the seedlings of Broad Bean, Scarlet Runner, and Sunflower, as well as others, will be required. Get seedlings ready in different stages of growth.

Meanwhile examine and germinate the seeds of various other plants for comparison with those of the Broad Bean. If you are really interested in Plant Life and have the necessary time, you will find it worth while doing this with all sorts of plants, both wild and cultivated. This easy and interesting work with seeds and seedlings is perhaps unrivalled as a means of gaining an insight into the physiology, adaptations, and evolution of plants, using only the simplest apparatus and the cheapest materials—the seeds of hundreds of cultivated species can be bought in penny packets.

76. Seeds with Food stored in the Young Plant.—In the following notes we shall take first seeds which resemble the Broad Bean in having nothing within the seed-coat except the young plant, which therefore contains the food-store, usually in the cotyledons—the Brazil "nut" is exceptional in having the food stored in the hypocotyl.

It will be noticed that in some cases the term "akene" is used for what are usually called seeds. This means that the apparent seed is in reality a one-seeded fruit, corresponding to a Bean pod in which only one seed has developed and the shell or fruit-wall does not split open to let the seed out—this is true of most, though not all, one-seeded fruits. Note also that in **akenes** (often spelt *achenes*) the actual seed-coat is thin, since the shell or fruit-wall amply protects the young plant and there is no need for a stout seed-coat; also that it is, of course, useless to look on the outside of an akene for the micropyle and the scar of the seed-stalk, since the seed itself lies within the shell and is attached to the inner surface of the latter by the seed-stalk.

You can easily tell an akene from a seed, especially if you get the whole collection of akenes produced by the plant, *e.g.* the "cob" of Maize or the fruiting head of the Sunflower, for a seed is developed inside a fruit, while an akene, being itself a fruit, is carried on the outside of the plant and usually shows some traces of the style and stigma.

77. French Bean (*Phaseolus vulgaris*) **and Scarlet Runner** (*P. multiflorus*).—In both, note the position of the scar; the micropyle, made very conspicuous by its raised margin; the beautiful wrinkling of the coat when the seed is soaking; the two large first foliage-leaves of the young shoot, plainly showing the veins. Sketch the seeds and the seedlings, comparing them with those of the Broad Bean (Fig. 22).

Sow the seeds and note that in the Runner the cotyledons remain below, as in Broad Bean, while in French Bean they are pushed up into the air along with the plumule, because in the latter plant the hypocotyl—that portion of the young plant's axis which lies between the root and the insertion of the cotyledons—grows in length, carrying up cotyledons and plumule. You will find that most seedlings show this **epigeal** type of growth—epigeal meaning that the cotyledons come above the soil, while only a few besides Broad Bean and Scarlet Runner have **hypogeal** (below ground) cotyledons. It is simply a question of whether or not the hypocotyl grows in length. You will also notice that epigeal cotyledons sooner or later turn green, grow larger and thinner, and are more like foliage-leaves than in

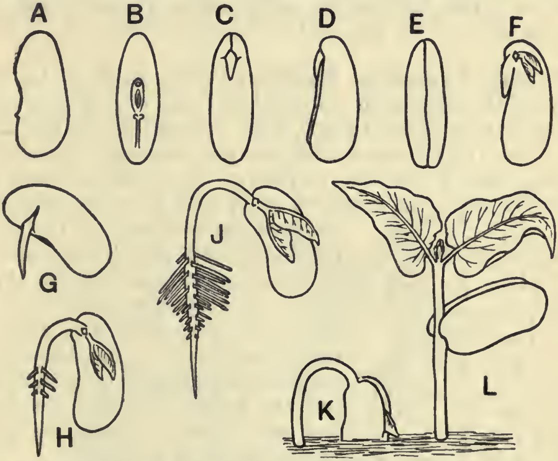

Fig. 22.—French Bean. A and B are views of the entire seed; C to F are views of the embryo (seed-coat removed); G to L are stages in germination.

the case of hypogeal cotyledons, which do not turn green (unless they happen to be exposed to the light) and which soon shrivel up.

Notice that in the different species of *Phaseolus* (Dwarf and Climbing French Beans, Scarlet Runners) we get a transition from the hypogeal to the epigeal type. Note that in these plants the first two foliage-leaves are simple and heart-shaped and stand opposite each other, while the later leaves are compound, having three leaflets, and arise singly from the stem; what other differences do you notice between the first and the later leaves, and between the hypocotyl and the axis of the plumule?

78. Culinary Pea (*Pisum sativum*) **and Sweet Pea** (*Lathyrus odoratus*).—In the former, note through the transparent coat of a soaked seed the scar, micropyle, and root, all lying in the same line with the root-tip pointing to the micropyle; the cotyledons are hypogeal; the earlier leaves are small and like those of the Broad Bean seedling; the later leaves differ in that the uppermost leaflets are developed as tendrils. In Sweet Pea, note the foliage-leaves have only two leaflets; in what other respects does this seedling differ from that of the Culinary Pea?

79. Oak, Sycamore, Sunflower.—To make a thorough study of the akenes or "seeds" of these plants, you should get the flowers of each plant, with ripe and unripe fruits.

Get ripe Oak acorns, also unripe ones still attached to the cup, noting the scar at base of acorn where it was fixed inside the cup; the withered style with its three stigmas at the free pointed end of the acorn; the hard shell (fruit-wall) and the thin skin (seed-coat) inside it; the two large cotyledons, the root, and the small plumule; the abundant starch stored in the cotyledons; the splitting of the shell on germination and the pushing out of the young root and shoot by elongation of the cotyledon-stalks (Fig. 23).

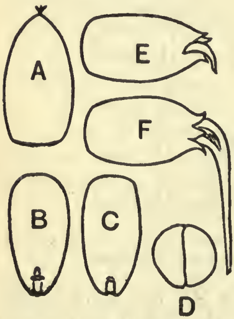

Fig. 23.—Oak. A, entire acorn; B, C, embryo with cotyledons split apart; D, embryo cut across; E, F, stages in germination.

Get Sycamore "keys," which are at first joined in pairs (sometimes in threes), each having a wing. Watch the keys being blown from the tree on a windy day, noting their spinning or whirling movement through the air. What makes the keys whirl, are they carried far from the tree, and does the whirling enable them to bore into soft moist soil? Throw keys into the air or drop them from a height; repeat the experiment with keys from which the wing has been removed, comparing the times taken for winged and wingless keys to fall through the same distance and the course they take in windy weather. The two keys split apart when ripe, but for a time dangle at the ends of a Y-shaped thread whose lower end is attached to the top of the flower-stalk.

Open a ripe key, noting the hairs inside the shell; the brown-coated seed; the embryo with its long radicle, long strap-shaped green cotyledons, and very small plumule; the stages of germination, in which the cotyledons are carried up and unfold, while the plumule grows very slowly; the simple outline of the earliest foliage-leaves (Fig. 24).

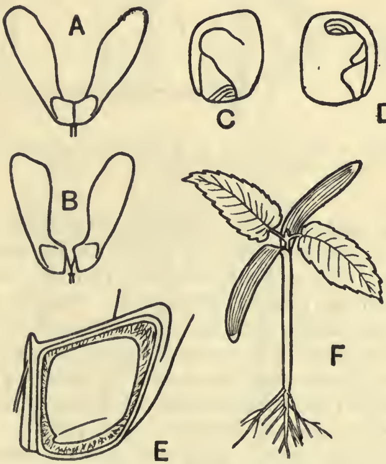

Fig. 24.—Sycamore. A, fruit; B, with the half-fruits ("keys") split apart; C, D, views of embryo; E, "key" opened up, showing seed; F, seedling with the first two foliage-leaves.

Get ripe Sunflower "seeds," also Sunflower heads of different ages showing flowers and developing fruits, noting the scar left at the broad end of the akene where the upper parts of the flower fell off; the scar (often a hole) at the lower pointed end of the akene where it became detached from the plant; the seed, attached by a short stalk inside the shell; the thin seed-coat, the cotyledons, radicle, and small plumule. Test cut surface of a cotyledon with iodine solution, which gives only a brown stain; there is no starch, but proteids and oil are present (Fig. 25).

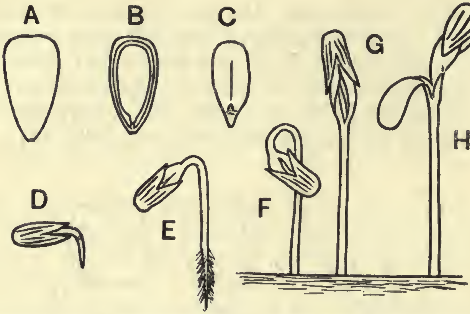

Fig. 25.—Sunflower. A, akene ("seed"); B, same with half of the shell removed; C, embryo with one cotyledon removed; D to H, stages in germination.

80. Maize and Wheat.—Get Maize grains, also a Maize "cob," from a corn merchant; the White Horsetooth variety is best, being larger and more regular in form, for examining the structure of the grain. If possible, examine a young cob, noting the long feathery stigma which falls off from the broad free end of the grain as it ripens. In the grain, note the oval patch on one side, showing two marks (sometimes furrows and sometimes ridges) in a straight line, one towards the top (broad end) and one towards the bottom of the patch.

Peel off the thin tough skin and with a needle raise the plumule and radicle which cause the two marks already noted; lay a grain on the table and make a clean slice through the middle of the patch—if this is carefully done you will see the plumule and radicle, attached to a thick body which projects into the grain (Fig. 26, C); smear the cut surface with iodine solution, which stains the young plant (radicle, plumule, and single cotyledon) brown, and the rest of the grain dark blue—if the grain has been soaking in water for a few days, some starch will be present in the embryo, because part of the starch stored in the other part of the grain has been changed into sugar by diastase, transferred to the embryo, and there re-converted into starch.

Wheat germinates more readily than Maize, at comparatively low temperatures, but the seedlings of both should be studied. In Wheat note the groove running down one side, opposite the embryo. The shield-like body which in these seeds lies on one side of the radicle and plumule is, apparently, the single cotyledon, and its function is to secrete diastase, in order to digest the food stored in the rest of the seed, and to pass it on to the growing root and shoot. Note the colourless

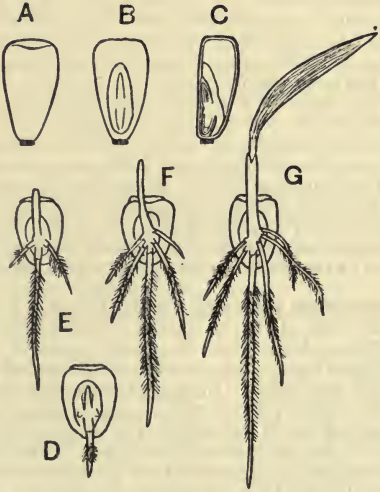

Fig. 26.—Maize. A, B, two views of outside of grain; C, grain cut longitudinally; D to G, stages in germination.

sheath which protects the young shoot and through which the foliage-leaves emerge; and the grass-like leaves with parallel veins.

The starch-containing part of the Maize or Wheat grain is something not represented in any of the seeds we have studied so far. It is called the *endosperm*. Seeds like Maize and Wheat are said to be *endospermic*, because in addition to the young plant, which is present in all seeds, there is in this case a special region in which the reserve food is stored. Seeds which do not include endosperm, and in which therefore there is nothing except the young plant, are called non-endospermic, *e.g.* Beans, Peas, Acorn. See Art. 83.

* **81. Further Work with Seeds and Seedlings** should be carried out as time permits. Soak, dissect (remove coat, cut sections), and examine with lens as many different seeds as possible. Test cut surfaces with (1) iodine solution for starch (blue) and proteids (brown); (2) a drop of strong sugar solution, followed by a drop of strong sulphuric acid (bright red colour = proteids); (3) nitric acid and ammonia (yellow colour = proteids). Practically all seeds contain proteids, together with starch or oils. If the seed gives only a brown colour with iodine, showing the absence of starch, try the tests for oil (Art. 69), and for cellulose (Art. 86). Cut thin sections and examine them with the microscope. In Maize and Wheat note the outermost layer of cubical cells in the endosperm, packed with proteid grains ("aleurone-grains"), also the layer of columnar cells (epithelium-layer) on the surface of the cotyledon, which secretes ferments.

Sow the seeds in moist sawdust or soil, note the temperature required (or most favourable) for germination in each case; examine and sketch the seedlings from time to time. In moistened seeds of Linseed, Cress, Turnip, Mustard, notice the jelly formed by the swelling of the gummy seed-coat when it absorbs water. Small seeds—*e.g.* Cress, Wheat—should be grown on muslin or flannel stretched over a tumbler filled with water; examine the roots for root-hairs and rootlets.

* **82. Seeds with Food stored in Young Plant.**—Examine the seeds and seedlings of Linseed, Cress, Mustard, Turnip, Radish, "Garden Nasturtium" (*Tropaeolum*), Horse Chestnut, Vegetable Marrow, Melon.

In nearly all cases the cotyledons are carried up into the air by the lengthening of the hypocotyl. In Horse Chestnut the large cotyledons are partly fused together; notice that on germination the young stem and root are pushed out of the seed by the lengthening of the cotyledon stalks. In Vegetable Marrow and Melon notice the method by which the seedling gets its cotyledons out of the cavity enclosed by the rigid walls of the flat seed; an outgrowth ("peg") is formed to hold down the lower half of the seed-coat against the soil, while the growing shoot raises the upper half of the seed-coat and thus gets free.

In Mustard the cotyledons are two-lobed, in Cress (Fig. 13) they are three-lobed. In the "Nasturtium" (*Tropaeolum majus*) the later leaves have a nearly circular blade with even margin, and the stalk is inserted at the centre of the lower side of the blade, but in the earliest leaves of the seedling the leaf-blade is lobed and the stalk inserted at the lower margin, as in the adult leaves of the closely-allied leaves of the Canary Creeper (*T. canariense*). In Brazil "nut" (really a seed) the hard shell is the seed-coat; the minute cotyledons occupy the broader end of the embryo, the root being at the narrow end. The greater part of the embryo consists of the swollen axis (hypocotyl), whose cells contain proteid and oil. The two cotyledons and the plumule can be seen in a section examined with the microscope—if the section has been cut in exactly the right place.

83. Endospermic Seeds.—In many seeds the stored food is not contained in any part of the young plant itself, but in a special part of the seed called the **endosperm,** which lies within the seed-coat but outside of the young plant (embryo). In some cases the endosperm surrounds the embryo (*e.g.* Castor Oil, Ash). In others the embryo is coiled around the endosperm, *e.g.* Buckwheat. In Maize, Wheat, and other Cereals and Grasses the embryo and endosperm are sharply separated by a plane drawn across the seed. In all cases, however, the radicle of the embryo is close to the surface of the seed, just within the micropyle.

Unfortunately the old term "albumen" is often used instead of endosperm, and this sometimes leads to confusion. Endospermic or "albuminous" seeds are seeds whose food is stored in a part *outside of the embryo,* and this food may be chiefly starch (*e.g.* Maize) or largely oil (*e.g.* Castor Oil), or cellulose in the form of much-thickened cell-walls (*e.g.* Date). The term "albuminous" does not, therefore, imply the presence of egg-albumin, though seeds *do* contain proteids, and exactly the same *kinds* of food are stored in endospermic and non-endospermic seeds alike.

Note the following common error (often found in carelessly written books): "the Bean seed contains endosperm in its cotyledons" (what is wrong in this statement?). Another common mistake is the generalisation about Dicotyledonous and Monocotyledonous seeds mentioned in Art. 91.

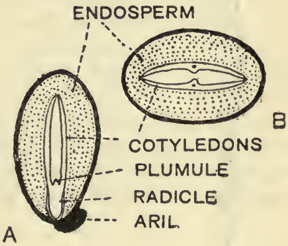

Fig. 27.—Seed of Castor Oil.
A, Longitudinal section; B, Transverse. The dark outline represents the seed-coat.

*** 84. Castor Oil.**—Notice the spongy mass covering one end of the seed; the hard seed-coat, the oily endosperm, the embryo in the middle of the endosperm, with thin cotyledons pressed together (try to find root and shoot); cut longitudinal and transverse sections. The spongy mass (aril) soaks up water; prove by placing seeds in hot water that this mass lies close to the micropyle. See Fig. 27.

* **85. Ash.**—Steep the fruits ("keys") of Ash-tree in water, then cut open the fruit-cavity and notice the flat seed suspended at the end of a long stalk which runs along one edge of the seed. Slice away one of the flat sides of the seed and expose the straight embryo, lying in the horny tissue (endosperm) filled with reserve food.

* **86. Date.**—Examine a Date seed (*i.e.* the "stone"). Notice the deep groove along one side. Scrape the surface on the other side, to see the small embryo embedded in the stone (endosperm). Cut the stone across at this point; then dip the stone in dilute sulphuric acid and apply iodine (test for cellulose). Plant some Date stones in damp sawdust or soil, set in a warm place (a heated greenhouse, if possible), and sketch stages in their germination. Open the stone in some of the seedlings, and then notice the softening of the stone and the extent to which the cotyledon has grown inside it. Notice in sections of the stone that the cell-walls become thinner, and that starch appears in the young root and shoot, in darkness as well as in light. The digestion (conversion into sugar) of the reserve food (cellulose) is due to the secretion of a ferment (cytase) by the cotyledon.

Fig. 28.—Seedling of Pine

* **87. Onion.**—Examine a seedling of Onion before the embryo has finally withdrawn its cotyledon from the seed. Observe (*a*) the long slender *root*, (*b*) the slight swelling at the base of the root marking the position of the relatively short *stem* from which arises (*c*) the long, hollow *cotyledon* whose tip is still within the seed-coat. Remove the seed-coat and observe the colourless end of cotyledon coiled like a watch-spring within the seed. During germination the cotyledon absorbed the food from the endosperm and passed it on to the growing parts. In older specimens observe how the air-exposed tip of the cotyledon withers; also note the formation of secondary roots from the base of the short stem, and slit open the hollow sheath at its base to see the delicate pale-green plumule within. In older specimens the plumule has split the sheath as a result of its growth.

* **88. Pine.**—In a Pine seed notice the thin wing, serving for wind-dispersal. Dissect the seed and notice the embryo (consisting of radicle, hypocotyl, and numerous cotyledons in a circle around the plumule) surrounded by the endosperm. Sketch the stages in germination (Fig. 28).

89. The Uses of Cotyledons.—From the seedlings you have studied, you will observe that the cotyledons, or first-formed leaves of the young plant, have different functions or uses in different plants. They are always concerned with the feeding of the young root and shoot, but they carry out this duty in different ways. When the seed contains no food stored outside of the young plant, the cotyledons usually contain food. In a few plants—*e.g.* Broad Bean and Peas—the cotyledons are food-stores and nothing more; they remain below the ground, simply yielding up the food to the growing root and shoot, and are termed "hypogeal" (= below ground).

In *most* non-endospermic plants, however, the cotyledons are carried up into the air and become green, and like all green leaves *manufacture* food (Ch. IV.); even in these cases, where the cotyledons are "epigeal" (= above ground), they contain more or less food, though the amount is often scanty—*e.g.* Cress, Mustard—and they have a double function, first supplying stored food and then making fresh supplies. In seeds whose food is stored outside of the embryo, the cotyledons either remain within the seed and act as digesting and absorbing organs, as in Wheat, Maize, Date; or they first digest and absorb the food-store in the endosperm, and then emerge from the seed and become the first green leaves of the plant (Castor Oil, Ash, Onion, Pine).

90. Types of Germination.—From the foregoing, it is easy to see that the various seedlings we have studied fall under one or other of four main types, distinguished by presence or absence of endosperm in the seed and by the behaviour of the cotyledons in germination. As we have seen, the chief functions of cotyledons are (1) to *store* food, (2) to *digest and absorb* food stored in the endosperm, (3) to *manufacture* food. The cotyledons may perform only the first or only the second of these three functions, or they may proceed to carry on the third function after they have discharged one or other of the first two. The four types of seedling are then those in which (1) the cotyledons merely store food, (2) the cotyledons serve only as digesting and absorbing organs, (3) the seed is non-endospermic, but the cotyledons besides containing some food come up into the air and make more food, (4) the seed is endospermic and the cotyledons first digest and absorb the endospermic food and then come out of the seed and make food. Examples have already been given of the four types.

91. Monocotyledons and Dicotyledons.—Of the seeds we have studied, Maize, Wheat, Onion, and Date belong to the class of Seed-Plants known as Monocotyledons, while all the others (except Pine) belong to the larger class of the Dicotyledons. This apparently trivial difference is, on the whole, so absolutely constant, and goes along with so many other differences, that it was long ago recognised as a basis for dividing up the higher Seed-Plants into these two groups.

A general statement often made is that while most Dicotyledons have non-endospermic seeds, all Monocotyledons have endosperm, but this is wrong. As a matter of fact, there are many Monocotyledons which have no endosperm in their seeds, or very little, and probably half of the known species of Dicotyledons have endospermic seeds.

92. The Early Foliage-Leaves of Seedlings.—You will notice, in your studies of seedlings, that in many cases the first foliage-leaves, above the cotyledons, are simpler in form than the later or "adult" leaves. Good examples are seen in Broad Bean, French Bean, Scarlet Runner, and Pea, which have already been mentioned; "Nasturtium" (*Tropaeolum*), whose early leaves have the stalk inserted in the ordinary way at the edge of the lobed blade, but the later leaves have the stalk inserted at the middle of the underside of nearly circular blade; Gorse, whose early leaves are three-lobed, while the later ones are simple, narrow, and pointed. Look for other examples of this interesting feature, which is usually held to be a case of the individual repeating, or recapitulating, in its own development the stages through which its ancestors passed in the course of evolution.

Make lists of the various seeds you have examined, arranging them according to (1) the presence or absence of endosperm; (2) the number of cotyledons in the embryo; (3) the hypogeal or epigeal character of the cotyledons; and (4) the nature of the reserve food-substances.

QUESTIONS ON CHAPTER II.

1. How can you show that water is essential for the germination of a seed? Why is the young plant in a seed said to be "dormant"?

2. Give the results of experiments you have made as to the volume of water which a Broad Bean seed can absorb as compared with its own volume.

3. How could you prove that a germinating seed respires (breathes), just as a living animal or a human being does?

4. How could you prove that germination does not occur in the absence of oxygen?

5. Why do seedlings grow badly in soil that is too liberally watered? How could you measure and compare the amount of air in different samples of soil?

6. Why should seeds not be planted very deep, nor merely laid on the surface of the soil?

7. How could you prove that warmth is required for germination, and how could you find, roughly, the best (optimum) temperature for germination in the case of some particular plant? What is meant by (*a*) the minimum, (*b*) the maximum, germination-temperature of a plant?

8. What are the effects of darkness and of light on the germination of seeds?

9. How could you prove that a germinating seed loses in weight when grown in darkness, that the loss is due largely to the oxidation (or burning) of carbon, and that the cotyledons contain carbon?

10. Compare the food stored in a Bean seed with that supplied to young birds in eggs and to young mammals in milk.

11. What is a carbohydrate? Mention the chief carbohydrates, stating how they are distinguished from each other.

12. What is a proteid? How do proteids differ from carbohydrates? By what simple tests could you detect the presence of a proteid?

13. How are oils distinguished from carbohydrates and proteids?

14. How are the reserve food-substances present in a seed made available for the nourishment of the young plant?

15. What is meant by digestion? How are starch, proteids, and oils digested? To what extent are the processes of digestion similar in plants and animals?

16. How could you measure roughly the work done by a seedling in emerging from the soil? Where does the necessary energy come from?

17. What is the usual appearance of the top of the shoot of a young seedling, and what is the advantage of this? How do seedlings of Maize and Wheat differ from most other seedlings in this respect, and how do they emerge from the soil?

18. What is the difference in structure between endospermic ("albuminous") and non-endospermic ("ex-albuminous") seeds? Show that both kinds of seeds may contain the same kinds of food, and explain why the old terms "albuminous" and "ex-albuminous" often lead students into wrong ideas about seeds.

19. Describe, with sketches, the seed, the mode of germination, and the seedling of the following plants: Pea, Kidney Bean or Scarlet Runner, Oak, Ash, Wheat, Maize, Cress, Linseed, Sycamore, Onion, Cucumber or Gourd or Vegetable Marrow, Sunflower, Date, Pine, Horse Chestnut, Castor Oil plant, Mustard.

20. Write an essay on the uses, and the behaviour during germination, of the cotyledons in the various seeds whose germination you have watched.

21. Enumerate the chief reserve materials of food which are stored in the seeds of plants. Give an example of each, and explain how the embryo or seedling is enabled to utilise the food.

22. Explain why it is that certain seeds—for example, Peas and Beans—split readily when the testa is removed. Name as many other such seeds as you can, and describe in some detail the germination of any one of them.

23. Suppose you had two flourishing seedlings of the same size, and you grew one in the dark and the other in the light. How would each differ from its original weight in the course of a few weeks? If one of them had gained considerably, how would you demonstrate exactly to what the increased weight was due? What other differences would you notice between them?

24. What are the chief points you would emphasise in a lesson on the germination of seeds? What material would you select for the practical work of the class?

25. What is respiration, and how is it affected (*a*) by heat, (*b*) by light, (*c*) by increased rapidity of growth?

Two lots of Peas, one of which had been soaked in water at 100° C., the other in water at 15° C., were passed into the vacua at the tops of two parallel tubes of mercury. How would the height of the mercury column be affected in each case? Would the after addition of caustic potash solution make any difference to the height of the columns?

26. Compare the seedlings of Sycamore and Lupin. Note the points of resemblance and difference.

27. What are the practical difficulties in the way of germinating seeds in an ordinary class-room, and rearing the seedlings for some weeks? Show how these difficulties can be overcome.

28. Explain, with drawings, how certain seedlings withdraw their seed-leaves from the seed-coat.

29. Mention two or three experiments on digestion which can be performed with very simple appliances in an ordinary schoolroom. Give full practical instructions for one such experiment.

30. Describe the seedlings of three plants in which the cotyledons have entirely different functions.

31. Describe experiments of a chemical nature by which you could show (*a*) that starch is changed by the action of your saliva, and (*b*) that your expired air contains carbonic acid gas.

32. Name the necessary conditions of germination, and describe experiments, which you have seen or performed, to prove what you say.

33. Describe exactly how you would obtain the dry weight of a seedling.

What difference would you expect to find between the dry weight of (*a*) a seed, (*b*) a seedling of the same plant grown in the dark for some time, (*c*) a similar seedling grown under normal conditions for the same time?

Give reasons for your answer, explaining clearly the source or fate of the materials gained or lost.

34. Draw (roughly to scale) the young seedlings of any five plants belonging to different natural orders, showing fully the relation of the cotyledons to the rest of the plant, and explain exactly how the food reserve for the seedling is stored in each case.

CHAPTER III.

THE MICROSCOPE AND CELL-STRUCTURE.

93. Microscope Work, if not allowed to occupy time which would (in the case of a beginner) be better spent in making physiological experiments and in studying flowers, fruits, plant-associations, etc., is valuable in helping one to understand more fully the life-processes and adaptations of plants, especially if minute structure is studied in close connection with physiology.

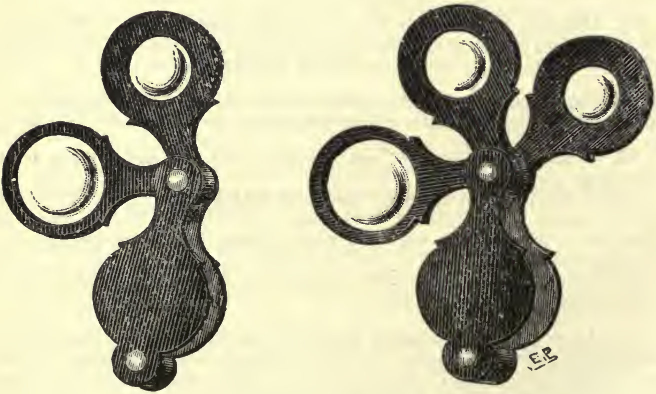

Fig. 29.—Folding Pocket Lenses (Double and Triple).

Lenses.—The use of the simple lens has already been mentioned (Art. 4). A **double** or **triple folding lens** (Fig. 29) is a great improvement on the simple lens, giving greater magnifying power when the lenses are used together. A lens of this kind is absolutely indispensable.

94. Compound Microscope.—The simple microscope can be used for all purposes where a magnification of not more than 20 diameters is required, and is an extremely convenient instrument for this low-power work. When higher magnification is desired, we must use the compound microscope, in which the image of the object is obtained by one lens (or a set of lenses) called the **objective,** and this image is magnified by a second lens, the **eye-piece.** The objective is screwed into the lower end of the brass **body-tube,** which is blackened inside (why?); the objective consists usually of several lenses screwed together. The **eyepiece,** which magnifies the inverted image of the object produced by the objective, consists of two lenses, the one **next** the observer's eye being called the eye-glass and the lower one the field-glass.

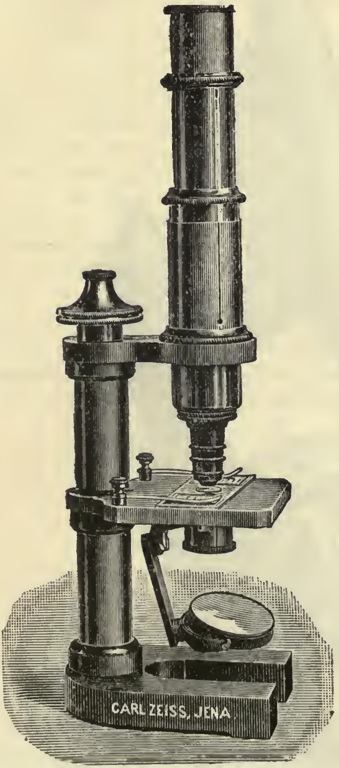

Fig. 30.—Compound Microscope with Sliding Coarse Adjustment.

In the cheaper form (Fig. 30) the tube which carries the lenses is moved up and down, to bring the objective near the object and thus bring the latter clearly into focus, inside another tube fixed to the stand; this is called the "sliding coarse adjustment." In the more expensive microscopes (Fig. 31) there is a rack-and-pinion movement for raising or lowering the body-tube. The

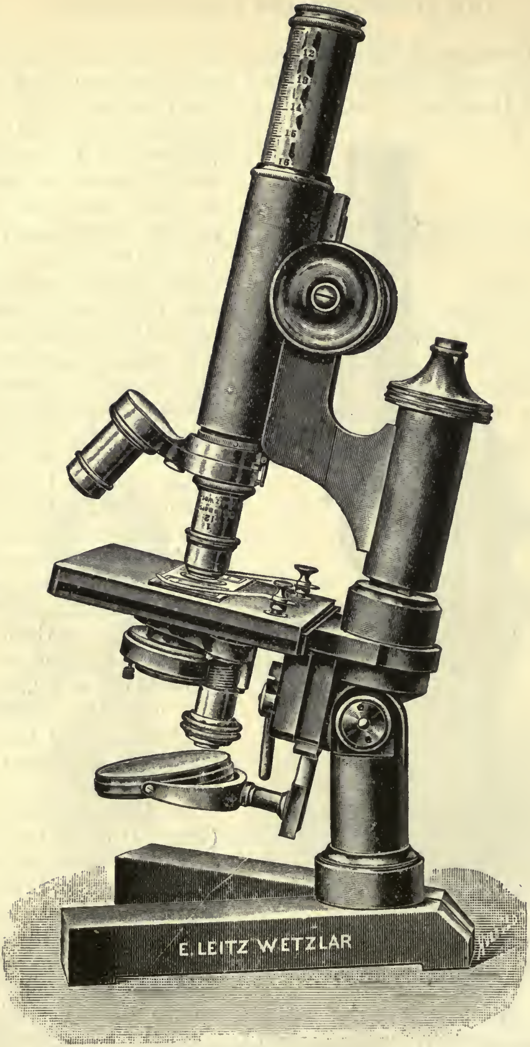

Fig. 31.—Compound Microscope with Rack-and-Pinion Adjustment, Double Nosepiece and two Objectives.

coarse adjustment brings the outlines of the object dimly into focus, but to get more accurate focussing (especially when using a high-power objective) we use the **fine adjustment,** by turning a screw at the top of the stand, behind the body-tube.

The object to be examined is placed on the stage, which has two clips for fixing a slide in a definite position, but these need not be used except for high powers, or while sketching. There is usually a black plate, with holes of different sizes, under the stage; this can be rotated so as to bring the desired size of hole (*diaphragm*) under the central opening of the stage. More expensive microscopes have an *iris diaphragm*. A small hole is used with high power and a large one with low power.

For ordinary work two objectives are required, one for low power (magnifying 60 to 80 diameters), and the other for high power (300 to 400 diameters). The most useful are 1 inch or $\frac{2}{3}$ inch low power objective and $\frac{1}{4}$ or $\frac{1}{6}$ inch high power objective. Of the two eyepieces the one with shorter body and narrower eye-glass is the more powerful.

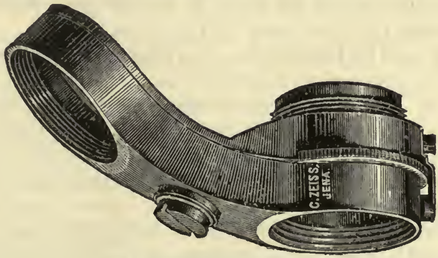

Fig. 32.—Double Nosepiece.

In most modern instruments the magnifying power can be increased by having the body-tube constructed like a telescope; the upper part (**draw-tube**), carrying the eyepiece, can be drawn out. To avoid the inconvenience of having to screw and unscrew a lens every time a change of magnifying power is required, it is worth while to get a **nosepiece** (Fig. 32), which is screwed to the lower end of the body-tube and carries the two objectives; by rotating it we can quickly change from low to high power and vice versâ.

95. Notes on Use of Compound Microscope.—If the stand is without rack-and-pinion, see that the tube moves easily, but not too easily, up and down; if stiff, take out the tube, rub it with a little olive oil or vaseline.

See that the lenses are clean; dust the mirror, adjust it so as to send light through the body-tube, and insert first one eyepiece and then the other. Rotate each eyepiece; if any specks are seen to rotate with it they must be on the eyepiece lenses, and should be removed with a chamois leather or soft cloth. If the specks are dim, the dirt must be on the objective; wipe the latter very carefully, and if necessary wash its front lens with a jet of water from a wash-bottle and wipe it dry. Do not rub lenses much, or unnecessarily; do not unscrew the separate lenses of a high objective unless it becomes absolutely necessary, and then do it with great care; in cleaning the lenses do not remove the black coating on the inside of the tube.

Never use direct sunlight, and also avoid using artificial light. The best light is that reflected from white clouds in a northern sky. If a south aspect is the only one available, direct sunlight must be cut off, by using a white blind or fitting a piece of white card on the mirror.

Always use the low power objective first, and never use the high power unless the object is covered with a cover-glass.

With the low power use the flat mirror and a large hole of the diaphragm below the stage; with the high power use the concave mirror and a small diaphragm, otherwise (though the field may look brighter) the outlines of the cells, etc., will not be so sharply defined.

Never use the fine adjustment until the focus has been obtained with the coarse adjustment, whether by sliding or by rack-and-pinion. With the low power objective (the one with the larger front lens), slide or rack down the tube to about $\frac{1}{2}$ inch from the object; then, looking through the eyepiece, slide or rack the tube upwards till the object comes into view, and focus clearly by turning the milled head of the fine adjustment screw to right or left. With the high power lower the tube to about $\frac{1}{4}$ inch from the object, then very carefully slide or rack the tube down while looking through the eyepiece, till the object just becomes visible, and focus with the fine adjustment.

Great care is necessary in using the high power, since the objective when in focus is so close to the object. Do not let the high objective touch the slide, and above all do not go on ramming or racking the tube down after passing the position of focus, or you may ruin the objective, besides breaking cover-glass and slide and damaging the specimen. Always use a cover-glass with the high objective; if you cannot see anything clearly, stop at once, move the tube upwards, wipe the objective, remount the specimen (if examined in a drop of water, which is liable to flow over the cover-glass and wet the objective), clean the cover-glass, and start again.

Keep both eyes open when using the microscope; this lessens the fatigue of microscope work, and is not at all difficult if you practise for a few minutes each time you start work. Accustom yourself to using either eye indifferently. Never work by artificial light if you can help it.

96. Accessories for Microscope Work.—The following apparatus is necessary for work with the microscope (Fig. 33) :—

(1) A good razor, slightly hollow-ground or, better, with one side flat, and a strop and hone for sharpening it; cost of razor, about 1s. 6d.

(2) A few dozen glass slips, 3 ins. × 1 in. (4d. per dozen).

(3) An ounce of $\frac{7}{8}$ in. square cover-glasses (No. 2 thickness, 3s. per ounce).

(4) A pair of fine-pointed forceps (about 1s.).

(5) A scalpel (about 1s.) or a sharp pen-knife.

(6) A pair of fine scissors with sharp points (about 1s.).

(7) A few fine camel-hair brushes (about 1d. each).

(8) A few mounted needles (about 1s. 3d. per dozen); these can be made by fixing a needle, point outwards, into one end of a penholder (Fig 33, D), or a handle adjustable for any needle (Fig. 33, E) can be bought for about 9d.

(9) A few flat-bottomed watch-glasses (about 1s. 6d. per dozen).

(10) A few ointment-pots with lids, and a few wide-mouthed stoppered or corked glass bottles of different sizes.

(11) A small spirit lamp (4 oz. size, 9d.).

(12) Gummed labels, $\frac{7}{8}$ in. square, for naming slides (2d. per hundred).

(13) A coarse duster, a finer cloth (*e.g.* an old, but clean, handkerchief), and a small chamois leather.

(14) Bottle for Canada-balsam or glycerine-jelly, with cap and glass rod (2 oz. size, 8d.). Fig. 33, G.

(15) Small narrow-mouthed stoppered bottles for the following reagents; glass rods are used for bringing drops of the reagents from the bottles to the slide (Fig. 33, H).

(16) Reagents :—(*a*) **glycerine** diluted with an equal volume of water; (*b*) a 2% solution of **caustic potash** in water; (*c*) **iodine** tincture diluted with three times its volume of water; (*d*) **aniline chloride** solution; (*e*) a 5% solution of **common salt**; (*f*) **Schulze's solution** solution (chlor-zinc-iodine).

(17) Two **wash-bottles** (Fig. 11), one for *alcohol* (methylated spirit, diluted with its own volume of water), the other for *water*.

(18) Elder-pith for section-cutting (about 9d. per bundle).

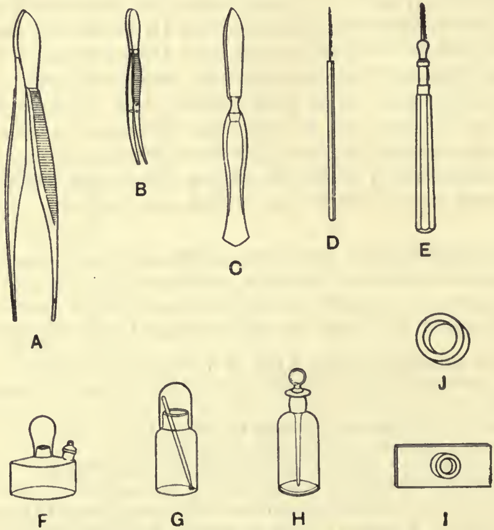

Fig. 33.—Accessories for Microscopic Work.

A, B, Forceps; C, Scalpel; D, Mounted Needle; E, Needle-holder, into which fresh needles can be fixed; F, Spirit-lamp; G, Canada-balsam Bottle; H, Reagent-bottle with Dropping-rod; I, J, Glass Ring and Slide fitted with same, for cover-glass hanging-drop preparations.

97. Cells in Apple Pulp.—Cut a "mealy" apple in halves, remove a small bit of pulp near the core, place it in a small drop of water on a clean slide, tease it out gently with two needles. Carefully lower a clean and dry cover-glass over the drop, so that one edge is first wetted and no air-bubbles get in; hold the cover with dry forceps or sup-part it with a needle and gently lower it. If air-bubbles get in, or any water flows over the upper side of the cover-glass, start all over again.

(*a*) Using the low power objective, note the numerous colourless *cells*, more or less egg-shaped, either isolated or connected in groups; some may have been injured by teasing, but most of them will be alive. Find a place where the cells are not too crowded, and put on the high objective. Note, in a cell, the thin smooth *cell-wall*, lined inside by a film of fine-grained *protoplasm*, and the large cell-cavity (*vacuole*).

(*b*) Put a drop of salt solution on the slide, close to one edge of the cover-glass, but do not let it flow over the upper side of the cover (if it does, make a fresh preparation), then push a bit of blotting-paper along to the opposite edge of the cover, so as to *irrigate* the cells with the salt solution as the blotting-paper soaks up the water. Watch the cells; the protoplasm film shrinks from the cell-wall as the cell is *plasmolysed*, but the wall itself shows no apparent change.

(*c*) Mount a fresh bit of pulp in the same way in a drop of water and irrigate with glycerine (or mount at once in glycerine); the cell is strongly plasmolysed, as with the salt solution, and the cell-wall also shrinks and becomes folded as the cell collapses.

(*d*) Treat another preparation with iodine solution; the wall is not stained (or only stained faintly yellow or brown), but the protoplasm becomes dark-brown and a small rounded or oval body (*nucleus*) becomes prominent by staining more deeply than the rest of the protoplasm.

(*e*) Mount another preparation in Schulze's chlor-zinc-iodine, and let it stand for a few minutes; the protoplasm stains brown, as with iodine solution, but the cell-wall is stained violet (reaction of *cellulose*).

98. Spirogyra.—Mount in water and examine with the microscope a small quantity of *Spirogyra*, a green filamentous freshwater Alga, commonly found in floating masses, in summer, on ponds and slow streams.[1]

(*a*) The threads feel slimy, owing to a coating of mucilage on the surface. Notice the unbranched filaments, each consisting of a row of cylindrical cells, separated by cross-walls at intervals, and each containing one or more green spiral bands.

[1] *Spirogyra* is supplied by Mr. Bolton, 25, Balsall Heath Road, Birmingham, at almost any time, in shilling tubes. Any other material for practical work can be bought from Mr. Bolton, or from the British Botanical Association, Holgate Nurseries, York.

(*b*) With the high power notice (1) the smooth, colourless cell-wall; (2) the thin film of granular **protoplasm** immediately within the cell-wall, in which are embedded (3) the flat **green bands**, which have ragged edges, and show at intervals small rounded highly refractive bodies, the **pyrenoids**; (4) the large central cavity (*vacuole*) of the cell, containing colourless transparent **cell-sap**; and (5) the highly refractive spherical or lens-shaped **nucleus** in centre of cell.

(*c*) Stain some filaments with iodine, and observe that the pyrenoids have become dark purple or almost black, owing to the presence of crowded small **starch-grains**, and that the nucleus is connected with the outer layer of protoplasm by fine threads, each usually ending at a pyrenoid.

(*d*) Mount some *Spirogyra* filaments in water, place at one edge of the cover-glass a few drops of salt-solution, and while watching a filament, draw the solution under the cover-glass by holding a piece of blotting-paper at the other side. Notice that the protoplasm shrinks from the cell-wall, as water passes by diffusion (osmosis) from the cell-sap in the vacuole into the salt-solution outside. Sketch the contracted or *plasmolysed* cell, then draw a little water under the cover in the same manner, and notice the cell return to its normal *turgid* condition.

(*e*) Place some *Spirogyra* filaments in alcohol, and after a day or two notice that the spiral bands have become colourless, the green colouring matter (chlorophyll) having been dissolved by the alcohol, which also contracts or plasmolyses the cells.

99. Other Simple Preparations.—Many other interesting and instructive preparations can be made by using fresh materials simply mounted in water, *e.g.* leaves of Mosses, of water-plants (*Elodea*, *Nitella*, etc.), roots of seedlings (note the root-cap, root-hairs, rootlets).

(*a*) Mount in water a few whole leaves of a thin-leaved Moss (try several kinds and select those which show large and clear cells), or a Fern prothallus. Note the polygonal cells, joined to form a plate, without any spaces between them, and in each cell note the protoplasm, the vacuole, the nucleus (seen especially well on staining with iodine solution, which, however, kills the cell), and the numerous small disc-like chloroplasts or chlorophyll-corpuscles (stained purple with iodine if they contain starch).

(*b*) In Moss cells you can see the chloroplasts in the act of dividing. The chloroplast becomes lengthened and then nipped across the middle so as to resemble a dumb-bell, eventually separating and forming two chloroplasts.

(*c*) Get some Canadian Waterweed (*Elodea*), which grows abundantly in many rivers and canals, having long submerged stems and leaves arranged in threes at each "node." Mount a few leaves in water, and look for the *streaming movements* of the protoplasm, which may be started or hastened by gently warming the slide. Similar movements can be seen, even better, in the long cells of Stoneworts (*Nitella* and *Chara*), which grow in sluggish streams, and the cells forming the hairs on the stamens of *Tradescantia* (often grown in greenhouses) show more complicated protoplasmic movements.

(*d*) A "moist-chamber slide" is very useful for observing circulation of protoplasm in *Elodea*, etc., also for watching the growth of pollen-tubes. A ring of glass is cemented to a slide, and the *Elodea*-leaf, or some pollen, is placed in a small drop on a cover-glass, which is then inverted over the ring. A slide of this kind can be bought (Fig. 33, I) or can easily be made by using a ring of cardboard.

100. Section Cutting.—In examining the cellular structure of a solid mass, *e.g.* a stem, root, or leaf, we can learn a certain amount by crushing, teasing, or macerating the tissues, but the best results are obtained by cutting thin *sections* in different directions. Fresh tissues may be used for cutting, but it is often better to use "pickled" material. The pickling fluid used for ordinary work is methylated spirit diluted with about half its volume of water. Stems, roots, leaves, etc., preserved in this way in glass jars are always ready for use. Delicate plants, flowers, etc., may be preserved in 4 to 6 per cent. solution of formalin; formalin as sold is a 40 per cent. solution.

In taking a section, the tissue to be cut should be held between the thumb and fingers of the left hand; the razor in the right hand. The tips of the four right fingers should rest on the back of the razor, and the thumb in front, just behind the cutting edge. The cutting edge is therefore directed inwards, towards the operator. The arms should be brought up close to the body. Tissue and razor should both be wet with alcohol. The blade of the razor may rest gently on the forefinger of the left hand with the edge against the tissue. Then the razor is drawn through the tissue with a sliding movement. *With practice*, extremely thin sections may be cut.

The sections should be removed from the razor by means of a brush, and placed in a watch-glass containing alcohol or water. Several may then be transferred to a slide and examined in water under the low power, so that the best may be selected. By means of the linen rag the excess of water may be removed, and iodine or other reagent added according to the special points which the student wishes to determine. The reagent should then be washed off with water, the excess of water removed, a drop of glycerine added, and finally the cover-glass put on. The section should always be mounted in the centre of the slide. The cover-glass should be rested on its edge and let down gradually by means of a needle. The section *must not be allowed to get dry* during the process, or air-bubbles will make their appearance. If these do appear, soaking the section for some time in alcohol will remove them. The cover-glass must be perfectly clean and dry.

Neatness and cleanliness are of great importance in practical work. At first you will find that the sections are rather thick and often obliquely cut. These are difficulties which can be got over only by care and practice Do not attempt to draw a bad section.

Very slender or delicate tissues, or thin structures like leaves, should be cut by embedding in pith or carrot. If carrot be used, a piece 1 in. × ½ in. × ¼ in. will be found convenient.

101. Structure of Bean Cotyledon.[1]—A thin section across a Bean cotyledon shows an outer layer or skin (epidermis) of small cells containing only fine-grained protoplasm and a nucleus. The inner cells contain, besides protoplasm and nucleus, large starch-grains and small proteid-grains. With iodine solution, the starch-grains are seen to turn blue, while the protoplasm and proteid-grains turn brown and the nucleus is deeply stained. The cotyledon has feebly-developed veins, appearing in section as irregular streaks and patches of small narrow cells.

The dry Broad Bean seed contains about 60 per cent. of starch, 25 per cent. proteids, 3 per cent. oil, and 4 per cent. ash ingredients (calcium, magnesium, potassium, sulphur, phosphorus, etc.); the residue consists chiefly of cellulose (in cell-walls) and some silica (in seed-coat).

102. Slide Mounting.—Sections and other specimens may be mounted *permanently* in **glycerine jelly.** The bottle of jelly is set in a cup or dish of hot water until the jelly melts, then the superfluous water is drawn from the specimen by using a bit of blotting-paper, the specimen covered with a drop of melted jelly (taken out with a glass rod), and a cover-glass put over it. The jelly is apt to liquefy by absorbing moisture from the air, but this may be prevented by painting round the edge of the cover-glass with a **cement,** *e.g.* Canada-balsam or gold-size.

More lasting preparations are made by mounting in Canada-balsam, but all water must be extracted first, by washing or steeping in absolute alcohol, or in strong methylated spirit; then the specimen is treated with oil of cloves and (after removing excess of oil with blotting-paper) mounted in a drop of balsam.

Preparations of *Spirogyra*, Moss leaves, or other green parts will often keep their green colour for a long time if the fresh specimens are mounted in a drop of acetate of potash (strong solution) and ringed with balsam or size.

103. Staining.—Many staining substances are used in advanced work, or to pick out the different tissues in sections of stems, roots, etc. For instance, lignified (woody) cell-walls stain deep red with safranin, which does not stain cellulose walls or only faintly; haematoxylin stains cellulose but not lignified walls. Instead of safranin

[1] See Slide No. 1 in *Plant Biology Collection of Microscopic Slides.*

we may use any aniline stain (*e.g.* aniline blue or violet) for lignified walls, and carmine instead of haematoxylin.

In any case, the stain, dissolved in water or alcohol, is applied in drops to the specimen on the slide, or the specimen is dipped into the staining solution in a watch-glass and lifted out after some minutes with a brush; the stained specimen is then washed with water or alcohol, and if necessary placed in a second staining solution for double staining, *e.g.* safranin and haematoxylin, or aniline blue and carmine, and finally mounted.

Ready-stained preparations (sections of stems, roots, leaves, etc.) can be bought. The *Plant Biology Collection of Microscopic Slides* (see Preface) contains a good selection of preparations.

QUESTIONS ON CHAPTER III.

1. Describe the parts of a compound microscope, with a sketch showing the parts labelled. What is the use of a nosepiece, a cover-glass, a concave mirror, a draw-tube?

2. Describe the structure of a young parenchymatous cell and explain how it differs from that of a fully-grown cell of the same kind.

3. How would you obtain a living green cell for examination with the microscope? Describe, with sketch, the appearance of the cell, mounted in water.

4. How would you obtain, for microscopic examination, a living but not green cell? Sketch the cell as seen (*a*) in water, (*b*) in salt solution, (*c*) after treatment with iodine solution.

5. Describe and sketch the cells seen in sections of (*a*) Bean cotyledon, (*b*) Date stone.

6. Describe the circulation of protoplasm as seen in any living cells you have examined; name the plant used and sketch one of the cells.

7. Describe and sketch the appearance of a cell of Spirogyra, (*a*) in water, (*b*) in salt solution, (*c*) after treatment with iodine solution, (*d*) after treatment with alcohol.

8. Describe, with sketches, what you have seen (i) with naked eye and lens, (ii) with the microscope, of (*a*) the structure of a grain of Wheat or Maize, (*b*) the origin of a rootlet, (*c*) the structure of a young stem, *e.g.* Sunflower.

9. Make a drawing of some living green cell which you have yourself observed. Name the various parts you figure, and state in a few words the use of each in the life of the cell. How was the cell obtained and prepared? By how many diameters does your drawing magnify the size of the original?

10. Explain the operation of cutting and mounting sections of plant structures for examination under the microscope. Why are such sections cut thin ?

11. How would you withdraw the water from a living cell without killing the protoplasm ? Draw its appearance when thus treated, under the same power, and explain, so far as possible, the process that has taken place.

CHAPTER IV.

PHOTOSYNTHESIS AND RESPIRATION.

104. Questions arising from Work on Seedlings.—The observations you have made on the growth of seedlings must have raised many questions, such as the following: Why does the young main root grow vertically downwards, no matter how the seed is placed? Why does the shoot grow upwards? Why does a seedling remain yellow when kept in darkness and ultimately die, while a seedling set in the light has green leaves and keeps on growing? Is it possible to make a main root turn from the vertical direction which it usually takes? How does growth take place? Where, and how, is the force shown by growing roots and shoots developed? How would the growth of a young Bean plant be affected if one cut off the cotyledons, or the root, or the shoot? How does the seedling get food when that stored in the seed is all used up?

The only way in which one can gain any real knowledge on these points is to put each question to a living plant and make the plant itself give the answer—in other words, to make experiments. Write down any other questions that occur to you as your work proceeds. In each case keep a record of (1) the inquiry, (2) methods and apparatus used, (3) observations and results, (4) inferences.

105. How do Plants Feed?—After the seedling has used up the food laid up for it in the seed (in the embryo itself or in another part of the seed), it must, in order to go on living and growing, get food in some other way. From what sources, and by what processes, does the plant obtain food? What substances does the plant need for healthy life and growth? Seedlings grown in darkness lose in dry weight and eventually die (Art. 65); the smaller the amount of food stored in the seed, the shorter is the life of the darkened seedling. Some further experiments will serve to emphasise this point.

* Remove (*a*) one cotyledon, (*b*) both *cotyledons*, from soaked Broad Bean or Scarlet Runner seeds just beginning to germinate. Place some of these seeds, along with untouched seeds, in the light; place others, also with untouched seeds for comparison, in darkness.

* Remove the *foliage-leaves* from (1) a young Bean plant which has not yet used up the food in its cotyledons, (2) an older plant whose cotyledons have fallen off (if they have shrunk considerably, but are still attached, pull them off). Does the removal of the foliage-leaves check the growth of the plant, as compared with that of similar plants left untouched? In which case, (1) or (2), is the effect greatest?

106. Comparison of Cotyledons and Foliage-Leaves.—We have seen that the cotyledons of the Broad Bean resemble the foliage-leaves in the fact that branches arise in their axils. By growing a seedling in coloured water it can be shown that the cotyledons have veins, which can also be seen in sections examined with the microscope. It is always a useful plan to tabulate—*i.e.* to write down in parallel columns—the chief differences between different plants or different parts of the same plant, as regards their position, form, structure, etc.—and then to find out as completely as possible, by observation and experiment, the *reasons* for these differences. In comparisons of this kind always try to discover whether differences in *structure* can be explained as due to differences in *function*.

Cotyledons.	**Foliage-Leaves.**
opposite	alternate
small	large
simple	compound
pale yellow	green
thick	thin
veins obscure	veins conspicuous
no stipules	stipules present
remain below ground	formed above ground
gradually turn smaller	gradually turn larger
fall off after a time	remain on a long time

Can you add any further differences? Try, as you proceed with your study of the green leaf and its work, to explain these differences in form, texture, duration, etc., between the cotyledons and the foliage-leaves of the Broad Bean.

Gather and examine leaves of various kinds, living or fallen, evergreen or deciduous, stalked or unstalked, simple or divided (compound). What is there common to nearly all leaves, however they may differ in detail? In what surroundings do you find plants with thick fleshy leaves? Does the general broad and thin form of the leaf-blade suggest anything as to the functions of the leaf? Do most leaves seem to expose as much surface as possible to light and air? We saw that the seed-leaves of Broad Bean and of many other plants contain food, and that if they are removed from a soaked seed which is beginning to germinate, the growth of the young plant is stopped.

107. Do Leaves contain Food?—We have seen that seed-leaves often contain food-materials—*e.g.* starch, proteids, oils. It will be easy to find out whether foliage-leaves contain any of these foods. Let us test them for the presence of starch, by using iodine solution. To do this we must try to remove the green colour.

* Boil in water some leaves taken from a Bean seedling, or some other plant with thin flat leaves, which has been growing in the light. The colour does not come out. Place the boiled leaves in alcohol, and notice that the leaves gradually lose their colour, while the alcohol turns green. Try several different plants: in some the extraction of the green substance takes place very slowly, in others (*e.g.* Broad Bean, Tropaeolum, Primrose) much more quickly.[1] When the leaf is colourless, place it in a saucer and pour dilute iodine solution over it. The depth of colour produced shows roughly how much starch is present. If there is abundance of starch, the colour is nearly black; if little starch, it is bluish; if no starch is present, the iodine merely turns the leaf brownish.

108. Does the Green Leaf make Starch?—Where does the starch come from? Is it *made* in the leaf?

We have seen that when a Bean seed germinates in the dark the seedling has small pale leaves which do not become green, while starch stored up in the cotyledons gradually disappears. If an ordinary green plant were set in darkness for some days, would its leaves contain starch?

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[1] Do not *boil* leaves in alcohol; this is dangerous, wasteful, and (if suitable plants are used) unnecessary.

* Keep a plant in darkness until the leaves no longer show starch when tested with iodine, then cut off several leaves and set them in tumblers or bottles of water; the stalk should dip into the water. Set some in sunlight, the others in darkness, and after two days decolorise and test with iodine the two lots of leaves. Those kept in darkness show no starch, but starch is found in those that have been exposed to light. This means that starch is *made* by leaves when in the light, but not when in darkness.

109. Is Light required for Starch-Making?—The preceding experiments show that starch is found in leaves that have been exposed to light, whilst it is absent from the leaves of the same plant after it has been kept in darkness for a day or two. This suggests (1) that light is required for starch to appear in the leaf, (2) that the starch formed in the light disappears in darkness.

* Set some plants—*e.g.* Broad Bean, Primrose, Tropaeolum—in pots in darkness for at least a whole day. In the morning take off some of the leaves, decolorise them, test with iodine; they give only a light brown colour, starch being absent. Choose a day with sunshine or good diffused light for these experiments:—

(*a*) Let some of the leaves on the plant remain untouched.

(*b*) Fix a strip of tinfoil across the leaf, on both sides (above and below); or pin to the leaf two flat slices of cork opposite each other on the two sides; or stitch to the upper side of the leaf a piece of black paper or cloth. The object in each case is, of course, to exclude light from a portion of the leaf.

(*c*) With a knife or scissors, cut the words "starch," "light," your initials, etc., in capital letters out of a series of cards; fasten each card to a broad leaf (a Primrose plant, dug up and grown in a pot, or in a jar of water, answers well), and, after letting the plant stand for a full day in darkness, expose it to light for several hours, then decolorise and test. In this way we can get what might be called a **"starch print,"** from analogy with a photographic print.

A beautiful modification of the experiment is to place a "sharp" or "hard" photographic negative (*i.e.* one with sharp distinctions of light and shade) over the leaf and expose to light.

In each case expose the plant to light from morning till late afternoon, then take off the leaves which have been treated in these various ways, tying to each a label, decolorise them and test with iodine solution. Make notes of your observations and conclusions as to the conditions under which starch is made by leaves. After being tested with iodine, the leaves may be preserved in alcohol and thus made colourless again, and on being soaked in hot water will again give the starch reaction with iodine. **The same leaves can therefore be**

used again and again; starch once formed remains in leaves which have been killed by boiling. In class-teaching, however, it is always better to start experiments from the beginning.

110. Is Air needed for Starch-Making?—It is very easy to prove that the green leaf contains air and bears openings (stomates) communicating with the atmosphere; these openings are usually most abundant on the underside of the leaf. This at once suggests a method of finding out whether air is concerned in starch-making.

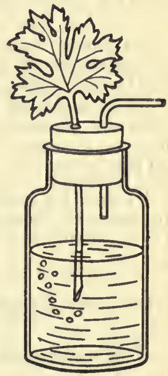

Fig. 34.

* (*a*) Dip the leaves of various plants into very hot (just boiled) water in a warmed tumbler, and notice the expulsion of air-bubbles. In many leaves the bubbles only appear on the lower surface, *e.g.* Laurel, Rhododendron; in others they appear on both sides, but more abundantly on the lower surface, *e.g.* Broad Bean. Cut a large leaf (*e.g.* Laurel) across and dip the cut edge under water, observing the streams of bubbles given off.

* (*b*) Try to blow through leaves dipping into water, first with the stalk and then the blade under water. The simple apparatus shown in Fig. 34 may be used to suck air through a leaf. Suitable leaves are Lesser Celandine, Chinese Primrose, Marsh Marigold, Water Lily.

* (*c*) Even when one cannot force air through a leaf with the lungs, the presence of air-spaces and of openings on the surface can easily be shown by using an air-pump or exhausting syringe to suck air through, or a bicycle-pump to blow air through. The leaf-stalk should be fixed in a bored cork, with another hole for a short glass tube to connect with the syringe or pump by means of rubber-tubing. The cork is fixed into a wide-necked flask or bottle, and the whole made air-tight with plasticine and vaseline.

What has the air, which can readily enter the leaf by the stomates and circulate in the air-spaces within the leaf, got to do with starch-making? We shall study this question in some detail presently. Meanwhile let us see what happens if air is prevented from entering a leaf which is otherwise placed under conditions favourable to the process of starch-making.

Here again it seems necessary to emphasise the necessity for making "control" experiments. The following four experiments, for instance, are not conclusive or satisfactory unless in each case you also test leaves on the same plant which have been left untouched; in this case, as in the experiments of Art. 109, the leaves which are being investigated must be left on the living plant.

* (*d*) Smear the *lower surface* of a leaf with vaseline; this will block the stomates, which in many leaves are mostly or even entirely found on the lower surface. Find out the distribution of stomates on the two sides of each leaf you experiment with by tearing off and examining with the microscope pieces of the lower and the upper skin. If you have no microscope, dipping the leaf into hot water gives a rough idea on this point.

* (*e*) Smear a small circular area of the leaf with vaseline, applying it to *both sides*, so that this part of the leaf will be shut off on both sides from communication with the atmosphere through the stomates.

* (*f*) Smear with vaseline the *upper* surface of another leaf.

* (*g*) Smear *both* surfaces of another leaf.

The results of these simple experiments will show that the air is, somehow or other, concerned with the process of starch-making (Art. 113). What about leaves which grow under water, like those of submerged aquatic plants?

* (*h*) In an experiment on germination we prevented the access of air to seeds by covering them with water, and in the preceding experiments we have excluded air by covering the leaf with vaseline. Tie the stalks of the leaves of some ordinary land-plants to a stone and sink them under water in a glass jar. Expose to light, and afterwards test the leaves for starch.

* (*i*) Repeat the last experiment with the leaves of a plant which lives submerged in water—*e.g.* Water Starwort, Canadian Water-weed, or any other plant you find growing below water in ponds or streams. Do these submerged leaves possess stomates?

111. Is Warmth needed for Starch-Making?—It is very easy to find out whether temperature has any influence on starch-production by leaves. Place a leaf in a saucer or jar kept cold by ice, expose to light, and after several hours test for starch.

112. Is Chlorophyll needed for Starch-Making?—Have you noticed, in your experiments with leaves of Broad Bean, Tropaeolum, or Primrose, that the *veins* remain unstained even when the rest of the leaf is black with the iodine-test? This in itself shows that starch is only formed in the **green** parts of the leaf.

* (*a*) Try variegated leaves (*e.g.* varieties of Geranium or Ivy), making a careful drawing of each leaf before it is decolorised and tested with iodine, and observe that only the green parts produce starch. In leaves whose veins are colourless, or nearly so (*e.g.* Primrose), owing to the absence of chlorophyll above and below them, you will notice that the veins stand out from the rest of the leaf when the iodine-test is applied, by the absence of starch.

* (*b*) Grow seedlings (Bean, Pea, etc.) in darkness, then put them in the light for a day and test the leaves for starch. Leave them in the light until their leaves turn green, then test again for starch.

These results show that the green substance (chlorophyll) is essential for the process of starch-making by leaves.

113. How is Air concerned in Starch-Making?—We know from previous experiments that starch can be broken up, by heating it, into carbon dioxide and water, and that carbon dioxide is always present in the air, being produced by all processes of burning when the substance undergoing oxidation contains carbon. We shall see later on that a plant increases in dry weight when grown in a culture solution which contains no carbon, though more than half of the plant's dry weight consists of carbon.

If you consider these facts carefully you will probably conclude that the carbon in the starch made by the leaf comes from the carbon dioxide in the air. Does the leaf in some way make carbon dioxide and water come together to form starch? If so, a plant which is exposed to light and is making starch must be taking carbon dioxide from the air. What will be the effect of exposing green leaves, in light, to air containing no carbon dioxide?

* (*a*) Heat in a dry test-tube (1) pieces of laundry-starch, (2) leaves, (3) pieces of stems, (4) pieces of roots, (5) any other plant tissues. Notice that water is given off as vapour which condenses in the upper part of the tube, and that a black charred mass remains (charcoal, *i.e.* carbon). Fix a J-shaped tube into a cork to fit the test-tube, and let the longer limb dip into lime-water in a bottle or test-tube; notice that

carbon dioxide is given off, causing a white precipitate, when these substances are strongly heated. These experiments show that all parts of plants contain carbon, and that starch (the formation of which in plants has been proved in the preceding experiments) also contains carbon.

* (*b*) Put a "Nasturtium" (Tropaeolum) leaf in a small bottle containing water, so that its stalk dips well into the water while its blade rests on the neck of the bottle. Pour some caustic potash into a wide-necked glass jar, and lower the bottle with the leaf into this jar; then cork the jar tightly, and smear the edges of the cork with vaseline. The leaf should be taken from a plant which has previously been kept in darkness for two days. The leaf is now exposed to air whose carbon dioxide is absorbed by the potash solution. Set up a control experiment in which the arrangements are the same, but leave the jar open or cover it with a cork (or a piece of wood) in which a hole is bored to admit air.

* (*c*) Use the same apparatus, but, instead of pouring caustic potash into the jar, pass through a hole in the cork closing the jar the tube of a funnel which is filled with soda-lime, or with lumps of caustic potash. This will admit air, but absorb the carbon dioxide it contains. As a control, use a similar apparatus, but place in the funnel gravel instead of soda-lime or potash.

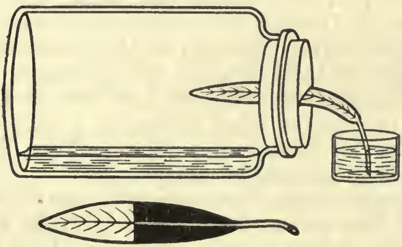

Fig. 35.—Moll's Experiment.

* (*d*) Fit a wide-mouthed bottle with a cork cut in two across the middle. Smear with vaseline the edges of each half of the cork; pour some clear lime-water into the bottle. Then lay the bottle on its side and place between the halves of the cork a Primrose leaf of convenient size, so that half the leaf is inside the bottle and the other half outside (Fig. 35). The base of the leaf, outside of the bottle, should dip into water in a small dish. See that the halves of the cork are securely sealed with vaseline, then cover the whole apparatus with a large bell-jar, and set it in a good light. After some hours, remove the leaf, decolorise, and test with iodine. If the experiment

has been properly arranged, the part of the leaf inside the bottle (*i.e.* in air free from carbon dioxide, which has been absorbed by the lime-water) contains no starch, while the part outside it does. If you do not get this result at first, try the experiment again. This is known as Moll's experiment. Baryta-water or potash may be used.

114. How is the Volume of the Air affected by Starch-Making?—If some living leaves are placed in a closed vessel, how does their absorption of carbon dioxide affect the volume of the air? Does the volume diminish?

* Place a few fresh leaves (from a plant which has been previously kept in darkness for a day) in a glass jar fitted with a bored cork through which passes a twice-bent tube (J-tube) and let the outer limb dip into water coloured with red ink in a small bottle, as in Fig. 36. Charge the air in the jar with carbon dioxide as before; cork tightly and seal with plasticine or vaseline. Cause the coloured water to rise a little way in the outer tube, by warming the jar gently and then letting it cool. Mark the level when the preparations are complete, and set the apparatus in good light (not direct sunlight).

Does the volume of air in the apparatus (and therefore the level of the water) alter at all? Since changes in temperature affect the level (why?), it is well to prevent draughts by placing a bell-jar over the apparatus, or to set up a control experiment (omitting only the leaves); note the temperatures by hanging a thermometer near the apparatus or passing it through a hole in the cork of the jar. Test the air in the jar for carbon dioxide after a day's exposure to light, by pouring in some lime-water or baryta-water. This experiment shows that **when carbon dioxide is absorbed by green leaves, an equal (or nearly equal) volume of some other gas is set free.**

115. How does Starch-Making change the Composition of the Air?—Have you ever noticed, on a warm sunny day, brisk streams of gas-bubbles arising from plants growing under water in a pond or an aquarium?

* (*a*) Collect some of these submerged water-plants—*e.g.* Water Starwort (*Callitriche*) or Canadian Water-weed (*Elodea*)—and test their leaves for starch. Place them in a large glass vessel (*e.g.* a bell-jar resting on a wooden support); if necessary tie them to a stone to keep them together at the bottom. Are the gas-bubbles given off in darkness? Cover the vessel with a black cloth and see if the bubbling stops after a short time, then expose the vessel to light again. Water-cress or Mint will do, if the plants mentioned cannot be obtained.

* (*b*) What do these bubbles consist of? Is the gas ordinary air, or oxygen, or carbon dioxide? We know that water contains dissolved air, and that this dissolved air is richer in carbon dioxide than

ordinary air. Press a glass funnel down on the plants, and either fit a piece of rubber tubing to the tube of the funnel, or, better, invert over the latter a test-tube filled with water, so as to collect the gas given off by the plants. That this gas is **oxygen** (in reality, *air rich in oxygen*) can easily be proved by its causing a glowing splinter of wood to burst into flame, or by corking the end of the tube while still in the water, transferring the tube to a vessel containing solution of pyrogallol in caustic potash and opening it, when the gas will be almost entirely absorbed by the solution ; see Art. 56 (*c*).

* (*c*) Keep your water-plants in darkness until the leaves show little or no starch, then transfer them to water which has been boiled (to expel the dissolved gases) and then cooled. Expose them to light, with funnel and test-tube as before. Is any oxygen given off by the plants, and do they make any starch?

116. Which Parts of the Plant absorb Carbon Dioxide?—Are the leaves (or other green organs) *alone* able to absorb and use the carbon dioxide of the atmosphere?

* (*a*) Get five wide-mouthed bottles, with tightly fitting corks. Wash each bottle out with water, to keep the air inside it moist, and label each with a number (1 to 5). Leave 1 empty, to serve as a check or "control." Into 2 and 3 put some living green leaves; into 4, some green leaves which have been killed by boiling ; into 5, some pieces of living wood cut from a branch, or some roots, or mushrooms, or any other living but *not green* tissue. Charge the bottles with carbon dioxide by breathing into each several times. Another plan is to pour into each jar some "plain soda-water" from a syphon (a convenient method is to use a Sparklet syphon, charging it without adding soda) ; the "soda-water" is of course simply water charged with carbon dioxide. Cork each bottle tightly, smearing the edges of the corks with vaseline. Place bottle 2 in the dark, the others in the light, for a whole day. Then test each bottle for carbon dioxide by pouring in a little lime-water and seeing whether it turns milky.

Try the experiments several times, and record your results, with the inferences to be drawn from them. If carefully carried out, these experiments will show (1) that living green leaves absorb carbon dioxide from the air in sunlight, (2) that they do not absorb it in darkness, (3) that dead leaves do not absorb carbon dioxide, (4) that living but not green parts of plants do not absorb it.

* (*b*) Repeat the observations on the giving-off of oxygen by water-plants, but put into the water, along with the water-plant, pieces of living roots and of mushrooms. Do these living but not green tissues give off oxygen? If any gas-bubbles escape from them, do they come off in light only, or in darkness as well?

117. Does the Leaf gain in Weight by making Starch?—We saw that seedlings grown in darkness lose in dry-weight, while seedlings exposed to light gain in dry-weight. It is easy to prove that the loss and the gain are due chiefly to loss and gain of *carbon*. *How* could you prove this by experiment? To what process do you suppose the gain in dry-weight is due when a seedling is grown in the light? It is very easy to find out.

(*a*) Take a plant which has been growing in the light, and set it in darkness for a day or two—until a leaf picked off, decolorised, and tested with iodine, shows no starch. Remove a second leaf, kill it by holding it in the steam issuing from a boiling kettle, dry it in an oven, or simply put it in a warm dry place, and weigh it. Now expose the plant to bright light for several hours (from morning until evening); remove a third leaf (as nearly as possible similar in size to the second), dry and weigh it, and compare its dry-weight with that of the second leaf. If a Broad Bean seedling or a Tropaeolum plant be used, it will be easy to select leaflets, or leaves, of the same size.

(*b*) Repeat the preceding experiment, using leaves severed from the plant and set in water in small bottles or tubes.

(*c*) A more accurate result will be obtained if you use *pieces of the same leaf* for comparison. Use a plant with large leaves, *e.g.* Sunflower, Primrose, Vegetable Marrow, Rhubarb. If the plant used is growing in a pot or box, keep it in darkness overnight; if it is growing out-of-doors, you must either get up with the sun to start the experiment or, if practicable, cover the plant in some way the previous evening so that it gets little or no light until you are ready to begin.

Choose about six symmetrical leaves, divide each in two longitudinally, cutting along close to the midrib. Find the area of the removed half-leaves by cutting out a paper model of each half-leaf and weighing the papers against strips of similar paper an inch (or 2 or 3 inches) wide, until by balancing you get the total area of the half-leaves. Kill these with steam, dry them, and record the dry weight. Expose the plant to light until evening, remove the remaining half-leaves (cutting along by the midrib), dry, and weigh.

Experiments of this kind have shown that the leaves of Sunflower and Vegetable Marrow produce in a summer day of fifteen hours about an ounce of starch per square yard of surface. The increase in weight due to starch-formation does not represent the total amount of carbohydrate produced; in the Sunflower, for example, only one-sixth of the manufactured carbohydrate appears as starch, the rest being largely carried from the leaf to other parts of the plant as sugar.

118. Structure of the Leaf.—A fuller knowledge of the structure of the leaf will help us to understand its functions better. Even if you have no microscope, you can learn a good deal about leaf-structure by simple methods.

The leaf (Fig. 36) is covered externally by a layer of flattened cells (skin or *epidermis*), and the outer walls of these skin-cells are chemically changed, the cellulose being *cutinised* by the addition of a substance (cutin) which is almost impermeable to water and gases. This substance,

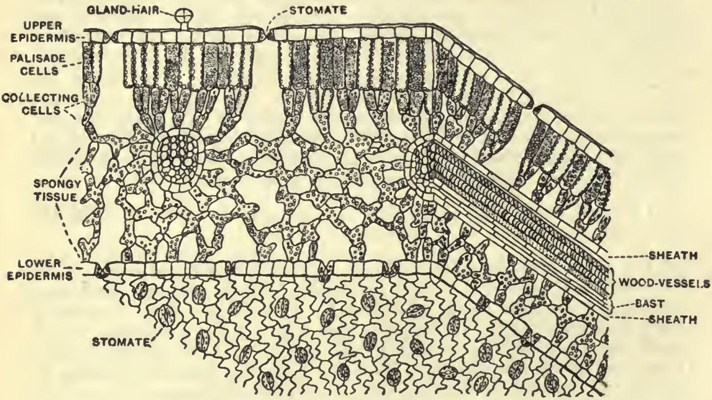

Fig. 36.—Structure of Part of a Broad Bean Leaflet.

which resembles cork in some respects, is most abundant in the outer part of the cell-wall, so that the epidermis is covered by an outer sheet or **cuticle**. The cuticle acts as a protection against drying; it is especially well developed in the leaves of plants that grow in exposed situations and in those of "evergreen" plants, while it remains undeveloped in plants which grow submerged in water.

The epidermis is discontinuous at certain points, leaving narrow oval apertures called **stomates**, each of which is surrounded by a pair of special curved guard-cells. The latter are able to open or to close the stomates, for when they are quite tense (*turgid*) they curve apart, but when less so they collapse and come together. The stomates are very minute but extremely numerous, and in *bifacial* leaves which have distinct upper and lower surfaces they are usually more abundant on the lower surface.[1]

The centre of the leaf is occupied by ground tissue, through which strands of conducting tissue run, the latter being the "veins" of the leaf. In bifacial leaves the ground tissue (*mesophyll*, or central-leaf tissue) is usually divided into an upper region in which its cells are long and narrow in the vertical direction (*i.e.* lengthened at right angles to the surface of the leaf), and a lower region in which the cells are branched and loosely arranged. The upper tissue (palisade tissue) is compact, the cells being close together or separated only by narrow spaces, whilst the lower tissue (spongy tissue) contains large spaces between the cells. The cells of the palisade and spongy tissue all contain green grains; so do the guard-cells of the stomates, but not the other cells of the epidermis, nor those making up the veins.

It is easy to discover that the spaces between the cells of the middle tissue of the leaf contain air, and that they communicate with each other throughout the leaf, with the air-spaces in the corresponding tissue (ground tissue, cortex) of stem and root, and with the external air by means of the stomates. The green grains (chloroplasts), present in the cells of the middle tissue (mesophyll) and in the guard-cells are spongy protoplasmic bodies containing liquid chlorophyll, which can be dissolved out of the grains, leaving them colourless.

* (*a*) The following is a good method of examining the structure of a leaf. Boil some small entire leaves (those of Box or Privet answer well) in caustic potash for about ten minutes. Hold a leaf under water, and with scissors cut off a strip round the margin; the leaf is then readily separated, with the aid of a mounted needle, into three parts, which should be mounted on separate slides and examined with the lens, and then covered with a cover-glass and examined with the microscope. The three parts are (1) the upper skin or epidermis, (2) the mesophyll, containing the veins, (3) the lower skin.[2]

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[1] A square millimetre of Broad Bean leaflet gave, as the average of several countings, 90 stomates in the upper epidermis, and 140 in the lower; a leaflet with area 10 sq. cms. therefore bears over 200,000 stomates.

[2] See preparations of Box-leaf, made in this way, in the *Plant Biology Collection of Microscopic Slides.*

The upper and lower skins are thin and transparent, each one cell in thickness; they are, of course, continuous with each other at the edge of the leaf. In the upper skin all the cells fit closely together without any spaces between them, but in the lower skin there are numerous openings (stomates). Tease the middle tissue with needles, so as to separate the cells in one portion; notice the shapes of these cells, some being cylindrical, others branched. You will probably find some of the cylindrical cells still attached to the inside of the upper skin, and some of the branched cells to that of the lower skin.

* (*b*) Fold a large leaf (*e.g.* Laurel or Rhododendron) several times, and cut thin sections, keeping the razor wet with alcohol. Mount in water, examine with a microscope, and sketch a thin part. Cut some sections with the razor dry, and mount in water; notice the presence of numerous irregular air-bubbles between the cells of the spongy tissue, then run in some alcohol and observe the expulsion of most of the air in the form of spherical bubbles. This shows that the spaces between the cells of the spongy tissue contain air. How did this air get in? In thin sections, try to find stomates leading into the air-spaces.

* (*c*) Strip off a piece of the lower epidermis (Broad Bean, Narcissus, Arum, and Ivy-leaved Toadflax answer well), mount in water, and examine with the microscope. Notice the stomates (are they open or closed?) and the presence of chlorophyll-grains in the guard-cells (do they occur in the other cells of the epidermis?). Find an open stomate with the high power, put a drop of 3 per cent. salt solution at one side of the cover-glass, and draw it through with blotting-paper. Notice the effect of this on the stomate. Now put a drop of water at one side and draw it through, until the stomate opens again. Sketch the stomate opened and closed. The salt solution draws water out of the guard-cells, and then the stomate closes as the guard-cells lose their turgidity and collapse. When water is added, the guard-cells absorb it and swell up, becoming turgid, and the stomate opens.

* (*d*) Cut sections of leaves that have been exposed to light for several hours. Examine some sections to see what parts contain the green grains, then treat others with alcohol and test with iodine. Notice that starch-grains occur only in cells which contain chlorophyll. Tear off bits of the upper and lower epidermis-layers, and notice that only the guard-cells of the stomates contain starch. The starch-grains are very small and are formed inside the chlorophyll-grains.

A good method is to immerse a thin leaf (e.g. *Tropaeolum*) in a strong solution of chloral hydrate, made by dissolving a few crystals of this substance in a little water, in a watch-glass, and add a few drops of iodine solution. The leaf soon becomes transparent and the starch-grains stained by the iodine.

119. The Store of Carbon Dioxide in the Atmosphere.—Enormous quantities of carbon dioxide are absorbed by green leaves from the air, although the latter usually contains not more than 0·03 to 0·04 per cent. of this gas. A large Sunflower leaf may absorb, during a single hour's exposure to sunlight, the carbon dioxide contained in many cubic feet of air, making about 2 grammes of starch per hour per square yard of surface.

About half of the dry weight of a plant consists of carbon, and the 4 litres of carbon dioxide contained in 10,000 litres of air contain only 2 grammes of carbon. A tree having a dry weight of 5,000 kilograms must therefore (to obtain its $2\frac{1}{2}$ million grammes of carbon) deprive 12 million cubic metres of air of their carbon dioxide. But the atmosphere contains an astounding amount of carbon dioxide, which is placed at the disposal of plants owing to its uniform distribution by diffusion.

The actual supply of carbon dioxide in the air is estimated at 3,000 billion kilograms, containing 800 billion kilograms (about 800 million tons) of carbon, which would be sufficient for the earth's vegetation for several years, even if the supply were not being continually renewed by the respiration and decomposition of organisms, by processes of burning, etc. Since an adult breathes out daily more than 400 litres of carbon dioxide, the 1400 millions of human beings in the world give to the air annually about 100 billion kilograms of carbon. The amount of coal burnt annually has been estimated at 400 billion (400,000,000,000) kilograms, yielding to the air over 300 billion kilograms of carbon (coal contains about 80 per cent. carbon). Even larger amounts of carbon dioxide are doubtless produced by the Bacteria of the soil.

120. How Carbon Dioxide enters the Leaf.—In a seaweed or a submerged flowering-plant carbon dioxide is absorbed, and oxygen given out, by diffusion through the whole surface of the plant. In the case of an ordinary plant with stomate-bearing green organs, the gaseous exchanges[1] between the atmosphere and the plant's tissues take place through the stomates almost exclusively. The stomate-bearing leaf is a much more efficient organ of gaseous exchange than it would appear at first sight.

The actual opening of a stomate is only about 0·0002 sq. mm.—small enough to hinder the entrance of dust or water. The stomates are very numerous; a Sunflower leaf, for example, has about 12 millions. A square millimetre of Broad Bean leaflet gave, as the average of several counts, 90 stomates on

[1] These exchanges are (1) entrance of carbon dioxide and escape of oxygen, (2) entrance of oxygen and escape of carbon dioxide, (3) escape of water vapour, in the processes of Carbon-assimilation, Respiration, and Transpiration respectively.

the epidermis and 140 on the lower; a large leaflet, with area about 20 sq. cms., therefore has nearly half a million stomates. Still, the total area of the air-openings is only about 0·01 of the total leaf-area.

It has, however, been found that the rate of diffusion of gases through a plate with small openings is much greater than through a single opening of the same total area, and that when the small openings are placed about ten times their diameter apart the rate of diffusion is as rapid as when no partition is present. These requirements are met by the size and the distribution of the stomates on a leaf, and a given area of a leaf has been found by experiment to absorb two-thirds the amount of carbon dioxide taken up in equal time by area of potash solution exposed to the air.

121. Carbon Assimilation; Photosynthesis.—In the green leaf exposed to light and air a somewhat complicated series of processes goes on, leading usually (but with some exceptions) to the appearance of *starch* at one stage. What we have learnt from our experiments on plants, together with our knowledge of the composition of water and of carbon dioxide, would seem to suggest that a process of *synthesis* occurs in the green parts of plants. One method of proving the composition of water is to produce it by synthesis—*i.e.* by bringing together hydrogen and oxygen gases and making them unite to form water. Many complex substances, *e.g.* sugars, can be produced by synthesis.

When starch is heated, carbon dioxide and water are given off. This suggests that possibly carbon dioxide and water are brought together, in the green leaf in sunlight, to form starch. This is not exactly what happens, but the fact that a plant can, when supplied with water and carbon dioxide, make starch (containing carbon, hydrogen, and oxygen) suggests that water must be concerned in the process. The formation of starch in a plant exposed to light is clearly seen in a simple water-plant like Spirogyra (Art. 98); this plant, placed in water containing a few simple salts (Art. 143) and carbon dioxide, produces starch within a few minutes after exposure to light after having been kept in darkness.

It is therefore obvious that in some way carbon dioxide and water are broken up and their elements rearranged so as to produce carbohydrates, oxygen being given off in volume equal to that of the carbon dioxide absorbed.

Is it possible, by any artificial method, to cause the atoms of carbon, hydrogen, and oxygen in carbon dioxide (CO_2) and water (H_2O) to arrange themselves so as to form an organic substance? To break up carbon dioxide into carbon monoxide (CO) and oxygen requires great heat. How can water be broken up (analysed) into its elements? It is clear that a large amount of energy is required to effect these two processes of decomposition. But carbonic acid (carbon dioxide dissolved in water) can be decomposed by a comparatively weak electric current ("silent discharge").

Here we come to an interesting point—the chief product of this electric action is formaldehyde (CH_2O), a substance which in watery solution ("formalin") is used for preserving and disinfecting. Now, by various simple methods (*e.g.* boiling with lime), formaldehyde can be converted into a sugar, its molecules being condensed or packed together to form the large sugar-molecules ($C_6H_{12}O_6$)—this process is sometimes called polymerisation.

In green plants, sugar—usually, however, cane-sugar ($C_{12}H_{22}O_{11}$)—is formed in the green leaf-cells, though starch is the first *visible* product; the starch appears as grains inside the chloroplasts, while the sugar is dissolved in the cell-sap. Probably part of the sugar produced is converted into starch because the excess of sugar dissolved in the cell-sap would cause injury to the living substance (protoplasm); the starch, practically insoluble in water, is evidently a temporary storage substance, which is later removed after being converted back into sugar.

Formaldehyde is a poisonous substance, its solution ("formalin") being used as a germ-killer. Yet it occurs in small quantities in leaves, and a green plant like Spirogyra can make starch when placed in water containing no carbon dioxide but containing a substance which readily breaks up and yields formaldehyde.

It is now known that (1) the amount of formaldehyde produced in assimilating leaves varies in exactly the same way, according to the intensity of illumination, as (2) the amount of carbon dioxide used and (3) the amount of starch formed, being greatest in diffuse light, least in intense light or in darkness. Further, it appears that (4) the strength of the electric currents in green organs also varies according to the light-intensity. The optimum, in all four cases, is about one-fourth of direct sunlight.

It has therefore been suggested that the light received by the green tissue is transformed into electric energy and that this energy causes the production of formaldehyde from carbon dioxide and water.

The term **photosynthesis** is often applied to what we have so far called "starch-making," because it includes a building-up of simple inorganic substances into complex organic substances. The term **photolysis** has also been used, because the earlier stages involve a breaking-down of carbon dioxide and water. The simpler term **carbon-assimilation** is perhaps better than either.

The term **photosynthetic carbon-assimilation** is used to distinguish the normal process in green plants from the **chemosynthetic carbon-assimilation** carried on by certain Bacteria (nitro-bacteria) which use carbon dioxide but do not obtain energy from light. A green plant can grow and make starch when deprived of carbon dioxide, but supplied with sugar or with glycerine. Light is not required for this form of assimilation.

122. Why is Light required for Photosynthesis?—Since energy is required for the carrying on of photosynthesis and light is essential for this process, it follows that light is necessary because it is the source of energy. It is important, therefore, to study some of the properties of light.

In books on Physics, study carefully the following topics: the cause of light; photometry and the law of inverse squares in light intensity; the composition of white light; refraction; the continuous spectrum; the physical and chemical properties of the less refrangible rays (red) and the more refrangible rays.

123. Effect of Light-Intensity on Photosynthesis.—It is easy to show that the rate at which a green leaf makes starch varies according to the intensity of the light. In weak light no starch is formed, and this is also the case when the light is too intense, but between the two extremes the amount of starch formed corresponds roughly with the light-intensity.

The optimum intensity is usually that of bright diffuse daylight.

It must, however, be remembered that the leaves are never all equally illuminated, and even when a plant with close foliage is exposed to bright sunlight, the average intensity of the light received by the leaves as a whole may not be greater than that of bright diffuse daylight. Hence the plant can afford to risk slight injury to the more exposed leaves, in order that the rest may be able to assimilate more actively. Similarly, plants with thick fleshy leaves or green stems prefer bright sunlight because otherwise the inner assimilating layers only receive very weak light.

The intensity of the light is also affected by the angle at which the sun's rays strike the earth, being greatest when the sun is overhead and least when it is on the horizon. This effect is, of course, due to the absorption of the light-rays by the earth's atmosphere. Owing to the longer days during the summer of temperate regions, however, plants actually receive more light per summer day than they do in the twelve hours' day of the tropics.

Even in shade-loving plants photosynthesis stops when the light-intensity is reduced to ·001 that of sunlight; in sun-loving plants the minimum is reached long before this.

(*a*) Cover half of a leaf with thin paper, or a piece of ground glass, and expose it to light; test for starch and note result. Compare the colour, after testing with iodine, with that of an uncovered leaf on the same plant.

(*b*) Place some healthy cut branches of Elodea or other water-plant under water, and select one which gives a good stream of oxygen-bubbles (fairly rapid and constant) from its cut end. Count the time required for, say, 10 bubbles to be given off, and repeat the counting several times till you get a fairly constant result. Then remove the jar into the shade, or cover it with a sheet of thin white paper to weaken the light, and take times as before, noting the change in the rate of bubbling.

(*c*) Cover the jar containing the water-plant with a black cloth except at one side, and throw light on the plant by placing an incandescent gas lamp, acetylene lamp, or electric lamp at different distances from it, noting the distances and the rates of bubbling. Bring the lamp into such a position that bubbles begin to come off, and count the rate; when it becomes fairly constant, bring the lamp to half this distance from the plant and count again. Part of the effect, however, is due to the heat given out by the lamp; a flat-sided bottle, or other vessel, containing water (kept cold by constant renewal) should be used as a screen to absorb the heat.

124. Amount of Light received and absorbed by the Leaf.—A leaf receives only a small proportion of the light which falls on it, even when exposed to full sunshine, the greater part being lost by reflection and absorption. A smooth and shiny cuticle reflects the light, while much of it is absorbed by a thick cuticle or a dense covering of hairs. In either case the result is the same; the green tissue (mesophyll) of the leaf in most cases actually receives only about one-tenth of the incident light.

However, in most leaves the epidermis absorbs but little of the available (*i.e.* unreflected) light, and, on the other hand, most of this light is used by the green tissue. Thin leaves transmit a good deal of the light, but such leaves usually belong to plants which grow in shaded places, so that in any case the absorption of the light received is practically complete in most plants.

Only a small proportion—probably less than 5 per cent.—of the light received by the green mesophyll cells is actually used in photosynthesis; the remainder is converted into heat and causes vaporisation of the water in the chloroplasts.

(*a*) A photographer's "exposure meter" should be used to compare the intensity of light in open and shaded places, etc. This instrument, some forms of which are very cheap, consists essentially of a strip of sensitised paper and an arrangement for exposing a small piece of the paper at a time, the period of exposure in seconds being noted.

(*b*) Expose pieces of the sensitive strip to the light for 1, 2, 3, 4, and 5 seconds successively, about noon on a bright day, and note the differences in tint in the five pieces. After exposure put the light-prints into a light-tight box, which should only be opened in ruby light (or gaslight if "gaslight paper" is used).

(*c*) Strip a piece of epidermis from a leaf, place it over the opening in the meter, and expose to sunlight.

Take an exposure, for the same length of time, with the same leaf or a similar one, over the sensitive paper.

Take a print by exposing the paper itself to the light.

On comparing the three prints we get a rough idea of the amounts of light shut off by the epidermis, absorbed by the mesophyll, and transmitted through the leaf.

In the Sunflower the epidermis allows roughly 0·1 of the incident light to pass; the paper covered by a piece of epidermis needs to be exposed nearly ten times as long as the uncovered paper to give the same tint. The whole leaf allows very little light to pass, only about 0·005; paper covered by a leaf takes three minutes or more to acquire the tint produced by full light in one second. The mesophyll, therefore, gets 0·095 of the light which falls on the leaf.

(*d*) Make and compare "epidermis prints" and "leaf-prints" of the leaves of plants growing naturally in open and in shaded places, plants with shiny cuticle (*e.g.* Holly, Cherry, Laurel), leaves with hairy covering, etc., at the same time making ordinary "light prints" as a standard for comparison.

125. Which Light Rays are concerned in Photosynthesis?—It is fairly easy to test this by comparing the effects of exposing plants to light of different colours—*i.e.* allowing only certain rays to fall upon the leaves. It is found that the rays at the red end of the spectrum are more active than any of the rest in promoting photosynthesis, and that for most plants the curve obtained when the results of experiments are plotted on squared paper shows two "humps" or maxima, a higher one in the orange and a lower in the blue, with the lowest intermediate part (minimum) in the green.

(*a*) A rough comparison may be made by setting a plant, or a leaf with its stalk dipping into a bottle of water, in a box, one of whose sides is replaced by a sheet of *red* glass, another in a box with a side of *green* glass, another with *blue* glass. After several hours' exposure to light, test each for starch with iodine solution. However, coloured glass is hardly ever pure, in the sense of allowing only rays of one colour to pass through it. This can easily be seen by testing coloured glass with a spectroscope (an excellent direct-vision spectroscope can be had for 25*s*.), or with a lantern and prism.

* (*b*) A better method is to use a pair of double-walled bell-jars, the space between the two walls being filled with a coloured solution. One should be filled with watery solution of potassium dichromate; the other with watery solution of copper sulphate, to which ammonia has been added. The first solution allows red and orange rays to pass through, the second one blue and violet rays. In this way we can at least divide the spectrum into a red-end half and a blue-end half. Set each bell-jar on a folded cloth, or in a saucer of dry sawdust, so as to shut out any white light, place under each a plant in a pot or a seedling that has been dug out and had its root set in a bottle of water. Set both bell-jars in diffused light; in direct sunlight the temperatures in the two would not be the same (why?). The plant in the red-orange light will be found after exposure to light (let the experiment last for two days) to have formed abundant starch, that in the blue-violet light will be almost free from starch.

(*c*) Watch the bubbles of oxygen arising from a submerged water-plant, and time the rate of bubbling. When this is fairly regular, cover with the blue bell-jar, and notice that the bubbling becomes slower after a short time. After about five minutes (take several readings during this time) take off the blue jar and put on the red-orange one, taking records of the rate of bubbling as before, noting the increase in red-orange as compared with blue-violet light.

126. Chlorophyll.—Since only the green parts of plants can carry on photosynthesis and the green colour of these parts is due to chlorophyll, it is necessary to study the properties of this substance.

Chlorophyll is a colouring substance, or pigment, of a complex nature; its composition is not yet fully known. It contains magnesium and phosphorus in addition to carbon, hydrogen, oxygen, and nitrogen. It is probably a mixture of several pigments.

In nature, chlorophyll is readily decomposed by bright light, and it probably undergoes continuous changes, being built up as rapidly, in ordinary conditions, as it is decomposed. It is a fluid or semi-fluid substance, produced in, and held by, the special masses of protoplasm called chloroplasts. The chlorophyll present in a chloroplast only forms about 0·1 per cent. of the latter's substance.

Chlorophyll can be extracted by means of alcohol, ether, chloroform, etc. A solution of chlorophyll is fluorescent—it is green by transmitted light, dark red by reflected light. When the solution is held against the light and examined with a spectroscope, or placed in the path of a beam of light, which is then passed through a prism, the spectrum shows dark bands, in the red, blue, and violet regions especially; the band in the red is very marked, appearing even if a weak solution is used. These dark bands (also seen on examining a thin green leaf with a spectroscope) are of course due to the *absorption* by the chlorophyll of these rays of light, the other rays being allowed to pass through the leaf.

* (*a*) Extract chlorophyll from green leaves (*e.g.* Bean, Grass; almost any leaves will do, but leathery ones should be chopped up) by boiling them in water, draining off the water, and covering the leaves with alcohol. Then place the dish containing the leaves and alcohol in the dark; light destroys the colouring matter in the solution. Filter the solution, and place it in a corked bottle.

* (*b*) Notice the colour of the filtered extract by holding the bottle up to the light, and by holding it against a black surface; it is green by transmitted light, red by reflected light. Obtain a continuous spectrum on a screen by fastening on the lens of an optical lantern a card with a vertical slit, and holding a prism in the path of the light. Hold a test-tube of alcoholic chlorophyll-solution against the slit, and notice that the colours in several parts of the spectrum are replaced by dark bands. The most prominent dark band appears in the red part, but if the solution is strong bands will also be seen in other regions of the spectrum.

Try the effect of interposing pieces of glass of various colours, or bottles containing solutions of dichromate of potash and of copper sulphate. In each case certain rays of light are stopped, that is, *absorbed*, and *the places of these rays in the spectrum are occupied by dark bands*, that is, by darkness.

We see now that chlorophyll absorbs certain light-rays, allowing the rest to pass through it, and we may conclude that these absorbed rays in some way supply the energy which is needed in carrying on the work of photosynthesis. A direct-vision spectroscope will show the absorption-bands, especially that in the red part of the spectrum. A very useful additional piece of apparatus is a wedge-shaped bottle ("indigo prism") by means of which one can examine different thicknesses of the solution.

(*c*) It will be noticed that the extreme end of the red region (that nearest the invisible infra-red) is not absorbed by the chlorophyll solution. If you hold up to the light a thick layer of strong leaf-extract (using the thick end of an "indigo-prism" or a flat-sided glass vessel) you will find it appears red instead of green.

(*d*) Place some leaf-extract in a test-tube, dilute with a few drops of water, then add benzol, shake, and allow to settle. The benzol, which floats above the alcohol, dissolves out a bluish-green colouring-matter, leaving a yellow substance dissolved in the alcohol. These two pigments present in the extract can also be separated by using ether or olive oil instead of benzol. Find out, by using the spectroscope, or lantern and prism, which light-rays each of these substances absorbs.

* (*e*) Fill three test-tubes with leaf-extract, cork them, and place A in sunlight, B in diffused light, C in darkness. Carefully boil some extract in a fourth test-tube (D), and place it with A in sunlight. Notice, after a day's exposure, that A becomes brown, C is unchanged, while B and D are only slightly changed; the absence of oxygen in D hinders the destructive effect of light.

(*f*) Add some 10 per cent. solution of copper sulphate to some leaf-extract in two test-tubes; a copper compound is produced which is not red by reflected light, and which is not destroyed by light. Verify the latter point by placing one tube in sunlight, the other in darkness, in each case with a tube of ordinary leaf-extract for comparison

127. Under what conditions is Chlorophyll produced?—We have seen that seedlings grown in darkness differ from those grown in the light in several respects. In most Flowering Plants chlorophyll is not formed in darkness; the chloroplasts are present in the cells of the stem and leaves of darkened seedlings (or of the shoots produced, say, by a potato-tuber kept in darkness), but in the stems the chloroplasts remain colourless, while in the leaves they become yellow. Hence the stems remain white and the leaves turn yellow. The yellow colour of the leaves is due to the presence of a pigment called **etiolin,** developed in the chloroplasts instead of chlorophyll, and the plant is said to be etiolated.

It is easy to prove that chlorophyll is formed in light too weak to allow of photosynthesis. It is produced in shaded places with light-intensity of less than 0·001 that of full sunlight, though very few flowering plants can thrive in such feeble light, *e.g.* in very dense Beech woods.

What other conditions, if any, are essential (in addition to light) for the formation of chlorophyll? It is easy to discover by experiment whether warmth, oxygen, and carbon dioxide, for instance, are required. The presence of *iron* is essential, but it is not so easy to prove this; sometimes one comes upon a case in which the leaves are pale and sickly (*chlorotic*) owing to lack of iron, and can cause the production of chlorophyll by adding iron to the plant's food (*e.g.* in water-cultures, Art. 143) or by applying a weak solution of an iron salt to the leaves with a camel-hair brush.

* (*a*) Grow seedlings, *e.g.* Cress or Mustard, in darkness, then place some of them in a good light, close to a window, and note the time required for the production of a distinct green colour. Place the others in a dark part of the room, and when they have become green test the leaves for starch. These observations will show that (*a*) a green tinge, due to formation of chlorophyll, may be developed in an hour, or less, in good light; (*b*) light too weak for photosynthesis is strong enough for the production of chlorophyll.

(*b*) Sow in the same pot or box some seeds of Pine and of Bean or Pea, keeping them in darkness, and compare the colour of the Pine-seedlings with that of the others.

(*c*) Place some etiolated seedlings (Cress, Mustard, Bean, etc.) in a bottle or small glass jar, cover with a glass plate, and set it in a larger jar half filled with water. Keep the water at 30° C. In a similar apparatus keep some of the seedlings in cool water, or water kept at 10° C., by adding bits of ice from time to time. Compare the depth of the green colour developed in the two sets of seedlings after an hour or two of exposure to light.

* (*d*) To show that oxygen is necessary for the formation of chlorophyll, fill a test-tube with water, invert it in water, and pass under its rim some etiolated Mustard seedlings. Though exposed to light, the seedlings do not become green, owing to lack of oxygen. Another method is to place heavier seedlings—*e.g.* Bean, Pea—in a glass jar and cover it with water. In each case similar etiolated seedlings should be placed on wet blotting-paper at the bottom of a jar, whose mouth must of course be left open.

128. Etiolation.—The effects of darkness on a green plant in producing starvation and loss of dry weight have already been studied (Art. 65). Apart from these effects and the non-production of chlorophyll, various changes of form and structure are produced by darkness.

The stem-internodes and the leaf-stalks (if the plant has stalked leaves) are unusually long, giving the plant a "drawn" appearance. In this way there is a chance of shoots reaching the light, as, *e.g.*, in seedlings smothered by other plants. In etiolated plants, also, the leaves remain small and scaly, there is a great development of soft tissue and a meagre formation of hard woody tissue. Large leaves would be useless in darkness; we might say, therefore, that the plant devotes all its energy to the formation of long "internodes" which may be of use to it. Many examples of etiolated plants will readily occur to the mind of the student —*e.g.* celery (leaf-stalks), grass covered by a roller or a board.

A green plant must of course have a reserve store of food to draw upon in order to grow in darkness at all.

* Grow in darkness (in each case with plants of the same kind grown in light for comparison) various plants which have a good store of food in their seeds or in such storage-organs as bulbs, corms, tubers. Sow seeds of Broad Bean, etc.; plant Potato-tubers, corms of Crocus, bulbs of Onion, Tulip, Narcissus, etc. Also compare the growth in darkness and in light of plants which normally have a tufted or rosette habit (*e.g.* Crassula, London Pride, Daisy) and note that in darkness the internodes in most cases become elongated.

129. The Main Function of the Leaf is to act as a laboratory for the manufacture of organic food from the carbon dioxide of the air and from the water absorbed by the roots. To carry out this process energy is necessary, and this energy is supplied by the light which the green chloroplastids absorb. During the process more complex substances such as sugar are formed, and a corresponding amount of energy is stored up in this manner. At the same time a volume of oxygen gas is liberated, equivalent to the amount of carbon dioxide assimilated. Hence green plants exposed to sunlight tend to purify the air rendered foul by the breathing of animals.

When a plant is burnt, oxygen is consumed and carbon dioxide and water produced, while the stored energy is liberated again in the form of heat. This energy was stored up in latent form during the assimilation of carbon dioxide, and it really represents that portion of the sunlight absorbed by the plant, which was utilised in the process, and which provided the energy necessary to produce a chemical change of this kind. Coal consists of the remains of plants of past ages, and hence, when a piece of coal burns, the heat and light which are liberated simply represent so much sunlight which has lain dormant for millions of years.

130. What becomes of the Starch formed in the Foliage-Leaves?—Is it absorbed by the plant, like the starch stored in the cotyledons of the Bean? If so, we ought to find less starch in the leaves in the morning than in the evening, since the leaf cannot make more starch until it is again exposed to light.

* (*a*) Remove some leaves from a plant in the early evening (an hour or two before sunset) and place them in alcohol. Early next morning remove some more leaves from the plant, and also cut out differently shaped pieces from some of the leaves and place them in alcohol overnight; then compare their starch-test with that given by the rest of the leaf the next morning. The starch formed in the leaf during the day is found to have disappeared, more or less completely, in darkness.

* (*b*) Would the starch have disappeared had the leaves not been left on the plant? Repeat the experiment, but cut some of the leaves off, set them in a tumbler with their stalks under water; cut pieces out, test them for starch, then test the rest of each leaf in the morning.

131. How does Starch disappear in Darkness?—We saw that the starch stored in the Bean cotyledons is on germination converted by the action of a ferment (diastase) into *sugar*, which is soluble in water and therefore able to travel by diffusion to the growing parts of the young plant and supply them with food. We have seen that the leaf when exposed to light produces starch, which disappears during the night, and if we cut out small pieces from the same leaf every day and tested them, we should find that the alternate production and disappearance of starch go on day after day. By cutting out pieces of leaf of a certain area, drying them and weighing, we should find that the dry weight of the leaf is increased at the end of a sunny day, that it decreases after some hours of exposure to darkness, increasing again on exposure to light. These facts suggest that the starch formed in light is digested and carried away during darkness, and we find that the leaf-cells produce *diastase* just as do the cells of the cotyledons in the Bean seedling.

Keep a plant in darkness for two days, then expose it to sunlight for several hours. Remove some leaves, dry them in a slow oven (or on a sand-bath), then powder them and let them soak in cold water for about half an hour. Filter the extract thus obtained, and try its effect on starch-paste, testing with iodine, and later with Fehling's solution. An extract of leaves of Tropaeolum or of Broad Bean, made in this way, quickly converts starch into sugar; try these and other plants.

132. Respiration.—Every living being, plant or animal, needs a continual supply of energy, without which, for example, neither growth nor active movement is possible.

Like animals, all plants respire—that is, they absorb oxygen and exhale carbon dioxide—losing carbon during the process. Germinating seeds and fungi respire as actively as do warm-blooded animals. The process of respiration is one of slow combustion, and, although the carbon is oxidised at a comparatively low temperature, enough heat is produced to keep an animal warm, or to raise the temperature of a plant by a few degrees. Plants have, however, so large a surface relatively to their bulk that they lose heat very rapidly, and are usually at almost the same temperature as that of the surrounding medium.

When a green plant respires it simply consumes organic material, which it itself had previously constructed from simple compounds by the aid of the energy contained in sunlight. Thus starch is produced from water and carbon dioxide, and a certain amount of energy fixed and oxygen liberated. Then, at a later date, starch may be consumed in respiration, oxygen being absorbed, carbon dioxide and water liberated, and the "fixed" energy set free. Green plants are unable to make direct use of the energy of sunlight they absorb, but, instead, adopt this apparently roundabout method. Its utility is, however, sufficiently obvious, for if plants were directly dependent upon the radiant energy of the sun for their supplies of energy, they could only grow during the daytime, and even then the more deeply situated tissues would receive very little energy as compared with the outer tissues.

We saw that seedlings grown in darkness lose in dry weight (Art. 65). In an experiment the dry weight of 100 Wheat grains was found to be 4 grammes, that of 50 Peas 11 grammes. In each case a batch of seeds, equal in number and practically equal in weight, was germinated in darkness, and in three weeks the dry weight of the 100 Wheat seedlings was found to be 1·5 grammes, that of the 50 Pea seedlings 6 grammes.

The intensity of respiration varies greatly in different species, in different plants of the same species, and in the same plant at different stages of its life. Oily plants and shade-loving plants respire feebly; flowers and opening buds, as well as germinating seeds, respire much more actively than fully-grown roots, leaves, etc.

At about 15° C. the following plants absorb, per gramme of their fresh weight, the following volumes of oxygen in cubic centimetres:—Cacti, 3 to 25; Stonecrop, 70; Spruce Fir, 44; Broad Bean, 96; Wheat, nearly 300.

At 15° C. the volumes of carbon dioxide produced by the following, per gramme of dry weight, are:—Mustard seeds, 50 c.cs.; Poppy seeds, 120 c.cs.; Lilac buds, 35 c.cs.; Lime-tree buds, 70 c.cs.

The spadix of *Arum* (Cuckoo-pint) was found to use up during its opening 700 c.cs. of oxygen in twenty-four hours, the volumes (in c.c.) used in the first six hours being 50, 70, 100, 140, 80, 40. A gramme of spadix substance may give out as much as 30 c.cs. of carbon dioxide in an hour, and half of the stored substance (starch and sugar) may be used up in a few hours.

The volumes of oxygen used up in twenty-four hours by the reproductive parts of flowers (anthers and pistil), taking the volume of these parts as unity, was found to be:—Wallflower, 18; Tropaeolum, 16; Cucumber (male), 11; Cucumber (female), 7.

The volumes of oxygen used by the leaves (in darkness) were (volume of leaf = 1):—Wallflower, 4; Tropaeolum, 8; Passionflower, 5; Holly, 0·9; Aspidistra, 0·5 (which, doubtless, largely explains why this plant withstands unfavourable conditions indoors).

133. Respiration affected by Temperature.—Respiration is not affected much by *light*, either by its presence or absence, or its intensity, but *heat* is of great importance. The optimum temperature for respiration is nearer to the maximum than is the case with other vital processes. In germinating seeds, 10 to 20 times as much carbon dioxide is produced near the maximum temperature (35° to 45° C.) as at 0° C.

In Broad Bean seedlings the amounts of carbon dioxide produced at 30°, 35°, 40°, 45°, and 50° are (in milligrams per gramme of fresh weight) 550, 800, 660, 600, and 200. In sprouting Potato-tubers the amounts at 10°, 20°, 30°, 35°, 40°, 45°, 50°, 55°, and 60° are 120, 220, 460, 780, 1020, 1220, 1110, 1030, and 270 milligrams per gramme of fresh weight.

134. Respiration Experiments.—Most of the points just mentioned can be demonstrated by simple experiments. If time allows, some **quantitative** experiments should be

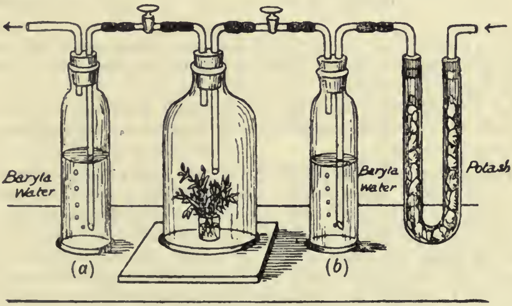

Fig. 37.—The Arrows show the Direction of the Current of Air, which is drawn through by attaching an "Aspirator" at the left of the Apparatus. The two pieces of glass tubing fitted with stop-cocks may be dispensed with and clips used on the rubber tubing (shown black).

made, *e.g.* with the apparatus shown in Fig. 37. In any case make the following experiments:—

* (*a*) Get nine glass jars of equal capacity. Into 1 pour a little water. Into 2 put some soaked peas, and into the others put an equal weight of the following fresh materials: 3, living roots (cut from seedlings); 4, mushrooms; 5, onions sliced in half; 6, sliced carrots; 7, pieces of herbaceous leafy shoots; 8, living woody stems. In 9 put some peas killed by boiling and then washed with formalin (to prevent growth of moulds and germs). Set all the jars together, after corking them and sealing the corks with vaseline, in darkness. After twenty-four hours lower a lighted taper into each jar in turn, noting the time required for the extinction of the taper in each case.

* (*b*) Repeat the experiment, this time keeping the jars exposed to the light on a bright day, or for two days.

* (*c*) Repeat the experiment, but instead of using the taper pour into each jar (at the end of the experiment) an equal volume of baryta-water; replace the cork, shake the jars well, and compare the degree of milkiness produced in each case. Make the experiment twice—in darkness and in light.

(*d*) Suspend three healthy laurel leaves by threads from the well-fitting cork of a large bottle containing lime-water, and expose them to bright light. After several hours the lime-water is still comparatively clear. Cover the bottle with black cloth, and in a few hours the lime-water will become quite milky, owing to the respiration being no longer masked by the re-assimilation of the carbon dioxide it produces.

(*e*) Place some green leaves in a glass jar (Fig. 37), through which a slow current of air is passed. This air is deprived of its carbon dioxide by the potash contained in the U-tube, so that the lime-water or baryta-water in both bottles remains clear so long as the leaves are exposed to sunlight or very bright daylight, whereas if the bell-jar is covered with a black cloth, the liquid in the left-hand bottle soon becomes turbid and milky.

In Fig. 37, the plant used is covered with a bell-jar standing on a glass plate, its rim being smeared with plasticine and vaseline to make the junction air-tight.

(*f*) Using the same apparatus, we can make rough **quantitative** experiments. The amount of carbon dioxide produced is determined by weighing the left-hand bottle before and after putting in the baryta-water and again at the end of the experiment. The gain in weight of the baryta-water represents the weight of barium carbonate ($BaCO_3$) produced, and from the atomic weights of barium, carbon, and oxygen we calculate the weights of the carbon dioxide and from that its volume.

A simpler plan, if the necessary apparatus and chemicals are available, is to "titrate" samples of (1) the baryta-water put in the bottles before the experiment begins, and (2) the clear baryta-water above the precipitate at the end of the experiment, using standard solutions of oxalic acid and of phenolphthalein (see books on Volumetric Analysis).

135. Comparison of Photosynthesis and Respiration.—These are, to a certain extent, antagonistic processes, the first involving a production of organic material, a consumption of carbon dioxide, and a liberation of oxygen; the second, a consumption of organic material, a liberation of carbon dioxide, and a consumption of oxygen. Photosynthesis is twenty or thirty times more active than respiration in most healthy green organs exposed to bright light and supplied with sufficient carbon dioxide, so that these parts do not appear to respire during the day-time, or at least do not evolve any carbon dioxide. In darkness, however, it can be shown that they respire only, as is the case with roots and all other not-green parts, in both light and darkness.

Photosynthesis.	**Respiration.**
A feeding process, associated with building-up of plant's substance.	A breathing process, associated with breaking-down of substance.
Starch is (usually) formed.	Carbon dioxide formed.
Plant gains in dry-weight.	Plant loses in dry-weight.
Only occurs in light.	Occurs in darkness as well as in light.
Only occurs in green plants and in green parts of plants.	Occurs in all plants and all parts.
Carbon dioxide passes in, oxygen passes out.	Oxygen passes in, carbon dioxide passes out.

136. The "Balance of Nature."—Animals and non-green plants are all ultimately dependent upon green plants for their organic food. In order to obtain a sufficient supply of energy, without which life is impossible, the greater part of this food is consumed in respiration, the carbon being re-oxidised into carbon dioxide, which is ultimately again assimilated by green plants.

The whole series of these interchanges between the self-supporting (chlorophyllous plants and animals) and the dependent members (non-green plants and animals) of the organic world forms what is known as the "Balance of Nature." If more organic food becomes available animals and non-green plants tend to increase, and hence produce larger quantities of carbon dioxide, which favours the development of green plants. The balance maintained between the processes of respiration (in all organisms) and photosynthesis (in green organisms) keeps the amount of carbon dioxide in the air practically the same.

QUESTIONS ON CHAPTER IV.

1. What differences exist between the cotyledons and the foliage-leaves of the Broad Bean? How may these differences be accounted for?

2. How could you prove that a leaf has air-spaces inside it and air-pores on its surface?

3. Describe the structure of a typical foliage-leaf.

4. How could you prove that a green leaf makes food when exposed to light?

5. Under what conditions is starch formed in the foliage-leaves of an ordinary land plant? Give experiments in proof of each statement.

6. What is a stomate, and how does it work? Why do people often syringe or sponge the leaves of plants grown indoors or beside a dusty road?

7. To what substance do the green parts of plants owe their colour? State and explain the nature of the work which only the green parts of plants are able to perform.

8. Explain how it is that a green plant cannot carry on its nutrition in darkness.

9. What constituent of plant-food is obtained from the atmosphere? What changes do plants affect in it? Describe an experiment to demonstrate this.

10. What is meant by the term Photosynthesis? What is the first *visible* (solid) result of this process, and how would you detect it in a leaf?

11. What gases would you expect to find in the air of a closed glass vessel exposed to light before and after leaving a green plant within it? State the relative quantity of the various gases, and how the presence of each can be detected. How could you measure the quantity of each gas?

12. Two leaves, while still attached to the plant, are kept in the dark for twenty-four hours; then one is exposed to sunlight for some hours, while the other still remains in the dark. By what after-treatment would you distinguish between the two? Explain your exact procedure and the reasoning on which you base your conclusions.

13. Explain as fully as you can how it is that the guard-cells of a stoma are enabled to alter the size of the aperture between them.

14. What is the importance of carbon to a plant? From what source does a green plant get its carbon, and how is it assimilated?

15. What do you consider the essential characters of the foliage-leaves of a green plant—*i.e.* the characters in which all or nearly all leaves you know agree? How are these features of leaves of service to the plant?

16. On what law does the intensity of light depend? How does light-intensity affect Photosynthesis?

17. What is meant by Refraction? What is a prism, and how could you prove by its use that white light consists of rays having different colours?

18. Describe the continuous Spectrum. How is the appearance of the spectrum affected by an extract of chlorophyll being placed between the prism and the screen on which the spectrum is received?

19. What is the function of Chlorophyll? Under what conditions is it formed, and how does it occur in the plant?

20. Explain the term Photosynthesis. What gases would you expect to find in the air of a closed glass chamber exposed to the sun

before and after leaving a green plant within it? State the relative quantity of the various gases, and how the presence of each can be detected. Explain briefly how you would attempt to measure the quantity of each gas present in the mixture.

21. Bubbles of gas arise when a green water-plant in a bowl of ordinary tap-water is placed in sunlight. What is this gas, and how is it produced? Give as full an explanation as you can of the effect of (*a*) replacing the tap-water by previously boiled water; (*b*) introducing lumps of ice into the original bowl of water.

22. What process is meant by the term Photosynthesis? State as briefly as possible the conditions necessary for such a process. Describe accurately an experiment you have seen which demonstrated that a plant was carrying on the process.

23. Describe any experiments which throw light on (*a*) the passage of fluids through membranes by osmosis, (*b*) the passage of gases by diffusion through small openings. What have these experiments to do with plant life?

24. Describe as many experiments as possible showing the effect of temperature on the physiological processes of plants.

25. Sketch a course of work on a green leaf for an elementary class which is not provided with microscopes.

26. Describe the minute structure of a small bit of a green leaf. Show that it is specially fitted for absorbing and liberating certain gases.

27. A seed (*e.g.* a Bean) is germinated in a dark cupboard. Describe the seedling plant developed under these conditions, and point out in what respects it differs from a plant grown in the light.

28. How would you obtain, and prepare for examination, living, under the microscope, the green cells of a foliage-leaf? Draw carefully, and describe in detail, the structure of such a cell, naming the different parts, and mentioning, so far as you can, their uses.

29. What conditions are essential in order that a green leaf may form starch? Give an account of the experimental evidence on which your answer is based.

30. Explain as fully as you can the reasons for the lanky appearance exhibited by many plants when grown in the shade of trees.

31. To what substance do the green parts of plants owe their colour, and what is the use of this substance to the plant?

32. What is meant by respiration in plants? Describe any anatomical features in one of the higher plants which are suited to facilitate the respiratory processes.

33. How would you identify the gases of which the atmosphere is composed? Do you know how to determine the proportion by volume in which the two principal gases exist? Which of the gases of the

atmosphere are used by plants? What differences in the constitution of the atmosphere do plants bring about under different conditions?

34. Describe and explain the various methods with which you are acquainted by means of which air can be deprived of its oxygen.

35. What changes in the composition of the air are brought about (*a*) by green plants, (*b*) by animals? At what stage of its life does a plant behave in this respect like an animal? Explain the phrase "balance of nature."

36. Plants both absorb and give out carbon dioxide. State precisely the circumstances upon which each process depends.

37. Give an account of the process of Respiration, and sketch apparatus by which you can investigate the gaseous interchanges associated with it. What is the physiological importance of respiration?

38. How would you make an experiment to study the periodic increase in weight of a growing plant? Supposing determinations of weight were made every three hours during a summer day and night, and expressed by means of a curve, give the probable form of the curve.

39. What is meant by a "starch print"? How may it be prepared and what conclusions as to the formation of starch can you draw from it?

40. Seedlings of Bean are cultivated severally under the following conditions:—(*a*) the absence of light, (*b*) the absence of oxygen, (*c*) the absence of CO_2. Describe the manner of their behaviour in each case.

41. You have discovered starch in the tubers of potatoes; sugar in the roots of carrots; and oil in the seeds of nuts. Were these reserve substances actually made in the tubers, roots, and seeds, and if not, where were they made, and how did they get to where you found them?

CHAPTER V.

WATER ABSORPTION AND TRANSPIRATION.

137. The Food Materials of a Green Plant.—If we make a chemical analysis of a plant—an analysis of the gases given off and the residue or ash left behind on burning the plant—we find the following chemical elements: carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, calcium, magnesium, potassium, iron, sodium, silicon, and chlorine; traces of other elements are sometimes present. Of all these elements, only the first six actually enter into the composition of the living substance (protoplasm) of the plant. It is evident that all the elements found in the plant must enter it in the food materials absorbed. All the carbon required by an ordinary green plant comes from the carbon dioxide of the air, which is absorbed by the green parts of the plant, while the other elements are absorbed by the roots, usually in the form of nitrates, sulphates, phosphates, chlorides, and silicates of potassium, sodium, calcium, magnesium, iron, etc.

138. Water, Carbon, and Ash in Plants.—In several of our experiments we have seen that **water** is present in fresh plant-bodies, even in "air-dry" parts like seeds as sold in shops, and that the water can be driven off by drying plants in an oven without charring them. In woody parts the percentage weight of water is about 50, in herbaceous parts (*e.g.* fresh leaves or whole seedlings) about 75, in fruits and in fleshy plants (*e.g.* Stonecrop) from 85 to 95, and in water-plants and Algae from 95 to 98. The residue in each case—the dried substance—gives the "dry weight."

When the dried parts are burnt, the organic substances of which they largely consist are converted into inorganic substances, chiefly carbon dioxide and water, which escape during the process of burning; the nitrogen, as well as the carbon and hydrogen, disappears into the air when the plant is burnt. If the dried substance is charred instead of being entirely burnt, we get charcoal, and if we collected the carbon dioxide given off in complete combustion we should find that a large percentage of the dry weight is represented by **carbon** —as much as one half.

The incombustible residue, or **ash**, represents the mineral substances, but in the process of burning these undergo changes, so that they occur in the ash in chemical combinations different from those present in the fresh plant-body.

139. Analysis of Plant Substance.—To make an exact chemical analysis of plant-substance requires considerable skill in qualitative and quantitative methods of chemistry. But it is fairly easy to get a rough idea of the composition of plants by simple experiments.

* (*a*) Weigh some freshly-picked leaves and record the weight. Let them lie in a dry place until they become apparently dry ("air-dry") and weigh again. From your work on transpiration you will know that the loss of weight is due to loss of water.

* (*b*) Dry the leaves in an oven and weigh them twice or thrice until they show no further loss of weight. In this way you get the percentage weights of water and of dried substance. As a check or "control," heat some other "air-dry" leaves gently in a test-tube and note the deposition of water in the cooler upper part of the tube: this represents the "hygroscopic" water which is driven out by heating.

* (*c*) Dry and weigh a porcelain crucible, place in it the oven-dried leaves, and heat thoroughly. The dry material chars and may flame for a time while burning; in ten minutes or so it is reduced to fine ash. Find the weight of the ash, weighing the crucible and its contents twice or thrice until no further loss occurs. To ascertain roughly the amount of carbon, heat some weighed oven-dried leaves in a weighed crucible, after covering them with a weighed quantity of dry sand; after about ten minutes' heating turn out the contents and find the weight of the charcoal.

140. The Ash Constituents.—The amount of the ash increases with the age of the plant (why?). It also varies in the different parts of the same plant at different stages in its growth and life-history.

The following table gives, for several common plants, the approximate percentage weights of (1) the ash in the plant's dried substance, (2) the metallic oxides, the acids, and chlorine in the ash itself.

Plant.	Ash in 100 parts of dry substance.	100 parts of Ash contain								
		Potash.	Soda.	Lime.	Magnesia.	Iron oxide.	Phosphoric Acid.	Sulphuric Acid.	Silica.	Chlorine.
Red Clover ...	6·8	31	0·2	35	11	1	10	3	2	4
Wheat (grain) ...	2	30	2	3	10	1	46	0·4	2	0·2
,, (straw) ...	5	14	1·4	6	2·5	0·6	5	2·5	72	2
Rye (grain) ...	2	32	1·5	3	11	1·2	48	1·3	1·4	0·5
,, (straw) ...	4·5	22	1·7	8	3	2	6	4·3	49	2
Pea (seeds) ...	2·7	43	1	4·8	8	0·8	36	3·4	1	1·6
,, (straw) ...	5	23	4	37	8	1·7	8	6·3	7	5·6
Potato (tubers) ...	3·8	60	3	2·6	5	1	17	6·5	2	3
Grapes	5·2	56	1·4	10·8	4	0·4	15	5·6	2·7	1·5
Apples	1·5	36	26	4	9	1·5	14	6	4	—
Tobacco (leaves) ...	17	29	3·2	36	7·4	2	4·7	6	5·8	6·7
Cotton (fibres) ...	1·1	40	13	17·5	5·4	0·6	10·6	6	2·4	7·6
Spinach	16·5	16·5	35	12	6·3	3·3	10·2	6·8	4·5	6·2
Horsetail	27	8	0·6	8·6	1·8	1·4	1·4	2·8	71	5·6
Almond seed ...	4·9	28	0·2	8·8	17·6	0·5	43	0·4	—	—

Note the striking difference between the seeds and the straw (stalks and leaves) of Cereals and Leguminous plants in the proportion of more important (*e.g.* magnesium) and less important (*e.g.* silicon) elements.

141. Ash Analysis.—The chief elements to be tested for, in analysing the ash of plants, are calcium, potassium, magnesium, phosphorus, sulphur (the two latter being present as acids). The ash should *not* be heated so strongly as to make it burst into flame.

(*a*) Is the ash soluble in (1) water, (2) dilute hydrochloric acid, (3) strong hydrochloric acid? Find out in each case by boiling some of the ash in a test-tube with water or acid, allowing the undissolved part to subside and evaporating some of the liquid, or heating it to dryness, on a watch-glass or evaporating-dish. The insoluble residue, after treatment with strong acid, contains chiefly silica.

(*b*) Place about 10 grammes of ash in a 500 c.c. flask, moisten it with a small quantity of strong nitric acid, then add about 20 c.cs. strong hydrochloric acid and heat on a tripod (or "digest" it for half an hour on a water- or sand-bath at boiling-point). Rinse the contents of the flask into an evaporating basin and heat to dryness. Moisten the residue with strong hydrochloric acid, add about 200 c.cs. of water, and filter. Make the filtrate up to 600 c.cs. with water and divide it into four parts.

(i) To one part add, in a large test-tube, some barium chloride solution. The finely-divided white precipitate (barium sulphate) indicates the presence of **sulphur** (as sulphuric acid). Verify this by mixing some dry ash with carbonate of soda, heat on charcoal with the reducing blowpipe-flame, and (1) put a few drops of dilute hydrochloric acid on the fused mass (the sulphuretted hydrogen given off is easily recognised by its odour), (2) put a little of the mass on a silver coin and add a drop of dilute acid (a black stain of silver sulphide is formed). These "dry" tests may fail, however, if but little sulphuric acid is present.

(ii) To some ash-solution in a test-tube add an equal bulk of strong nitric acid, then three or four times its bulk of ammonium molybdate. A yellow precipitate indicates presence of **phosphorus** (as phosphoric acid).

(iii) To test for **iron**, add potassium ferrocyanide: a dark blue precipitate (Prussian blue) is produced.

(iv) It is necessary to remove the phosphates from the ash solution, as follows. Neutralise with ammonia, then add acetic acid till the solution is distinctly acid again, and then ammonium acetate in excess. Now add ferric chloride till no further buff-coloured precipitate (ferric phosphate) is produced and the solution becomes red (owing to ferric acetate). Boil the solution till it is colourless, filter, and reject the precipitate.

To the solution thus obtained add ammonium chloride, ammonia, and ammonium carbonate; a white precipitate indicates the presence of **lime**. Filter, and to the filtrate add sodium phosphate; a white precipitate (often formed only after shaking the liquid and letting it stand for some minutes) shows that **magnesia** is present.

Filter, evaporate the filtrate to dryness, and test the residue for soda and potash. Add a few drops of platinic chloride to the residue, evaporate again, then add some alcohol; a yellow crystalline precipitate shows that **potash** is present. Or dip a clean platinum wire into hydrochloric acid and hold it in a Bunsen or spirit-lamp flame until it no longer colours the flame yellow (owing to presence of soda). Then dip the wire, moistened with hydrochloric acid (strong), into the residue and put it in the flame. **Potash** turns the flame *violet*, but if the *yellow* (**soda**) colour is too strong look at the flame through a *thick* piece of blue glass: the soda colour is cut off and the reddish-violet potash flame is seen.

If you are working in a chemical laboratory, you should try to make rough quantitative analyses of the ash of a few plants, using the methods given above, with the help of a book on Quantitative Analysis.

142. Essential Elements of Plant-Food.—All the elements named in Art. 137, and several others, occur in the composition of plants and their food. In fact, nearly all the chemical elements known to occur in soil, water, and air have been detected in analyses of plants. It has been found by experiment, however, that for most green plants the **essential elements**—*i.e.* the elements absolutely necessary for healthy growth—are **carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, calcium, potassium, magnesium,** and **iron.**

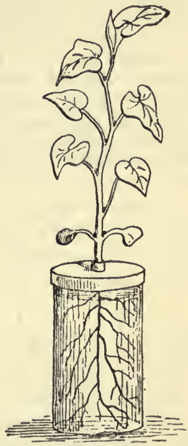

Fig. 38.—A Plant of Buckwheat grown with its Roots in a Culture-solution.

143. Water Culture.—It has long been known that a plant can be grown in water containing salts in which all these elements are present with the exception of *carbon*. That carbon is essential is easily proved, as we have seen, yet this element need not be present in the solution supplied to the roots. That all the other elements are essential, and must be supplied to the roots, has been shown by the method of **water culture.** Several plants of the same species are grown in glass jars (Fig. 38), their roots dipping into a culture solution. With most plants there is healthy growth only if the solution contains *potash*, *lime*, and *magnesia*, combined with *nitric*, *phosphoric*, and *sulphuric* acids, together with a trace of an *iron* salt.

* **144. Experiments with a complete Culture Solution.**—Get some large glass jars, each holding at least a quart, for water-culture experiments. Sachs' solution consists of 2 grammes of potassium nitrate, 1 gramme each of sodium chloride, calcium sulphate, magnesium sulphate, and calcium phosphate, and a drop or two of iron chloride (or iron phosphate) to 2 litres of distilled water. Knop's solution, which is perhaps better, consists of 2 grammes of calcium nitrate and 0·5 gramme each of potassium nitrate, magnesium sulphate, and potassium phosphate, with iron as before, in 4 or 5 litres of water. Perhaps the best plan is to get 4 oz. of calcium nitrate and

1 oz. each of potassium nitrate (saltpetre), magnesium sulphate (Epsom salt), and potassium phosphate, and powder these salts to make them dissolve more readily. These quantities will be sufficient for 32 gallons of culture solution; but the latter should be made up as required, so that the above quantity of each salt should be subdivided according to the volume of solution required each time.

Another method is to prepare strong solutions of the salts and dilute them as required. Make (1) a solution containing 2 grammes $Ca(NO_3)_2$, 1 gramme KNO_3, and 1 gramme KH_2PO_4 to every 100 c.cs. of water; (2) a solution containing 0·5 gramme $MgSO_4$ to every 100 c.cs. of water.

Grow seedlings of Bean, Pea, Maize, Buckwheat (these answer well, but other plants should be tried, different plants each time you start a series of cultures) until the roots have grown a few inches long, then fix each seedling into a cork or a wooden cover. The cork or cover should have a hole in the centre for the plant, a slit somewhat narrower than the hole running to the edge of the cover (so that the plant can be removed easily when necessary), and another hole for a stick to tie the plant to (Fig. 39). Take care to keep the cork, or wooden cover, as well as the part of the plant which is in contact with it, quite dry; most failures in water-culture are due to "damping off" at this part (caused by fungi). If a stick is used to support the plant, there is no need for any packing material. Cuttings of Willow and other trees may be used as well as seedlings.

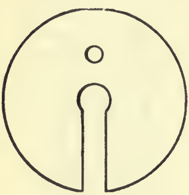

Fig. 39.

Darken the roots by covering the jars with black cloth or paper; add water each day to replace that lost by evaporation and transpiration (using a funnel, and not letting the cork, or wood cover, get wet). Once a month take the plant out, wash its roots gently in a basin of water, pour out the culture solution, and let the plant remain with its roots in plain water for two days before placing it into fresh culture solution.

The culture solution should not be alkaline, or the roots suffer; if it turns red litmus to a blue colour, add acid (*e.g.* phosphoric acid) until it gives an acid reaction.

The roots should be supplied with air; the simplest plan is to force air into the solution every day or two with a bicycle-pump or a condensing syringe. Plants in culture solutions are apt to suffer badly from lack of oxygen, the amount of which is far below that present in a well-aerated soil. If possible, use vessels of 1 gallon capacity.

*** 145. Experiments with incomplete Culture Solutions.**—Choose seedlings as nearly equal in size and general growth as possible, then place some in a complete solution, others in a solution from which one or other of the essential elements is wanting. To deprive the plant of potassium, use sodium nitrate instead of potassium nitrate, and calcium phosphate instead of potassium phosphate. Deprive others of calcium by omitting the calcium nitrate; of phosphorus by omitting the potassium phosphate; of magnesium by using calcium sulphate in place of magnesium sulphate; of sulphur by using magnesium chloride instead of the sulphate; of nitrogen by using sodium chloride and calcium sulphate in place of calcium and potassium nitrates; of iron by omitting the iron salt (which should be added in all other cases).

146. Essential Soil-Substances.—A soil must contain the same essential elements as the full culture solution in order to allow plants grown in it to come to maturity, and these elements must be in a form available for use by the plant. Soil-water contains most of the essential elements in the form of dissolved compounds. The composition of the water present in a soil can be learned by analysis of drainage water, and we can test soils for soluble substances by letting distilled water drain through them and then applying to it tests for the essential elements given above.

* (*a*) Compare the growth of seedlings (of the same kind of plant) which have been supplied with (1) distilled water; (2) tap water; (3) culture solutions (some complete, others with one element or other omitted in each case). If you grow the plants in washed sand, water with (1), (2), or (3) daily. In either case compare also with plants grown in good garden soil. After, say, six weeks, dry thoroughly and weigh the seedlings, and compare their dry weights; then burn them and compare the ash weights.

* (*b*) Place some dry, fine garden soil in a funnel, plug the tube lightly with cotton-wool, and pour water slowly on the soil. Collect the first few drops that ooze through and repeat the test with diphenylamine. The presence of nitrates is shown by the production of a deep blue colouration. A fertile soil always contains nitrates.

* (*c*) Continue to pour water through the soil in the funnel, and after collecting what comes through, evaporate it to dryness and compare the residue with what is left after evaporating an equal volume of the water used.

147. Formation of Nitrogenous Substance.—The elaboration of nitrogenous substance is not so clearly understood as that of carbohydrates. Perhaps the simplest process, leading to the formation of soluble nitrogenous organic compounds (*amides* or *amido-acids*, containing carbon, hydrogen, oxygen, and nitrogen), that one can suggest is the inter-action of sugar and nitrate of potash, the chief products being an amide called *asparagin* (widely distributed in plants) and oxalate of potash. The latter, like oxalic acid itself, is poisonous, but it combines with the lime brought up in salts from the soil, forming oxalate of lime, which is insoluble in water, and therefore crystallises out and is rendered harmless. This is probably one source of the oxalate of lime which occurs so abundantly in crystals in plant-tissues.

These crystals (Fig. 40) are more abundant in leaves exposed to full sunlight than in shaded leaves, and in the green than in the not-green parts of variegated leaves.

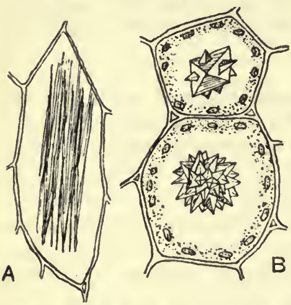

Fig. 40.—Cells containing Crystals of Oxalate of Lime of Different Shapes.

The disappearance of nitrate from leaves shows the same relation to light and to the presence or absence of chlorophyll as does the accumulation of oxalate of lime. Nitrate disappears from cut leaves in a few days, if they are exposed to light; in variegated leaves the nitrate disappears only from the green parts.

148. Formation of Proteids.—Thus we have explained, as far as possible, the building up of soluble carbohydrates (sugars) and soluble nitrogenous compounds (amides) in the green leaf. With the exception of what is used directly by the assimilating cells, the sugars and amides are transferred to the various parts of the plant. *All* living cells contain these soluble carbohydrates and nitrogenous compounds conveyed to them in the cell-sap. The living protoplasm makes use of these as food substances. Together with sulphur and phosphorus they are built up first of all into more complex (*proteid*) substances, and, finally, into protoplasm.

One of the chief forms in which sulphur enters the plant is calcium sulphate. The sulphur is liberated, and thus enabled to combine with the organic food substance, by the action of an organic acid. This acid appears in many cases to be oxalic acid. The calcium of the sulphate combines with the oxalic acid to form calcium oxalate.

149. Use of the Metallic Elements.—Potassium, calcium, magnesium, and iron do not enter into the composition of the living substance, yet they are essential elements. Now we have seen that iron, although it does not enter into the composition of chlorophyll, is necessary for its formation. This gives us a hint as to the use of the other elements. It would seem that potassium in the same way is a necessary condition for the formation of carbohydrates, and that calcium and magnesium are necessary for the distribution of carbohydrates. Calcium is also of importance in the formation of more complex substances from carbohydrates, since it combines with, and thus makes harmless, the poisonous by-product (oxalic acid) which is formed in these processes.

150. What are the Chief Functions of the Root?—Refer to the parts of Chapter I. in which the root of the Broad Bean is dealt with, go over the observations you have made on the roots of seedlings which you have grown, and examine the roots of as many plants as possible, wild and cultivated, pulling or digging them up and examining them as directed in Chapter I. for the root of Broad Bean. What characters do nearly all roots appear to possess in common, from your own observations on roots of various plants? What do you think are the chief uses, or functions, of roots? How could you test your ideas on this subject by simple experiments? Try any methods that occur to you, before going further.

* (*a*) In a Bean seedling grown in sawdust or soil, cut across the main root just below the cotyledons: the plant falls over. Support the plant by tying it to a stick, and keep the soil or sawdust moist around the cut place: notice the new roots formed from the base of the stem.

* (*b*) Repeat (*a*) with another seedling, planted by itself in a pot or box, but after tying it to a stick allow it to remain *unwatered*. What changes does it show, from day to day, in the colour, shape, and position of the leaves, and in any other respects? How would you describe these changes, and what ultimately becomes of the shoot? For comparison, allow some *uninjured* seedlings to remain unwatered: do they show the same changes? What do these simple observations prove as to the work of the root?

* (*c*) Fix a seedling with its root dipping into water in which some powdered vermilion has been shaken up vigorously. After an hour or two, cut across the root a short distance above the surface of the coloured liquid. Has any of the colouring-matter (which consists of grains *suspended in the water*) entered the root?

* (*d*) Fix a seedling with its root dipping into red ink (colouring-matter *in solution*), and after a time (try several seedlings, and give them different lengths of time) cut across the root, to see how far upwards the colour has spread, and in what part of the root it travels. Also cut across the *stems* of seedlings that have been in red ink for a day or two, and notice the red-stained bundles: how does the liquid travel in the *leaves*?

The root, therefore, fixes the plant in the soil and also absorbs water and passes it upwards through the stem into the leaves. The water absorbed from the soil is not *pure* water: it contains dissolved substances of great importance in the nutrition of the plant, as we shall see later.

Do you know of any plants whose roots have other functions besides those of fixing the plant and absorbing water with dissolved salts?

151. Transpiration.—Everyone knows that a leaf, plucked from a living plant, becomes dry and withered after a time. A Bean seedling becomes limp when pulled up and allowed to "wilt," but recovers when set in water.

Have you noticed that wherever plants are enclosed by glass—*e.g.* in greenhouses, or bell-jars covering plants—moisture often collects on the glass? Does this moisture come from the moist earth, or from the plants, or from both? It is easy to show by experiment that a healthy and vigorous plant gives off water-vapour, which escapes chiefly from the leaves. This escape of water-vapour from a plant is called *transpiration*, and the current of water which passes from roots to leaves is called the *transpiration current*.

The root absorbs a very dilute solution of salts, hence the excess of water must be got rid of by evaporation from the leaves. Transpiration is, however, something more than mere evaporation, for the leaf can control the rate at which the water vapour is given off.

Before returning to the subject of root absorption, we shall study the transpiration current.

152. The Transpiration Current.—The amount of water conveyed upwards from the roots to the leaves is often very great, the water flowing upwards at from 6 ins. to 6 ft. per hour in trees (as much as 20 ft. per hour in climbing plants with long slender stems, *e.g.* cucumber).

If the stem of a Vine or similar plant is cut in spring, large quantities of watery sap escape from the cut end attached to the roots,[1] and if a tube filled with mercury or water is attached to this cut end, by stout rubber tubing, the escaping sap may support a column of mercury several inches high, or one of water several feet in height.

A Sunflower, $3\frac{1}{2}$ ft. high and with a surface of 5,600 square ins., has been found in summer to exhale a pint of water a day, which is about a cubic millimetre from each square inch. Excessive and unchecked transpiration is, however, highly dangerous, and hence arises the importance of an impermeable

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[1] This only takes place when the plant is fully charged with water. Hence, in summer, no "bleeding" is shown, although if all the leaves are removed it may commence after a longer or shorter interval.

cuticle, for it allows transpiration to be regulated by the opening and closing of the stomates.

The guard cells collapse and close the stomates in darkness, and also where there is a deficient supply of water, or when transpiration is too active. The leaf is unable to assimilate carbon dioxide in the absence of light, so that the stomates may close in darkness without detriment to the plant, and in this way unnecessary evaporation and its accompanying cooling effect are largely avoided.

153. Transpiration Experiments.—Does the water-vapour escape from both sides of a flat (bifacial) leaf to an equal extent? Through what channels does it pass in the leaf? Does the rate of transpiration vary, and what conditions cause it to vary? What other questions regarding transpiration occur to you, and how would you attempt to get the plant to answer your questions?

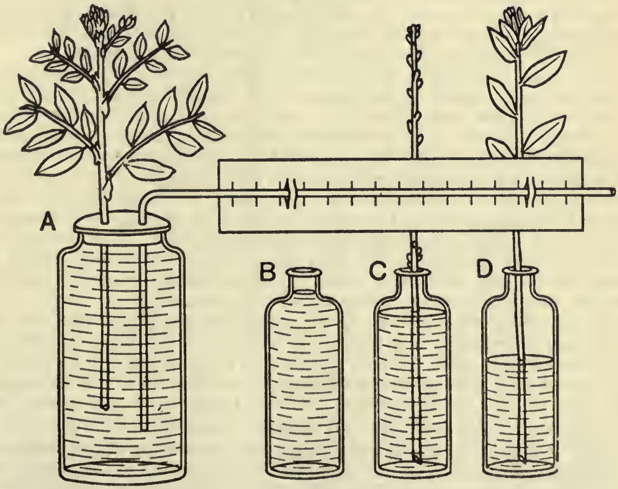

Fig. 41.

* (*a*) Get three similar bottles full of water (Fig. 41, B, C, D). Into one (D) place a leafy shoot, into the second (C) a shoot deprived of leaves, and leave the third (B) as a control. See that the level of the water is

the same in all three bottles at first; after some hours' exposure to light compare the amounts of water left in the bottles. Which loses most water, and which least?

* (*b*) Fix a long-stalked leaf (or the upper part of a Broad Bean or shoot, *e.g.* Dead Nettle) in a card, passing the leaf-stalk (or the stem) through a hole in the middle of the card and sealing it up with putty or plasticine. Place several cards, each with a leaf or shoot fixed into it, over tumblers nearly filled with water, and over each of these tumblers invert a dry empty tumbler, resting on the card. Notice the drops of water formed on the inside of each empty tumbler, by condensation of the water-vapour given off by the leaves. Ascertain whether any water-vapour is given off when (1) the upper surface, (2) the lower surface, of the leaf is smeared with vaseline to block the stomata.

* (*c*) Get any leaves with broad, thin blades and fairly long stalks—*e.g.* Lesser Celandine, Garden Geranium.[1] Place them in bottles of red ink, with the cut lower end of the stalk dipping into the ink, and note the coloration of the veins. Cut a Grass shoot above the creeping stem, and try the same experiment, noticing the parallel arrangement of the veins, as indicated by the red lines which appear in the leaves in a day or two; a Maize or Wheat seedling may be used.

(*d*) The sucking force exerted by the leaves can be demonstrated by attaching a leafy branch, cut under water, to a tube filled with water and dipping into a coloured solution. It will be found that the latter ascends the tube even when the latter is many feet in length.

Get a branch of Willow in which the young leaves have become fully expanded, and attach it by means of a piece of stout indiarubber tubing to a glass tube about 9 ins. long, with the end farthest from the branch bent at right angles for about 2 ins. Arrange the branch vertically, the longer limb of the glass tube horizontally, and the short terminal part dipping into water tinged with red ink. It is best to cut the branch and attach the tubing under water in a large basin, so as to prevent the entrance into the stem of air-bubbles, which would diminish the flow of water. Lift the glass tube out of the water when the branch is fixed up, and notice that the coloured water soon begins to travel along the horizontal tube. This apparatus may be used to roughly measure the rate of the transpiration current.

(1) Ascertain whether the flow is different on bright and on dull days, and (2) whether it is influenced by opening door and window so as to cause a draught. What is the effect of smearing the surfaces of the leaves with vaseline? On different branches smear (1) the upper surfaces, (2) the lower surfaces, (3) both surfaces, of the leaves, and note the rate of the transpiration current in each case.

* (*e*) A useful piece of apparatus for observations on transpiration is the **potometer.** The essential part of the apparatus is the potometer-tube (Fig. 42 A), a straight tube (*a*) about half an inch in diameter with

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[1] In winter the long-stalked heart-shaped leaves of Garlic Mustard are very useful for experiments on transpiration. In spring use leaves of Lesser Celandine or Violet.

a bent tube (*b*) annealed to it about half way. The object of the branched tube is to prevent the accumulation of air-bubbles below the cut end of the shoot at *a*. Any air-bubbles passing up the narrow tube (inserted through a cork at the lower end of the straight limb) will usually collect at *b*, and the cork at *b* is then removed and water poured in. If air collects at *a*, simply turn the apparatus round so that the straight limb lies horizontally above the side-limb, when the air passes up to *a*.

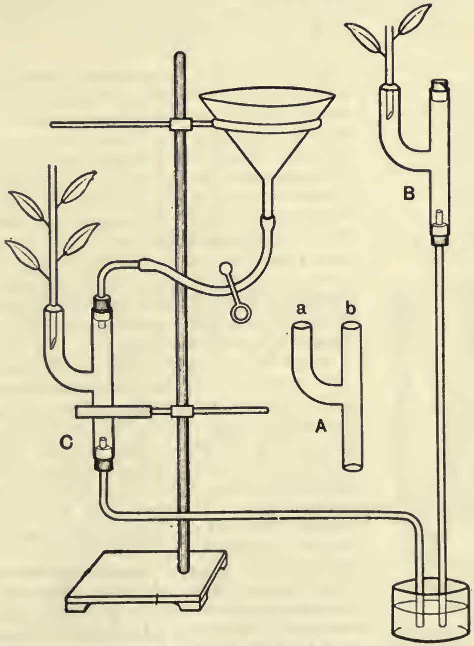


Fig. 42.—Potometer Apparatus.

(*f*) Fix up the apparatus shown in Fig. 42 B, and take readings as in the preceding experiment. From the inside diameter of the narrow tube you can easily calculate the volume of water sucked along in a given time by reading from the cardboard scale and multiplying the tube-diameter by itself, by 0·8 (strictly 0·785), and by the length.

(*g*) Fig. 42 C shows an improvement on the ordinary potometer, consisting of a funnel connected with the potometer-tube by a piece of rubber tubing. A clip is kept on the latter, the funnel filled with water, and water passed into the potometer-tube, when required, by releasing the clip.

* (*h*) For experiments with small plants (*e.g.* Bean seedling) or even single leaves, the apparatus sketched in Fig. 41 A is convenient. The rate of flow is roughly measured by the paper scale fastened to the long horizontal tube; care must be taken to make the cork and the joinings of plant and tube with it air-tight by using plasticine or wax. This apparatus has, of course, the disadvantage that air-bubbles collect below the cut end of the plant and stop the water-current, hence it is not so convenient to use as the potometer.

Fig. 43.—Apparatus for estimating the Absorption of Water by the Roots, and the Loss by Transpiration from the Leaves.

(*i*) By the aid of a simple piece of apparatus (Fig. 43) and a weighing balance, the amount of water lost by a leafy stem can be determined, and at the same time it can be proved that the amount transpired is approximately the same as that absorbed by the roots. A plant is fixed by means of an air-tight indiarubber cork in a bottle filled with water. As water evaporates from the leaves and is absorbed by the roots, the level of the water in the graduated tube falls. This gives the amount absorbed by the roots, and on weighing the apparatus it will be found to correspond to the total amount lost by evaporation from the leaves and stem.

Each of the larger divisions on the graduated tube corresponds to a cubic centimetre of water, so that when the roots have absorbed that amount the entire apparatus will have lost about one gramme in weight. The vertical tube attached to the side of the vessel, if not graduated by engraved lines, may have a scale drawn on a narrow strip of paper and fixed to it. The divisions should represent definite volumes, such as cubic centimetres. Fill the vessel with water, replace the stopper firmly, and set aside for observation. The volume of water becomes less, and the amount of loss may be seen by observing the scale. Enter in a book the amount of loss in equal intervals of time, and note that it is less during darkness than in the light, and also that it varies with atmospheric conditions.

(*j*) Fix a Wallflower or large Bean seedling in the apparatus shown in Fig. 43, and determine the amount of water lost under the optimal conditions (*i.e.* in a warm, airy, well-illuminated room), either by weighing at intervals, or by watching the attached register. Then remove all the leaves and cut out twice their area in thick note-paper, to which add a piece the same length as the stem and three times its breadth.

Weigh all the pieces of paper together, and also a piece a foot square. The former weight divided by the latter will give the approximate surface area of the plant in square feet. From these data the average amount of water evaporated in a given time from a square inch of surface can be calculated.

(*k*) Another method is based on the fact that dry **calcium chloride** greedily absorbs water vapour, and if exposed to the air for a few days even in dry weather it will absorb so much as to dissolve the salt, showing that water vapour is always present in the air. Fix a seedling in a bottle full of water, plugging up the hole in the cork, through which the stem passes, with plasticine; or get a plant growing in a pot of soil and cover the soil with a rubber sheet, or with a layer of melted wax. Place beside the plant a watch-glass containing dry calcium chloride, weighing watch-glass and salt; cover the whole with a bell-glass, and expose to light; after a few hours, weigh the watch-glass and chloride again, and note the increase in weight. To make the experiment more accurate, set up a "control," by placing under a similar bell-glass a watch-glass containing an equal weight of dry calcium chloride, and expose along with the other apparatus, containing the plant, for an equal time, to find out how much of the water-vapour absorbed was already present in the air before the plant began to give off water-vapour by transpiration.

Instead of calcium chloride, **copper sulphate** may be used, though it is not quite so effective. This salt when dry is white, but when moist it becomes blue; thoroughly dry the salt and place a weighed quantity of it in a dry weighed watch-glass, and arrange the experiment in the same way as before.

* (*l*) Another method is to use a small plant, *e.g.* a garden Geranium, growing in a tin fitted with a split cork through which passes a tube for watering. Make water-tight with plasticine, and note the loss of weight. Set beside the plant a vessel, *e.g.* a saucer containing water, and in order to compare the loss of water from the plant and from an equal area of water determine the area of the transpiring surface and that of the water in the saucer.

* (*m*) Cut three healthy leaves of Indiarubber plant or of Rhododendron, plug the cut ends with plasticine, cover the *lower* surface of one (A) with vaseline, cover the *upper* surface of the second leaf (B) with vaseline, and leave the third (C) untouched except for the plug over the cut end. Tie a piece of wire or string to each leaf, weigh each leaf carefully, then hang them up near each other and weigh them each day. After several days the leaf whose stomates are blocked (A) will be still green and fresh, while the others will be more or less withered and brown.

* (*n*) Get some **cobalt chloride** (nitrate or sulphate); make a solution (about 5 per cent.) in water, and soak some filter-papers or sheets of thin blotting-paper in the solution. Dry the papers, and observe that they turn blue. Put a drop of water on one of the dried papers, or simply breathe on it, and notice the change in colour. These cobalt-

papers afford a delicate test for water-vapour. Place a thin leaf between two cobalt-papers, and keep them flat by placing between two dry pieces of glass. Notice which surface of the leaf gives off most water-vapour, as shown by the change of colour.

(*o*) The cobalt-paper method enables us to tell whether the stomates are open or closed. Put two plants (*e.g.* Broad Bean seedlings) in darkness and in the morning expose one (A) to light for about an hour, keeping the other (B) in the dark. Remove and test simultaneously a leaf or a few leaves from each plant, noting the time taken for the paper in contact with their lower surfaces to turn pink ; there should be a decided difference between A and B.

(*p*) Cut off a leaf (*e.g.* Tropacolum) and let it lie on the table until it has become limp (not long enough to let it get dried up). Then cut off a fresh leaf, and put the two leaves (each with lower side upwards) below a cobalt-paper. Which leaf, the fresh or the wilted, reddens the paper more rapidly? The experiment shows that the stomates close when the leaf withers.

(*q*) Since evaporation causes cooling there must be a difference in temperature between a fresh leaf (with stomates open) and a wilted leaf (stomates closed). Wrap and tie round the bulb of a thermometer (1) a leaf cut from a Tropaeolum, (2) a leaf still attached to the plant (exposed to light), and note the readings of the two thermometers. When the cut leaf has wilted, its temperature will have risen (sometimes as much as 5° C.). Repeat the experiment, keeping the leaves in *darkness* ; the temperature of the two leaves remains practically the same (why?).

(*r*) That salt-solution causes the stomates to close may be shown, without using the microscope, by means of cobalt-paper. Water a Bean or other seedling in a pot with 0·5 per cent. solution of common salt (1 gramme of salt in 200 c.cs. of water) for a few days. Test with cobalt-paper leaves from this seedling (A) and leaves from a seedling (B) watered in the ordinary way. The leaves of A redden the paper much more slowly than those of B. Why is it that a *weak* salt-solution actually keeps cut or dug-up plants fresh? Plants sent by post will wilt much less if sprinkled with a weak solution of salt.

154. Absorption and Excretion of Liquid Water by Leaves.—Unless there is a thick waxy unwettable cuticle on their surface, leaves can absorb a certain amount of the rain water falling on them. In Flowering Plants, however, this capacity for absorbing water by the leaves is not nearly so marked as in some of the lower plants (especially mosses and lichens), and in many cases it is prevented by the very same adaptations which the leaves possess for hindering excessive transpiration (Art. 155).

When the stomates close at night, water is still absorbed by the roots, and in this way a plant which has become wilted on a hot day recovers its turgidity at night. Drops of water may be forced out of the leaves, usually through special openings (water-stomates) at the margin of the leaf. A water-stomate has two guard-cells, but these remain always apart, so that the stomate does not open and close like an ordinary stomate. Water-stomates occur at the ends of the bundles (on the teeth when the leaf-margin is toothed—well seen in Fuchsia) and are connected with the bundle-endings by means of a mass of glandular tissue (water-gland). In Saxifrages there are hairs close to the water-stomates, on which lime is deposited as the excreted water evaporates. In Grasses the water escapes between the ridges of the leaf and, in seedlings at any rate, from the tip of the leaf.

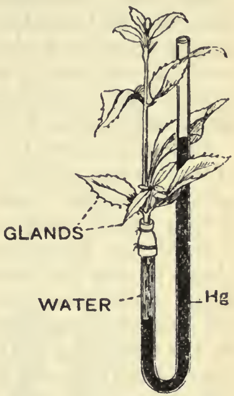


Fig. 44.—Mode of demonstrating the Excretion of Fluid Water from Leaves.

* (*a*) Try several plants and find out whether their leaves can absorb water directly. Cut and weigh a leafy twig, or a leafy shoot, or a well-grown seedling; then plunge it into water, immersing the leaves, for a few minutes; carefully wipe it dry with blotting-paper or a soft cloth, and weigh again.

* (*b*) Cover various growing plants with a bell-jar overnight and look for water-drops excreted by the water-stomates. The plants should be growing in pots, and the following will usually give good results:—Fuchsia, Tropaeolum, London Pride (a Saxifrage, with chalk-glands). In a cut twig of Cherry, set in water and kept under a bell-jar, drops of water are seen oozing from the glands on the leaf-stalk.

(*c*) Cover seedlings of Wheat or Maize with a bell-jar, and note the excretion of water from the tips of the young leaves.

* (*d*) Fix a cut piece of a Fuchsia into the short limb of a J-tube, as shown in Fig. 44. Pour some water into the tube and then pour in mercury. Drops of water are caused to escape from the "water-glands" on the teeth of the leaf-margin. A water-gland is a mass of tissue at the end of a vein, communicating with the water-stomates on the leaf-teeth.

155. How Leaves are Protected.—We shall see later that young leaves nearly always have some mode of protection against loss of water; they are often covered with hairs, which may disappear as the leaf grows to its full size, or they may be bathed in a gummy or resinous liquid; or they may be rolled or folded up at first. These protective arrangements are especially necessary when the leaf is young and its tissues tender and liable to lose water readily, or to be injured by strong light or by cold.

In many plants the mature leaves show similar protective arrangements, which are especially marked in plants which grow in places where they are exposed to strong light, to drying winds, cold, and other injurious conditions, such as a scanty or precarious supply of water. Most evergreen plants have a thick cuticle, or a layer of clear cells below the upper epidermis, and the stomates are often sunk below the level of the epidermis. Transpiration is also diminished by the rolling up of the leaf (Heather, etc.), by a thick covering of hairs (Woolly Mullein, etc.), and by a covering of waxy "bloom" which makes the surface unwettable (Broad Bean, Tropaeolum, etc.).

(*a*) To imitate the effect of a hairy covering, use the apparatus of Fig. 41 A or Fig. 42, after tying with thread a piece of cotton-wool over each leaf, so as to cover the lower surface of the leaf (vary the experiment by covering *both* surfaces, or only the *upper* surface), and note the effect this has on the rate at which the leaves give off water vapour.

(*b*) The effect of rolling can be observed by folding each leaf or rolling it up longitudinally to form a tube, with the lower epidermis on the inside, and tying it with threads, and noting the reduced rate of transpiration.

(*c*) Take two leaves from an Indiarubber Plant, and remove the "bloom" from one by sponging its surface carefully with warm water; weigh both leaves, and hang them up; the bloom-less leaf will lose water more rapidly than the untouched one.

156. Root-Pressure.—We have studied in some detail the current of water, with dissolved salts, which passes upwards from roots to leaves. How is this transpiration current set up and maintained? What part does the root play in the process?

In the first place the evaporation from the leaves tends to suck fresh supplies upwards to replace that removed by the air in the form of water-vapour, and in the second place the root may exercise a pushing force (**root-pressure**), driving water upwards. Experiments with leaves or shoots cut off and set in water prove that the leaves *draw* water upwards. How can we find out whether water is *forced* upwards by the root? See Art. 159, however.

* (*a*) Choose a healthy Bean seedling growing in soil in a pot, and cut across its stem about 3 ins. above the soil. Tie a bit of stout rubber tubing, a few inches long, on the stump, and fill this tube with water, then tie into the rubber tube a glass tube of fine bore (capillary tubing). Support the glass tube horizontally by means of a cleft stick; squeeze the rubber tube so as to force some water out of the end of the glass tube and absorb it with blotting-paper, then release the rubber tube so that air is drawn into the glass tube. Watch the advance of the water (which should be coloured with red ink) along the glass tube. Try this experiment with vigorous plants of various kinds growing in pots.

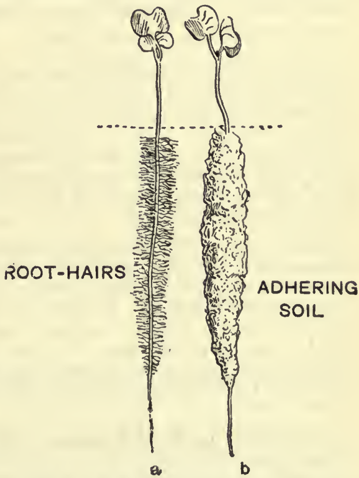


Fig. 45.—Mustard Seedlings grown in Sand (*a* has been gently shaken in water).

(*b*) Cut off the stem close to the ground, and connect the stump to a long, straight piece of glass tubing; lash this tube to a stick placed in the soil, pour a little water into it, then a drop of oil, which will float on the water and prevent evaporation. Measure the ascent of the water in the tube, and find out how the rate is affected by temperature.

157. Root-Hairs are developed on roots a short distance behind the root-cap. They soon die away from the older parts of the root. They come into very close contact with the earthy particles, so that when the root of a seedling is lifted from the soil a portion of the latter adheres wherever root-hairs are present (Fig. 45), but not where they are absent.

The surface of the root is increased at least fifty or sixty times by the root-hairs. The root-hairs come into contact with the water around the soil-particles, and each hair becomes surrounded by a film of water. Some roots contain sugar (Carrot, Beet, Parsnip, etc.), and by chemical tests we always find in roots sugar or other substances that are capable of "attracting" water. We have here the conditions under which *osmosis* occurs—two solutions separated by a permeable membrane (cell-wall of root-hair), and we may infer that soluble substances in the soil-water diffuse into the root-hair, while some of the substances dissolved in the cell-sap of the root-hair diffuse into the soil.

* (*a*) Root-hairs are especially well seen on the roots of seedlings (Figs. 12, 13, and 45). In seedlings of Wheat, Radish, Turnip, Cress, or Mustard, grown on muslin stretched over a tumbler of water, the hairs are very abundant. An even better method is to place the seeds in an earthenware dish, or on pieces of brick or broken plant-pots, and keep them moist, covering them with a sheet of glass or a bell-jar; the root-hairs are freely developed in the damp air, forming a white fleecy covering on the roots.

* (*b*) Make a rough model of a root-hair out of a long potato-tuber. Cut off one end of the tuber so that it will stand upright, and with a knife scoop out the middle part, leaving on the outside a layer about a quarter of an inch thick. Half-fill the tuber with salt solution or sugar solution (about 5 per cent. in each case), coloured with red ink, and stand it in a dish of water, the level of which should not exceed that of the salt or sugar solution inside the tuber. From day to day observe the rise of the coloured solution, showing that water has been absorbed.

158. How is Root-Pressure set up?—The process of osmosis through the thin cell-wall of a root-hair is largely influenced by the layer of living substance (protoplasm) within the cell-wall, which allows only weak solutions to pass into the hair, and which retains the water in the cell-sap at a high pressure. The tense condition of the root-hair thus set up is called turgidity. It is really osmotic pressure, regulated by the influence of the living protoplasm layer. If the "artificial root-hair" is placed in a solution stronger than that which is inside it, water is drawn out. Exactly the same occurs with the real root-hair. Its stiffness or turgidity is, like the stiffness of an inflated bicycle-tyre, due to the pressure inside it. This pressure in the root-hair is due to absorption of water—hence, when we draw this water out the root-hair collapses or becomes flaccid. The presence of salts in large amounts in soil-water hinders absorption by the root; this is exactly what the root has to endure in salt-marshes and peat-bogs.

When the pressure thus set up in the root-hair reaches a certain point the protoplasm of the root-hair undergoes a change, so that it allows the cell-sap to be forced into the cells of the cortex at the base of the root-hair. Each cell in turn, as we pass inwards in the cortex, repeats this process, alternately becoming turgid and collapsing, so that the water with dissolved salts eventually reaches the central cylinder, and is forced into the wood-vessels.

The effect of the millions of root-hairs absorbing water and passing it on to the cortex-cells, which pump it into the vessels, is to produce considerable pressure, which we may regard as a force driving the water into the wood-vessels and upwards. In some plants it is very marked, especially in spring; but it can be demonstrated in most plants while active growth is going on and there is sufficient water in the soil. Many plants "bleed" when cut; this is often seen in trimming or pruning plants, especially in spring or early summer.

159. "Negative Pressure" in Stems.—The importance of root-pressure in connexion with the maintenance of the transpiration-current has been greatly over-estimated. It is easy to show that in an actively transpiring plant there is often no root-pressure at all, but a partial vacuum or "negative-pressure."

Take a Bean seedling which has been pulled up and allowed to lie for some time, till the leaves have begun to wither. Place the seedling with its stem under water coloured with red ink, then cut across the stem under the coloured water. Take the stem out and notice that the water has run up, in the bundles, for some distance. This shows that when the leaves are transpiring and the roots are not absorbing enough water, there is a **"negative pressure"** in the water-carrying channels, so that when the stem is cut under the coloured water the liquid rushes in.

160. Available Plant-Food in Soil.—We have seen that root-hairs can only absorb dissolved substances. Salts insoluble in pure water and required by plants are brought into solution in various ways, chiefly by the carbon dioxide present in soil-water and by the changes due to the various chemical processes we have just mentioned. It is easy to prove that root-hairs give out acid sap, and that they give out carbon dioxide, which accounts partly, at any rate, for the acid reaction they give with litmus. In these different ways the elements essential for plant-food are made available for the use of plants.

A complete chemical analysis of a soil, though giving the limits of the plant-food the soil can supply, often gives little practical information as to its fertility or its need for manures. It is necessary to know, as far as possible, the amounts of the essential elements which are directly available for the use of plants. One method, used to determine the amount of available phosphoric acid, for example, is to treat the soil with a 1 per cent. solution of citric acid, which represents roughly the average acidity of the sap of roots and root-hairs.

(*a*) Grow seedlings with their roots resting on wetted blue litmus paper, or dipping into blue litmus solution, and notice the change of colour, due to the acid substances excreted by the root-hairs.

(*b*) Grow seedlings in a layer of sawdust or soil resting on a slab of polished limestone. After a week or so, when the roots have reached the slab, remove the latter and examine the surface closely for the tracks eaten into it by the roots.

(*c*) To show that roots give out carbon dioxide, it is only necessary to grow seedlings for a short time with their roots dipping into lime-water; set up a control experiment, with a jar containing lime-water but no plant.

161. The Soil is the medium in which land-plants may place their roots in such a manner as to enable them to stand erect in the light and air, and it is a storehouse of moisture for the use of plants. The productiveness of a soil depends largely on the amount of water it can hold, and on the readiness and completeness with which plants growing in it can withdraw the water for their use as required. The soil is also a storehouse from which plants get the necessary ash ingredients of their food, the lime, potash, phosphoric acid, etc., which are formed by the breaking-down and solution of the soil-grains. The soil is also a laboratory in which various lowly plants (fungi and bacteria) are at work breaking down dead organic matter, and converting it into nitric acid and other forms in which it becomes available for the use of higher plants.

Find out all you can, from books on Geology, Physiography, Agriculture, and Gardening, about the origin of soil; the work of running water, freezing and thawing, wind, earthworms, and other agencies by which soil is formed; sedentary and transported soils; the structure of soil; sand, clay, humus, chalk, loams, marls, and other kinds of soil; the free, capillary, and hygroscopic water of the soil; how the water-content of soils is influenced by the nature of the soil, by the rainfall, by the humidity of the air, and by the physiographic factors (altitude, slope, exposure, covering of vegetation); the composition of soil-water and of soil-air; how soil-temperature is influenced; the specific heats of different soils; how soil is improved physically (ploughing, harrowing, digging, rolling, draining, etc.), and chemically (by manures and fertilisers); tilth, tillage, mulching; nitrogenous, phosphatic, potassic, and other fertilisers, natural and "artificial"; the meaning of "rotation of crops"; the work done by nitrifying and nitrogen-fixing Bacteria.

QUESTIONS ON CHAPTER V.

1. What chemical substance forms the great bulk of the weight (*a*) of a living plant, (*b*) of a plant-body after it has been thoroughly dried in an oven? If the dried body is now carefully burned and the ash collected, of what substances will it be found to consist, and what has been lost in the process of burning?

2. How would you yourself determine the percentage of water and the percentage of ash present in a plant? Name the elements most generally present in a plant, and state how you would determine which of these elements were absolutely necessary to the life of the plant.

3. How would you determine the best strength for a culture solution? How would you discover if the strength of the solution was altered by the growth of the plant in it?

4. Explain how you would proceed to make a water culture. Indicate the effect, on the plant, of the omission of salts containing calcium, potassium, and nitrogen respectively.

5. How are water-cultures carried on? What are the commonest causes of failure, and how may they be guarded against?

6. Pea seedlings with their roots in distilled water will sometimes grow and produce leaves and flowers. Name the elements that the plant must have obtained from some source or other, and explain how the feeding of the plant in this case must have (*a*) agreed with, and (*b*) differed from, that of a Pea seedling grown in earth.

7. In what form is (*a*) hydrogen and (*b*) nitrogen absorbed by a plant?

Explain as fully as possible the part played by each of these elements in the economy of a green plant.

8. Give results of actual experiments which show that seedlings of common green plants are nourished (*a*) by air and sunlight, (*b*) by substances taken up from the ground.

9. What are the essential elements of an ordinary green plant's food? In what forms are these elements obtained?

10. What is meant by "water-culture"? Name the substances which are used in making up a culture-solution for a green plant.

11. Describe the method by which the importance of the various mineral constituents of a plant's food has been most satisfactorily ascertained.

12. What materials compose the food of plants? Explain the differences you have observed between the nutritive processes of a young seedling and those of an adult plant.

13. Describe simple experiments which show through what part of the stem water ascends. How would you arrange an experiment to show the relation between the volumes of water absorbed and given off?

14. Describe some ways by which you could demonstrate that leaves give off water vapour. How do external conditions affect the magnitude of this process? What is the significance of it in the life of the plant?

15. Give an account of the process of transpiration. By what means does the plant regulate its transpiration?

16. If on a warm sunny day a plant growing in a pot had become limp and "wilted," how could you restore it to its normal condition without watering it in any way?

17. Why does the inside of a Cabbage consist of lighter-coloured, thicker, and more succulent leaves than the outside?

18. Explain why it is that plants droop on a hot day, and recover their freshness in the evening.

19. Describe experiments you have made on Transpiration, and explain how the rate of transpiration is affected under different conditions.

20. How does a plant dispose of the water which it absorbs from the soil? Describe any arrangements with which you are acquainted for regulating the quantity of water in a plant.

21. Indicate the probable presence or absence of Respiration, Transpiration, and Photosynthesis in the green and white parts, respectively, of the variegated leaf of a plant under normal conditions, (*a*) in the daytime, (*b*) at night. Give brief reasons for your answers.

22. Mention all the gases given off by a foliage-leaf under different conditions. Explain briefly how you would demonstrate by experiment the evolution of these gases; and give an account of the processes leading up to their formation.

23. Explain, so far as you can, exactly how plants grown in pots in sitting-rooms are affected by draughts, by burning gas, by one-sided illumination, by the different aspects of windows, by a dry atmosphere, by injudicious watering, and by other conditions to which they are likely to be exposed.

24. Describe carefully, with illustrative diagrams, two methods of finding out which side of an ordinary dorsiventral foliage-leaf gives off more water vapour. To what structural features and to what biological advantage is the observed difference related?

25. What would be the result of smearing both surfaces of all the leaves of a plant with vaseline or other greasy substance? How would you determine experimentally the effects so brought about?

26. What are the "veins" of a leaf? What are their uses? How would you show, by experiment, the correctness of your statements?

27. If you take two similar open vessels full of water, and place a leafy shoot with its cut end in one, from which will the water disappear more rapidly? Explain, as fully as you can, the reason for the observed result, and the nature of the processes involved.

28. Explain why it is that a shoot which is cut off from a plant begins to wither and droop. How can this be prevented? How can a flagging branch be revived?

29. What purposes are served by the process of transpiration? Under what conditions is this process accelerated and retarded?

30. A green plant is in ordinary life continually giving off water. Explain how this is effected, and what is its purpose. How is the process affected by changes in the air and in the soil?

31. How would you prove (1) the nature of the gas given off by a green plant in sunlight, (2) the nature of the gas given off by a green plant in the dark, (3) the nature of the liquid deposited on the inside of a bell-jar covering a growing plant? Give an account of the processes leading to the formation of the liquid.

32. Trace the path followed by a particle of water, from its entrance into the root to its exit, as vapour, from the leaf.

33. On what part of the root are root-hairs found? Under what conditions are the most conspicuous root-hairs produced? What is the function of root-hairs? How can you imitate the process involved by a mechanical contrivance?

34. Show how some of the commoner operations of gardening, such as digging, manuring, raking, transplanting and watering, may be conducted, so as best to minister to the chemical and physical conditions of plant life.

35. How would you examine a handful of soil to see if it contained any soluble salts? How could you prove that nitrates (of soda, potash, or lime) are present in a fertile soil?

36. Describe carefully and illustrate by diagrams the details of the procedure you would follow in order to find out the differences produced in the roots of seedlings by growing (*a*) in ordinary soil, (*b*) in water-culture solution, (*c*) in damp air. What differences would you observe between the roots in the three cases, and how are they related to the different conditions of life? What would be the ultimate fate of the three sets of seedlings?

37. Explain why it is injurious to plants grown in pots to be too frequently and too abundantly watered.

38. Can you measure the moisture present (*a*) in the soil, (*b*) in the air? State exactly what effect each has on a growing plant, and how you would demonstrate the effect in each case.

39. What are root-hairs? Where do they occur, and what is their function?

CHAPTER VI.

LEAVES AND BUDS.

162. Summary of Chief Functions of the Green Leaf.—These functions may be thus briefly summarised :—

(1) Leaves are the respiratory organs of the plant, since they allow a free exchange of gases with the atmosphere by means of their stomates.

(2) The chlorophyll of the leaf, which, as we have proved, is itself formed only under the influence of light, has the power, under this same influence, of decomposing the carbon dioxide of the atmosphere, and of building up with the carbon so obtained, together with the dissolved mineral substances absorbed by the roots from the soil, the sugar, starch, and other organic compounds of the plant. Some of the material thus formed in the leaves is transmitted to the stem and root in a soluble state, and often stored in these organs in large quantities.

(3) Water absorbed by the roots passes up the stem to the leaves, where a large proportion of it is lost by evaporation through the stomates. Water lost by evaporation in this way is being continually replenished by the roots, and thus there is a steady upward current by means of which new mineral matter is constantly supplied. The stomates are reduced in size by the collapse of the guard-cells when transpiration is too active, and when the water supply in the soil is deficient. They also close in darkness, when no carbon assimilation can take place; and by so doing they also prevent the plant from becoming too cold, for evaporation is always accompanied by a reduction in temperature.

The leaf primarily acts as an organ for absorbing radiant energy, and storing it up as potential energy in the form of food. It also promotes gaseous exchange in general, and usually forms the main transpiring surface of the plant.

163. Adaptation of the Green Leaf to its Functions.—It is interesting to note how the structure of the ordinary bifacial type of foliage-leaf is adapted for its work.

Its flattened form and its position are the most favourable for absorbing carbon dioxide and for catching light. The epidermis and cuticle prevent excessive evaporation, besides acting as a screen against undue heating and other ill-effects of strong light. Both palisade and spongy mesophyll cells, containing numerous chloroplasts, are adapted for assimilation. The palisade tissue is adapted to protect the chloroplasts from the effects of too bright light; when the light is diffused, the plastids are arranged chiefly along the upper and lower walls of the columnar palisade cells, but in strong light the protoplasm moves in such a way as to arrange chloroplasts along the side-walls of the cells with their edges (the chloroplasts are disc-shaped) presented to the light. The spongy-tissue, with numerous air-spaces communicating with the atmosphere by means of the stomates, is equipped for carrying on the gaseous exchanges concerned in respiration, photosynthesis, and transpiration.

The spreading veins, the larger ones projecting on the lower side of the leaf, while the smaller ones run between the palisade and spongy mesophyll, carry water (with dissolved salts) *to* the mesophyll cells and elaborated food (sugar, etc.) *from* them.[1] The mesophyll cells are arranged more or less definitely in groups extending from the epidermis to the veins. This is clearly seen in most leaves with well-marked palisade mesophyll, the cells of the latter being arranged in a fan-like manner as seen in vertical section (see Fig. 36), and the cells which converge towards the veins have been called "collecting" or "converging" cells. The veins also serve in the best way to support the leaf; the larger veins have bands or cords of hard fibrous tissue below or above, or in both positions.

164. Forms of Leaves.—Before quitting the study of leaves we must observe a number of their general characters—their variety of form, arrangement of veins, etc. In order to do this we shall have to

[1] The water, with dissolved salts, travels in the vessels of the wood, the dissolved sugar in the long cells of the bundle-sheath, and the proteids in the sieve-tubes of the bast.

examine a considerable number, and to this end the student should take country rambles, supplied with a book for notes and sketches, and a lens. The following instructions must be accepted as merely suggestive, and by no means exhaustive.

A typical leaf consists of a basal more or less sheathing portion, called the leaf-sheath or leaf-base, a stalk or petiole, and a flattened terminal portion, the blade or lamina. The leaf-sheath is usually simply the flattened basal portion of the petiole, but in most grasses it is of considerable size, and ensheathes the stem for some distance above the node from which it arises.

A sheathing **leaf-base** is frequently absent, but is especially well developed in such plants as Buttercups, Grasses, Docks, Umbellifers. The mode of insertion of different leaves exhibits a wide range of variation, but they always arise from the shoot or its branches. The so-called "radical" leaves simply arise from a very short stem (Primrose, Dandelion). In some cases the base of the leaf is *decurrent*, and forms membranous outgrowths on the main axis (*e.g.* some Thistles), while it may even unite around the stem so as to form a *perfoliate* leaf (*e.g.* Yellow Gentian).

Occasionally the leaf-base becomes thick and fleshy, and forms an irritable organ or organ of movement known as the *pulvinus*, which reacts to light in such a manner as to place the lamina under the best possible conditions of illumination. This is possible owing to the fact that the pulvinus retains the power of growth for some time after that of the rest of the leaf has ceased, as can easily be observed by watching Kidney Beans and altering the position of the stem from time to time.

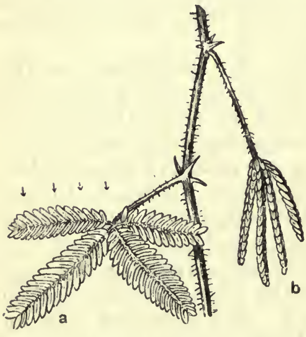


Fig. 46.—Leaves of Mimosa pudica (the Sensitive Plant).
a, Expanded day position ; b, Drooping folded night position.

In some plants the pulvinus responds quite rapidly to changes in the direction and intensity of the light. Thus the compound leaf of the Sensitive Plant (Fig. 46) places itself at right angles to the light falling upon it. Each leaflet, however, has a pulvinus of its own, and when the leaf is exposed to strong sunlight these pulvini curve in such a manner as to cause the leaflets to fold together in a few minutes, before they have time to be injuriously affected. At night, also, the leaflets fold together and go to sleep, as it were, while the whole leaf sinks downwards. In this position the leaf loses less water by evaporation, and remains warmer than it would be if expanded. The closing movements can also be induced by contact, heat, and other stimuli.

165. Stipules.—Very commonly wing-like outgrowths arise from the base of the petiole, and frequently these simply assume the form of lateral outgrowths of the leaf-base. The organs in question are known as **stipules,** although they cannot always be sharply defined. The stipules vary much in size, form, and colour. When they are quite small, dry, pale, and membranous they are usually functionless, but frequently they form large coloured protective bud-scales (Magnolia, Fig, Beech), and fall when the leaves unfold. In the False Acacia (*Robinia*) the stipules are metamorphosed into spines (Fig. 98), and in *Smilax* they become tendrils. In Peas (Figs. 97, 98) they are large and green, and take the place and function of the foliage-leaves, which are more or less completely modified into tendrils.

Stipules are often relatively large while the leaf is young, and in such cases they serve as a protection to the young buds or young foliage, frequently falling off as the leaf expands. When present upon adult leaves, the stipules aid in the production of organic food if they are green, and they may also help to lead away rain-water from the plant so that it can dry rapidly, or to direct the water to those regions of the soil where the absorptive organs (root-hairs) are most abundant.

In the Rhubarb family (Polygonaceae) the two stipules join to form a tube (*ochrea*) enclosing the stem for a short distance above its junction with the leaf. The basal portion of a Grass leaf ensheathes the stem for some distance, and just between the stem and the base of the free portion of the leaf there is a small crescentic scale on the upper surface of the latter. This scale is termed the *ligule.*

166. Petiole.—Note that while some leaves have a distinct stalk (**petiole**), in others the lamina extends down to the stem of the plant. The latter are called *sessile leaves.*

The petiole is usually directly prolonged into the lamina as the midrib, but in the Garden Nasturtium (*Tropaeolum*) and in the Pennywort (*Cotyledon*) the stalk is attached to the middle of the under-surface (peltate leaf). A transition stage is shown by the leaves of the Water Lily. The petiole may be winged, and it is usually cylindrical or semi-cylindrical, being frequently flat or even grooved on the upper surface.

The petiole is a special secondary structure developed in order to enable the lamina to expose itself to suitable illumination, and it is not always present. It contains strands of vascular tissue, which are continued into the lamina as the branching veins of the leaf. There is usually a large median vein, lying above a prominent midrib, although in other cases a number of veins of equal size enter the leaf from the petiole. In Garden Nasturtium (*Tropaeolum*) and Clematis the petiole has the power of coiling around supports, and hence it acts as a tendril in spite of the presence of the lamina or blade.

167. Veins.—The veins are simply conducting bundles which run outwards from the stem into each leaf, and undergo considerable branching throughout the substance of the lamina. The larger veins usually project as ridges on the under-surface, but the smaller veinlets are buried in the tissue of the leaf. The arrangement of the smaller veinlets and the number of the larger veins differ in different leaves. This is what is termed the venation of the leaf.

Note that the leaves of all grasses, orchids, flags, wild hyacinths, and daffodils have all their principal veins running parallel through the entire length, and that these leaves are more or less elongated and blade-like. The leaves of most of our trees and herbs, however, have their principal veins branching off from the midrib on either side, while the smaller ones form a delicate network such as we observed in the bean leaf. The former arrangement (*parallel venation*) is characteristic of Monocotyledons, the latter (*reticulate venation*) of Dicotyledons (but also found in some Monocotyledons, *e.g.* Arum).

If leaves are allowed to decay in water until the softer parts can be brushed away, skeletons of the harder parts can be obtained which directly exhibit the venation, but in most cases it is sufficient to hold up the leaf to the light to render the smaller veins plainly visible.

168. Simple and Compound Leaves.—Some leaves are *simple*; that is, their flat part or blade (*lamina*) is not divided into distinct portions, though they may be very deeply divided. Such is the case with the leaves of the Oak, Hazel, Ivy, Dandelion, etc. These simple leaves exhibit a great variety of form, and the student should make a series of drawings illustrating the more typical shapes.

In compound leaves, of which we have already seen an example in the Bean, the blade is divided into distinct parts called leaflets, which may be arranged in opposite pairs along the central stalk as in Rose, or may all radiate from one point of the stalk as in Horse Chestnut.

The outline of the lamina assumes a great variety of forms, and special technical terms are given to the more strongly marked and more commonly occurring of these. All gradations exist between leaves of widely different shape, and since no general principles are involved in the application of these terms, they need not be discussed here. The following list includes the commonest shapes :—

(1) **Blade broadest near the base**—*e.g.* **cordate** (heart-shaped), **sagittate** (arrow-head-shaped), **reniform** (kidney-shaped), **ovate** (egg-shaped), **lanceolate** (lance-head-shaped, much longer than broad, tapering to pointed tip).

(2) **Blade broadest near the tip**—*e.g.* **obcordate, obovate, oblanceolate** (outline as in cordate, ovate, and lanceolate, but with the narrow end at the base), **spathulate** (spoon-shaped, *e.g.* Daisy).

(3) **Blade as broad in the middle as anywhere else**—*e.g.* long narrow forms, as **acicular** (needle-shaped), **linear** (long and narrow, with parallel margins), **cylindrical**; and rounded forms, as **orbicular** (circular), **elliptical, oval, peltate** (shield-like, blade nearly circular, but with stalk near the middle of lower surface).

Next observe the different kinds of **margins** of the blades. Some are even or *entire*, while others have sharp teeth which usually point towards the tip of the blade and resemble the teeth of a saw (*serrate* leaves), or have rounded teeth (*crenate* leaves). Note also the hairy (*ciliate*) margin of the Beech leaf, the wavy or *sinuate* margin of the Oak, the irregularly toothed edge of the Dandelion, the spiny margin of the Holly, and various other types of leaf margins.

Very frequently the margin of the leaf is deeply indented, and if the indentations are regularly arranged, and are so deep as to reach the midrib, a compound leaf composed of a series of leaflets is produced. This will be *pinnate* or *palmate*, according to the arrangement of the main veins (Fig. 47), for the incisions will naturally fall between these.

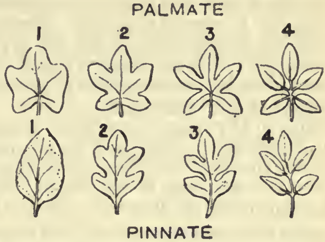


Fig. 47.—Formation of Palmate and Pinnate Compound Leaves by the gradually increasing incision of Laminas with Palmate and Pinnate Venation respectively.

Compare the simple leaves of the Ivy and the Beech, both of which are of the net-veined type. Note that in the former the principal veins all radiate from one point at the base, while in the latter they branch off from the midrib almost throughout its length. Now since a compound leaf is produced by the division of the lamina between the principal veins, it is easy to see that the former, so divided, would produce a compound leaf with radiating leaflets. Such an arrangement of veins is termed *palmate venation*, and the leaves, both simple and compound, more or less divided in this fashion, are called *palmate leaves.* The arrangement of veins in the second instance is called *pinnate venation*, and by the incision of the lamina a *pinnate leaf* is produced, which, in the case of the compound leaf, would have opposite leaflets.

A compound leaf is easily distinguished, even by beginners, from a branch bearing leaves because of the absence of any apical bud or growing point, and by the fact that a bud occurs in the axil of the main petiole, whereas there are no buds in the axils of the leaflets.

169. Leaf-Arrangement.—Observations should also be made of the different ways in which the leaves are arranged on the stem. There are two ways in which leaves are arranged—*alternate* (one leaf arising at each "node," *i.e.* the leaves coming off *singly* from the stem) and *whorled* (two leaves, rarely more, arising at each node).

The simplest type of alternate arrangement is that seen in the Broad Bean and in Grasses, where the leaves come off alternately from opposite sides of the stem, so as to form two rows; this is called the $\frac{1}{2}$ arrangement, because each leaf is separated from the next above and below it by one-half the circumference of the stem. The next arrangement ($\frac{1}{3}$) is seen in young shoots of Hazel, where the leaves are in *three* rows. Alternate leaves obviously form a *spiral*, the nature of which may be easily determined by tying a piece of cotton to the base of a leaf, and carrying it in order to the bases of the leaves above, twisting it around each one. Suppose, for instance, we do this in the case of a young shoot of the Hazel; we find that each leaf is one-third round the stem as compared with the one below it, and consequently the fourth leaf is vertically above the first, being the starting-leaf of a second turn of the spiral.

One of the commonest spiral or alternate arrangements is the $\frac{2}{5}$, seen in Wallflower, Oak, and many other plants; here the sixth leaf is above the first and the spiral goes twice round the stem in passing from the first leaf to the sixth. Another fairly common spiral is the $\frac{3}{8}$, seen in Daisy, Plantains, etc. Do you notice how these commoner spiral arrangements are related to each other?

When leaves are arranged in pairs, the two leaves being on opposite sides of the "node," each pair is usually set at right angles to the pair above and the pair below. That is, the leaves are in four rows, the pairs being crossed. This *decussate* arrangement is very common, *e.g.* Nettles, Labiates, Sunflower, Sycamore, Ash, Lilac, Horse Chestnut, Campions, Stitchworts, Chickweeds. Comparatively few plants have three or more leaves in a whorl or circle at each "node"; this is seen in Mare's-tail (*Hippuris*), Canadian Waterweed (*Elodea*), Juniper, Heaths. The leaves are *apparently* in whorls in Goosegrass and Bedstraws, but only two of the organs in each circle are true leaves (how can you tell this?).

170. Leaf-Mosaics.—Instead of giving further details here about the various modes of arrangement of leaves on the stem, we will call attention to the *reasons* why leaves have such varied arrangements and shapes. It is not always easy to explain the different forms of leaves in different plants, but some general principles can be inferred by remembering the *functions* carried on by leaves while studying their form and structure. The main fact to remember is that leaves require to catch as much sunlight as possible, especially in a country like ours, where the number of hours of sunshine is rather scanty. The south coast of England only gets about 1,600 hours of sunshine annually, and in the rest of Britain the number is usually far below this.

A leaf which receives very little light or no light at all during its development grows feebly, and cannot, of course, carry on carbon-assimilation. Moreover, when a leaf is shaded by another leaf being placed between it and the light, very little assimilation occurs. Hence we find that in many plants the leaves tend to fit together like the bits of glass in a mosaic or the tiles in a pavement, so as to avoid shading each other and to lose as little sunlight as possible. This tendency is easily seen in (1) plants whose leaves are crowded together and form a rosette close to the ground—*e.g.* Daisy, Hawkweed, Plantain, London Pride; (2) many plants with whorled leaves—*e.g.* Woodruff; (3) twigs of many trees—*e.g.* Horse Chestnut, Beech, Elm, Lime; (4) twigs of plants which creep along a wall or bank—*e.g.* Ivy. In Labiates (*e.g.* Dead-Nettle) and Stinging-Nettles the lower leaves have broader blades and longer stalks than the upper ones.

Even when the "mosaic" tendency is not at first glance apparent, careful study of the plant *in its habitat*, or home, will often show adaptations for efficient light-catching. It must, of course, be remembered that the strongest light does not, in this country, come from directly above, but at an angle, even when plants are growing on level ground. In studying the plants dealt with in the later chapters of this book, you should notice and try to account for the position, stalk-length, shape of blade, and other arrangements of the leaves, remembering that, besides the tendency to catch as much light as possible, the forms of leaves are often influenced by other causes—the necessity to withstand high winds, to carry away rain which falls on the blade, to catch the light when growing in dense masses (*e.g.* grasses and plants growing among them in fields), etc.

This interesting subject can only be studied by personal observation; any field, wood, hedgerow, or garden will afford abundant material to illustrate the points here mentioned, and to show how the arrangement and shapes of leaves help plants in the struggle for light and air, which is keenest where plants are growing in crowded fields or hedge-rows.

171. Decay and Fall of the Leaf.—Leaves which fall before the vegetative season is over are *caducous*; *deciduous*, if they fall at the end of each season, as in most cases of our forest trees; *persistent*, if they remain on the plant for more than one season, as in evergreens. The leaves of such plants as Grasses, Lilies, Irises, etc., simply wither on the stem, but in most trees the fall of the leaf at the end of the vegetative season is brought about by the plant itself. When the activity of such leaves is nearly over, and they have been partly emptied of the food-substances they contain, a layer of cork-tissue forms across the base of the leaf, and by interposing an impermeable layer between leaf and stem, cuts off from the former all supplies of water and mineral salts.

The exact structure and development of this **absciss-layer** cannot be fully gone into here, but what occurs in the actual "fall" of the leaf is the splitting of this layer in such a way that the leaf only hangs on by the veins which pass from it into the stem, and then these snap, leaving the scar of attachment of the leaf already healed and covered with cork. The process is a vital one due to the activity of the living plant, for if a branch is killed by means of hot water the leaves wither upon it without being shed. On the other hand, leaves can be made to "fall" in summer by wrapping them in a damp cloth.

Whenever the plant requires to throw off certain organs at a definite time (petals and other floral parts after fertilisation; fruits and seeds when ripened) it generally makes use of similar absciss-layers.

172. Buds.—Before the young stem branches, it is in most cases easy to see that between the base of each leaf and the upper portion of the stem (*i.e.* in the axil of the leaf) there is a young bud (*axillary* bud or side-bud), which may grow into a shoot bearing leaves only, or flowers only, or both leaves and flowers. The apex of the stem is usually occupied by a *terminal* bud (end-bud).

Buds appear as little prominences on the outer surface of the stem, and are produced by outer tissue, whereas secondary roots arise from *within*. Each bud consists of a short "condensed" stem in which the "internodes" are undeveloped, so that the young leaves are closely packed together. The formation of a bud depends on the fact that the slowly growing end of the shoot elongates less than the leaves which it has produced, and these bend over its tip and protect it. The apex of the stem of the bud is occupied by a growing-point, which grows and elongates when the bud opens; since it is not exposed to friction against the soil, there is no need for any such structure as the root-cap, which covers and protects the growing apex of the root.

173. Brussels Sprout.—To get a good idea of bud-structure, first examine some Brussels Sprouts.

(1) Pick off the leaves one by one, starting from the outside, and note that each leaf has a small bud in its axil. How do the inner leaves differ (in size, form, texture, colour) from the outer ones? How may these differences be accounted for?

(2) Slice down through the middle of another sprout, and notice the conical end of the stem, with small outgrowths at its extreme tip; these outgrowths are the youngest leaves. Below these are older leaves, gradually becoming distinctly divided into blade and stalk; lower still come leaves whose blade is folded between the veins. In the axil of each leaf is a small bud, resembling a miniature sprout; some of these buds may be cut through in the slice (if not, make more slices). Notice the strings (veins or vascular bundles) in the stem of the Sprout. Sketch a good clear longitudinal section, at least the natural size.

(3) Cut a series of *cross* sections, beginning at the top of the Sprout and proceeding to the base; lay the sections out in order, then compare and sketch them.

(4) Set a Sprout with its cut end in red ink, and after a time cut slices and notice the bundles which extend nearly to the extreme tip of the stem and give off branches to the leaves and buds.

(5) Remove most of the larger outer leaves, and notice that the inner ones soon become wilted if the sprout is set in a dry place.

(6) Weigh (*a*) an entire sprout, (*b*) one from which all the large outer leaves (which overlap and protect the young inner ones) have been removed; set both in a dry place, and in a few hours, or a day, weigh again and compare the loss in weight in the two cases.

Lettuces and Cabbages may be used in addition to Sprouts. Why are the inner leaves softer and lighter-coloured than the outer leaves? What other differences do they show?

174. Winter-Buds (Resting-Buds).—In cold climates the buds formed at the close of the year do not develop at once, but remain dormant after the leaves have fallen. When a resting-bud is about to be formed, the last foliage-leaves on the shoot sometimes grow in the ordinary way, but the stem stops growing and these leaves enclose the young leaves formed inside the bud. Naked resting-buds of this kind occur in herbaceous plants, their structure being essentially like that of a Brussels Sprout, Lettuce, or Cabbage.

In most woody plants, however, the bud is covered by special scales (*bud-scales*), each representing a leaf or part of a leaf and being usually thick, hard, corky, gummy, resinous, or hairy, and these scales protect the delicate and sappy young leaves within from injury by rain and frost, but especially from loss of water. In cold weather the roots are

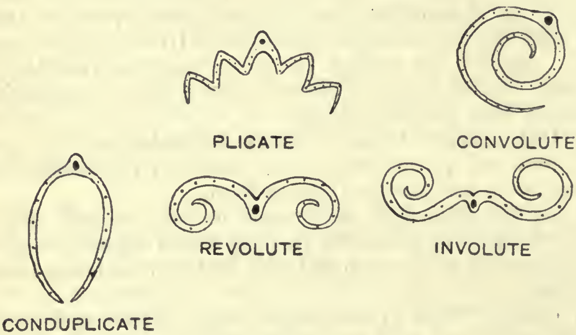


Fig. 48.—Vernation of Leaves.
(In each case the young leaf is shown cut transversely.)

hardly able to absorb any moisture from the soil, so that loss of water at such a time, when there is little or no transpiration-current flowing up in the stem, would be fatal to the young shoot inside the bud. When a cold dry east wind comes after the buds have expanded in spring, the young leaves are often killed, whereas an equally cold but moist westerly wind hardly affects them.

The scales of resting-buds may represent whole leaves (Privet, Lilac), leaf-bases without stalk or blade (Sycamore, Horse Chestnut), stipules of leaves which develop a blade (Alder, Elm, Hazel), or stipules of leaves which do not develop a blade (Oak, Beech).

175. Folding (Vernation) of Young Leaves.—To ensure the close packing of the leaves in the bud each one is usually rolled up longitudinally (more rarely rolled up transversely); but sometimes the leaves are nearly flat, *e.g.* Privet, Holly, Ivy, Willows. Dealing only with longitudinal folding, the leaf may be simply doubled on itself along the midrib (Fig. 48, *conduplicate*), or it may be pleated so as to resemble a fan (*plicate*), or the edges of the leaf may be rolled inwards (*involute*) or outwards (*revolute*), or the leaf may be rolled up from one side, so that one leaf-margin is within the coil and the other outside (*convolute*). The young leaves are conduplicate in Cherry, Rose, Elm, Hazel, Oak, Lime, Ash; plicate in Maple, Sycamore, Birch, Beech, Hornbeam; involute in Poplar, Apple, Pear (also in Violet); revolute in Plane and Rhododendron (also in Docks); convolute in Plum.

176. The Opening of the Bud.—In spring or early summer the winter-bud resumes its development. The young shoot grows and lengthens, pushing aside the bud-scales, which then fall off. Since each scale leaves a scar on the lower part of the bud-axis and this part remains short, a series of closely-set scars is left on the stem. A series of bud-scale-scars ("girdle-scars") is of course seen at the base of each branch, and by examining a twig and noting these series of scars we can easily tell how much the twig has grown each year, often for many years back; later on these marks are obliterated by the formation of bark, but in smooth-barked trees (*e.g.* Beech) one can trace the growth back for twenty years or even more by these girdles of scars.

As the bud-axis elongates, the leaves grow in size and spread themselves out (the leaf-stalks of course helping in this, if present), becoming spaced out on the young shoot. Buds then appear in the axils of the leaves, and these may either develop at once or remain dormant, some of them of course becoming the resting-buds for next year's growth.

It is easily understood why *all* of the axillary buds do not usually develop into branches, for if they did the foliage would be too closely packed together, and sufficient light and air could not reach all of the branches and leaves. As we shall see later, trees differ very much in their mode of branching and in the arrangement of their leaves; thus in the Horse Chestnut and the Beech the outer leaves are densely packed together, so that buds within the crown of foliage have but little chance of developing into leafy branches, owing to the small amount of light which reaches them. In the Birch and Larch, however, the foliage is more open, and the buds nearer to the stem have perhaps as good a chance of developing as the buds at the tips of the branches.

Whenever any of the branches are pruned away or broken off by high winds or by the weight of snow, buds develop which would otherwise have remained dormant, and in this way trees are able to rapidly fill up gaps in their canopy of foliage. So also pollarded willows soon form a crown of new shoots, and many of these arise from deep-seated buds, or from *adventitious* ones. The latter are buds which develop out of their normal order, or without any relation to the leaves. Adventitious buds may be formed not only upon the stem, but also on roots or leaves. Some Begonias are artificially propagated by placing sliced leaves on damp soil; buds appear on the wounded edges, strike root, and develop into new plants. Adventitious buds may appear on the roots of the Hawthorn, Dandelion, and other plants, and may give rise to leafy or even flowering shoots. For example, the roots of the Hawthorn, if chopped into small pieces and covered loosely with damp soil, produce buds and ultimately new plants. Most people are familiar with the fern-like shoots produced when the top of a Carrot (partly stem, partly root) is cut off, scooped out, filled with water, and hung up by strings; try this simple experiment for yourself.

177. Sycamore (see Art. 392).[1]—Examine twigs at different times of the year, noting the arrangement of the leaves, and therefore of the axillary buds, in crossed pairs, forming four rows on the stem (Fig. 49). The twigs are, in the younger parts, grey-green to yellow-brown in colour and are dotted with small lenticels. The leaf-scars are shallow, V-shaped, with three slight projections (bundle-scars). The buds are egg-shaped, with four projecting ridges owing to the boat-like form of the bud-scales. The scales, which are arranged in opposite pairs, overlapping each other regularly, are greenish below and brown at the tips and around the edge. The large end-bud, which generally has two small side-buds just below it, frequently contains an inflorescence in addition to young foliage-leaves.

Dissect a bud, carefully removing the parts and laying them out on a sheet of paper. Note that there are six or seven pairs of scales altogether, though only four or five pairs are, as a rule, visible on the outside of the bud. How do the inner scales differ from the outer ones in colour and texture? Examine the tips of the scales: do any show here a small undeveloped leaf-blade, with three or five lobes? To what

[1] If you do not know these trees in their winter aspect, cut twigs and put them into bottles or jars of water and keep them in a warm room; in many cases the buds will open, since warmth hastens growth. In this way you can study very conveniently the unfolding of buds (sketch the stages observed) and at the same time identify unknown trees or shrubs by the leaves in many cases.

part of an ordinary foliage-leaf—the leaf-base or the leaf-stalk—does the bud-scale correspond? Note the young foliage-leaves in the centre of the bud: how many are there visible, and what portions of the leaf are already developed? Note the fan-like manner in which the young leaf-blade is folded; try to cut out from a sheet of paper a model of the young blade. Is the young leaf smooth and bare, or has it any protective covering of hairs?

Cut buds through, some longitudinally and some transversely, to see how the leaves inside are folded up.

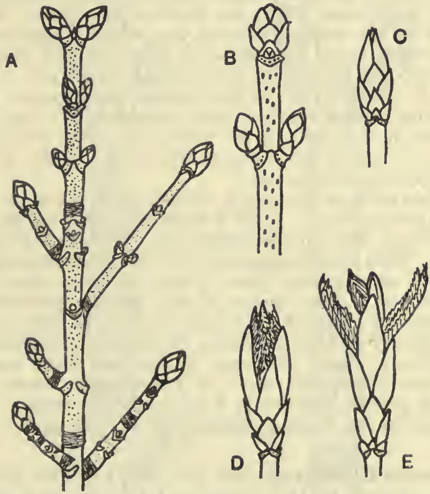


Fig. 49.—Twigs of Sycamore and Stages in Opening of Bud.

In spring, notice how the buds swell up. Make careful observations on the opening of the buds. It is possible to cause them to open in winter by setting a cut twig in water and keeping it in a warm room. Notice how the inner scales, as well as the young foliage-leaves, expand and lengthen, pushing aside the outer scales, and how the young leaves unfold themselves. The buds open at end of April or early in May.

Make notes and sketches of all the stages in the opening of the bud. Note that the stalks of the young leaves, which have hitherto been very short, rapidly lengthen and carry out the leaf-blades beyond the scales. The lower part of the stem of the bud hardly lengthens at all, so that when the bud-scales fall off they leave a number of crowded scars, while the upper part of the bud-axis grows out to form a shoot, the leaves becoming spaced out (in pairs) upon it.

Now look backwards along the twig, to find the place where *last* year's end-bud was: how does this enable us to see exactly how much the twig grew each year, at least for several years back? Why is it that a series of these "girdle-scars" or bud-scale-scars is always found at the base of a side-twig, where it joins the parent-twig? Does a twig always grow equally long, or bear an equal number of foliage-leaves, every year? In the case of a horizontal branch, which buds grow into the most vigorous (as regards length of stem and number of leaves) twigs—the upper ones, the lower ones, or those on the flanks of the branch? Why do you suppose the horizontal branches differ in this respect from those which are erect or nearly so? If you recall your studies on the work of leaves, you will probably conclude that *light* is the chief factor concerned, but you should stop and think the matter out. If you cut off a horizontal branch and set it erect in water, how do the four rows of buds behave after opening?

At what time of year are the resting-buds *formed*? Can you see any trace of them, in the axils of the new leaves, just after the bud has opened and the young shoot has grown out? Notice how the buds grow in size during the summer.

Is it possible to cause the young buds to grow out at once instead of resting until next spring? Try the effect of pulling off the leaves from a twig; the buds may thus be caused to grow out a year before the proper time. This precocious growth of buds is sometimes seen in the Sycamore and several other trees, owing, in some cases at least, to external causes (*e.g.* a late period of wet weather preceded by a dry early summer and followed by a mild autumn, or the early dying of leaves through dry cold spring winds, or attacks of insects), or simply to excess of food; these "Lammas shoots" are often seen on Oaks, Beeches, Horse Chestnuts, etc. In these cases leaves which had arrested their growth in order to form bud-scales resume growth and become foliage-leaves, bearing resting-buds in their axils.

178. Horse Chestnut (see Art. 393).—The arrangement of leaves and buds on the stem, and the general structure of the buds, are the same here as in the Sycamore. The twigs (Fig. 50) are thick, smooth, grey or brown, with conspicuous lenticels. The large leaf-scars vary from being shield-shaped to half-moon-shaped, with scars of from five to nine bundles. The uppermost bud is generally larger than the others and contains a young inflorescence in addition to young leaves, but the true end-bud is often missing and represented by the saddle-like scar of the fallen inflorescence.

The buds are egg-shaped, pointed, brown, shiny, and sticky. Remove the hard concave scales, which are more or less cemented together by the sticky substance. Note the arrangement of the scales in pairs, set at right angles to form four rows; the two lowest (outermost) scales are smaller than those of the next pair, and these are again smaller than the third pair; then come two or three pairs of still larger scales which cover the top of the bud. Within these we see a pair, or two pairs, of soft greenish sticky scales, each often having at its tip five little lobes; then come the foliage-leaves, covered with down and folded up. While dissecting the bud, keep dipping it into alcohol to make it less sticky

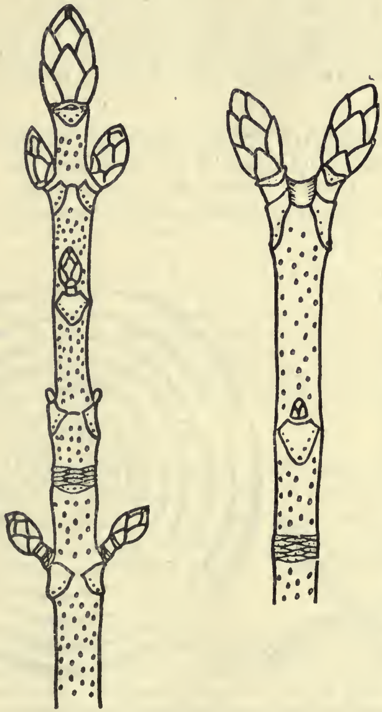


Fig. 50.—Twigs of Horse Chestnut.

and easier to examine. How many young leaves are visible? In the large uppermost buds the axis is prolonged above the young leaves and bears numerous young flowers in tufts.

When the bud is about to open it swells up considerably, then the scales become loosened, the inner scales grow up and bend outwards, and the young leaves emerge with the leaflets (how many to each leaf?)

erect, each leaflet being folded along the midrib and the side-veins as well. As the leaf-stalk lengthens (the leaflets are sessile on its end), the leaflets spread open and bend downwards. Later, the leaflets rise up again and spread out horizontally; meanwhile the stem of the bud has been growing in length. The bud-scales fall off; the white hairs covering the leaflets become brownish and fall away.

Here, as in Sycamore, it is easy to see, as the bud opens, that the structures lying between the hard, externally visible scales and the young foliage-leaves are intermediate in nature between bud-scales and ordinary leaves. The buds usually open about the middle of April.

179. Oak (see Art. 388).—Here the leaves and buds are arranged singly and spirally on the grey or brown twigs (Fig. 51). In passing from any leaf, or bud, to the next one directly above it, we go twice round the twig and pass four

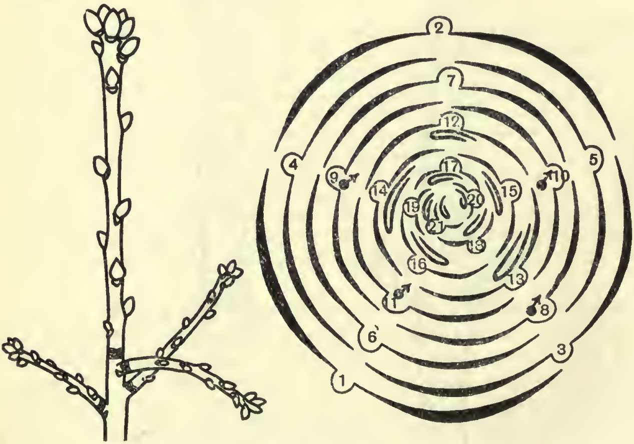


Fig. 51.—Twig of Oak and Ground-plan of Bud.

other leaves, or buds; there are therefore five rows of leaves, as can generally be seen on looking along the twig. The buds, which are crowded at the tips of the twigs, are brown, smooth, egg-shaped, and slightly five-angled. The clustering of the buds towards the tip of each twig is of course simply due to the upper leaves being clustered in this way so as to form a rosette. The leaf-scars are small and triangular, with numerous bundle-scars; the lenticels are small.

Examine a bud and notice that it begins with a few tiny thick scales at the base; then come about twenty thinner scales, arranged in five rows and becoming more delicate, as well as narrower, as they pass inwards. Then come the young foliage-leaves; the outer ones are very small, each being flat and standing between two stipules, while the inner ones are larger and folded along the midrib (conduplicate); and finally come small ones again in the centre of the bud. Careful examination shows that the bud-scales, after the two lowest, are arranged in pairs; this fact suggests that these scales are *stipules*, and, by observing the opening of the bud and also the way in which the bud is formed, one can prove that this is the case. Towards the end of the summer the last leaf-structures to be formed are stipules, which become the outer bud-scales. The buds open in May.

As a rule, the lower resting-buds on a twig remain dormant, and do not open in the spring of the year succeeding that in which they are formed. The Oak is a light-loving tree and tends to have its leaves in rosettes at the tips of the branches so as to catch as much light as possible. Taking the case of a complete flower-containing bud, as soon as the bud-scales become loosened the male catkins, which arise in the axils of the upper bud-scales, grow out first and hang downwards, then come foliage-leaves (each with a young resting-bud in its axil), then leaves with groups of female flowers in their axils, and then again leaves with axillary buds.

180. Scots Pine or "Scotch Fir" (see Art. 377).—Each twig (Fig. 52) shows, as a rule, an end-bud with a few (usually 3 or 4) side-buds just below it and forming an apparent whorl. One or more of the side-buds may be replaced by a seed-cone (Fig. 52 B). The buds open about the middle of May.

Examine a bud and note the very numerous (100 or more) scales, covered with whitish resin and arranged spirally. Each scale (except the lowest ones) bears in its axil a small bud, so that the resting-bud of a Pine is clearly a "compound bud"—a bud of buds. The lowest scales (those without axillary buds) are hard and remain at the base of the young shoot into which the resting-bud grows. Each of the other scales is at first green below and membranous above, with pointed tip and fringed edges, but when the resting-bud opens the base of the scale hardens and the upper part falls off.

The axillary buds on the "compound" resting-bud are the buds of the dwarf shoots which are so characteristic of Pines. Each bears about ten scale-leaves which form a sheath around two young foliage-leaves ("needles"), set face to face.

When the resting-bud unfolds, the pairs of green needles emerge from the axils of the scales as the shoot grows out; the needles grow in size, and the scaly sheath persists around the base of each two-leaved dwarf shoot. When the shoot stops growing in length, it shows at the tip a terminal resting-bud and a circle of lateral resting-buds

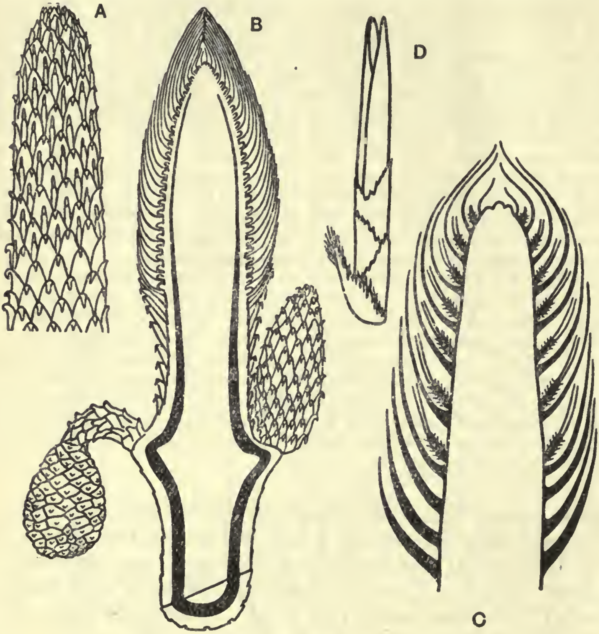


Fig. 52.—Scots Pine.

A, Bud beginning to open; B, Longitudinal Section of End-Bud (a Side-Bud is shown on right, a Cone on left); C, Diagram of Longitudinal Section of Bud; D, Young Dwarf Shoot.

just below it, ready for next year's growth. The lateral resting-buds grow out just like the terminal one, at first growing more or less parallel with it, but later bending away from it.

QUESTIONS ON CHAPTER VI.

1. What do you consider the essential characters of the foliage-leaves of a green plant, *i.e.* the characters in which all or nearly all leaves you know agree? How are these features of leaves of service to the plant?

2. Mention the different forms which may be assumed by the stipules of plants. Give one example of such, and state the special use of the stipules in each case.

3. How are the leaves arrayed on the twigs of a Horse Chestnut (or a Sycamore)? Point out any special adaptations which bring about the full exposure of the leaves to the light.

4. How would you distinguish a compound leaf (*a*) from a simple leaf, (*b*) from a branch bearing leaves?

5. Mention some leaves which show movements. Of what use are the movements to the plant?

6. How can you distinguish by the aid of bark, buds, and general appearance between any six native British trees in winter?

7. Describe, with sketches, the stages seen in the opening of a Horse Chestnut bud in spring.

8. Why are the buds of Scots Pine called *compound* buds? Describe the structure and mode of opening of a Pine bud, giving sketches.

9. Explain why one can tell how much a Pine branch has grown each year.

10. How can you tell the nature of the bud-scales in different trees? Give examples.

11. How can you *hasten* the opening of buds? Which buds have you succeeded in getting to open before they would have opened out of doors, and how long before in each case?

12. Describe, with sketches, the external appearance of a branch of Sycamore or Horse Chestnut, explaining all the features shown.

13. Explain how one can tell how much a Sycamore or Horse Chestnut branch has grown each year.

14. Describe a branch of Oak as seen in winter. Why do the buds tend to be crowded at the tip of the branch?

15. Describe various ways in which the young leaves are protected in the bud. Why are they usually folded up? Give examples and sketches.

16. What kind of plant produces Brussels Sprouts? What *are* the sprouts, and in what position do they stand on the parent plant?

17. Describe the buds of Larch, and the way in which they unfold.

18. Why are Willows and Poplars "polled" or "pollarded"? What is the effect of this operation on the growth of the tree?

19. Why do not *all* the buds on a tree branch open in spring? Why do some buds produce long shoots and others very short ones? How could you make a short shoot (dwarf shoot) of, say, Beech grow into a long shoot?

20. Describe the structure of the winter-bud of one of our trees, and explain what happens in the spring when it expands into a leafy shoot.

21. Make outline drawings of the leaves and describe the appearance of the bark of any five British trees. Mention the time of flowering in each case.

22. Sketch, and shortly describe, the leaves of the Oak and Sycamore. How can these two very different shapes of leaves be accounted for?

23. What is a stipule? Describe the stipules of any four British plants, and explain their use in each case.

CHAPTER VII.

THE GROWTH OF ROOTS AND STEMS.

181. As we have seen, the green leaf makes organic food from the raw materials which it takes from the air and from the soil. It also serves as the chief means by which the air within the plant communicates with the atmosphere, and by which the gaseous exchanges concerned in respiration and transpiration are carried on. These functions are also carried on by the other green parts of plants, *e.g.* by young stems, both in herbaceous and woody plants, since the rind (cortex) contains chloroplasts, and the stomates (on herbaceous stems and the youngest parts of woody stems) or lenticels (in older parts of woody stems) communicate between the air-spaces in the plant and the atmosphere outside.

We have already learned something about the growth of roots and shoots from our work on seedlings and on the nutrition of the green plant. We may now take up the questions on the growth of root and shoot raised in Art. 104. It is absolutely necessary to grasp thoroughly the main facts in the nutrition of plants—above all, the **work of the green leaf,** which is the great fundamental process and which may be said to form the key to the right understanding of the structure and development of root and shoot and all the varied forms and adaptations of the vegetative organs.

*** 182. How to measure the Growth in Length of Root and Stem.**—Seedlings of Broad Bean, Garden Pea, and Scarlet Runner are suitable for experiments on the growth in length of root and stem. Place the seeds in damp sawdust with the scar downwards. Runner Beans are especially useful for measurements of the growth of the stem.

When the root has grown about 2 inches long, dry its surface carefully, stroking it with torn bits of blotting-paper, and with a fine brush mark it at intervals of $\frac{1}{8}$ inch, starting at the tip, with dots or transverse lines of Indian ink.

The stem of a French or Runner Bean seedling should be marked in the same way, starting at the point where the first pair of foliage-leaves stand on the stem and working downwards; seedlings of Sunflower or Mustard may be used, the hypocotyl being marked starting from the cotyledons.

* **183. Where does Growth in Length occur?**—Pin a seedling with marked root to the cork of a glass jar, exactly as in Fig. 15. Examine from time to time and note the positions of the marks; after a few days, the marks just behind the tip of the root will be widely separated, while those farther back have changed little, or not at all, in position. What conclusion can you draw from the results of experiments like this? To what region of the root is growth in length almost entirely restricted?

A neat method of arranging this experiment is to put the seedling into a thistle-funnel and let the root grow down the tube; the latter is set in a jar of water, while the seed is covered with some wet blotting-paper or cotton-wool. This plan, allowing the roots to grow very long, gives striking proof of the fact that growth in length chiefly occurs just behind the root-tip. An ordinary glass funnel may be used instead of a thistle-funnel.

Daily observations and measurements of the hypocotyl of a French Bean seedling, or the young shoot of a Runner seedling, will show that in the stem, as in the root, growth in length is much more vigorous just behind the tip than farther back.

184. How the Young Root enters the Soil.—You have seen that the root end of the axis is the first part of the young plant to emerge from the seed, and that on emerging it grows downwards, in whatever position the seed has been placed. Have you tried the effect of moving the seed at this stage, and then turning it over each time the root has curved so as to be directed downwards? Have you noticed how, if a seed is laid on firm soil, root-hairs grow out and fix the root to the soil, giving it a "purchase," so that it can push its tip down with greater force? Have you noticed how the lighter kinds of seeds are often raised up or turned over by the struggles of the root to bore into the soil? Can the downward pushing power of the root be *measured*, say in a Broad Bean seedling?

* (*a*) You have probably used mercury in various experiments, and know that it is a very heavy liquid ($13\frac{1}{2}$ times heavier than water). Fix a seedling (Bean, Pea, etc., should be tried) to the side of a small dish containing mercury with a layer of water above it, and see whether the root will grow down into the mercury. The seeds may be pinned to a cork which is securely fixed to the rim of the dish (*e.g.* a saucer) by making a slit in it and jamming it tightly on the rim; each seed should of course be fixed by *two* pins.

(*b*) One method of roughly measuring the pushing power of the root is to make it press a cork, or a chain of corks, downwards into water. Cut a slit in a cork so that it can be firmly fixed to the rim of a tall, narrow jar or a large test-tube, and to this cork pin a Bean seedling (with a root about 2 ins. long) so that its root projects into the mouth of the tube. Then place in the tube a number of corks, one above another, of such size that they can move freely inside the tube; the row of corks should be about half as long as the tube. In the uppermost cork make a cavity for the root to press downwards against, and pour some water into the tube so that the root fits into this cavity. Place a vertical strip of paper on the tube, on which to mark the position of the lowest cork from day to day, and put some wet cotton-wool or blotting-paper over the seedling to keep it moist.

Each day pour a little more water into the tube (which should be fixed in the vertical position), and thus increase the resistance against which the root has to push downwards. When the root seems unable to push the chain of corks any farther down, mark the position of the bottom of the lowest cork, then take the seedling out and find what weight (*e.g.* of shot in a test-tube) is required to depress the corks to the mark. By finding the diameter, and from this the area, of the root just above the tip, you can calculate the pressure of the down-growing root in grammes or ounces per square centimetre or square inch.

(*c*) Fix a young Bean-seedling so that its root grows in a small tube filled with moist soil or sawdust, and place this tube within a larger one containing a spring. The root grows downwards with a force equal to over 300 grammes (about 11 oz.); measure the diameter of the root and calculate the force it exerts per square centimetre or square inch.

185. What makes the Main Root grow downwards and the Main Stem upwards?—Most likely this question would not have occurred to you at all, or if it had you would probably have thought of anything but the right answer or the right way to test the matter. It is clear that the root *does not simply bend down by its own weight*, like a rod of plastic material, for it exerts great force in its downward growth. Besides, this "explanation" would not apply to the shoot, nor even to the side-roots; the former grows upwards, the latter grow away from the parent-root.

If the young root is placed horizontally, it soon begins to bend downwards, the curvature taking place just behind the growing apex. This curvature is soon rendered permanent by the growth and hardening of the tissues affected, but a new terminal straight portion of the root is soon formed as growth continues, and if this be again laid horizontally a downward curvature is produced as before. This curvature is due to the fact that **gravity**, the attractive force which the earth exerts on all bodies, acts as a stimulus upon the protoplasm at the apex of the root, and causes the growing region to bend towards the centre of the earth.

The growth-curvatures by which root and shoot respond to the stimuli of gravity, light, moisture, etc., are called **tropic** movements (Greek *tropos*, direction). In most plants, the root is positively geotropic, negatively heliotropic, and positively hydrotropic, while the shoot is negatively geotropic (response to gravity), positively heliotropic (response to light), and negatively hydrotropic (response to moisture).

* (*a*) That it is not the action of the *soil* which causes the root to grow downwards is readily shown, *e.g.* by growing seedlings in moist air. Choose a few Bean seedlings with straight roots about $1\frac{1}{2}$ ins. long. Dry the roots gently by stroking with pieces of blotting-paper, and mark each radicle at intervals of $\frac{1}{8}$ in. by making transverse lines with Indian ink, beginning at the tip. Pin the seedlings to a piece of wood or a cork, and invert it over a wide-mouthed jar containing a little water. Fix different seedlings with the radicle pointing upwards, downwards, and horizontally. From day to day observe and sketch the appearance of the seedlings, noting the direction of growth of the shoot and the root.

(*b*) Grow Bean or Pea seedlings in your box with a sloping glass front. When the side-roots have grown out, mark on the glass the positions of a few of these, also of the main root; note especially the position of the *tip* of each root. Then tilt the box up at an angle of about 45°, and notice how (1) the main root and (2) the side roots change their direction of growth: how does the *shoot* behave?

(*c*) What happens if a shoot, laid horizontally, is fixed so that it cannot curve upwards? Lay a few Bean-seedlings on moist sawdust and keep the shoots down with a piece of thick glass, or fix them to a sheet of cork by means of crossed pins, and set them in moist air for about six hours. Then remove the glass or the pins: the shoot will quickly bend upwards. How can you explain this result?

(*d*) Fit a Bean-shoot into a bottle or tube of water, using a bored or split cork and sealing with plasticine, and let the shoot project horizontally. Stick a pin or needle into the free end of the shoot and set up beside it a foot-rule; note the position of the index-pin on the scale. After half an hour (the shoot will have made little or no upward movement in that time), turn the bottle round through 180°, taking care to keep the free end at the same point on the scale. The shoot soon begins to curve *downwards*, then it comes to rest, and finally it curves *upwards*. Now try to account for these results. Remember that there is an interval between (1) the *perception* of the stimulus and (2) the visible *response* made by the root.

186. How does Moisture affect the Direction of Growth?—Is the main root bound to grow vertically downwards in *all* circumstances, or could it be induced to change its course by some other stimulus? We know that roots require moisture. Would the main root leave its vertically downward course in order to grow towards a moister part of the soil? Would this be a useful thing for the root?

* (*a*) Lay a glass jar on its side (a jar with flat sides is best) and put a sponge, soaked with water, in the closed end. Fit the jar with a cork (bored with a hole for ventilation), and to the inner side of the cork fix a Pea or Bean seedling by putting two pins through the cotyledons. Fix the cork so that the root lies horizontally. Does the root bend and grow towards the wet sponge, the shoot towards the mouth of the jar?

(*b*) Grow seeds in a box with a bottom of wire gauze, and hang the box up or tilt it by putting a wood block under one end. The roots grow down through the gauze into the dry air, but they soon curve and grow upwards again. Why?

(*c*) Take a tumbler or jar about a quarter filled with water, tie over it some muslin, and on it place some damp sawdust with several soaked seeds, then invert a larger tumbler over the whole. The roots on emerging from the sawdust do not turn back, but grow down in the damp air. Compare with (*b*).

(*d*) In the middle of a box of dry soil or sawdust place a flower-pot, first plugging the hole in it by a cork. Place some soaked seeds in the sawdust around the flower-pot, but do not water except by pouring water into the flower-pot, and filling the latter up as the water evaporates. After a few days, gently pull up a seedling and see whether its root has curved towards the pot.

187. How does Light affect the Direction of Growth?—Have you noticed the appearance of plants growing near a window? The shoot grows towards the light, the stem placing its axis parallel with the direction of the light, while the leaves place their surfaces at right angles to it.

* (*a*) Set some seedlings in such a position that the light falls on them mainly from one side, and notice the effect this has on their shoots. After marked bending has been observed, turn the seedlings round and see whether the shoots again respond to the "attraction" of light.

(*b*) Take the wide-mouthed glass jar and cover it outside with black paper or cloth, leaving a narrow vertical chink on one side. Fix a Bean seedling horizontally inside the jar, at right angles with the chink. Does the root bend, and does it bend towards or away from the light? In what direction does the shoot bend?

(*c*) Pass the roots of germinated Cress, Radish, or Linseed through holes in muslin tied over a tumbler filled with water. Set the tumbler close to a window, or in a box with a vertical slit in the side turned to the light, or use a black sheet, as in the preceding experiment. Observe the opposite directions in which root and shoot grow.

188. How does Contact affect the Direction of Growth?—As we shall see later, some parts of plants are very sensitive to contact, *e.g.* tendrils. Has the root this kind of sensitiveness? How does the growing young root behave when it comes against an obstacle which it cannot push out of its way? The root can force itself through loose soil when young and soft, and when it grows old and hard, becoming thicker year by year, it can exert enormous pressure against anything around it.

* (*a*) To the inner side of the glass in your box with glass front fix with sealing-wax small pieces of wood, and plant seeds a little above these obstacles. Notice that the roots diverge from their course only so much as is absolutely necessary to avoid the obstacles, and resume their original course as soon as they have passed one.

(*b*) Another method is to use a glass funnel filled with moist soil or sawdust; plant the seeds close to the glass near the top of the funnel, and fix the obstacles an inch or more below them.

189. Test-Tube Experiments.—For demonstration to a class, some of the foregoing experiments may be duplicated by arranging them on a small scale in test-tubes, which are handed round the class. The following will serve as examples:—

(*a*) Get a test-tube with a cork to fit, pin to the cork a Pea-seedling with a straight root 2 ins. long, put a strip of blotting-paper in the tube, and run in water to soak it. Fix the seedling in the tube with its root pointing to the closed end, and keep the tube in a vertical position, with the corked end uppermost.

(*b*) Fix a similar seedling in a tube, but keep the tube inverted, so that the root points vertically upwards.

(*c*) Get a similar seedling and tube, but with a razor or sharp knife cut off the extreme tip of the root, and keep the tube in the same position as in (*b*).

190. The Root-Tip a Sensitive Organ.—From the foregoing experiments it is clear that the root responds, by changing its direction of growth, to the influences or stimuli of moisture, light, and contact. We have also seen that the main roots always grow vertically downwards, towards the centre of the earth, except when deflected from this direction by one of the stimuli just mentioned. It will be noticed that the shoot of a seedling grows towards light and away from moisture, its responses to these stimuli being the opposite of those made by the main root. The force of gravity also has a stimulating effect on the growth of root and shoot; the root responds by growing down in the direction of the force, the stem by growing up in the opposite direction.

That these opposite tendencies of root and stem are to be ascribed to gravity has been determined by experiment. There is a machine called the **clinostat**, consisting essentially of a plate mounted on a horizontal axis, and therefore rotating vertically. A plant is attached *horizontally* to the plate, and the axis is rotated *slowly*—a revolution in from 15 to 30 minutes. A little reflection will show that the influence of gravity is eliminated. Stem and root simply continue to grow straight onwards in whatever direction they have been placed at the beginning of the experiment.

Another experiment is to attach a plant to the edge of a wheel which rotates *rapidly* and *vertically*. Here another force—centrifugal force—comes into play. If the opposite tendencies of root and stem are to be ascribed to gravity, we should expect similar tendencies to be exhibited under the action of centrifugal force. This is the case; in seedlings fixed to the vertically revolving wheel, the roots bend away from the centre of the wheel and grow straight out in the direction of the radius, while the stems grow straight in towards the centre of the wheel.

What will happen if the wheel revolves *horizontally*? *Two* forces now act on the plant, the centrifugal force and that of gravity, and the root bends obliquely outwards, the stem obliquely inwards.

Side-roots are but little sensitive to gravity; they grow out from the parent root, each growing in a definite direction. If the growth of a side-root is towards, say, the east, and it is interrupted by a stone, as soon as the root has reached the edge of the stone it will resume its eastward direction of growth. The branches of the side-roots, again, grow away from these, and may therefore grow in a downward, or horizontal, or even upward direction.

We have also found by experiments that the attraction-stimulus of gravity may, even in the case of a main root, be overcome by the "attraction"-stimulus of moisture or by the "repulsion"-stimulus of light, while contact with an obstacle like a stone causes the root to change its direction of growth for a time, though it resumes this direction as soon as it reaches the edge of the obstacle. It is clear, therefore, that the root is a sensitive organ, its sensitiveness or "irritability" being much the same as that of an animal.

It is very important to understand that geotropism and other forms of irritability in plants answer to the various kinds of sensation in animals, and also to try to see the *reason* for each response made by each part of a plant to each kind of stimulus from outside it. If you have carried out the preceding experiments, stop here and think out for yourself *why*—*i.e.* to what advantage—the main root of a bean or pea (or other plant you have worked with) grows downwards, *why* it grows towards moisture, *why* it grows away from light, *why* a root turns off on meeting an obstacle and goes on its former course after getting to the obstacle's edge, *why* a branch-root grows away from its parent-root. In each case remember the two great functions of the root (what are these?) and the need for the root-system to explore the soil thoroughly and to come into contact with as much soil as possible, in order to do its work efficiently.

The fact that the removal of the root-tip destroys the power of the root to respond to the stimuli of gravity, etc., goes far to prove that this is the sensitive region of the root, but such experiments are not conclusive, because curvatures due to the injury usually take place; the root sometimes forms a new tip, and then responds as before.

The fact that the root-tip alone is sensitive to the stimulus of gravity has been shown by the following method:—Seedlings of Broad Bean are rotated on a clinostat and their roots caused to grow into small L-shaped glass tubes, open at one end, so that the root is sharply bent at about $\frac{1}{16}$ in. from its tip. They are then placed in various positions, each having this small glass boot on its root. If the tip is vertical and the basal part of the root horizontal (┌), *no curvature takes place*—the radicle grows in the horizontal direction. If the tip is horizontal (L), the vertical part of the root outside of the tube bends until the tip of the root is brought into the vertical position.

191. Regions of the Root.—From your observations on the growth of roots, it will be evident that the increase in length of a root is almost entirely due to the elongation of the region lying a short distance behind the root-tip, also that root-hairs only arise where the root has ceased to lengthen, and that branches only arise still farther back (*why* do not root-hairs and branches arise where the root is still growing in length?). The following regions may be distinguished in a root:—(1) growing-point, covered by root-cap; (2) elongating region; (3) region bearing root-hairs; (4) thickening region, which may bear branches (rootlets).

192. How is the Root-Tip protected against injury as the root pushes its way into the soil?

A little behind the actual tip of the root lies the growing-point, which is covered and protected by the root-cap. The growing-point consists of cells which are constantly dividing, growing after each division, then dividing again, so as to produce new cells. Most of these cells go to form the main mass of the root, but those formed towards the tip of the root add to the root-cap. The root-cap is, therefore, continually renewed from within as it wears away outside; compare with this the way in which one's skin is renewed. The onward growth of the root is due to the formation of new cells at the growing-point and to their elongation (and further division) behind the growing-point. The growing-point is not only the factory where new cells are made; it is also the sensitive part of the root, which alone can perceive the stimuli of gravitation, etc., and by sending them on to the region behind cause the bending movements.

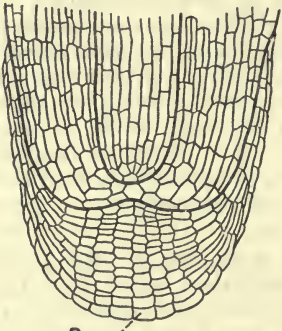


Fig. 53.—The Root-Tip, in Section, magnified.

Examine with the microscope the roots of any small seedlings (Cress, Mustard, Wheat) mounted in water on a slide. Focus on the upper surface, and notice the outer layer of cells (skin-layer or epidermis) immediately behind the extreme tip. Sketch part of this, then focus deeper so as to get an "optical section" of the growing-point, and try to make out the tissues as shown in Fig. 53, the root-cap covering the denser layers of cells which form the growing-point, and which gradually pass backwards into the central cylinder, the rind (cortex), and the epidermis.

Trace the origin of root-hairs, each of which is a long slender tube, closed at the free end; each hair arises as an out-growth from a single cell of the skin-layer. Farther behind the root-tip the root-hairs are longer, but they are absent from the oldest parts of the root—*i.e.* those nearest the stem. Crush a root by pressing it under the cover-glass, and observe the vessels in the central cylinder; some vessels have a spiral fibre coiled inside them, others show small spots (pits), which are thin places in the wall. Notice also the large cells of the rind (cortex). Try to find the beginnings of side-roots and different stages in their growth.

193. The Conducting Channels of the Stem.—From your study of the functions of the leaf you should be able to draw some conclusions regarding those of the stem. Some further experiments will give additional information about the part played by the stem in the process of transpiration.

* (*a*) Place whole plants, or seedlings, or cut twigs, into water coloured with red ink, set them where the conditions are favourable for transpiration, and after an hour or so cut across the root and stem at various points. If the coloured water has risen in the stem, trace it upwards by means of successive cuts, then replace the plant in the liquid, and after a time notice its appearance in the leaves, as shown by the colouring of the veins. Note that in the root the stained veins are at the centre.

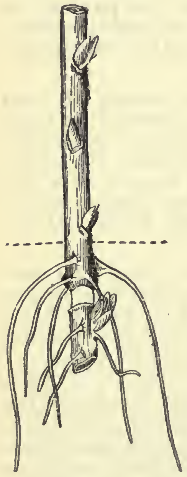
(*b*) Make thin cross-sections and longitudinal sections of these plants. In most cases notice that the bundles are arranged in a single ring; this arrangement is found in most Dicotyledons. In Grasses, Lilies, and other Monocotyledons the red-stained bundles will be seen to be scattered through the stem. Notice that in most cases only the inner part of each bundle is stained. In Vegetable Marrow or Cucumber the bundles are in a double ring, and here the central part of each bundle is stained.

(*c*) Place a twig of a tree—*e.g.* Oak, Beech, Elm, or any other hard woody plant—in the coloured water, and when the leaf-veins become coloured cut across the stem, starting in this case at the top where the stem is soft and green. At the top notice that the bundles are separate; but as we pass downwards, making successive cuts, the bundles appear to fuse and form a continuous ring.

(*d*) Cut two twigs of a woody plant—*e.g.* Willow—about equal as regards length and the number of leaves. Cut round one of the twigs, a few inches from the lower end, as far in as the hard woody part, and remove from the lower part of the stem the whole of the soft outer tissue. Leave the other twig uninjured, and set both twigs into red ink. Notice that the removal of the outer tissue makes little or no difference as regards the rise of the red ink in the stem and its appearance in the veins of the leaves.

The foregoing experiments show (1) that one function of the stem is to carry water from the roots to the upper parts of the plant, and (2) that the water travels through the inner portion of each bundle when the bundles are separate and through the hard woody part of a stem when the bundles are joined to form a continuous cylinder.

Since only the green parts of a plant (in most cases, the foliage-leaves) can manufacture organic food for themselves, they must supply with some of this food all the other parts, which cannot carry on photosynthesis. Hence there must be some channels for conveying the leaf-made food to the roots, buds, and other parts which are either growing or storing up food as a reserve for future growth. Through what channels do the organic substances produced in the leaves travel to other parts of the plant? If these also travel along the bundles, they must pass through the soft outer tissue in the case of a woody stem; and in that of a stem, with separate bundles, these substances must pass either through the part of each bundle which was not stained by the red ink or else through the other tissue of the stem, or by both routes.



54. — A Ringed Branch of a Willow sprouting in Water.

Before considering this question, we must know more about the structure of the stem; but the following experiments will give a clue as to the paths by which the leaf-manufactured food travels.

(*f*) Place a Bean seedling or a Garden Nasturtium (try various other plants) in darkness for a few days, then remove some leaves and test them for sugar by boiling them in Fehling's solution. There will be little or no red coloration, showing that sugar is absent, or nearly so.

Expose the plant to sunlight for several hours, then place it in darkness (after having tested some leaves, or parts of leaves, for starch), and after a time test some leaves for sugar, which will be indicated by the red colour produced around the veins. If the presence of sugar is detected in this way in the leaf-blade, test sections of the leaf-stalk at different levels, to find out by what paths the sugar travels towards the stem. Also test sections of the stem itself. By using Fehling's test, we find that the sugar travels in the leaf itself along the tissue surrounding the veins (bundles), and in the stem it is to be found in the ground tissue in which the bundles are embedded.

(*g*) Make two cuts round the lower part of a Willow twig, about an inch apart, and remove the soft outer tissue of the stem between these cuts, so as to leave only the hard woody portion of the stem for this distance. Then set the twig in water (which should be changed every day) or in culture-solution, and notice that it begins to sprout after a few days (Fig. 54). Below the injury the development of buds and new roots takes place but slowly, whereas above it new roots are rapidly formed and nourished by food conveyed from the upper parts of the branch by the tissue lying on the outer side of the wood. This experiment usually succeeds best in spring or early summer. Later in the year it is advisable to remove the leaves in order to diminish the loss of water, since there are no roots on the cutting to keep up the supply of water. The rapid development of buds and the formation of roots above the ringed part show that food passes down chiefly through the soft outer region of the stem.

194. Chief Functions of the Stem.—The leaves must be exposed to air and light in order to carry on their work of food-making, and in this work they require supplies of water containing dissolved salts. The food made by the leaves has to be carried to other parts of the plant which are living and growing or acting as storage-organs. The roots, having no chlorophyll and not being exposed to light, cannot, of course, carry on photosynthesis, and must therefore be supplied with organic food made in the leaves.

From these considerations, and from the results of our simple experiments, it is clear that the ordinary functions of a stem are (1) to bear the leaves and help in spreading them out to light and air; (2) to convey water with dissolved salts from the roots to leaves and other parts of the shoot; (3) to carry organic food from the leaves to other parts. These are the primary functions of the ordinary stem, but in addition to this stems often have to take on special functions. Thus they may serve as organs of vegetative propagation, as store-places of nourishment, etc.

195. Structure of the Stem.—In Dicotyledons, both in herbaceous stems and in woody stems when young, isolated bundles run through the stem, forming a hollow cylinder (a ring, as seen in cross section). In Monocotyledons the bundles are scattered through the ground-tissue of the stem. This is because in the former case the bundles (veins) which run into the stem from the leaves remain near the surface, ultimately joining bundles from other leaves and increasing in size, whereas in Monocotyledons the bundles from each leaf run deep into the stem and curve outwards lower down, tapering away as they do so. Hence the bundles on the outside of a transverse section are in this case smaller than the central ones, whereas in the Dicotyledon the smaller bundles alternate with the larger ones (Figs. 55, 56).

Fig. 55. — Longitudinal Course of the Bundles in a Monocotyledonous Stem.

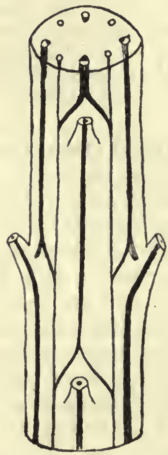


Fig. 56.—Course of the Bundles in Stem of a Dicotyledon.

It is important to realise that the bundles in the stem are continuous with the veins of the leaves on one hand and with the veins in the vascular cylinder of the root on the other.

(*a*) Soak the stem of a Broad Bean or Dead Nettle (try other herbaceous Dicotyledons) for two days in dilute potash, and then for two days in dilute nitric acid. Brush and scrape away the softer parts, leaving a skeleton of the vascular tissue. Note the way in which the bundles from the upper leaves join on to those of the lower leaves.

(*b*) Another method of showing that the vascular bundles (veins) of the leaf are continuous with those in the stem is to cut thick longitudinal slices through the stem and the bases of the leaves, and place the slices in caustic potash.

(*c*) To observe the continuity between the bundles of the stem and those of the root, split a Bean seedling longitudinally in the part where stem and root meet, and treat with caustic potash or aniline chloride solution[1]; the former makes the soft tissue transparent, the latter stains the hard woody tissue yellow.

196. The Vegetable Marrow (or the Cucumber) is a suitable plant in which to study the tissues of the stem.

* (*a*) Cut across the middle of several "internodes" in the older parts of the shoot, and in each piece thus obtained notice that (1) the "node" gives off a leaf, a special climbing organ (tendril), and usually either a leafy branch or a flowering branch, or both; (2) the internode is hollow, so that the stem forms a tube, with (usually) five ridges, and furrows alternating with these; (3) the bundles (usually ten) are arranged in two rings (a small outer bundle to each ridge, a larger inner one to each furrow).

(*b*) Scrape gently the outer surface of the stem, and remove part of the epidermis or skin, which is thin and colourless and bears hairs, some of them large and prickly. Notice the soft tissue which lies between the bundles; this is the ground tissue (*parenchyma*), and its cells can easily be seen with a lens. After removing the epidermis, scrape away the soft tissue which lies below it, and notice the hard tissue, which forms a wavy tube around the stem, outside of the bundles. Slit a piece of stem by two longitudinal cuts, and by scraping isolate a strip of this hard tissue (*sclerenchyma*). Bend it, pull it by the two ends, and try to split it; notice that it is easily split longitudinally, but is difficult to break by pulling at the ends. This hard tissue, then, is fibrous, very strong, and it gives mechanical support to the stem; it is really a part of the ground-tissue, which has become fibrous and hard.

(*c*) Now examine the bundles which are embedded in the soft ground-tissue within the sheath or tube of hard tissue. Notice in each bundle (1) a whitish hard portion, consisting chiefly of tubes of various sizes, and occupying the centre of the bundle; (2) two greenish soft portions on the inner and outer sides of the hard portion. Place a piece of the living shoot with its cut end dipping into red ink, and notice that the ink rises in the middle portion of each bundle. This portion is the *wood*, and the tubes it contains are the *vessels*, which carry water upwards from the root. Split a long piece of stem so as to get a strip containing a single bundle; put one end into a glass of water and blow through the other, noting the air which escapes in bubbles after passing through the vessels. This shows that the vessels are long, open tubes.

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[1] Dissolve some aniline chloride (about 1½d. per ounce) in a little alcohol, add water to make a 10% solution, then a little hydrochloric acid. A wooden match, or a splinter of wood, turns bright yellow after being dipped into the solution, which gives a ready test for woody substance (*lignin*).

(*d*) Next cut across a piece of fresh stem with a dry knife or razor, and notice the juice which oozes out of the soft greenish outer and inner portions of each bundle. These portions are the *bast*,[1] and they also consist chiefly of tubes; but the bast-tubes, instead of carrying water up the stem as the wood-tubes (vessels) do, carry organic food-substances from the leaves to other parts of the plant. Notice that the juice which oozes out of the bast-tubes is thicker than water; collect some of it, place it on a glass slide, and test it (1) for starch, (2) for proteids, (3) for sugar. To test for (1) and (2) add a drop of iodine solution; for (3) place some Fehling's solution on the slide with the juice and warm it, or collect enough juice to place in a test-tube and heat with some Fehling's solution.

(*e*) In sections through the youngest parts of the Marrow stem, notice that the ground-tissue is complete right across the stem; the cavity found in the older parts is formed by the central region of ground-tissue (pith) becoming torn as the stem grows thicker. Also notice that the wood contains only the narrow spiral and ringed vessels, and that the collenchyma and sclerenchyma are not yet distinguished sharply from the ordinary ground-tissue.

197. Sunflower Stem.—Cut transverse and longitudinal sections of stem of Sunflower, and compare its structure with that of the Marrow stem (see Fig. 57). In the Sunflower the stem is cylindrical, not furrowed; the central ground-tissue does not become torn to form a cavity; the hard tissue (sclerenchyma) is in separate strands, one immediately outside the bast of each of the larger bundles. In an old stem, notice that there is a continuous layer of wood, with a complete layer of growing tissue (cambium) on its outer side.

198. Maize Stem.—(*a*) Cut transverse sections of stem of Maize. Notice that the bundles, although "scattered" through the ground-tissue, are most crowded towards the outside, and that in each bundle the bast side points towards the epidermis and the wood side towards the centre of the stem. In thin sections stained with aniline chloride, notice (1) the epidermis of small thick-walled cells; (2) the narow band of sclerenchyma below the epidermis; (3) the ordinary ground-tissue (parenchyma) of large thin-walled cells, separated by air-spaces at the corners; (4) the vascular bundles, each with a sheath of sclerenchyma.

In a single bundle, notice the four conspicuous vessels arranged like a V, thus:

with narrower vessels lying between; the patch of clear-looking tissue

[1] The Marrow, Cucumber, and some other plants are exceptional in having bast on the inner side of the wood as well as on the outer side. In most stems the bast occurs only on the outer side of the wood. The bast-tubes are called *sieve-tubes*, because they are interrupted by cross-walls which are perforated like a sieve (*sieve-plates*).

(bast) lying partly between the two larger vessels ; and the more or less complete sheath of fibres around the bundle. The larger wood-vessels are pitted ; the smaller ones have rings or spiral thickenings. The bast, which stands out distinctly in sections treated with aniline chloride (its walls being of cellulose and therefore not stained),

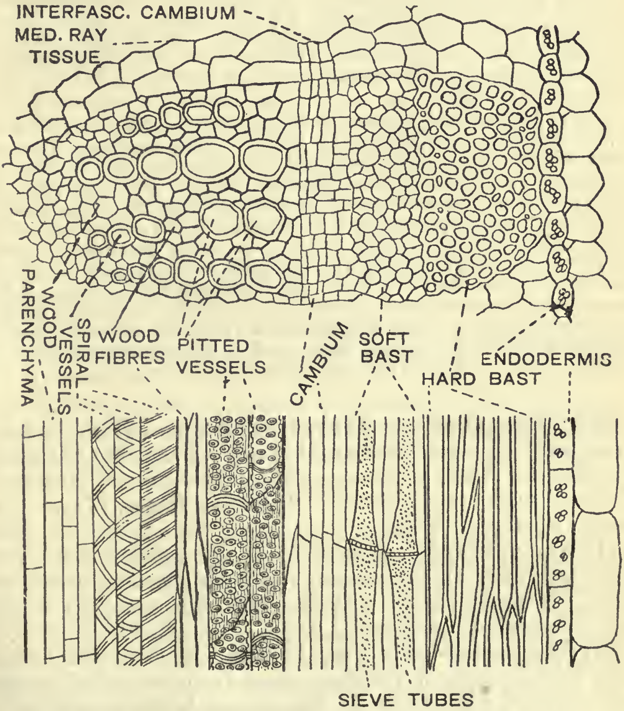

Fig. 57.—Transverse (upper) Longitudinal (lower) Sections of Part of a Sunflower Stem.

consists of sieve-tubes alternating regularly with narrow cells (companion-cells), but the tubes are narrow and rather difficult to make out clearly. Compare the relative amounts of sclerenchyma and of vascular tissue (wood and bast) in bundles in different parts of the section. It is easy to see that the hard tissue (stained yellow with aniline chloride) is more strongly developed towards the outside of the stem.

In many Monocotyledon stems the outer bundles are embedded in a layer of hard tissue which forms a complete tube; this is well shown in shrubby plants like Butcher's Broom and Asparagus. Cut sections of the stems of these and of other Monocotyledons, also of the flowering stems of Lily, Hyacinth, etc. In all cases the bundles are more crowded towards the outside, and the hard tissue is developed as a layer in the outer part of the ground-tissue. In the erect stems of Monocotyledons, therefore, the "skeleton" or supporting tissue is disposed in the form of a tube, in spite of the "scattered" arrangements of the bundles.

(*b*) Cut longitudinal sections of the Maize stem (or those of other Monocotyledons), and notice the course of the bundles. This can easily be done by cutting thick sections passing through the bases of several leaves and placing them in caustic potash for some time. In these plants, and in most other Monocotyledons, the leaves have a broad insertion, and from them a number of bundles can be traced into them. Their downward course in the stem is not parallel to the surface, but curved. They first run obliquely downwards towards the centre, and then bend outwards again towards the surface. After running through one or two internodes, they join on to bundles passing in from other leaves. Hence at all levels we have bundles situated at varying depths in the ground-tissue, and so the transverse section of the stem shows a "scattered" arrangement of the bundles.

199. Tissues of the Herbaceous Stem.—From the foregoing work on stem-structure it is evident that the tissues of a herbaceous stem (and the young parts of a woody stem) are of three kinds: (1) epidermis, (2) ground-tissue, (3) vascular tissue (wood and bast).

(1) The epidermis consists of a single layer of cells, with thickened outer walls (cuticle), and bears stomates and often hairs. It agrees closely with the epidermis covering the leaf, and is continuous with it.

(2) The ground-tissue consists mainly of thin-walled cells, those in the centre of the stem often becoming dried up and torn asunder, while those in the regions between and on the outer side of the bundles have various important functions. The cells in the outer region (cortex) usually contain chloroplasts, and are supplied with air which enters by the stomates and traverses the spaces between the cortex-cells; these cells are therefore, like the cells of the ground-tissue (mesophyll) of the leaf, able to make organic substance by photosynthesis. The outermost cortical cells often become thick-walled, and

form supporting tissue (collenchyma) which differs from ordinary hard tissue in consisting of living cells.

The ground-tissue is also modified in places to form sclerenchyma, consisting of thick-walled woody fibres, which contain no living substance but only water, and which, therefore, serve a purely mechanical function. The sclerenchyma is found outside of the bundles, either forming (1) a complete tube around the whole stem, or (2) a strand on the outer side of each vascular bundle, or (3) a sheath around each bundle (what plants afford examples of these three arrangements?). The sclerenchyma of the stem is continued into the leaf, where it usually forms a supporting band below each chief vein or above it or in both positions. The ground-tissue also serves for the conduction of sugar from the leaf, and for the storage of starch. In Dicotyledons the new strips of cambium, which are required to form a complete ring of growing tissue around the stem, are formed in the regions of ground-tissue (rays) which lie between the vascular bundles.

(3) The most important structures in the wood and the bast are the wood-vessels and the sieve-tubes; the former serve to carry water upwards from the roots, the latter to carry organic substance, especially proteids, to the growing parts of shoot and root. The wood serves also as mechanical (supporting) tissue; it usually contains fibres and ordinary cells (parenchyma) in addition to vessels.

200. Structure of the Root.—The root, like the stem, contains vascular bundles, but the wood-bundles are separate from the bast-bundles and lie on alternate radii, whereas in the stem the wood and bast are joined to form each bundle. The vascular cylinder of the root contains from two to about eight bundles of wood and an equal number of bast-bundles in Dicotyledons, while in Monocotyledons the number of bundles is generally much larger.

* (*a*) Place the root of a Bean or Pea seedling (try others as well) in some water on a slide, and scrape off the soft outer tissue (epidermis and cortex), first on one side and then on the opposite side. Wash off the scrapings (using your wash-bottle), place on the scraped root some aniline chloride solution, add a drop of glycerine (which makes tissues more transparent), put on a cover-glass, and examine. Notice the yellow-stained wood-vessels, and the long cells associated with them; sketch what you see.

* (*b*) Cut transverse sections of a Bean root at different levels, starting a little behind the root-tip; it is easier to do this if the root is held between two grooved pieces of elder-pith or of carrot. Keep your razor wetted with 50 per cent. spirit, cut thin sections, stain some with aniline chloride, others with iodine solution.

Notice the tissues shown in Fig. 58, the skin-layer, many of whose cells grow out to form root-hairs; the rind (cortex) consisting of cells

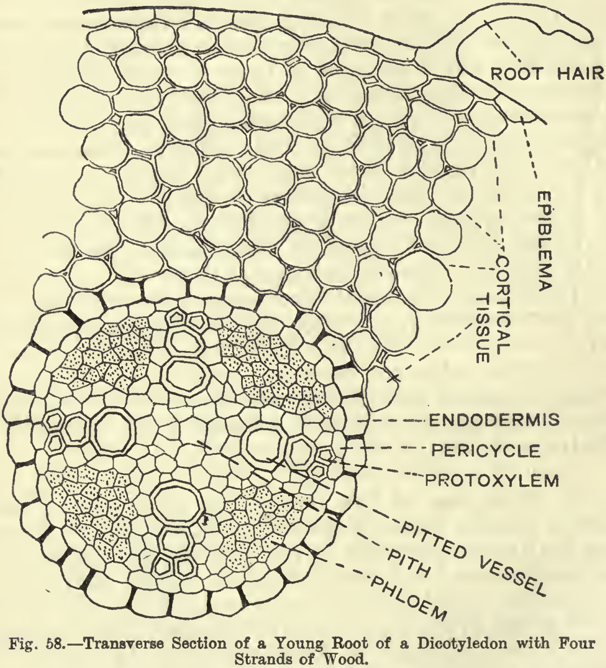

Fig. 58.—Transverse Section of a Young Root of a Dicotyledon with Four Strands of Wood.

which are separated at the corners by air-spaces and often containing starch-grains; the central cylinder consisting chiefly of the wood-bundles (stained yellow with aniline chloride), the bast-bundles (*phloem*) alternating with these, the packing-tissue between the bundles, and the sheath surrounding the whole cylinder. The inner wood-vessels are pitted, the outer ones are spiral; the latter are narrow and are formed before the inner vessels, hence the term "protoxylem" is applied to these outermost and narrowest vessels. The bast-bundles consist chiefly of long tubes, called *sieve-tubes*, because at intervals each is crossed by a partition which is perforated like a sieve, so that the contents (which are proteid substances) can pass through the pores in the *sieve-plates* from one part of the tube to another. The *sheath* consists chiefly of two layers of cells (*endodermis* and *pericycle* in Fig. 58), but these two layers are not very sharply marked in the Bean root. The pericycle is a very important layer, because its cells remain capable of dividing and giving rise to new cells; from the pericycle arise (1) the *rootlets*, (2) part of the *new wood and bast* formed as the root grows older and thicker, (3) the *cork* which covers the surface in the older parts of the root.

(*c*) In roots of Cress, Mustard, etc., mounted whole and stained with aniline chloride or red ink, also in sections through roots of Bean or Pea, notice the formation of rootlets as small swellings (arising from the pericycle) opposite the wood-bundles; these swellings grow out, eating their way through cortex and skin-layer, and escape as small pegs which grow into rootlets. The rootlet is enabled to digest the tissues through which it bores its way, by the cells covering its tip producing ferments similar to those found in germinating seeds. Do you see why rootlets are arranged in a definite number of longitudinal rows?

(*d*) In older parts of the root of the Bean and other dicotyledons new tissues are formed, and the root grows thicker. This is because the cells of the sheath (pericycle) outside each wood-bundle, together with the cells of the central cylinder which lie inside each bast-bundle, divide actively and give rise to new bast and new wood.

Cut cross-sections of old parts of the main root of Bean, stain with aniline chloride, and notice the new wood and bast that have been formed; the original wood-bundles (primary wood) can still be seen in the centre of the root.

(*e*) In sections of the root of Maize or other monocotyledons notice the large number of wood and bast-bundles; no secondary thickening occurs in these roots.

201. Continuity of Tissues of Root, Stem, and Leaf. —It is very important to realise that the tissues (epidermis, ground-tissue, vascular tissue) of the root, stem, and leaves are continuous with each other.

The epidermis of the leaf and of young stems is a protective layer, preventing excessive transpiration for instance, and where necessary it bears a layer of cuticle or of waxy "bloom," or a covering of hairs, to help in this function; another important function is to allow of the passage of gases into and out of the plant, by means of the stomates. The epidermis of the younger parts of the root serves for absorption, and to increase the absorbing surface root-hairs are developed. In the older parts of the stem and root the epidermis may be replaced by cork, which serves chiefly for protection, but allows the passage of gases through the lenticels, which have the same function as stomates.

The ground-tissue, which is continuous throughout the plant, consists primarily of living thin-walled cells, separated by air-spaces which form a continuous system and allow gases to circulate through the plant. In the root the ground-tissue consists of colourless cells; its chief functions are to convey water from the root-hairs to the wood-vessels, to carry oxygen to the living and growing cells of the root, and to store up food. In the stem, the outer part of the ground-tissue consists of chlorophyll-containing cells which carry on photosynthesis, especially in plants whose leaves are very small or do not remain long on the plant—*e.g.* Horsetails, Gorse, Broom, Asparagus, Bilberry. Part of the ground-tissue of the stem is usually modified to form strengthening tissue (collenchyma, sclerenchyma).

The ground-tissue of the leaf is simply an extension of the green outer tissue of the stem, the cells having larger air-spaces between them, and being specially adapted to photosynthesis, while the epidermis contains more stomates.

The vascular tissue (wood and bast) is also continuous throughout the plant. In the root the wood and bast are in separate bundles, but in the transition region between root and stem the root-bundles change in position so that the wood and bast form double or "conjoint" bundles, the wood coming to occupy the inner side of each stem bundle, twisting round so that the first-formed vessels (spiral and ringed) are nearest the centre in the stem, instead of being external as in the root. The essential parts of the bundles (vessels and sieve tubes) run continuously from root to leaves, the stem-bundles bending outwards into each leaf so that the wood is on the upper side of each leaf-bundle (vein) and the bast on its lower side.

We have therefore three systems of conducting channels running through the plant: (1) the wood-vessels which carry water and dissolved salts; (2) the bast-tubes (sieve-tubes) which carry manufactured organic food, especially nitrogenous substances; (3) the air-passages between the cells of the ground-tissue, through which air circulates, the exchanges of gases between the atmosphere and the living plant-tissues taking place chiefly through the stomates (in leaves and herbaceous stems) and the lenticels (in woody stems).

202. The "Skeleton" of the Plant.—We might compare the hard parts of the stems, roots, and leaves of a plant with the skeleton of an animal, since these hard parts support the plant and help to keep it firm and strong.

Why are the hard tissues of the stem arranged in a hollow cylinder, or tube, like the pillars that support the galleries in buildings? Why are they packed together towards the centre in the case of the root, forming a tough central cord? Why are the chief bundles in the leaf-stalk arranged like the letter U in a cross-section? Why are the chief veins (bundles) of the leaflet arranged like a feather, and why do they project on the lower side of the leaflet? Why are the finer leaflet-veins arranged in a network?

Most of these questions can be answered by considering the results of simple experiments on the bending of a beam of wood (or other material) firmly fixed at one end and loaded at the other. The lowering of the loaded free end is (*a*) proportional to the load, (*b*) proportional to the *cube* of the length of the beam, (*c*) inversely proportional to the breadth of the beam, (*d*) inversely proportional to the *cube* of the depth of the beam.

From (*c*) and (*d*) we see at once why it is so much more advantageous to increase the depth than to increase the breadth of a beam. For when the beam is bending, the upper side lengthens and the lower side shortens, but the middle portion of the beam neither lengthens nor shortens. Exactly the same applies when the beam is set upright instead of horizontally, and force is applied to it from one side. Hence it is a good plan to put the hard material near the outside, and this is done in the **girder**, which is I-shaped in cross-section. If we want an upright *rod* to resist bending before winds coming from north, east, south, and west, we need two joined girders crossing at right angles. In such a structure the central part is clearly under little strain as compared with the outer parts, therefore it would be better to put all the material on the outside and make it into a tube (to resist the bending effects of winds coming from all directions).

Clearly, then, the strength of the upright structure (stem) is, *using the same amount of material*, very greatly increased if the hard material is placed *towards the outside, in the form of a tube*. If you think over these points in the "mechanics" of plants you will see how the plant successfully meets the mechanical needs of the various parts and at the same time the need for *economy* in the amount of material used to make the parts strong enough. The leaflets have to be supported and spread out to air and light; the stem has to carry the leaves and branches and has also to resist undue bending before the wind.

The root, on the other hand, being embedded in the soil has no weight to support, but it has to keep a firm hold of the soil (the root-hairs help greatly in this), and it must be able to resist pulling or tugging strains. Hence the best arrangement for the root is to have the hard tissue at the centre, forming a compact cord.

There is great diversity in the arrangement of the hard tissue (sclerenchyma), which is, next to the wood of the vascular bundles, the most important supporting tissue or "stereom" (hard-tissue) of the majority of erect herbaceous stems. Sclerenchyma-fibres, which occur among the vessels in the wood as well as in separate bands or strands outside of the bundles, are *dead* cells (like those which make up the wood-vessels); whereas *collenchyma*-cells are living, and can carry on assimilation, and are also capable of growth, the walls not being hard and woody, as in sclerenchyma. In some plants—*e.g.* Grasses, Sedges, Horse-tails—the epidermis contains flinty substance (silica) which helps in giving rigidity.

Cut cross-sections of various herbaceous stems, stain with aniline chloride, and examine with lens and microscope, giving special attention to the arrangement of the supporting tissue in the vascular bundles (wood), sclerenchyma, and collenchyma. Of special interest are ridged and winged stems (Gorse, Broom, Bilberry) and the stems of Grasses, Rushes, and Sedges.

203. Is the "Skeleton" alone able to keep the Young Shoot erect?—What happens if you pull up a whole seedling, *e.g.* Bean or Sunflower, or cut off the shoot, and let it lie on the table? Why does it turn limp? Weigh a shoot after cutting it off, then weigh it after it has been allowed to wilt: what has the shoot lost? How can you make the limp shoot become stiff again? Why is it useless to try to restore a shoot that has been allowed to lie too long and has become dry?

204. How are Limpness and Firmness produced?—It is due to *osmosis* that the shoot turns limp on losing water and recovers its firmness on being placed in water.

* (*a*) Cut off a seedling's shoot and put it into 5 per cent. salt solution; it becomes limp after a time (why?). Take the limp shoot out of the solution, wash it under a tap, and set it in water; what change occurs, and why?

(*b*) Is it necessary to put the whole shoot in the salt solution? Place one fresh shoot with its cut end and another with its free leafy end dipping into the solution and afterwards into water.

205. Plasmolysis and Turgidity.—The shoots used in these experiments are not killed unless the salt solution is made too strong or they are left too long in it. Prove this by pulling up whole seedlings and re-planting them, after making them turn limp, or *flaccid*, in the salt solution.

(*a*) Cut sections of a piece of fresh beetroot; mount sections separately in (1) water; (2) salt solution; (3) alcohol. In (1) notice the layer of protoplasm ("primordial utricle") lining the cell-wall, and the red sap filling the cavity (vacuole) of the cell; some of the cells will be cut open, allowing the sap to escape. In (2) notice that the primordial utricle contracts from the cell-wall, but still contains the red sap, which does not escape from the living cell. In (3) notice that the red sap diffuses out of the cells, which have been *killed* by the alcohol.

* (*b*) If you have no microscope, the following simple experiment will give you some idea of turgidity. Cut a piece, about 3 by 1 by 1 in., out of a fresh beetroot, and notice the way in which it resists being bent between your thumb and forefinger applied to its ends. Then place it in salt solution, and notice that it bends much more easily (why?); then place it in water until it becomes stiff again (by the cells becoming turgid). Then place the piece of root in boiling water for a few minutes, rinse it in cold water and see whether it can be made turgid again.

206. Tension Caused by Turgidity.—Are all the cells of a growing plant equally turgid? Have you ever noticed that the cut ends of flower-stalks (*e.g.* Daffodil or Tulip) dipping into water become split in a peculiar way, and that the split parts curve outwards and upwards?

* (*a*) Make short slits in the cut end of a seedling stem (or the flowering-stalk of a Daffodil, Tulip, Bluebell, etc.) and set it in water. The curling of the slit parts is evidently due to the inner cells absorbing water more rapidly than the outer ones.

In addition to the three supporting or "skeletal" tissues —wood-vessels, sclerenchyma, collenchyma—the ordinary thin-walled tissue (parenchyma) plays an important part in maintaining the rigidity of herbaceous stems as well as of petioles, leaf-blades, and flower-stalks, by the turgidity of its cells. In a herbaceous stem the pith has a strong tendency to elongate, but this is hindered by the outer tissue, and the state of strain thus set up tends to keep the stem rigid and erect. The outer tissue is on the stretch, tending to shorten, while the inner tissue is under compression.

If a strip of Sunflower stem 50 cms. long is cut out and the soft tissue (pith) separated from the outer tissue, the former suddenly lengthens to over 60 cms., while the latter shrinks to 45 cms. In the same way, if we cut a turgescent stem, say of a young Elder twig, flat on two opposite sides and then bisect it, each half bends outwards; the pith and cortex assume their proper lengths, the former expanding and the latter contracting.

By finding what strength of salt or sugar solution is needed to bring about plasmolysis, we get a rough idea of the osmotic force of the cell-sap. Saltpetre solutions are generally used; a 1 % solution of this salt (nitrate of potash, KNO_3) exerts a pressure of $3\frac{1}{2}$ atmospheres.

The osmotic pressure within living cells is often much greater than this. In the pith of Sunflower it is about 13 atmospheres; that is, a pressure of 13 atmospheres would be needed to prevent the isolated pith from expanding. In the pulvinus, or motor organ, of a Scarlet Runner leaf the pressure is about 11 atmospheres; in the cambium of trees about 15 atmospheres, and in their medullary rays about 20; in Onion bulbs and in Beet-root (which contain large amounts of sugar) about 20 atmospheres; and in the "nodes" of Grasses about 40 atmospheres, a pressure as great as that of the steam in a powerful engine.

* (*b*) Split a Dandelion stalk longitudinally into four strips, and notice that each strip at once becomes curved, with the epidermis on the concave side: why? Place some strips in water, others in strong (about 10 per cent.) salt solution, and observe the differences in the curvature caused by the changes in the turgidity of the inner tissue—*i.e.* that nearest the centre of the stalk.

(*c*) Cut a long narrow strip of Dandelion stalk and fasten the ends securely, by threads or pins, close together to a piece of wood. Dip the strip into water and carefully watch how it coils: part of it twists in one direction, part in the opposite direction, and between these there is a part where the spiral reverses. This gives an excellent illustration of the coiling of a tendril, which shows a similar reversed spiral when the free end has become fixed to a support.

* (*d*) Split a Dandelion stalk and cut the curled-up strips into rings. If the ring is placed in water it will become more tightly coiled; if in a very strong solution of salt or sugar, it will open out. In this way we can find out what strength of solution produces neither increase nor decrease of curvature and therefore equals the osmotic force of the soft tissue, *i.e.* the osmotic strength of the cell-sap.

* (*e*) Prepare a 5 % solution of common salt, by stirring 25 grammes of salt into 500 c.cs. of water. Get ten saucers ready, and into one pour 100 c.cs. of the solution. Then, using a graduated beaker, dilute the 5 % solution with water, so as to make 4 %, 3 %, 1 %, 0·5 %, 0·4 %, 0·3 %, 0·2 %, and 0·1 % solutions, pouring 100 c.cs. of each into one of the saucers. In each saucer place two or three rings, and find out in which saucer the rings become neither more nor less curved. For comparison place some rings into a saucer containing plain water.

(*f*) What would happen if *transverse* rings were used? With a dry razor cut sections across a Dandelion stalk and slit each ring at one point. Put some of the rings into water, others into salt solutions of different strengths. In water the rings become *more* curved in this case, because the pith-cells sink in the tangential direction.

(*g*) Measure an "internode" of young Sunflower stem, then extract the pith by using a cork-borer, and measure (1) the isolated pith, (2) the outer tissue: the former has elongated, the latter contracted.

(*h*) Another and simpler method is to use the long leaf-stalks of Rhubarb or of "Arum Lily" (*Richardia*). Lay the stalk down, cut the ends squarely, and measure the length carefully. Then remove a strip of the outer tissue and measure: it will be shorter than the whole stalk. Next strip off the whole of the outer tissue and measure the pith, which will be longer than the whole stalk.

(*i*) Hold a Rhubarb leaf-stalk by one end in a horizontal position; it is firm and rigid and hardly droops. Strip off all the outer tissue, leaving only the central portion (pith); the stalk now droops when held by one end (why?).

(*j*) Saw off a piece of Willow twig about 2 ins. diameter. Slit the "bark" down one side and remove it in a single piece. On trying to replace it on the wood, you will find that the ends will not meet now, showing that the bark was in a state of tension.

207. Growth in Thickness.—In almost all Monocotyledons the older parts of the stem are hardly any thicker than the younger ones near the growing apex. This is because the stem of a Monocotyledon usually does not undergo any continuous increase in thickness after growth in length has ceased. In Dicotyledonous shrubs and trees, however, a complete layer of growing tissue or *cambium* is present outside the wood but inside the bast, and each year this forms a new cylinder of wood outside the older one, also producing new bast within that previously formed. What are (1) the mechanical, (2) the nutritive, necessities which are met by "secondary thickening"? Remember the conducting functions of the wood- and bast-tubes, also that the fibres give strength, while the ordinary (living) cells store food.

The process of secondary growth in thickness is obviously correlated with the continual increase of leaf-area on one hand and of root-area on the other. Each bud which unfolds in spring produces a branch which bears buds; next year each of the latter may produce a branch, and so on. Meanwhile the root-system is also branching, each branch producing fresh crops of root-hairs. The increasing rates of transpiration and root-absorption are met by the provision of additional water-conducting tubes (vessels); while the increasing amount of organic food produced by photosynthesis is conducted by the additional sieve-tubes to buds, cambium, growing-points of root-branches, and to medullary rays. All these tissues are growing in extent year by year, their growth being intimately correlated.

That the increasing weight of the foliage borne by the branches of trees is practically counterbalanced by the increasing amount of wood formed each year is shown by the fact that the vertical distance between the drooping summer-position of a branch, when it is bent down by the weight of the leaves, and the winter-position, when it has risen owing to the loss of the leaves, remains practically the same year after year. It is most important to bear in mind the principle of **correlation of growth,** one aspect of which is beautifully illustrated by the cambium in connexion with secondary thickening. In examining felled trees in a plantation, or lopped branches, note the frequently excentric appearance of the wood-layers (annual rings) and try to account for it in each case.

208. Annual Rings of Wood.—In a cross section of a tree trunk or a thick branch,[1] a series of concentric rings (really, of course, *layers*) can be seen in the wood. Each of these rings corresponds (normally) to one year's growth.

The wood formed in spring has large vessels which are required for the rapid transport of water to the young leaves, and it is softer than the hard compact wood formed later in the year as the rapidity of growth decreases and the leaves transpire and assimilate less and less actively. In autumn the formation of new wood ceases, reserve foods are stored up, and the resting-buds (Ch. VI.) are usually by this time fully developed.

In spring the buds open and the young leaves expand; the cambium, being well supplied with food, again begins to grow actively and to form new spring wood. The transition from spring to autumn wood may be gradual, but there is an abrupt change from the autumn wood (containing narrow vessels) of one year to the spring wood (containing wide vessels) of the next.

209. Rays.—Running outwardly from the centre of the stem are numerous bands, the medullary rays,[2] which serve partly for the storage of starch and oil, and partly for the horizontal conveyance of food materials and water. They also serve to bind together the successive layers ("rings") of wood, and thus make the wood compact and strong. The rays are vertical plates; their height varies, but they must not be thought of as sheets of tissue running continuously

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[1] Old *roots* undergo growth in thickness (beginning in a rather different way), just as stems do, and show annual rings.

[2] The rays, though called medullary or pith rays, do not all extend into the pith; most of them stretch from the cambium to an annual ring (additional rays are formed each year).

from the base of the stem to the apex. The rays can often be seen very plainly on a square Pine match; two opposite faces show the rays as broad, shiny, horizontal streaks (radial faces), while on the other two (tangential) faces they appear as narrow vertical streaks.

210. Heart-Wood and Sap-Wood.—In old trees showing *many* annual rings, the central region of secondary wood is often distinctly marked off from the outer region. This is largely due to the wood-cells losing their contents and to changes in colour and in chemical composition of the walls of the wood-vessels. The central region (heart-wood) is harder and darker than the peripheral region (sap-wood).

It is almost entirely by means of the young sap-wood that water is conveyed upwards from the roots to the leaves. As the wood grows older it becomes unable to act as a channel for the passage of water. Hence the importance of the addition of new layers of wood is two-fold: first, it provides a connected series of new channels for the ascent of water as the old ones become functionless; and secondly, it increases the strength of the stem as the weight of the upper portion of the tree increases.

211. Knots.—The knots which occur in wood are branches which have become surrounded by the new layers of wood produced as the stem increased in thickness. Examine logs of various kinds of wood, and find out all you can about the history and mode of formation of the knots.

Do the knots run right through the tree-trunk from outer surface to centre? What has probably happened, and how many years ago, when the knot ends abruptly and is covered on the outer end by the new wood-layers? How does "Bird's-eye Maple" gets its name, and what are the "eyes" in its wood? Why is a knot usually much harder than the rest of the wood, and why does it fall out readily from a board?

212. Cambium.—The chief function of the cambium is to produce new tissues. The cells of the cambium-layer are living and capable of active growth and division, the new cells formed being mostly converted into new "water-tubes," new "food-tubes," and new fibres, while some remain unaltered (beyond growing in size and changing in shape) and add to the living cells present in wood, bast, and rays.

The shoot is continually growing and producing new leaves and buds, so that year by year the number of leaves is becoming larger. This involves a yearly increase in the weight of branches and leaves to be supported and spread out to light and air. The branching of the root means a continually growing area of absorbing surface, in the form of root-hairs, in the soil, and since the root can make no organic food to supply its increasing needs, more and more leaf-manufactured food must be conveyed to it.

All this means an increasing demand for more wood-tubes to conduct water and salts from the roots, more bast-tubes to conduct organic food from the leaves, more strengthening tissue (fibres, which act solely as strengthening structures, and wood-tubes, which serve this purpose in addition to that of conduction), and more tissue in which food can be stored (*e.g.* the rays).

It is obvious that this important zone of growth is most favourably placed in the plant. It is well protected from external influences, and well supplied with necessities of life. On its immediate inner side are the wood-vessels along which the water and inorganic salts pass from roots to leaves; while touching it on its outer side is the bast through which manufactured food materials are sent for distribution throughout the plant. Moreover, running through the cambium are the medullary rays, from which it can draw supplies of food when, as in early spring, no new food is being made by photosynthesis.

Besides the functions mentioned above, the cambium plays other parts under certain conditions. It is involved in the processes of **pruning, budding, grafting,** propagation of plants by **cuttings** ("slips"), and in the **healing of wounds** on the stem (Ch. XVI.).

213. Cork and Bark.—It is evident that the internal formation of secondary wood and bast must exert considerable pressure on the outer tissues, which are stretched and eventually ruptured. To provide for this there is the formation of new tissue from a growing layer developed in this region. This layer is the **cork-cambium.** In the majority of cases it arises in the outermost layer of the cortex, immediately below the epidermis. The young cells given off to the outer side of the cork-cambium form the **cork.** This tissue, being impermeable to water, cuts off the epidermis from nourishment. The epidermis dies and peels off as the first bark of the tree. The cork is developed to replace the epidermis and carry on its functions.

214. The Bark may be defined as the dead tissue lying outside an active cork-cambium. We have already indicated what the first bark consists of. The first cork-cambium formed may persist for a large number of years, or even throughout the life of the tree. In such cases, *e.g.* Birch, Beech, there may be a considerable formation of bark owing to the dying off of the older cork-layers. But in most cases this first cork-cambium dies, sooner or later in those plants where it has a superficial origin, early in those where it is deep-seated. It is replaced by a new cork-cambium developed in the deeper tissue. This produces a new cork-layer, and as a result all the outlying tissues (the original cork, etc.) die and are added to the bark. If the succession of secondary cork-cambiums is rapid, it often happens that the cork comes to lie close to the bast, and in some cases the new cork may even arise *in* the bast, *e.g.* Vine and Clematis.

In some trees the bark comes away in sheets, and is spoken of as **ring-bark**. This may be due either to the first cork-cambium being persistent or to the successive cork-cambiums appearing in the form of regular rings. But in most trees the bark is given off in scales (**scale-bark**); this is due to the fact that the secondary cork-cambiums do not arise as regular rings or layers, but in the form of curved strips.

215. Lenticels.—In the young green shoot the epidermis has stomates allowing for the free entry and exit of gases. When the cork-tissue is developed we usually find certain structures known as lenticels, which usually form small oval patches on the surface of the shoot. In Birch the lenticels are long, transverse, and very conspicuous on the white bark. Sections show that at these points the cork-cells are not in close contact, but have separated from each other and form a loose powdery mass through which gases can readily pass (Fig. 59).

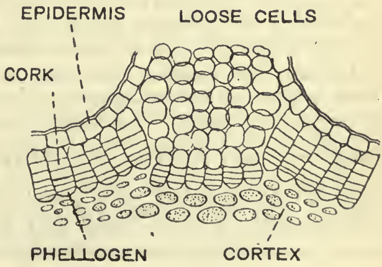

Fig. 59.—Section through a Lenticel. Phellogen = Cork-cambium.

These lenticels are as a rule developed immediately underneath the stomates. Where a thick mass of cork is developed they form long passages or canals, filled with the powdery cork-cells, as, for example, in the ordinary cork of commerce.

The lenticels are closed in winter by the formation of ordinary compact cork-tissue. There are air-spaces between the cells of the cortex and of the medullary rays, so that all the living tissues are aerated by way of the lenticels.

216. Practical Work on Woody Stems.—

(*a*) Cut sections of twigs of Elder, Willow, Elm, Oak, or other trees, and notice in the youngest parts the separate bundles arranged in a ring. In the older parts note that the continuous cambium has produced a solid mass of wood on its inner side, while the surface of the stem has become covered by a brown coating of *cork*. Peel off the cork, and notice the green cortex, then a zone of colourless tissue (bast), which is separated from the hard wood by a moist sticky layer (the cambium). Cut sections and stain some with aniline chloride, others with iodine. In the wood, notice the rays and the "rings." Look for trees showing stages in healing of wounds where branches have broken off. Compare the wood of various common trees; make a collection of polished slices. Find out all you can about timbers—density; hardness; uses; "silver-grain"; "burrs"; "shakes"; canker, dry rot, and other diseases, etc.

(*b*) Next cut a thin slice out of the thickest part of a branch with a saw, and rub down one of the cut surfaces on fine glass-paper until it is very smooth. Examine it with the aid of a lens, and note the parts as indicated in the preceding paragraphs (Arts. 207-215). Examine logs of wood showing the cut surfaces, or the cut stumps of trees.

(*c*) Strip the cork-layer from twigs of Elder and other plants which show lenticels plainly on the surface, and notice that lenticels are not merely surface-marks, but that they pass right through the cork to the green cortex-tissue. Strip off, layer after layer, the bark of a Birch twig, and notice that the lenticels go through all the layers.

(*d*) Dip a twig of Elder, Birch (or other plant which shows lenticels plainly), into boiling water, and notice the air-bubbles which escape from the lenticels. This shows that the cortex of the stem has air-spaces, and that gases can pass through the loose lenticel tissue.

217. Forms of Stem.—In some plants the aerial portion of the stem is very short, so that the leaves seem to spring from the top of the root, while arising from the centre of the tuft of leaves is the upright flowering axis. Such leaves are often said to be radical, and the condensed portion of the stem, together with the upper part of the root, is known popularly as the "root-stock." Very commonly this is perennial, and forms flowers and new tufts of leaves year after year, as in the Plantain, Daisy, and Dandelion.

Most stems grow in the air, but many are buried in the soil. Some are soft (herbaceous), others hard and woody (chiefly in *arboreous* or *arborescent* plants, *i.e.* shrubs and trees). In our later studies we shall find that the stems of plants assume an immense variety of forms in connection with special adaptations.

Many plants produce special branches which serve for vegetative propagation, *i.e.* multiplication apart from seed-formation. This is especially common among low-growing or "ground-hugging" plants.

218. Runners are long slender branches which grow along the surface of the soil. They are easily studied in Strawberry, Daisy, and Sweet Violet. In the House-leek and various Crassulas the runners or "**offsets**" are short, and carry out large rooting buds from the parent plant.

The "**suckers**" of Rose, Raspberry, and Mint are lateral branches arising below the level of the soil, which grow upwards to form sub-aerial stems bearing leaves and flowers. The underground portions of such stems resemble roots, and are white or pinkish in colour. Their true character can, however, be told by their axillary exogenous development, and by the occurrence of scale-leaves upon them. In some cases (Roses and Poplars) the suckers arise from roots.

219. Underground Shoots are commonly used for the storage of food, and they may serve either for the maintenance of the life of the individual when the parts above ground are killed by winter frosts, or for the production of new individuals by vegetative propagation. They may be distinguished from roots by the fact that they bear leaves or buds, and by their origin from buds borne in the axils of leaves or leaf-scales. The four chief types of underground shoots are Rhizomes, Tubers, Corms, and Bulbs.

220. The **rhizome** is a stout or slender stem, which usually grows horizontally a short distance beneath the surface of the soil. Stout and partially upright rhizomic stems are sometimes termed "root-stocks," but they can be distinguished from roots by the fact that they bear leaves and buds, as well as by their internal structure. Usually only small brown membranous scale-leaves arise directly from the rhizome, the green foliage-leaves being borne upon erect aerial shoots. Numerous adventitious roots are present, which grow out mainly from the under-surface of the rhizome, and usually near to the bases of scale leaves—that is, from the "nodes." Rhizomes often branch to a slight extent, and each branch when separated, either artificially or by the decay of the older parts, is capable of forming a new plant.

Year by year a rhizome travels to fresh portions of the soil, often slanting upwards, but in that case the new parts are dragged down to the same depth by the contraction of the roots.

As examples, you should study the rhizomes of various Grasses (*e.g.* Couch-grass) and Sedges (Fig. 60), Iris, Solomon's Seal (Fig. 113), Wood Sorrel, Wood Anemone.

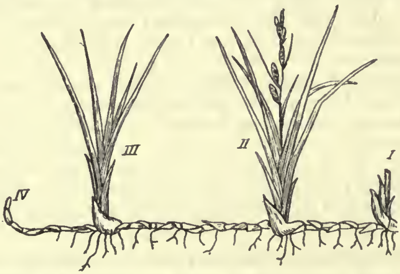

Fig. 60.—Rhizome of Sedge (Carex) in Summer.
Flowering shoots of (I) last year, (II) this year, (III) next year, (IV) year next but one.

221. The **stem-tuber** is a swollen underground branch containing stored food-materials and bearing buds. Examples are afforded by Potato (Art. 362) and Jerusalem Artichoke.

222. The **corm** is a shoot whose basal stem portion becomes swollen and filled with food-materials after flowering has taken place. The corms of two or three years often stick together so as to produce what may be regarded as a condensed form of rhizome bearing axillary buds either laterally (*Colchicum*), as in a creeping rhizome, or on the upper surface (*Crocus*), as in an upright rhizome or "root-stock."

223. The **bulb** only differs from the corm in the relatively smaller size of the stem, and in its investment by thick fleshy leaves, which contain large stores of reserve food. As in the corm, adventitious roots arise from the base of the stem, which usually assumes a discoid shape. In scaly bulbs (Lilies) the fleshy scales, of which the bulk of the bulb is composed, simply overlap at their margins, whereas in tunicated bulbs (Onion, Hyacinth) the outer leaves are large and completely ensheathe the inner portions of the bulb. The coloured membranous covering on the outside of such bulbs is formed by the remains of the leaves of a previous season.

Bulbs, tubers, and corms afford a means of perennation and also of vegetative propagation. They occur most commonly in the group of Monocotyledons.

224. Spines.—In many cases stems become metamorphosed into **spines** which terminate in a hard, sharp point instead of in a bud or soft growing-point. Many of the branches of Sloe, Hawthorn, etc., become modified into special protective organs of this nature. That they are really branches which have ceased to grow and whose tips have become hard and sharp-pointed is indicated by the fact that they arise in the axils of leaves, and that they may bear lateral buds or even small foliage-leaves. Spines possess a central cylinder of vascular tissue, continuous with that of the stem, as can be seen when they are torn off.

Fig. 61.—Branch of Barberry, showing transition of Foliage-leaves into Spines

Spines may also be developed either from entire leaves or from the edge of the blade. The branched spines of the Barberry are modified leaves, for in their axils buds are present which may develop into leafy branches or flowering ones. Moreover, the same Barberry plant (Fig. 61) often shows intermediate forms between leaves and spines.

The foliage-leaves of the False Acacia (*Robinia*) have a pair of spines which arise at the base of the leaf-stalk, and these are really modified *stipules*. The thorns of the Gorse (*Ulex europaeus*) are either modified branches or modified leaves, for some of them bear buds in their axils, and are flattish and narrow-pointed leaves, whereas others are cylindrical and form the hard sharp-pointed ends of branches.

225. Prickles and **Hairs** may be scattered irregularly over the surfaces of plants, the former mainly on the stem, but the latter on the stem, leaves, and roots. Hairs may assume a variety of shapes, but they are always derived from the layer of cells forming the epidermis, or first outer skin, of plants, and hence they fall off when cork is formed. The Stinging Nettle has several kinds of hairs, the largest of which are the stinging hairs. The point of the stinging hair is formed by a sharp, thin, brittle scale of silica, which breaks off in the skin, making a wound into which the acid juice contained in the hair is injected by the contraction of the swollen base of the hair.

Hairs are frequently glandular and often sticky. In the latter case they are of use as a protection against obnoxious creeping insects, which are frequently caught and retained by the secretion. The Henbane, Tobacco Plant, etc., catch large numbers of flies in this way, and the leaves of a few plants, such as the Butterwort and the Sundew, feed on insects which are captured in this manner (Art. 241).

Prickles such as those of the Rose are usually classified as "emergences." This term is applied to outgrowths from stems or leaves, which are neither hairs, roots, branches, leaves, leaflets, nor stipules, and which neither bear buds in their axils nor arise in the axils of leaves. Emergences arising from the stem usually contain no vascular tissue, and hence, when removed, they leave only a superficial wound (as in Roses and Brambles). Each of the stalked glands on the leaf of Sundew, which are also regarded as emergences, contains, however, a strand of vascular tissue arising from one of the veins of the leaf.

Prickles, of course, serve to protect the plant from the attacks of herbivorous animals, but they often do more, especially when they curve downwards as they do in the Rose and Bramble, for in this case they are so many hooks that help to support the stem, and therefore assist the plant in climbing among the surrounding bushes and herbage.

An acquaintance with plants in their habitats teaches us that the formation and development of hairs, spines, and prickles depend to a great extent on external conditions. Thus, the same plant that produces these structures when growing in a poor, dry soil fully exposed to the rays of the sun, assumes a much softer and less aggressive character when grown in a rich, moist soil. Under the former circumstances the plant, by converting some of its buds and leaves into spines, reduces the amount of its foliage, and thus economises its scanty supply of water.

The Rest-harrow (*Ononis arvensis*) has no spines when grown in moist soil, but in dry, exposed situations most of the branches end in hard, sharp points.

Many fleshy plants, however, which grow in dry situations, such as the Stone-crop or the House-leek, show little or no tendency to form hairs, prickles, or spines, since they have other means of checking transpiration (thick cuticle, etc.).

The hairs present on the stem and leaves are always cutinised, and usually almost impermeable to water. They serve to protect the plant, and especially the young growing organs, from an excessive loss of water. Hairs, when thickly set, also help to protect sensitive growing organs from too strong light, which retards their growth and may injuriously affect them. Similarly, a close covering of hairs is of some importance in retaining heat during the night and thus keeping the plant warm, while hairs are also of great value in preventing the surface of the plant from being wetted by rain. The hairs borne by the root (root-hairs), on the other hand, have no cutin, and are very permeable to water.

226. Roots as Storehouses of Food.—In annual plants the food produced by the plant during the growing season is mostly turned at once into new tissues. The only store of reserve food is that laid by in the seed for the use of the young plant when germination occurs. In biennial plants (which in the first year produce leaves and make and store up food, and in the second produce flowers and fruits) reserve food is often stored in the roots, which are greatly thickened, as in Carrot, Beet, etc. In these cases the so-called tap-root really includes part of the stem in addition to root proper, and in Turnip and Radish the whole of the swollen part corresponds to the hypocotyl of the seedling.

In perennial plants the roots may be annual, as in Lilies and other plants with bulbs or rhizomes; or biennial, as in Dahlias; or perennial, as in shrubs and trees. Roots that are annual—*i.e.* perishing the same year in which they are formed—contain no reserve food; but roots that last two or more years nearly always contain more or less food for the following year's growth.

Adventitious roots may be used for the storage of food, as in the tuberous roots found in many British Orchids. The tubers may be either palmate or globular, and they arise adventitiously from buds which appear at the base of the present year's stem. Next year a new stem develops from this bud at the expense of the nutriment stored up in the tuber. In the case of the Dahlia and Paeony, adventitious tuberous roots grow out from the base of the stem (Fig. 62), and these are put to a similar use as storage houses for reserve-materials. That these bodies are really roots is shown by their development as irregular endogenous outgrowths at the base of the stem, which do not arise in the axils of leaves and are at first covered by a root-cap.

Fig. 62.—Tuberous Roots of the Dahlia.

(*a*) In Radish seedlings, make sketches of young plants of different ages, showing the cotyledons and the red hypocotyl, the thickening of the hypocotyl, and the fully formed swelling. Cut thin cross-sections of the "root" (hypocotyl) of a young seedling, and notice the very marked circular transparent zone of growing tissue (*cambium*); test with iodine and notice the starch present in most of the cells except those of the cambium. The cambium consists of narrow oblong cells, arranged in the radial rows, filled with protoplasm, and continually dividing to form new cells on the outer side (bast) and on the inner side (wood) of the cambium-layer; the wood contains but few vessels.

(*b*) Study and compare the roots of Carrot, Parsnip, Beet. The Beet root is peculiar in having several layers of cambium instead of one only. Scrape the root of Carrot and that of Parsnip, put the scrapings in warm water, shake up, and filter. Test the filtrate for sugar with Fehling's solution. The reserve food in the Beet is also sugar, but it is cane-sugar, not glucose, as in Carrot, etc. Hence, in order to get the red precipitate with Fehling's solution, it is necessary to boil first with sulphuric acid in order to convert the cane-sugar to glucose.

(*c*) Examine the tuberous roots of Dahlia, which are formed in summer and store up food to be used by the flowering stems of the next year (Fig. 62). When exhausted of food they die off, but new tubers are formed as the old ones are emptied, so that the individual plants can carry on a perennial existence. The reserve food in this case is inulin, similar in composition to starch, but differing in being soluble in water, so that in a section of fresh root examined in water the cells appear empty. If a piece, or a section, of Dahlia tuber be placed in alcohol for some time, the inulin is deposited in the cells as rounded crystal-like masses.

QUESTIONS ON CHAPTER VII.

1. Explain how you would investigate the rate of growth in length of a root, indicating the precautions you would observe in conducting your experiments. Illustrate your answer by a diagram.

2. Describe simple experiments to show by what paths water travels through the plant from roots to leaves.

3. What are the main functions of roots? How are they adapted to carry on these functions?

4. How is the radicle of a seedling enabled to penetrate stiff soil? How may the force exerted by the radicle be measured?

5. How can it be proved that the direction of growth of a root is a response to the stimulus of gravity? Explain the term "geotropism."

6. How is the direction of growth of a root affected by moisture? Why is it advantageous to the plant that the stimulus due to moisture is able to overcome that due to gravity?

7. Describe the structure of the stem in any Monocotyledon, as seen in longitudinal and in transverse sections.

8. In what features of structure and function do the vessels of the phloem (sieve-tubes) differ from those of the wood?

9. What is the vascular bundle? Of what parts does a vascular bundle in the stem of a Dicotyledon consist, and what are their respective functions?

10. Explain the structure, as seen in transverse section, of a twig of any Dicotyledonous tree.

11. State generally what is the composition of a vascular bundle. Describe the longitudinal course of the vascular bundles in the stem of any Dicotyledon.

12. What is the cambium? Explain where you would find it in the stem of a tree, and what is its importance.

13. What is meant by a "vessel"? What are the differences between the vessels of the wood and those of the bast?

14. What is a "growing-point"? What is the difference between the growing-points of stems and those of roots?

15. Describe the way in which the stem of a Dicotyledonous tree grows in thickness, and explain how it is that its wood shows annual rings.

16. The stem of an Oak tree continues to grow in thickness so long as the tree lives, whereas the stem of a palm-tree does not grow any thicker when once formed. Explain the cause of this difference.

17. Along what tissue does the sap ascend in a stem in its passage from root to leaf? How would you endeavour to prove by experiment the truth of your statement? What other movement of liquid substance takes place in plants besides the ascent of the sap, and what is the path of this current?

18. Explain as far as you can the way in which water is absorbed from the soil by the roots, and the transpiration current maintained, in the case of trees.

19. What is meant by sclerenchyma? Give some account of its mode of occurrence in stems, and show how it is of use to the plant.

20. Describe the process of secondary thickening as seen in the root of a Dicotyledonous tree. What advantages does this secondary thickening confer on the tree?

21. Describe in the case of any seedling you may select how the structure characteristic of the root changes into that met with in the young stem. What do you think is the use of the change to the plant?

22. What method, other than watering, would you use to recover a plant, growing in the open, which had become flaccid from loss of water? Give reasons for the method adopted.

23. Describe accurately an experiment which you have seen in which the rate of growth of roots or shoots was measured. Which part of the root grows most rapidly in length, and which part absorbs most water? What advantages do plants gain by the increase of their shoots and roots in length and thickness?

24. How is the direction of a root's growth affected by light? How does a shoot differ from a root in this respect?

25. How is the growth of a root-tip affected by contact with a hard obstacle?

26. How can it be proved that the root-tip alone is sensitive to the stimuli of gravity, light, etc.?

27. In what part of a root does growth in length occur? How can it be proved that the curvatures in response to stimuli (gravity, light, moisture, contact) also occur in this part?

28. Describe the characters of the various regions of a root, starting from the extreme tip.

29. State all you know about the roots of land-plants, and in particular mention any observations you have yourself made on the roots of any plants.

30. Give an account of the influence of Light, Gravity, and Moisture on the growth of roots.

31. Describe carefully how you would fit up an experiment which would show clearly the effect of light on the direction of growth of the stem and root of a seedling. State briefly the *other* effects of light on plants.

32. What is meant by Geotropism? Write a careful account of any three experiments you may have performed in order to investigate the nature of geotropic phenomena in roots.

33. Write a short account of the distribution of mechanical tissue (stereom) in the stems of plants, illustrating your answer by reference to particular cases.

34. Very strong solutions of certain salts make plants wither; very weak solutions of the same salts are recommended for making them grow. How would you determine by experiment how strong and how weak solutions must be to produce these effects? How do you explain the contradictory results?

35. Describe the structure of a young root as seen in transverse section. What peculiarities in its structure are characteristic of the root?

36. If a leaf or a flower-stalk is removed from the plant and allowed to remain in dry air, it becomes flaccid and can no longer support its own weight. Why is this? Give experiments in support of your explanation.

37. How would you show whether it is the reaction produced by light, or by gravitation, or by both, that causes a stem to grow upwards and a root to grow downwards?

38. Mention an experiment which shows that organic substance formed in the leaves travels down the stem outside the cambium.

39. Show, by describing and drawing one example, that the branch of a tree may preserve a record of past seasons in its bark and wood.

40. Suppose you carefully pull up a young bean seedling, and fasten it by means of a pin through the seed to the edge of a shelf, so that the axis of the plant is in a horizontal position, and then keep the air round the plant saturated or nearly saturated with moisture. How will the plant behave during the next few days? Describe any experiments you have made bearing on such occurrences, and state what inferences you would draw from them.

41. What is meant by osmosis, diffusion, turgor, transpiration? How is the rigidity of a succulent flower stalk affected by placing it (*a*) in water, (*b*) in a strong salt or sugar solution? How would this treatment affect a living cell?

42. Draw from memory, and carefully describe the structure, as seen with the naked eye, of a block of oak (or of any other tree with which you are familiar) cut so as to include both the centre of the tree and the bark.

43. Describe the young main root of some named plant. Where does most rapid increase in length occur, and how can it be demonstrated? Draw a transverse section taken a little way above the region of most rapid growth.

44. Draw diagrams of longitudinal sections of a root and of a stem. Include the apex and the characteristic lateral appendages in each case. Minute structures, not readily seen with a hand-lens, need not be represented.

45. Give a short description of the root-system of a young dicotyledonous plant. Enumerate the more important functions discharged by roots, and explain how the roots are specially adapted to perform these functions.

46. The trunk of an Oak tree, when in full leaf, is sawn all round so deeply as to cut through the sap-wood. State and explain the effect of this operation.

47. Describe the features seen in a cross-section of a piece of wood (*e.g.* of oak or ash) when examined with a lens. Illustrate your answer by means of a diagram.

48. Explain the nature and mode of origin of "knots" and of "silver grain" in timber.

49. What is meant by a Medullary Ray? Where are medullary rays found, and what are their uses?

50. When the trunk of a dicotyledonous tree is cut across, the wood is seen to be disposed in rings. Explain this fact, and indicate its relation to the age of the tree.

51. Why does a succulent flower-stalk or petiole lose most of its rigidity when cut and in want of water? Could you produce this condition artificially without exposure to the air? How would you attempt to restore the rigidity of a stalk thus artificially wilted? Give reasons for your answers.

52. Describe and explain the changes that may be observed when a turgescent shoot is bisected longitudinally, and when the halves are placed successively in water and in strong salt solution.

53. The split stalks of cut flowers have been found to become limp in salt solutions containing 32·5 grammes of salt per litre, but to become turgid in solutions containing 3·25 grammes per litre. Assuming these facts and given a quantity of the strong solution, how would you most rapidly prepare a series of solutions of intermediate strengths so as to determine what strength of salt solution would just suffice to cause the freshly split stems to become perceptibly limp?

54. Explain why it is easier to split a piece of wood in the direction of the grain than across it.

55. Give an account of the structure and uses of Lenticels.

56. Describe and explain as fully as you can the appearance assumed by a tree growing in a position fully exposed to the wind from the sea.

57. How would you distinguish between (*a*) a simple leaf and a cladode, (*b*) a compound leaf and a short branch, (*c*) a slender underground stem and a root?

58. What are the chief points on which you would lay emphasis in a lesson on Turgescence? By what experiments would you illustrate the lesson?

59. Explain fully what is meant by Bark, and state the various ways in which it may be formed.

60. Describe carefully, with diagrams, five plants which reproduce themselves without the aid of seeds. Distinguish carefully between those cases in which food is stored up and those in which it is not. Point out also at what stage the new individuals become separated from the old.

61. Describe the anatomical structure of the root of a dicotyledonous plant. Show how it is adapted to its surroundings and to the work which it has to perform, and account for the differences in structure in such roots as tap roots and other fleshy roots, as compared with fibrous roots.

62. What functions other than the absorption of water do roots perform? Illustrate your answer by descriptions of any examples you may select.

63. Place beneath a bean seedling, fixed as in Fig. 15, a plate pierced by a hole big enough to give easy passage to the radicle. Place the hole so that it does not come immediately beneath the tip of the radicle. How can you cause the radicle (without touching it) to pass through the hole?

64. How can you induce radicles to grow upwards instead of downwards? How can you induce radicles to leave the earth and enter the air? How can you get radicles with dense or with sparse root-hairs at pleasure?

CHAPTER VIII.

CLIMBERS, PARASITES, SAPROPHYTES.

227. Climbing Plants.—Many plants have special means of growing up towards the light and air, and thus placing their leaves, flowers, and fruits in a favourable position, with the least expenditure of material. They are weak-stemmed plants which make use of living or dead plants as supports, without whose aid they would, after reaching a certain height by their own efforts, sink to the ground. Climbing plants save themselves the expense of forming rigid stems, but with a few exceptions (of which the Dodder is the only British example) they are not parasites, since they have earth-roots and take nothing from the plants to which they attach themselves, though when climbing over living plants they may injure them indirectly by shading them from the light.

The chief methods employed by climbers to raise themselves are:—(1) by twining their stems round the support; (2) by producing special attaching organs or tendrils; (3) by producing special attaching roots; (4) by producing curved prickles which hook on to the support.

228. Tendril Climbers.—It is necessary to distinguish sharply between plants which climb by twining their stems around supports and those which have special lateral irritable organs—tendrils—for this purpose. In a tendril-bearing plant, the stem itself grows straight on, while the tendrils differ entirely from twining stems in their mode of action. The tendrils can attach themselves to a support placed in any position, and can coil around these to right or left, downwards or upwards, differing in these respects from twining stems.

A young tendril, as it arises from the bud, is coiled up spirally, the convex side being the lower side, but in a few days it lengthens and becomes straightened out, at the same time sweeping slowly round through the air. The movements of the young tendril are "automatic," *i.e.* they are not made in response to any external stimulus, and after its vigorous growth has ceased the tendril begins again to grow more rapidly on its upper side, so that the lower surface now becomes concave. The tendril, if it has not met with any support, keeps on coiling in this way (owing to the more rapid growth of the upper side), and finally loses its sensitiveness when fully grown.

If, on the other hand, the tendril has, in the first period of its growth (the uncoiling stage), come into contact with a solid support, after sweeping around and "feeling" for one, it rubs against the support with its lower surface and begins to coil round it, and after making a few coils it becomes harder. The free part of the tendril, between the plant and the support, then becomes coiled and for mechanical reasons there occurs at least one reversal of the coil, sometimes several reversals; see Art. 206 (*c*). The spiral coiling of the free intermediate part of the tendril is due to excessive growth on the upper side, and is very important, since it draws the plant up nearer the support and also forms an elastic spring which enables the plant to yield to the wind and acts as a buffer against shocks that might tear the tendril from the support.

In most cases, the sensitiveness of a tendril is confined to the lower side and is greatest near the tip, though some plants have tendrils which are sensitive on both upper and lower sides. In any case, however, no coiling occurs if both upper and lower side of the tendril be stimulated at the same time. In shrubby climbers the tendrils undergo secondary growth in thickness; the tendrils of a shrub have to act for several years, while those of a herbaceous plant are only needed for a single season. To a certain extent the strength of a tendril becomes ultimately proportional to the weight it has to bear, so that if a number of the young tendrils be removed the remaining ones become stronger, provided they are still capable of growth.

Every student of Botany should read Darwin's *Climbing Plants* (Murray, 2s. 6d.). Very careful experiments made by later workers have shown that though an extremely slight blow made with a solid body causes coiling (*e.g.* the shock inflicted by a particle of cotton thread weighing only 0·00025 of a milligramme and placed on the tendril simply by a draught of air), but that *liquids* have no effect on tendrils. If water, watery solutions of salts, oil, or even mercury be allowed to fall on a tendril, no coiling occurs, but a response is made if there be any small solid particles in the liquid, *e.g.* chalk or mud in the water used. Moreover, a tendril is not stimulated by a glass rod coated with gelatine solution, which may be used to strike or stroke the tendril without result. This fact has led to some astonishing results in experiments, glass rods coated with gelatine being used to hold the tendril and to study the effects of different stimuli.

Blows inflicted by solid bodies cause coiling, but no effect is produced by mere continuous pressure; thus, if smooth glass threads, or a needle, be pressed carefully against the tendril, without friction and without any sudden increase in the pressure, no coiling occurs, though coiling at once results if these bodies are gently rubbed against the tendril. These facts are of biological interest, for they show that tendrils cannot be stimulated by rain or by general shaking of the plant by wind.

The general growth and behaviour of tendrils can be studied in the Sweet Pea, but those of Passion-flower or White Bryony are more suitable for experiments.

Why does a Sweet Pea seedling fall over and sprawl about if no support, *e.g.* a stick, is placed near it? Place sticks in a pot of seedlings, also strings stretched between sticks and running horizontally and at different angles. Are the tendrils able to coil around horizontal supports as well as inclined or vertical supports? Sketch a young leaf with tendrils which have not yet come into contact with a support: are the young tendrils straight or curved? Is it possible to make a young tendril coil without providing it with a support? Try the effect of stroking a young tendril with a stick, a string, a glass rod; stroke it at different points. Which part of the tendril is sensitive to contact and responds by coiling?

Choose a tendril of Passion-flower or White Bryony which has its tip slightly hooked, and with a pencil rub the inner side of the hook (lower surface of tendril) for about a minute. The tip should at once begin to coil, and in about two minutes the terminal 15 mm. will probably form a ring.

Many of the facts stated above can only be demonstrated by skilful manipulation, but it is easy to prove that a *smooth* body has no effect on a tendril. Dissolve two sheets of Marshall's sheet gelatine in a quarter pint of hot water, and dip into it a smooth rod of glass or wood about 3 mm. in diameter. Rub the cooled rod against a tendril. No effect is produced when the gelatine-covered part is used, but coiling occurs when the tendril is stroked with the uncoated part. It is an advantage to use two rods, touching the convex side of the tendril, which is not sensitive, with one rod and thus holding it owing to the stickiness of the gelatine, while the other rod is used for stroking the tendril.

229. In most native British tendril-climbers the tendrils are produced by modification of the leaves. In Peas and Vetches (*Lathyrus*, *Vicia*) they are modified leaflets in which only the mid-rib is developed. In Fumitories (*Fumaria* and *Corydalis*) the leaf is cut up into lobes any of which may act as a tendril. In *Clematis* the leaf-stalk coils around the support.

White Bryony (*Bryonia dioica*) belongs to the same family (Cucurbitaceae) as Cucumber, Gourd, and Vegetable Marrow, and has a thick tuberous rhizome, usually branched, from which arise the long annual shoots. Each tendril arises at a "node" beside a leaf, and in the upper flowering part of the plant we get leaf, tendril, and inflorescence arising together. In *Bryonia* itself, the tendril is unbranched, but in Vegetable Marrow it is sometimes branched and bears leaves; hence it is likely that the upper coiling part of the Bryony tendril is a modified leaf while the basal stiff part is a stem structure. The leaves are divided into 5 or 7 angular toothed lobes, and the whole plant is rough with small hairs.

230. Twining Plants.—In twiners the stem coils around supports, and the coiling is a special response made by the growing point of the stem to the stimulus of gravity. This response is termed transverse geotropism, and no coiling occurs if the plant is rotated, with the stem horizontal, on a clinostat (Art. 190). The mode of climbing of a twining stem is, therefore, totally different from the coiling of a tendril, the latter being due to a special kind of irritability set up by the support.

In most cases twining only occurs around supports which are vertical or nearly so, and which are not too thick, for the stems of twiners have a strong tendency to ascend directly upwards by the shortest possible path.

As an example of a twiner study the **Scarlet Runner.**

(*a*) Grow a seedling in a pot until the upper part of the shoot hangs over a few inches. Tie the lower part of the stem to a stick placed in the soil, set the pot on a sheet of paper, and record the position of the tip of the shoot, either (1) by drawing lines on the paper radiating from the centre of the pot, so as to show the direction in which the tip of the shoot points, or (2) by using a plumb-line (a string with a weight tied at one end) and marking the spot on the paper below the stem tip, or (3) by fixing a sheet of glass over the plant, resting on supports, and marking on it the position of the stem tip. Whichever method is used, record the time when each observation is made, and find out how long it takes for the stem-tip to swing round through a complete circle. In which direction does the shoot revolve—with the hands of a watch[1] or in the opposite direction?

(*b*) We know that warmth hastens the rate of growth of plants: does it hasten the rate of revolution of a twining stem? Compare the times taken by the same plant to make a complete revolution when kept first in a warm place and then in a cool place, and vice versa. At 33° C. a Runner revolved in 2 hours 20 minutes, while at 23° C. it took 3 hours 25 minutes.

Get several vigorous seedlings ready, each in its own pot.

Fig. 63.—Twining Plants: I., Convolvulus; II., Hop.

(*c*) In one pot set a long stick in a vertical position near the plant. Note that the stem swings round and stops at the point where it touches the stick, while its free end goes on revolving; in this way it finds a support and then goes on growing upwards.

(*d*) Must the support be vertical? Try setting the stick in an inclined position, in one pot at 30° from the vertical, in another at 45°, and so on. The Runner, like most other twiners, cannot climb up a stick set at a lower angle than 45° from the vertical. The Convolvulus, however, will twine around a horizontal stick.

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[1] The terms "with the sun" and "against the sun" are sometimes used instead of "clockwise" and "anti-clockwise." The plant (placed between sun and observer) points successively to East, South, and West in revolving "with the sun"; this occurs in the Hop and Honeysuckle. The plant points successively to West, South, and East in going "against the sun," *i.e.* in the anti-clockwise direction this occurs in most climbers, *e.g.* Scarlet Runner, Convolvulus.

(*e*) What happens if a thick stick or other thick support is used instead of a thin one? Use a large pot or a box, and place in it a thick cylinder of wood or a tube of cardboard; try several different thicknesses (diameters of 2, 4, 6, 8, 10 inches). The stem will not twine round a thick support (over about 3 inches diameter), evidently because the support is not curved strongly enough to allow the stem to hold on while the free growing tip swings round the support.

(*f*) Does the stem become twisted as it revolves? The best method for finding out is to paint a line along the convex side of the stem and watch what happens during a revolution. The line is seen to run round the stem, so that at the middle of a revolution it is on the concave side, while at the end of the revolution it is again on the convex side. The growth of the stem is not equal all round; a wave of rapid growth passes round the revolving part of the stem.

231. Native British twiners include **Hop** (Figs. 63, II.), whose stem bears prickles which help in catching on to the support; **Honeysuckle** (Art. 398); **Bittersweet** (Art. 395); **Great Convolvulus** (*C. sepium*, with large white flrs.) and **Field Convolvulus** (*C. arvensis*, with small reddish flrs.); **Black Bindweed** (*Polygonum convolvulus*), like Field Convolvulus in habit, with small flowers and with the sheath (*ochrea*, Art. 165) around stem at base of leaf, which is characteristic of the Polygonaceae; **Black Bryony** (*Tamus communis*), a Monocotyledon (though its glossy dark-green stalked heart-shaped leaves are net-veined); **Dodder** (*Cuscuta*), which differs from other British climbers in being a parasite (Art. 236) and in the fact that its stem acts like a tendril, being irritable to contact and friction and not transversely geotropic.

232. Root Climbers.—A few plants climb by means of attaching roots. The only native British example of a root-climber is

Ivy (*Hedera helix*), which climbs on walls, tree-trunks, etc., by means of numerous short roots springing from the stem along the shaded side; sometimes it creeps along the soil, especially on banks. It is not a parasitic plant; when growing on a tree-trunk the roots simply fix the plant to the bark and do not penetrate the trunk or tap the tree's supplies of water and food. The Ivy gets its water and dissolved salts from the soil by its main root, the climbing roots serving for fixation to the support.

Examine Ivy plants growing in different positions, *e.g.* on level soil, on sloping banks, on trees, on walls. Note the arrangement and form of the leaves. On flowering shoots the leaves are arranged spirally, in five rows, and the blades are not lobed; these shoots are only formed when the plant is well exposed to the light (why?), and they project from the rest of the plant and have no climbing roots. On the ordinary branches the leaves are arranged in two rows along the flanks of the stem. Note (1) the leaf-base, swollen and partly ensheathing the stem; (2) the cylindrical stalk, varying in length; (3) the blade, dark green, often pale along the veins or in patches, glossy, leathery, evergreen. The young leaves are all alike, but by the bending of the leaf-base or pulvinus, the amount of lengthening of the stalk, and amount of surface-growth of the blade, the leaves are brought into a horizontal position with the blades fitting together to form a "leaf-mosaic." The buds are covered with down, consisting of minute star-shaped hairs, which can be seen scattered over the stem and leaves after the bud has unfolded; by noting the arrangement of the hairs it is easy to trace the amount of growth of stem, leaf-stalk, and leaf-blade.

233. Hook Climbers.—Some plants climb, often in a rather straggling or rambling fashion (*e.g.* Brambles, Roses), by means of hooked prickles.

An interesting example is the Common Goosegrass (*Galium aparine*), which belongs to the same family (*Rubiaceae*) as the Bedstraws, and is very common in hedgerows.

The seedlings of Goosegrass (seen in autumn and winter) have large green oval cotyledons, and at first the shoot grows erect. The stem is 4-sided, and the leaves are arranged in circles or whorls, the number varying from 4 in a whorl in the seedling to 8 or 9 in the older parts of the plant. Note the small prickles on the stem and leaves. Are the prickles straight or curved? In what direction do they curve? Are they scattered evenly all round the stem? Sketch a part of the shoot showing the arrangement of the prickles.

Do you think all the parts in a whorl are really leaves? Do they all bear buds and branches in their axils? If not, how many do so? Note that the true leaves are in opposite pairs, the pairs of successive whorls being crossed, so that the true leaves are in 4 rows on the stem. The other appendages in each whorl are leaf-like stipules. There are always two leaves (distinguished by having buds or branches in their axils), and the number of other parts in the whorl depends on the extent to which the stipules branch on the one hand, or "fuse" (grow together) on the other. Note how the shoots of Goosegrass insinuate themselves between the branches and leaves of the hedge-plants.

One often sees the seedlings growing in crowded patches, some right below the hedge, others out in the open; which seedlings perish soonest, and why? The Goosegrass is one of the most interesting and instructive plants found in hedgerows, and careful observations, at frequent intervals, of patches of its seedlings offer a fine example of the fierce struggle for existence, which is keenest in places like hedgerows (why?), and of the advantages (and disadvantages) accruing to a plant which is adapted to a special mode of life, such as the climbing habit. Note the great extent to which the Goosegrass grows in a single season; it is an annual plant.

[**234. Cultivated Climbers.**—The following **twiners** are often cultivated :—**Scarlet Runner, Dutchman's Pipe** (*Aristolochia*), **Jasmine, Wistaria, Morning Glory** (*Ipomoea*), "**Tea-plant**" (*Lycium*), and various species of **Convolvulus, Honeysuckle,** etc.

Cultivated **tendril-bearers** show many points of interest. Some have ordinary coiling tendrils, which may be branches, *e.g.* **Passion-flower, Trumpet-flower** (*Bignonia*), **Vine,** various species of **Virginian Creeper** (*Ampelopsis*) ; or modified leaflets, *e.g.* **Sweet Pea, Garden Pea**; or whole leaves, *e.g.* **Cucumber, Vegetable Marrow**; or prolonged leaf-tips, e.g. *Mutisia* (Compositae), *Gloriosa* (Liliaceae) ; or sensitive leaf-stalks, e.g. *Clematis, Solanum jasminoides, Maurandia, Tropaeolum, Nepenthes* ; or modified stipules, e.g. *Smilax* ; or coiling roots, *e.g.* **Vanilla Orchid.** The tendrils of **Self-clinging Virginian Creeper** (*Ampelopsis veitchii*) differ from those of other Virginian Creepers in being branched, each branch ending in a sticky disc, so that this plant can climb up walls. In *Cobæa scandens*, a greenhouse climber, the tendrils are branched and each branch ends in a hook ; the tendril is very sensitive, and the hooks enable it to hold on to a support until it has had time to coil round it.

Among **root-climbers,** which send out negatively heliotropic attaching roots like those of Ivy, are the following cultivated climbers :—**Rooting Trumpet-flower** (*Tecoma radicans*, allied to Bignonia), **Poison Ivy** (*Rhus toxicodendron*, rather like a Virginian Creeper, but leaf with three leaflets only, and their margin is entire or nearly so), and the **Climbing Fig** (*Ficus repens*, with small leaves ; the climbing-roots secrete sticky juice, and as this dries the root-tip is firmly cemented to the support). These root-climbers can, like Ivy, climb up walls.]

235. Parasites and Saprophytes.—In our work on the nutrition of plants, we have so far dealt only with the manufacture of food by photosynthesis, the raw materials being water, dissolved earth-salts, and atmospheric carbon dioxide, the energy required for the process being derived from sunlight by means of chlorophyll. Some plants obtain their food in a totally different way, by living as **parasites** on other living plants (or on living animals in the case of some bacteria), or as **saprophytes** on dead organic matter.

Parasites and saprophytes are distinguished as *total* or *partial*, according to whether they get the whole, or part only, of their food in these ways. Plants which have no chlorophyll are necessarily total parasites or saprophytes, since they cannot use free carbon dioxide, and must obtain carbon in the form of organic compounds. Fungi and bacteria can usually obtain the nitrogenous part of their food from fairly simple nitrogen compounds—*e.g.* salts of ammonia—and some of them can fix the free nitrogen of the air, but for their carbon all chlorophyll-less plants appear to be dependent on the organic substances manufactured by plants which have chlorophyll.

236. Total Parasites.—Dodder, Broomrape, and Toothwort are British examples of flowering plants which are practically total parasites.

The **Dodder** (*Cuscuta*) belongs to the Convolvulus order. The commonest British species (*C. epithymum*) grows on Gorse, Ling, Thyme, and Clover. The seed, which contains a thread-like embryo, germinates in spring, sending a short radicle into the soil, while the shoot rapidly elongates and sweeps round in widening circles in the air. If it meets with a suitable plant (the plant on which a parasite grows is called, rather ironically, its "host"), the Dodder stem, which is endowed with tendril-like sensitiveness to contact, twines around the host-plant and sends into it root-like organs (termed *haustoria*, or "suckers") which, by means of ferments, eat as well as push their way to the bundles of the host.

The wood-vessels and sieve-tubes of these organs fuse with the wood-vessels and sieve-tubes of the host, and thus the Dodder draws from the host its supplies of organic food as well as water and salts. Meanwhile the radicle of the Dodder dies off. The thin reddish stem of the parasite branches copiously, bearing small scales (instead of ordinary leaves) and numerous clusters of flowers. If the Dodder seedling does not happen to reach a suitable host-plant it soon dies.

The **Broomrape** and the **Toothwort** are root-parasites, *i.e.* their earth-roots bear, at the ends of the rootlets, suckers which apply themselves to the roots of the host-plant and send in sucking organs like those of Dodder. The commonest British species of Broomrape are the **Greater Broomrape** (*O. major*), which grows on the roots of shrubby Papilionaceae (Broom, Gorse, etc.), and the **Lesser Broomrape** (*O. minor*), which grows on Clover and various other plants.

The **Toothwort** (*Lathraea squamaria*) has a creeping underground stem which branches and bears crowded fleshy leaves, while the erect shoots bear thin scaly leaves and end in a raceme of flowers. The leaves covering the creeping underground branches are hollow and are beset internally with short glandular hairs, which probably serve to excrete excess of water absorbed from the roots of the host-plant (usually Hazel), into which the Toothwort sends parasitic roots. The curious hollow leaves of the Toothwort are often described as traps for insects, which are supposed to be held fast and digested by the glands lining the branching cavity of the leaf, but this is probably a mistake.

237. Partial Parasites are plants which contain chlorophyll and have ordinary foliage-leaves, so that they can make at least part of their organic food by photosynthesis, while they draw their supply of water and dissolved salts from a host-plant. When the seed of the Mistletoe (whose sticky fruits are carried by the birds) germinates on the branch of a suitable tree (Apple, Oak, Hawthorn, etc.), the radicle penetrates the host, and the woody tissues of the two plants become continuous (Fig. 64).

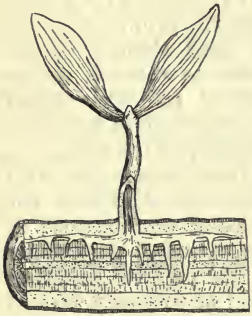

Fig. 64.—Young Mistletoe Plant, with Twig of Host-plant in Section.

Several members of the Foxglove family (*Scrophulariaceae*) are partial parasites, their roots being attached to the roots of other plants, chiefly grasses, though (like the mistletoe) the plant has green leaves which carry on photosynthesis. Examples are the Yellow Rattle, Lousewort, Eyebright, Cow-wheat, and *Bartsia*. Most of these plants grow in swampy grass-fields, and where their roots come into contact with the roots of Grasses, swellings are formed at the ends of the parasite's roots, from which sucking processes grow into the grass-roots. The suckers are formed in spring, and through the summer they absorb food from the living grass-roots; during this time the swellings contain no starch. In autumn the suckers store up reserve food, derived from the grass-roots.

Another British partial parasite, which has sucking-roots attached to the roots of Grasses and of various other plants, is the Bastard Toadflax (*Thesium linaphyllum*); it is not nearly so common as the plants just mentioned, and grows chiefly in dry chalky pastures in the south of England.

Examine the **Mistletoe**, if possible a plant growing on its host tree. It is shrubby, with smooth green stem, repeatedly forked at the swollen nodes. Each branch bears two opposite leathery green leaves (sometimes a circle of three leaves) and represents a year's growth; the leaves are evergreen. The flowers (March-May) are in groups of three or five in the forks of the branches. The fruits ripen in winter and have white pulp around a single seed; the very sticky coating of the seed prevents birds from swallowing the seed, which they scrape from their bill, and if this happens on a suitable tree germination occurs. The radicle forms an attaching disc from which a sucker grows into the wood of the host and gives off lateral roots which grow in the cortex and produce further suckers into the wood.

238. Total Saprophytes.—British examples of totally saprophytic flowering plants are the **Bird's-nest Orchid** (*Neottia*) and the **Yellow Bird's-nest** (*Monotropa*, allied to the Heather family). Both plants get their names from the nest-like mass formed by their numerous clustered roots, and both grow in shaded woods and plantations, *Neottia* in Beech woods, *Monotropa* in woods of beech, pine, and birch. Both have erect flowering shoots bearing brown or yellowish scales instead of green leaves and ending in a raceme of flowers. In both cases the plant can only grow in soil containing abundant decaying vegetable matter (humus), and is enabled to use this for its nutrition by the aid of a fungus which infests its roots. Humus is always permeated with the threads of fungi, and in *Monotropa* these threads form a dense felted covering on the roots, while in *Neottia* the threads enter the cortex of the root and actually grow in the living cells of the cortex.

Thus the flowering plant is supplied with digested and soluble organic food which it could not absorb in the ordinary way by its root-hairs from the soil. The fungus by its association with the roots also gains certain advantages, such as shelter from drought, so that the arrangement is an example of **symbiosis**, which may be defined as a mutually beneficial partnership, or an association of two organisms in a common life to the benefit of each. This particular kind of symbiosis is called a **mycorhiza**, *i.e.* an association of a fungus with the roots of a higher plant. Symbiosis must be carefully distinguished from parasitism, where one organism lives at the expense of another.

There is no dividing line between total and partial saprophytism; even *Neottia* has some chlorophyll.

239. Partial Saprophytes also obtain food by means of a mycorhiza, but since they have green leaves and therefore carry on photosynthesis, they are not so completely dependent on the fungus-servant.

The roots of most forest-trees, and of very many other plants, especially those which grow in the rich humus of woods and plantations, have an external mycorhiza like that of *Monotropa*, while in Ericaceae (Ling, Heaths, Bilberry, etc.) the mycorhiza is usually internal as in *Neottia*.

In the case of partial saprophytes with an external mycorhiza, it is probable that the fungus-threads act as root-hairs, and absorb water and inorganic salts in addition to organic compounds. The latter are probably chiefly absorbed for the sake of the carbon they contain, since the green plants can absorb carbon dioxide from the air. Plants provided with a mycorhiza produce few or no root-hairs, since the projecting fungus-threads form a far more effective means of absorbing food-materials than do root-hairs.

240. Assimilation of Nitrogen by Leguminous Plants.—The *free* nitrogen of the atmosphere, although abundant, is not made use of by the green plant. There is, however, one important order of flowering plants, the Leguminosae, in which the nitrogen of the atmosphere is *indirectly* used. It was for a long time recognised that leguminous plants would readily grow in a soil containing little or no *combined* nitrogen, and that as a matter of fact the soil was oftener richer in nitrogen after a leguminous crop had been grown. These facts, which were at first extremely puzzling, have now been explained.

Numerous small nodules or tubercles are found on the roots of these leguminous plants. When the tubercles are carefully examined they are seen to be filled with small oval unicellular bodies called **bacteroids**. By some these are regarded as bacteria; by others as the "spores" of a fungus. They are always present in the soil and infect the roots of leguminous plants through the root-hairs. In the root-hairs they give rise to fine tubes which, making their way into the cortical tissue, stimulate it to active growth and thus lead to the formation of tubercles. The developing tubercles are rich in starch, and later each receives a branch from the vascular bundle of the root. The bacteroids found in the fully grown tubercle are developed inside the invading tubes.

Analysis shows that the tubercles are very rich in nitrogenous substances, also in potash and phosphorus, and they seem to develop best in soils which are poor in nitrogen compounds. The tubercles do not develop in plants grown in garden or field soil which has been heated so as to kill any organisms present in it. On the other hand, they grow on roots of plants which have been germinated in garden soil and then placed in culture solution.

There can be no doubt that we have here an example of symbiosis. The fungus apparently makes use of the free nitrogen of the air, and brings it into combination, just as some true bacteria do; and it is probable that, while the leguminous plant gets the benefit of the nitrogen-compounds (nitrates) formed, the fungus is supplied with carbohydrates (sugar) manufactured by the green plant. The arrangement may be regarded as a special kind of mycorhiza.

Some striking results have been obtained recently by Professor Bottomley, who has taken a leading part in the investigation of nitrogen-fixing organisms. For instance, two lots of Tare (*Vicia sativa*) seeds were taken. One lot was inoculated with nodule-bacteria and planted in sterilised sand to which the requisite potash and phosphorus salts were added. The untreated seeds were sown in sand containing nitrate of soda in addition to potash and phosphate. The seeds were sown in May; in July the Tares supplied with nitrate of soda yielded 1·9% of nitrogen, while the inoculated Tares gave 3% of nitrogen. Three experimental field-plots of Tares gave the following results in September:—(1) No nitrogenous manure used, 3·41% nitrogen; (2) nitrate of soda used, 3·75% nitrogen; (3) inoculated seeds 4·04% nitrogen. In the case of field-crops the results are less striking, because fertile farm-soil always contains nitrogen-fixing Bacteria.

Professor Bottomley's work has led to a still more important result: plants other than Leguminosae can be inoculated with nitrogen-fixing Bacteria. Tomatoes have been made to yield a greatly increased crop by this means; the Bacteria were first cultivated in Tomato-juice. In Wheat the Bacteria can be induced to establish themselves in the rind (*cortex*) of the roots, though no nodules are formed.

Further information regarding the work of soil-Bacteria is given in *Plant Biology*, Chap. III. ("Roots and their Work") and Chap. X. ("Biology of the Soil").

241. Carnivorous or Insectivorous Plants obtain part of their nitrogenous food by catching insects in various ways, by means of modified leaves, and afterwards absorbing the soft parts of the insects. The British insectivorous plants are the Sundews, Butterwort, and Bladderwort.

The **Butterwort** (*Pinguicula*) has a basal rosette of broad leaves, whose upper surfaces are covered with sticky glands, while the margins are rolled inwards slightly. Small insects are caught by the sticky liquid and washed by rain to the edge of the leaf, which curls inwards and encloses them; the glands then secrete digestive ferments, absorb the products, and then the leaf becomes unrolled again.

The leaves of **Sundew** (*Drosera*) bear numerous stalked glands or tentacles which secrete a sticky fluid (Fig. 65). If an insect adheres to the tentacles, they bend down upon it and pour out a fluid which has the power of digesting, and rendering soluble, albuminous or proteid substances (white of egg, meat, etc.) in a similar manner to that occurring in the stomach of an animal. The secreted fluid is reabsorbed, together with the soluble nitrogenous products (peptones). When digestion is completed, the tentacles resume their former position, and are then ready to capture another insect, a process which may be repeated several times. The tentacles may be stimulated to movement by continued contact with any solid substance, but apparently no digestive fluid is secreted unless a suitable organic substance—*e.g.* a piece of raw meat or of boiled egg-albumen—is placed on the leaf.

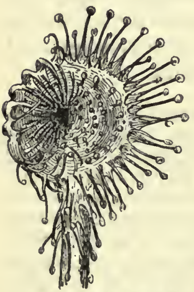

Fig. 65.—Leaf of Sundew. Tentacles expanded on the right; partially inflexed over an insect on the left.

The **Bladderwort** (*Utricularia*) is a submerged water-plant which has no roots; the submerged parts show no clear division into leaves and branches, but are finely divided, and the flowering shoots project above the water. The submerged parts bear curious bladders, each with a trap-door or valve which is easily opened by a push from the outside, so that small animals (insects, water-mites, water-fleas, etc.) cannot escape once they have entered the bladder. When these animals die their soft parts decay and are absorbed by branched hairs which occur on the inner surface of the bladder.

The leaves of Venus' Fly-trap[1] are two-lobed, and the midrib acts as a hinge. Each lobe bears on its upper surface three long sensitive hairs, and when one of these hairs is touched, the two lobes snap together, just as one closes an open book, and capture the insect that has caused the disturbance (Fig. 66). Digestion occurs as in Sundew. The leaves of Venus' Fly-trap are only slightly sensitive to chemical stimuli, but if the closing of the lobes has been

Fig. 66.—Venus' Fly-Trap (Dionaea muscipula).

caused by an insect they press tightly against each other and hold the insect fast (the interlocking teeth on the edges of the lobes prevent its escape after the sensitive hairs have been stimulated), whereas the closing remains incomplete, leaving a wide space between the lobes, if the hairs have been touched by, say, a pencil. In the latter case the leaf opens again, but if an insect has been caught the leaf remains closed until the digested products have been absorbed.

[1] A native of Carolina, where it grows in swamps; often cultivated in hot-houses.

In the **Pitcher-plants,** of which *Nepenthes* (Fig. 67) is the best-known example, the whole or a part of a leaf is developed as a pitcher with a lid attached to one side of the opening. The bottom of the pitcher contains water, usually swarming with Bacteria, and in *Nepenthes* a digestive ferment (pepsin) is secreted, so that the insects falling into this liquid are first drowned and then digested. The pitchers of *Sarracenia* (Fig. 68) are also modified leaves, but instead of digesting the captured insects they seem simply to absorb the products of their decomposition by Bacteria. In these and other Pitcher-plants, the lids of the pitchers are brightly coloured and serve to attract insects, but they have no power of movement, and cannot close when once they have opened.

Fig. 67.—Pitcher of Nepenthes Distillatoria.

Fig. 68.—Pitcher of Sarracenia.

The rim of the pitcher bears honey-glands, which help in attracting insects; below the rim there comes a zone covered with small glands sunk in pits on the inner surface of the pitcher, then comes a smooth slippery region, the lower part of which has hairs pointing downwards, and finally tne lowest part containing water. Insects crawling over the gland-bearing upper region soon reach the slippery zone, and are prevented by the hairs below this from crawling up again, so that they eventually fall into the liquid and are drowned.

Most insectivorous plants have enough chlorophyll to enable them to make all the organic food they need, and they can grow quite well when not supplied with insects. When fed with insects, raw meat, or boiled egg, however, the plants become stronger, flower more freely, and produce stronger and more numerous seeds. Most insectivorous plants grow in poor swampy soil, which is usually deficient in nitrates and other available nitrogen-compounds. By the capture and digestion of insects they obtain supplies of nitrogenous food independently of the soil, and can in this way grow in localities which would otherwise be unsuitable.

Experiments with Sundew.—Select leaves which have large drops of the secretion on the tentacles, avoiding the dark-red leaves which are too old to show the movements well.

(*a*) Carefully place a very small fragment of raw meat on one of the long outer tentacles, and watch the bending inwards of the tentacle by which the meat is brought towards the centre of the leaf. Do any of the other tentacles bend towards the piece of meat ?

(*b*) Carefully dust a little powdered chalk over the gland of a tentacle. In most cases no movement occurs, since the particles only touch the secretion and not the surface of the gland itself. Place on another tentacle a small solid body, such as a small particle of sand, heavy enough to sink through the secretion and touch the tentacle ; does this produce any movement ?

(*c*) Strike the gland of another tentacle with a match-stick. Note that a single tap does not produce movement. After watching the tentacle for about a minute, tap it repeatedly and see whether movement results.

(*d*) Cut off a few leaves and place some in distilled water, others in water made milky by stirring into it some powdered chalks. After about 5 minutes, notice that the leaves in the milky water show bending of the tentacles, while those in the pure water show none or very little. Vary this experiment by filling a narrow glass tube with water and letting drops fall on a gland for about a minute ; no movement occurs, but if water containing chalk is used, the tentacle bends inwards. Hence the tentacles are not sensitive to pure water, but are sensitive to water containing the finest solid particles.

(*e*) Place a minute piece of raw meat in the centre of a leaf ; the outer tentacles all bend in towards it. On another leaf place a piece of meat about half way between centre and edge of the leaf, and note that the tentacles bend, not towards the centre of the leaf, but towards the piece of meat. Hence a stimulus received by any tentacle is transmitted to the other tentacles.

QUESTIONS ON CHAPTER VIII.

1. Describe the organs by which six British plants climb.

2. What are the advantages, and the disadvantages, of the climbing habit?

3. Describe and compare modes of climbing in a twiner and a tendril-climber.

4. Describe two British examples in each case of (*a*) total parasites, (*b*) partial parasites.

5. Describe two British examples in each case of (*a*) total saprophytes, (*b*) partial saprophytes.

6. Describe (*a*) the chief British insectivorous plants, (*b*) three foreign insectivorous plants. Compare their methods of work.

7. Distinguish between the varying degrees of parasitism found among the British Phanerogams, citing special examples of the forms you describe.

CHAPTER IX.

FLOWERS AND THEIR WORK.

242. The Work of the Flower.—We have already examined the Broad Bean flower, and we have seen that after a time nothing is left of the flower except (*a*) the "young pod," which becomes greatly enlarged and contains the seeds; and (*b*) the calyx, which remains as a cup round the bottom of the pod. Evidently the great work of the flower is the production of seeds. Are any other parts besides the pistil concerned in this work, and, if so, what share do they take in it? You have noticed the yellow powder (pollen) which is produced in the anthers and is set free when they open, and which is then found inside the keel and on the upper parts of the pistil (style and stigma). Has the pollen anything to do with the production of the ripe pod and its seeds? Would the pistil grow into a fruit, with seeds, if no pollen came into contact with it?

(*a*) **Effect of removing the Anthers.**—Flowers which have not yet opened must be used in these experiments, because the anthers burst and shed their pollen at an early stage. Remove the anthers, making sure that you pick off the whole number, and that none of them have burst already. To prevent pollen from reaching the pistil from another flower, tie a small bag of paper or of fine muslin over the antherless flower, which must, of course, be allowed to remain on the plant. If the removal of the anthers has been carefully done, the flower will open much as usual. Treat several flowers in this way, in case any damage is done which might throw doubt on the results. Are any seeds formed? Leave some of the antherless flowers uncovered: do any of these produce seeds?

(*b*) **Effect of removing the Stigma.**—You will have noticed pollen adhering to the upper part of the pistil, *i.e.* the style, especially to the tuft of hairs and the little terminal process (stigma) just above it. Is this end part of the style the only part capable of receiving pollen? Open young flowers (with the same precautions as before) and remove the upper part of the style, cutting just below the tuft of hairs; cover some of these stigmaless flowers with small bags, and leave others exposed. Does this affect the result? To meet the objection that the removal of the stigma causes injury which might account for the result, try the effect of opening some young flowers and covering the top of the style with a small bit of plasticine.

243. Pollination.—The foregoing experiments show that ripe seeds are not produced unless pollen comes into contact with the upper part of the style—that is, unless pollination occurs. Will pollen from the anthers of the same flower suffice, or must the pollen come from another flower?

(*a*) Cover a young unopened flower with a paper or muslin bag, and see whether seeds are produced. Treat several flowers in this way, so as to have a number of results on which to base your inferences.

(*b*) Place pollen on the stigmas of newly opened flowers, using a fine brush; dip the brush into boiling water before using it again each time (to kill any pollen left on it). In some cases (A) place on the stigma pollen from the anthers of the same flower; in others (B) bring the pollen from another flower on the same plant; in others (C) bring it from a flower on another plant. In the two latter cases (B and C) the flower's own anthers must be removed before they have opened.

Simple experiments like these show that the Broad Bean can be **self-pollinated** (Art. 246), although self-pollination does not seem to occur so freely in this plant as in various other cultivated plants of the Bean family (Sweet Pea, Garden Pea, etc.). In the latter plants, in fact, pollination regularly occurs before the flower-bud opens, so that abundant seed is set in the entire absence of insect-visitors.

244. The Essential Organs.—It is now obvious that the only parts of the flower directly concerned in, and essential to, seed-production are the stamens and the pistil. The lowest seed-plants (*e.g.* Pine, Larch, Yew, Cycads) have their young seeds exposed (on flat scales in most cases) to the air, instead of being formed within a closed chamber or seed-vessel, as in the Bean; and the stalks of the stamens cannot be considered as essential (they remain undeveloped in some plants). The essential structures appear, therefore, to be the anthers and the "young seeds." We know that in the Bean, as in other seed-plants, these "young seeds" do not develop into mature seeds, but perish like the rest of the flower, unless pollen-grains are placed on the stigma.

245. Fertilisation.—In what way does the pollen-grain

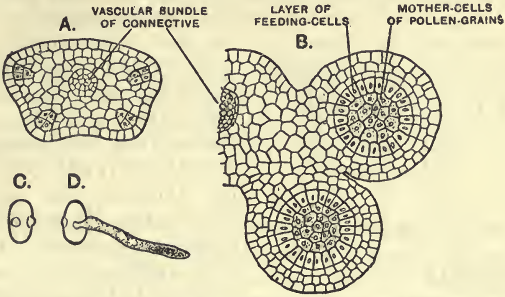

Fig. 69.—Broad Bean: A and B, Cross-sections of Young Anthers; C, a Ripe Pollen-grain; D, Pollen-tube.

induce the "young seed" (*ovule*) to develop into a mature seed? What happens when a pollen-grain is placed on the

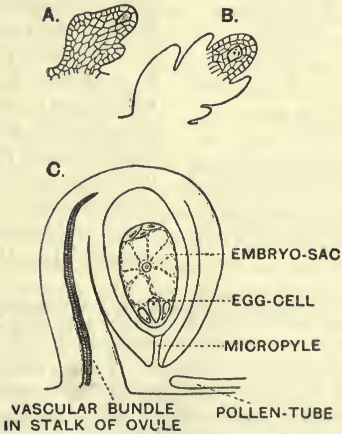

Fig. 70.—Development and Structure of Ovule ("young seed"), Longitudinal Sections.

stigma? We cannot give a full answer to these questions unless we study the minute structure of the parts concerned.[1]

[1] Preparations of specimens showing fertilisation and embryo-formation are included in the *Plant Biology Set of Microscopic Slides.*

In each ovule a cell, the *egg*, is produced. When the flower has opened the stigma becomes wet and sticky, so that pollen-grains are held on it. Each pollen-grain grows into a long fine tube which burrows down through the style and eventually enters the little opening in the ovule and its tip touches the egg-cell, which lies close to this opening, embedded in the ovule (Figs. 69-71). The pollen-tube opens, and a male cell passes from it to the egg-cell and fertilises it, *i.e.* fuses with it. Then the fertilised egg develops into the young plant (embryo); the part just outside of the embryo also grows to produce the endosperm, which may or may not be absorbed by the embryo before the seed ripens, the seed being non-endospermic ("exalbuminous") in the former case, endospermic ("albuminous") in the latter.

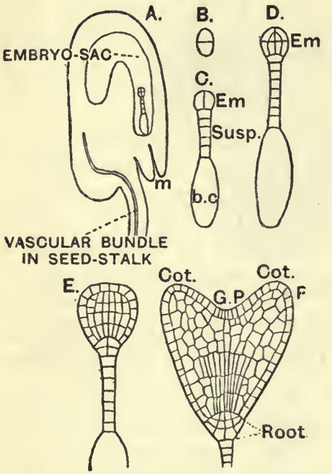

Fig. 71.—Development of Embryo in Shepherd's Purse.

A, Young Seed (treated with caustic potash) showing Embryo at micropyle-end of curved Embryo-sac; m., Micropyle; B-F, stages in growth of Embryo; G.P., Growing-point of Stem; Susp., Suspensor; b.c., Basal Cell; Cot., Cotyledon; Em., Embryo.

(*a*) Examine the stigma of a Tulip (or other flower with large stigma), and see whether it is wet. If so, shake over it some powder, *e.g.* flour or chalk, and then try to blow the powder off. Place a stigma on your tongue, and see whether it is sweet. Place a few stigmas in some Fehling's solution in a test-tube, and heat (test for sugar).

(*b*) Place some water in watch-glasses and add different amounts of sugar, so as to get solutions varying in strength from 5 to 20 per cent. Into each place some pollen; try various plants. In the case of the Broad Bean and the Sweet Pea a 10 per cent. solution is about right, and in an hour, or even less, you will see a slender thread growing from some of the grains; this is the pollen-tube, which resembles a root-hair in appearance (Fig. 69, D). If you have a microscope, fix a ring of cardboard or of plasticine on a glass slide; put a drop of sugar solution on a cover-glass, dust some pollen in it, then invert the cover over the ring. The drop will hang into a closed chamber, thus preventing evaporation; note the growth of the pollen-tubes.

(*c*) The development of the embryo is easily followed in the Shepherd's Purse, a very common weed which flowers nearly all the year round. Pick flowers from which the outer parts are falling or have just fallen. Open the young fruit and remove the young seeds to a slide, then cover them with a few drops of caustic potash solution. Tease the seeds with needles, or press them under a cover-glass, to isolate the embryos. Sketch the stages observed (Fig. 71).

246. Self-Pollination and Cross-Pollination.—In the Broad Bean, as in many other plants, it is found, on making experiments in artificial pollination, that it is better if the pollen comes from a flower on another plant of the same species (*cross-pollination*) than if it comes from the anthers of the same flower or from those of another flower on the same plant. The two latter cases are very similar in their results, and may be both included under the term self-pollination. When cross-pollination occurs, the resulting seeds are generally more numerous or heavier, and give rise to stronger offspring (superior in height, weight, fertility, etc.) than is the case with self-pollination.

In self-pollination there is a mixing of practically similar characters, while in cross-pollination there is a mixing of more or less dissimilar characters, especially when the plants that produce the male and female cells live far apart and under different external conditions. Also, any useful variation is likely to be transmitted and even strengthened when cross-pollination occurs. It is, therefore, an advantage to the species to secure cross-pollination, and we find many adaptations, some of them very remarkable, which favour cross-pollination and hinder self-pollination.

247. How Pollen is Carried.—Pollen-grains have no power of spontaneous movement. When the anthers are above the stigma, self-pollination may occur (if the two are mature at the same time) by pollen simply falling on the stigma, but for cross-pollination the grains must be carried to the stigma of another flower by water, wind, or animals. Water-pollination occurs only in water-plants, and only in a few of these. In this country insects are probably the only animals concerned in carrying pollen from flower to flower, but there are foreign flowers which are pollinated by birds (especially humming-birds), bats, and even snails.

248. Mechanism of Broad Bean Flower.—Here cross-pollination is brought about by bees, which may be seen at work on the flowers if you watch plants growing in the open during fine weather. Wind-pollination is out of the question in this case, since the stamens remain enclosed in the keel.

When a bee alights on the flower it stands on the two wing-petals, which bend down under the weight of its body. Since the wings are jointed with the keel, the latter is also pressed down. If you carefully watch the bee at its work, or imitate its action by pulling down the tip of the keel, you will see that when this happens a mass of pollen is brushed out of the keel by the tuft of hairs on the style, and the stigma projects from the keel as well. Some pollen is deposited on the bee's hairy body, which also rubs against the stigma; if the bee has visited another Broad Bean flower previously, some pollen will probably be left on the stigma. When the bee leaves the flower the keel rises to its former position, and the process may be repeated a few times when other bees visit the same flower.

Notice the long "tongue" (proboscis) which the bee pokes into the lower part of the stamen-trough below the free stamen. It is easy to see this if you pull off the standard and carefully watch the next bee that comes to the flower. What does the bee find here? If you take a newly opened flower, remove the calyx and corolla, and pull apart the stamen-trough and the pistil, you will notice the liquid which has collected at the bottom of the trough. Sugar is present in this liquid (the honey or *nectar*) which is produced by gland-cells at the base of the stamen-trough.

The bee is guided to the flower, in its search for honey, by the white corolla (easily distinguished among the foliage, and made more conspicuous by the velvety black spot on each wing-petal) and also by the fragrant odour of the petals.

The coloured streaks on the standard help to guide the bee to the opening below the free stamen; but its removal does not prevent a bee from finding this opening, as can easily be seen by making the experiment. These conspicuous streaks and spots are often called "honey-guides."

Since the honey can only be reached when the keel is pressed down with some force, and is produced at the bottom of the tube formed by the stamen-trough (closed above by the free stamen and the standard), it can only be reached by an insect with a heavy body and a fairly long tongue. The flower is specially adapted to the visits of bees. It is also visited by butterflies and moths.

Sometimes a bee when working at the flowers may be seen to bite through the calyx-tube and insert its tongue through the hole thus made, thus reaching the honey without entering the flower in the "proper" way, *i.e.* from the front. Many other "bee-flowers" (*i.e.* flowers specially adapted for bees' visits) show neat round holes bitten out by the bee in its short cut to the honey, of which it robs the flower without rendering any service in return.

249. Functions of the Calyx.—The calyx has three important uses in the Bean-flower. (1) It protects the inner parts of the young flower. In the bud, the stamens and pistil are enclosed in the keel, the wings are folded over the keel, and the standard over the wings, and the calyx is wrapped over the outside of all. (2) When the flower opens, the corolla expands, pushing aside the calyx-lobes, then the standard curves upwards, and the flower is ready for the visits of bees. The calyx then serves to hold the petals together and prevent their falling apart. (3) The calyx also protects the young fruit to some extent from becoming dried up.

The calyx often assumes other functions, *e.g.* the attraction of insects (Monkshood, etc.), seed-dispersal (many Composites).

250. The Parts of the Flower.—The outer floral parts, exclusive of the stamens and carpels, constitute the **perianth,** which may either be single or, more commonly, double. If the outer series of parts in a double perianth are distinctly differentiated from the inner, we term the former the **calyx** of (usually) green sepals, and the latter the **corolla** of (usually) coloured petals. In some flowers with a double perianth, it is hardly possible to distinguish between the sepaline and petaline parts (*e.g. Tulip*). Some flowers, however, have a perianth which is composed of a single ring or series of parts only, while others have no perianth.

The perianth forms the non-essential part of the flower, whereas the stamens and carpels are the essential organs, and one or both of these must be present to constitute a flower. A "typical" flower possesses sepals, petals, stamens, and carpels arranged in single or double alternating rings, each ring containing the same number of similar parts, but frequently the parts are arranged in a spiral, especially the stamens. Flowers which have no carpels are said to be "male" or staminate; those without stamens are "female," carpellary, or pistillate.

251. Perianth.—This term is sometimes used to include the calyx and corolla together, but more often it is applied to the flower envelope when there is no distinction, or very little, in colour and texture between the outer and inner parts of the envelope. For instance, the perianth of Tulip and Bluebell consists of six similar coloured leaves, free from each other (*polyphyllous*) or only slightly joined at the base. In Lilies and Hyacinths the perianth is *gamophyllous*, consisting of a lower tubular part and six free lobes. In Daffodil and Narcissus, besides the tube and the lobes there is a collar-like outgrowth or corona at the mouth of the perianth-tube.

Examine and sketch the perianths of the following flowers:—Tulip, Hyacinth, Solomon's Seal, Snowdrop, Daffodil, Narcissus (several kinds, to show variation in form of corona, Fig. 87), Early Purple Orchid, Bee Orchid, Twayblade Orchid, Lady's Slipper Orchid.

252. Calyx.—The primitive, or simplest, type of calyx consists of spirally arranged *sepals*, which arise directly from the receptacle, as small green sessile leaves. The individual sepals may be free (*polysepalous* calyx), or more or less united (*gamosepalous* calyx). However complete the union may be, the number of sepals which take part in the formation of the calyx is usually indicated by the pointed teeth borne on the upper margin of the tube.

When a calyx is present, it is usually composed of two (Poppy), three (Lesser Celandine), four (Wallflower), or five (Buttercup) sepals. More rarely the sepals are numerous, and retain their primitive spiral arrangement (Water-lilies, Cactuses).

The calyx commonly serves to protect the flower while it is still young, and hence, when the flower opens, the sepals either fall off (Poppy) or turn back (Dog Rose). Another of its functions, however, is to protect the developing fruit, and hence it often persists until the fruit is formed, as in the Bean, Strawberry, and Dead-nettle. A gamosepalous calyx affords not only a more efficient protection to the flower-bud than a polysepalous one, but also gives support and protection to the base of the adult flower and to the developing fruit. Hence the gamosepalous calyx never falls off when the flower is young. In "Winter Cherry" the calyx forms a red bladder round the fruit.

When the flowers and fruits are closely aggregated, they no longer need a protective calyx, which therefore becomes quite small, as in Umbellifers, and when a closely packed mass of flowers is surrounded by a ring of protective bracts, the calyx may either disappear (Daisy) or be represented only by hairs. These hairs in the Dandelion, Thistle, Hawkweed, etc., persist after flowering, and form a *pappus*, which is attached to the ripened fruit and aids in its dispersal by the wind.

The sepals are usually green, but the "petaloid" sepals of Monkshood, Winter Aconite, Christmas Rose, Larkspur, and Marsh Marigold are brightly coloured, and take on the attractive function of the petals, which are either developed as nectaries or are absent.

Examine and sketch (1) the entire calyx, (2) the individual sepals, of the following flowers :—Buttercup, Lesser Celandine, Wallflower, Sweet Pea, Gorse, Mallow, Rose, Cinquefoil, Strawberry, Cherry, Dead-nettle, Foxglove, Larkspur, Monkshood, Christmas Rose, Winter Aconite.

253. Corolla.—The primitive corolla consists of a spiral of free petals, but in most plants this has been changed into a single whorl (Foxglove, Geranium) or, more rarely, a double whorl of petals (Poppy). The corolla protects the stamens and carpels at the most critical period of their existence, and this is especially the case when the petals have grown together to form a tube enclosing the essential organs. The corolla-tube often serves as a receptacle for honey, while the coloured portion attracts the visits of insects. As soon as fertilisation has occurred, the seeds begin to develop, and an attractive corolla being no longer needed, it is usually rapidly shed. The withered corolla may, however, persist round the fruit (*e.g.* Heaths, Plantains, Clover).

When the corolla is polypetalous, the individual petals often consist of a narrow stalk or *claw*, and an upper broader portion, the blade or *limb* (Wallflower). The petals of the Pink have a scaly outgrowth (ligule) at the junction of the claw and limb, and in Narcissus there is a circular cup, or *corona*.

The corolla is said to be *regular* when all its parts are similar, *irregular* when they differ in shape from one another, and the same terms apply whether it is poly- or gamopetalous. In Christmas Rose and Winter Aconite the petals are represented by hollow nectaries, and the sepals form the showy attractive portion of the flower. The nectaries are represented in the Buttercup by tiny pockets placed behind a scale at the base of the inner surface of each petal. Hence the nectaries of the Christmas Rose are probably modified petals, as are undoubtedly the two posterior ones of the Monkshood.

Examine and sketch (1) the entire corolla, (2) the individual petals if free, of the flowers mentioned in Art. 252.

254. The **Andrecium** is the collective term applied to the whole of the stamens present in any single flower. Each stamen usually consists of two parts, a stalk or filament, and a head or anther. There may be no filament, so that the anther is sessile, or the anther may not develop, when what remains is known as a *staminode* or sterile stamen. The anther is usually divided into two halves or lobes, in each of which are two longitudinal compartments, filled, when ripe, with pollen grains. When the anther splits open, or *dehisces*, the partition between the paired pollen sacs of each lobe breaks down to a greater or less extent, so that each lobe appears to have only a single cavity (Fig. 72).

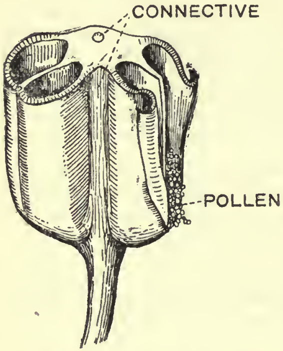

Fig. 72.—An Anther with the top cut off.

The right anther lobe is represented as being dehisced.

The prolongation of the filament between the two lobes of the anther is termed the *connective*. When the lobes are close together, this is narrow; but in Labiates and some other plants the connective is elongated laterally, and the anther lobes are widely separated. Special appendages are occasionally developed from the connective; each anther of the Violet has a membranous orange-coloured outgrowth at its apex, and in addition each of the two anterior stamens has an elongated process extending downwards into the spur of the anterior petal. The tip of this process is glandular, and secretes nectar into the spur.

As a general rule the different stamens of a flower are alike in shape, size, and in length of filament. Two of the stamens of the Wallflower, however, are shorter than the other four (*tetradynamous*), while the Dead-nettle has two long and two short stamens (*didynamous*).

The fully grown anther breaks open and allows the pollen to escape. It usually happens that the wall of each lobe splits longitudinally along the dividing line between its two compartments, but in many Labiates the anther opens transversely. In Potato, Rhododendron, Milkwort, etc., small pores are formed at the top of the anther. In the Barberry the whole side of each anther-lobe bends upwards; in the Laurel small doors or valves open at the sides of the anther.

Examine and sketch the stamens of the following flowers:—Buttercup, Gorse, Sweet Pea, Mallow, Potato, Violet, Pansy, Wallflower, Rhododendron, Heather, Dead-nettle, Foxglove, Barberry, Bay Laurel, Fumitory, Dicentra ("Bleeding Heart"), Garden Sage.

255. The **Gynecium** or **Pistil** is the collective term applied to the carpels present in a flower. In its simplest form the pistil consists of a single carpel, as in the Bean. Such a carpel corresponds to a leaf bearing ovules on its margins (Fig. 73), a condition in which the carpels of the Gymnospermous plant *Cycas* remain to the present day. We might suppose that as the higher flowering plants developed, the two halves of the carpellary leaf became folded longitudinally, and that their margins grew together along a line known as the ventral suture, which bears a double row of ovules on the two margins of the leaf.

Fig. 73.—Carpellary Leaf with Marginal Ovules.

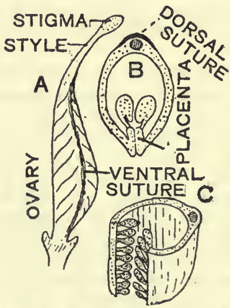

Fig. 74.—The Monocarpellary Pistil (*e.g.* Bean, Pea).

A, Entire; B, Transverse section of Ovary; C, Will indicate method of folding.

The purpose of this change is immediately obvious, for the young ovules are now protected within a hollow chamber known as the *ovary* (Fig. 74), which is formed from the swollen basal portion of the carpel. The apical portion of the latter forms a slender prolongation of greater or less length, the *style*, which usually contains a central canal communicating with the cavity of the ovary, but may be composed of loose, solid tissue with no definite central cavity. The *stigma*, or apical portion of the style, is usually swollen and covered with hairs (stigmatic papillae). The stigma forms the receptive surface for the pollen. The dorsal suture of the carpel corresponds to the midrib of a leaf; the cushion of tissue along the ventral suture, from which the ovules arise, is known as the *placenta*. In the Water-lily, Flowering Rush, and a few other plants, the ovules are scattered all over the inner surface of the carpels.

The flower of Buttercup or Rose contains several free simple carpels, and the pistil is therefore termed *apocarpous*. When several carpels are present in a flower, they are often united to form a compound or *syncarpous* pistil. The union may be confined to the base of the ovary (some Saxifrages), or may include the entire ovary (Campion), or only the stigmas may be free (Foxglove), or all three may be completely united together (Primrose). A syncarpous ovary may be divided into a number of chambers, each corresponding to the cavity of one carpel. Thus the Tulip has three carpels, and the ovary is divided into three chambers, each containing a double row of ovules.

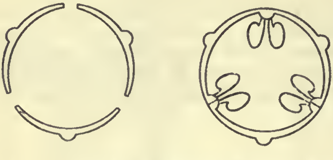

Fig. 75.—Diagram of Syncarpous Ovary, with Parietal Placentation.

The ovary of the Violet has a single chamber only, although it is composed of three carpels, as is indicated by the presence of three groups of ovules arranged in longitudinal rows upon its wall. When, as in this case, the ovules are attached to the wall of a compound ovary, the placentation, or arrangement of the placentas, is said to be *parietal* (Fig. 75); but when the ovules arise from the longitudinal axis in the centre of the ovary, the placentation is said to be *axile* (Fig. 76), *e.g.* Bluebell, Tulip. It will be noticed that when the placentation is axile, the ovules in each loculus are derived from the margins of the carpellary leaf that forms this chamber, whereas in the case of parietal placentation each group of ovules is derived from the margins of two adjacent carpellary leaves, half from each. In Chickweed, Stitchwort, Campions, Primrose, etc., the central axis of the ovary does not reach the roof of the latter, so that the ovules appear to arise from a mound in the centre of the ovary; this type of placentation is said to be *free-central.*

Fig. 76.—Diagram of Syncarpous Ovary, with Axile Placentation.

The number of chambers in an ovary usually corresponds, if there are more than one, to the number of carpels of which it is composed. In Labiates and Borages, however, each compartment of the bicarpellary gynecium is divided into two, so that there are four loculi, but only two carpels. The ripe ovary of the Flax becomes similarly divided into ten chambers instead of the five present at first.

Again, in unilocular ovaries with parietal placentation, each placenta usually corresponds to a single carpel. The number of styles or stigmas often corresponds to the number of component carpels, and the ripe fruit frequently splits into as many pieces as there are carpels.

In White Water-lily the numerous petals pass by gradual transitions into the more centrally placed stamens, all being spirally arranged on the receptacle; in double Roses the stamens, in double Buttercups both stamens and carpels, become petal-like; in White Clover the carpel sometimes remains open and produces green leaves on its edges; in Green Roses, double Cherry, etc., the carpels grow into green, white, or coloured leaves.

Examine and sketch (1) the entire pistil, (2) a cross-section of the ovary, (3) a longitudinal section of the ovary, of each of the following flowers :—Narcissus, Tulip, Buttercup, Marsh Marigold, Wallflower, Iris, Violet, Pansy, Mignonette, Dead-nettle, Foxglove, Snapdragon, Cherry, Primrose, Stitchwort, Red Campion, Sweet William, Mallow.

256. Cohesion and Adhesion.—"Fusion" between the parts of the same or of different whorls is of common occurrence. When the parts of the same whorl are united, they are said to be *coherent*, but when union occurs between the parts of different whorls, the term *adherent* is employed.

Adhesion is not so common as cohesion, but in most flowers which have a corolla-tube or perianth-tube the filaments of the stamens are usually adherent to the tube, so that the stamens appear to arise from corolla or perianth instead of from the receptacle. Adhesion between stamens and pistil occurs in Orchids and a few other plants.

The apparent "fusion" of parts is really due to the formation of a ring-like upgrowth of the receptacle, carrying with it the free parts of the young flower, which thus appear to have a common base.

When the parts of the same whorl are **free**, the perianth is **polyphyllous**; the calyx **polysepalous**; the corolla **polypetalous**; the andrecium **polyandrous**; the gynecium **apocarpous.**

By **cohesion** (union between *similar* floral parts) the perianth becomes **gamophyllous**; the calyx **gamosepalous**; the corolla **gamopetalous**; the andrecium **monadelphous** (stamens united by filaments, *e.g.* Mallow, Gorse), **diadelphous** (nine stamens united by filaments, one free, in most Papilionaceae), **polyadelphous** (stamens united by filaments into several bundles, *e.g.* St. John's Wort), or **syngenesious** (stamens united by their anthers, *e.g.* Compositae); the gynecium **syncarpous** (the styles or stigmas, or both, usually remaining free).

Adhesion (union between *dissimilar* parts) occurs only between the *stamens* and other parts; the stamens are **epiphyllous** when united by their filaments to the perianth; **epipetalous** when so united to the corolla; **gynandrous** when united to the style (Orchids).

257. Symmetry of the Flower.—Nearly all flowers are symmetrical, *i.e.* can be divided into two corresponding halves. When it can be so divided along one plane only it is said to be bilaterally symmetrical or *zygomorphic*, but when the flower may be equally divided in several planes it is radially symmetrical or *actinomorphic*. In regarding flowers from the biological point of view, we may restrict these terms to the perianth. A flower that can be visited from any side has a radially symmetrical ("regular") mechanism, whereas that of a flower which can be properly visited from one side only is zygomorphic ("irregular.")

258. The Floral Diagram.—The general structure of a flower and the arrangement of its parts may be graphically represented by means of drawings of vertical and horizontal sections. The latter are always drawn as a ground-plan showing all the parts in the same figure, and the term "floral diagram" is applied to them.

It is always of great importance in such diagrams to correctly represent the position of the flower with regard to the stem and bract connected with it. The face of the flower turned towards the stem is called the posterior face, that towards the bract is the anterior one. Cohesion of parts may be indicated by connecting lines. Difficulty is often experienced in correctly orienting the flower with regard to the stem, and it is useful to remember that there is a single posterior sepal in most Dicotyledons, if we except the Leguminosae and also a few plants in which the posterior sepal has not developed. The parts of the typical Monocotyledonous flower are arranged in regular cycles of three, and the odd sepal is usually anterior.

Make the diagram of good size (at least 2 ins. in diameter). To get a transverse section of a small ovary, do not remove the sepals, etc., but cut right across the flower, holding the flower upside down, and cutting thin slices with a razor or sharp knife (beginning at the base of the flower) until the interior of the ovary is exposed. In cutting a flower longitudinally through the middle, it is usually best to begin the cut at the base of the flower.

259. The Floral Formula.—As a means of readily and rapidly indicating the essential features in the structure of a flower, what are known as floral formulae are frequently employed, and these, together with the diagram and vertical (longitudinal) section (with the parts labelled), will represent all the essential features in the structure of the flower without a word of description being necessary.

The symbols ⊕ and † respectively denote radially and bilaterally symmetrical (zygomorphic) flowers. The signs ♂, ♀, ☿ respectively denote staminate, carpellary, and hermaphrodite ("perfect") flowers. The letters K, C, or P represent the calyx and corolla (or perianth), A and G the andrecium (stamens) and gynecium (pistil), and the figure following each letter gives the number of parts in each series. Cohesion is indicated by brackets enclosing the number of parts; a horizontal bracket ⌒ indicates adhesion between the parts of successive whorls; a horizontal line above G means that the ovary is inferior, a line below G that it is superior; the symbol ∞ is used when there are numerous parts in any series. The following are examples of floral formulas:—

Buttercup......... $\oplus K5, C5, A\infty, G\underline{\infty}$.

Narcissus......... $\oplus \overparen{P(3+3), A}3+3, G\,\overline{(3)}$.

Violet .... $\dagger K5, C5, A5, G\,\underline{(3)}$.

Dead-nettle...... $\dagger K(5), \overparen{C(5), A}4, G\,\underline{(2)}$.

Stitchwort ...... $\oplus K5, C5, A5+5, G\,\underline{(3)}$.

Draw the floral diagram and write the floral formula of the following flowers: Lesser Celandine, Marsh Marigold, Larkspur, Broad Bean, Gorse, Tulip, Iris, Early Purple Orchid, White Dead-nettle, Foxglove, Sweet William, Primrose, Wallflower.

260. Perigyny and Epigyny.—The shape of the receptacle or thalamus varies very much in different flowers. The receptacle of the Buttercup is convex, and the successive cycles of floral parts are placed upon it, one above the other, the sepals arising first and the carpels last. Flowers of this type are said to be **hypogynous**, and the pistil *superior*

(Fig. 77). In such flowers the young and succulent ovaries are exposed to various climatic influences, including strong winds, intense sunlight, and rapid changes of temperature, any of which may act injuriously upon the development of the ovules, if the carpels are thin and freely exposed. There is a tendency in most Flowering Plants to protect the ovary from the influences mentioned above, and this tendency finds expression in three distinct ways.

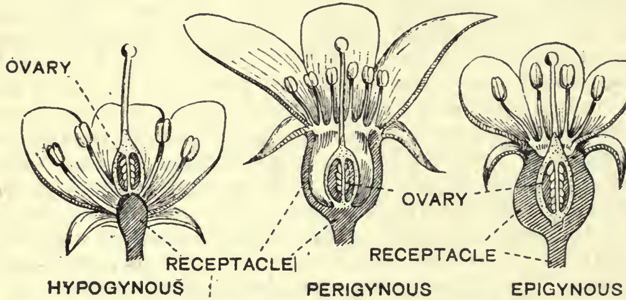

Fig. 77.—Vertical Sections of Flowers, showing different forms of the Receptacle.

(1) The petals tend to unite, as also do the sepals, thus producing flowers of very specialised character (generally in connexion with insect-pollination), in which the ovary is, at the same time, protected to a certain extent from injurious external influences.

(2) The receptacle becomes more or less concave, and so encloses and protects the carpel or carpels, leaving the stigma exposed at the end of the style (*e.g.* Cherry, Rose). Such flowers are said to be **perigynous,** but in many cases only the marginal portion of the receptacle is concave or flattened, so that the sepals and petals seem to have a common origin, while the carpels arise from a prominence in the centre of the flower (*e.g.* Blackberry). In perigynous flowers the pistil is attached to the receptacle by its base only, and it is still said to be superior even when the entire receptacle is concave and only the stigmas project above it.

(3) The receptacle grows around the ovary so that the latter becomes completely embedded in it, the style and

stigma remaining free. Here the ovary is said to be *inferior* and the flower *epigynous.* The ovary is thus protected, and an increased surface is offered for the passage of food to the developing ovules from the receptacle.

Make and sketch longitudinal sections of the following flowers: Buttercup, Narcissus, Tulip, Monkshood, Larkspur, Dead-nettle, Foxglove, Snapdragon, Early Purple Orchid, Violet. Pansy, Primrose, Sweet Pea, Canterbury Bell, Rose, Cherry, Bramble, Apple. Determine whether the flower is hypogynous, perigynous, or epigynous. In each case draw the floral diagram and write the floral formula.

261. Nectaries.—A nectary is a mass of glandular tissue which secretes sugary liquid (honey, or nectar). In most flowers the nectary is developed on the receptacle. When the flower is hypogynous, the nectary is usually a ring-like outgrowth round the base of the pistil (well seen in Tobacco Plant, Snapdragon, etc.), or it may be lobed or divided into a number of separate glands (*e.g.* Stonecrop). When the flower is epigynous, the nectary is usually a simple or lobed ring or "disc" on top of the ovary, while in perigynous flowers it usually lines the concave part of the receptacle. But nectaries may develop from, or upon, any part of the flower—sepals in Hollyhock, petals in Buttercup and many other Ranunculaceae, stamens in Violet and Pansy, in the partitions between the ovary-chambers in many of the plants belonging to the Lily and Daffodil families, and so on.

Examine and sketch the nectaries of the following flowers: Buttercup, Lesser Celandine, Christmas Rose, Winter Aconite, Monkshood, Larkspur, Violet, Pansy, Dead-nettle, Snapdragon.

262. Inflorescences.—Flowers may either be solitary or may occur in clusters. In the latter case they are usually subtended by special leaves termed bracts. Solitary flowers may be either terminal, as in Tulip and Daffodil, or may arise in the axils of ordinary leaves, as in Pimpernel.

The branching of an inflorescence may be either cymose or racemose. In racemose inflorescences the main axis is stouter and longer than the lateral ones, whereas in the cymose type the lateral axes branch more than does the main axis beyond them. The growth of the main axis is in this case strictly limited, and it bears usually one or two lateral axes, not many axes as in most racemes.

The order of flowering usually follows the order of development, and hence the order of flowering in racemes is centripetal, whereas that of cymes is centrifugal. In the first case the youngest flowers are nearest the apex (in a long inflorescence) or the centre (in a flat- or round-topped inflorescence). In the second case the youngest flowers are nearest the base or outside of the inflorescence.

The simplest type of **raceme** consists of an elongated axis or peduncle which bears stalked flowers (stalks about equal in length), *e.g.* Foxglove, Hyacinth. If the branches of the parent axis branch again so that each secondary axis bears several blossoms instead of one, we have what is known as the compound raceme or **panicle.** This is the most primitive type of inflorescence, for it is really the modified upper region of the plant, whereas the simple raceme is more highly differentiated and has become simple by reduction. Many terms have been applied to racemose inflorescences which look peculiar at first sight, but on further observation are seen to differ in small details only. The more important of these are—(1) **Corymb**: axis elongated, flower-stalks unequal in length, bringing the flowers to about the same level (Fig. 78, Candytuft); (2) **Spike**: axis elongated, flowers sessile (Plantain, Orchids); (3) **Catkin**: a spike bearing unisexual flowers of one kind (Willow, Hazel); (4) **Spadix**: a spike with fleshy axis, usually bearing unisexual flowers, enclosed by a large bract, the **spathe** (Arum); (5) **Simple umbel**: axis shortened, flowers stalked (Fig. 79, Cherry); (6) **Capitulum**; axis shortened and expanded, flowers sessile (Composites).

Fig. 78.—A Corymb.

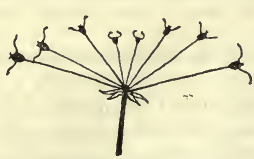

Fig. 79.—A Simple Umbel

Cymose inflorescences are those in which the axis ends in a flower after bearing one, two, or more daughter-axes, each of which may repeat the process. The daughter-axes may come off singly (**uniparous cyme**)—*e.g.* Forget-me-not and other Borages, Sundew; or in opposite pairs (**biparous cyme**)—*e.g.* Stitchwort and Campion Family, Red and Yellow Gentians; or in whorls of three or more (**multiparous cyme**)—*e.g.* Elder.

Examine and sketch the various kinds of **flat-topped inflorescences** met with, noting that plants with inflorescences of this kind are found in many different Orders—*e.g.* Cruciferae (Candytuft, etc.), Rosaceae (Cherry, Rowan, Meadowsweet, Hawthorn, etc.), Leguminosae (Clovers, *Lotus*, etc.), Umbellifers, Ivy, Dogwood, Elder, Valerians, Dipsaceae, Sheep's-bit, Compositae, etc.

It seems probable that all cymose inflorescences have been derived from racemose ones by a shortening of the main axis and a delay in the development of the lateral branches, to which the main power of growth is at the same time transferred. The cymose inflorescence is certainly an advance upon the racemose type, for in the former new flowers continually appear on the exposed surface of the inflorescence, while the fruits ripen securely buried among the older parts of the mass of branches. The tendency in racemes, on the other hand, is to simultaneous flowering, such as is exhibited more or less perfectly by so many umbels and capitula and especially by corymbs. In such cases there is an ever-present danger that the short period of flowering may occur at a time when the conditions are not suitable for the production of fertile seed.

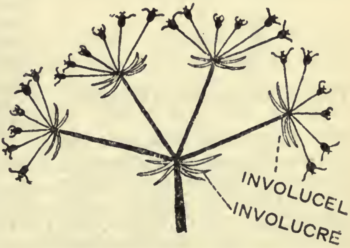

Fig. 80.—A Compound Umbel.

Racemes such as those of the Wallflower, in which the lower flowers may open months before the apex of the raceme ceases flowering, do not incur this danger, but the exposed position of the young succulent fruits is an obvious disadvantage here and in other Crucifers also. If the growing point of a young raceme is destroyed, the power of producing flowers may be temporarily lost, whereas the destruction of the apex of a cyme involves the loss of a single flower only, and the lateral axes continue their growth with even greater vigour than before.

Compound inflorescences are those in which the lateral branches are again branched in the same way as the parent axis. The commonest kinds are (1) **Panicle** (raceme of racemes or spikes), common in Grasses ; (2) **Compound spike** (a spike of spikes), in some Grasses, *e.g.* Wheat ; (3) **Compound umbel,** much commoner than the simple umbel (most Umbelliferae, Fig. 80).

In many cases **mixed inflorescences** occur—as, for example, racemes of spikes, capitulums, or cymes, spikes of capitulums, etc. It must, however, be borne in mind that there are only three main types of inflorescence, and these are (1) the raceme, with its reduction derivatives grouped around the generalised panicle type ; (2) the biparous cyme ; (3) the uniparous cyme. "Mixed" inflorescences arise owing to the fact that reduction or alteration has unequally affected the different parts of the primitive panicled inflorescence.

The inflorescence of the garden Geranium (*Pelargonium*) and of many Narcissi resembles an umbel, but the flowers in the apparent umbel are really arranged in little cymose clusters, so that the whole inflorescence has been termed an umbellate cymose head.

The apparent flowers of the Spurge (*Euphorbia*) are really inflorescences, which are sometimes termed cyathiums (Fig. 81). Each is surrounded by a cup-shaped involucre formed by the union of five bracts. Four crescentic glandular scales occur at the margin of the involucre between four of the bracts. Inside the cup there appear to be a number of stamens and a single ovary borne on a stalk. The latter is really a carpellary flower, and each of the former corresponds to a single staminate flower, as is indicated by the fact that each stamen is articulated to a short stalk, and that at this point a small scaly bract occurs. In some allied plants a small perianth is present at the base of every stamen, which clearly shows that each of them corresponds to a single reduced flower.

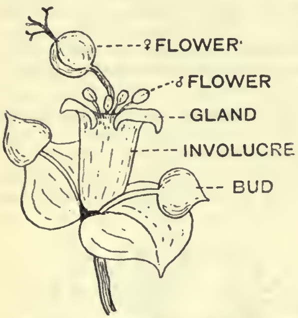

Fig. 81.—Inflorescence of Euphorbia.

The occurrence of bracts, and the positions which they occupy, are features of great importance in determining the nature of compound or mixed inflorescences. Bracts are usually green, and smaller and simpler than the foliage-leaves. In some Sages they are brightly coloured, and take on the attractive function of a corolla. They are absent from most Cruciferae and Papilionaceae, and the flowers (florets) of most Umbelliferae and Compositae are bractless. Sometimes a series of specially modified leaves which do not subtend flowers, and which therefore are, strictly speaking, not bracts at all, are grouped around the inflorescence. Thus the end of the Daisy or Dandelion has a ring or *involucre* of green "bracts" around it, although the individual flowers have none. In the head of the Sunflower, however, each flower arises in the axil of a true scaly bract. Sometimes, as in Narcissus, Arums, and Palms, the entire inflorescence is enclosed when young by a single large "bract" or spathe. The latter, however, is simply the uppermost leaf on the stem, and it is not a true bract at all, for the inflorescence is terminal and not axillary.

The student will usually have little trouble in making out the nature of any inflorescence if the foregoing paragraphs have been mastered. Specimens of all the plants mentioned should be examined carefully.

Examine the inflorescences of Buttercup (cymose), Foxglove, Bluebell, Wallflower, Candytuft, Cherry, Cowslip, Ivy, Cow Parsnip, Pelargonium, Stitchwort, Chickweed, Sweet William, Elder, Willow, Plantain, Sunflower, Daisy, Spurge.

263. Contrivances and Conditions favouring Cross-Pollination.—There are in flowers many forms, conditions, and mechanisms, the significance of which becomes clear only on the view that cross-pollination is advantageous, and that the flowers have become adapted to it. Such mechanisms, etc., either entirely prevent self-pollination, or tend to do so, and are distinct adaptations for cross-pollination.

To commence with, in many plants cross-pollination is absolutely necessary if seed is to be produced, owing to the flowers being unisexual. The staminate and pistillate flowers are either on the same plant (the *monoecious* or *monoicous* condition), *e.g.* Oak, or on different plants (the *dioecious* or *dioicous* condition), *e.g.* Willow. Some plants are self-sterile, *i.e.* the flower cannot be fertilised by its own pollen; this occurs in some species of Passion-flower, of Lobelia, of Abutilon, etc.

Dichogamy is a condition in which, though the flowers are hermaphrodite, the anthers and stigmas come to maturity at different times, and which, when completely developed, entirely prevents self-pollination. There are two kinds of dichogamy: (*a*) **protandry**, where the anthers ripen first: here the pollen grains are transferred to an older flower; (*b*) **protogyny**, where the stigma ripens first: here the pollen grains are transferred to a younger flower. Protandrous flowers are much more common than protogynous. Examples of the former are found in Composites, Labiates, Harebells, Ivy, Umbellifers, Willow-herbs, etc.; of the latter in Plantains, Woodrush, Figwort, Hawthorn, Christmas Rose, etc. Wind-pollinated flowers are more often protogynous than protandrous, but many are unisexual.

Wind-pollinated and insect-pollinated flowers have each special characters of their own, so that as a rule we can distinguish them at a glance. In wind-pollinated flowers the pollen is produced in great abundance, as much of it must be wasted; the flowers are small and inconspicuous; there is no honey or perfume; and frequently the stigmas are branched and feathery, to catch the pollen grains. See Art. 273.

The greatest variety, however, is shown in insect-pollinated flowers; there is no difficulty in recognising these as being the most highly specialised. As a rule they have large, conspicuous, brightly coloured corollas, or are arranged in conspicuous inflorescences; they usually secrete honey and give out perfume. Pollen is not usually produced in great abundance, as the provision for its transference is more perfect. The bright corollas, the perfume and honey, serve to attract insects. In return for the service rendered by insects the flowers sacrifice part of their nutritive substance in providing food to the insects (honey and pollen), and make a further sacrifice of material in developing a coloured perianth which will attract the insects.

A honeyless but otherwise insect-attracting flower is sometimes called a "pollen-flower," examples being seen in Poppies, Dog Rose, Rock-rose (not a true Rose), Wood Anemone, Traveller's Joy, St. John's Wort, Gorse, Broom, Meadow-sweet.

In many cases the corolla is so modified that the insect must alight on the flower or enter it in a special way (*e.g.* Labiates, Papilionaceae); the same result may be attained by the secretion of nectar into special receptacles or spurs (*e.g.* Violet); or the insect, on entering a flower, pushes against special processes or outgrowths which move the stamens and bring the anthers in contact with its body (Sage), etc.

The general result of all these devices is that the insect receives the pollen on a special part of its body, and when it enters another flower the pollen is deposited on the stigma. In many protandrous flowers this is secured by the style bending over so that the stigma is in the position formerly occupied by the stamens.

The condition known as **heterostyly** is seen in the Primrose, which has two types of flower borne on different plants. One kind has long stamens (with anthers in the throat of the corolla tube) and a short style; the other has a long style and short stamens; thus in the two types the positions of anthers and stigma are simply reversed. Evidently pollination will be most readily effected by transference between these two forms, and not between two flowers of the same form; and experiment has proved that the best seed is produced when this is the case.

In the Primrose there are two kinds of flower; this is the *dimorphic* type of heterostyly. In Purple Loosestrife (*Lythrum*) there are three—with long, short, and medium styles; this is the *trimorphic* type. Heterostyled flowers also occur in Lungwort, Bog-bean, Buckwheat, and Flax; these are dimorphic, but some species of *Oxalis* (Wood Sorrel) are trimorphic like *Lythrum*.

(*a*) Examine flowering plants in which the staminate and pistillate flowers are distinct and either occur on the same plant, *e.g.* Hazel, Oak, Pine, Beech, Birch, Dog's Mercury, or on different plants, *e.g.* Willow, Poplar, Red Campion.

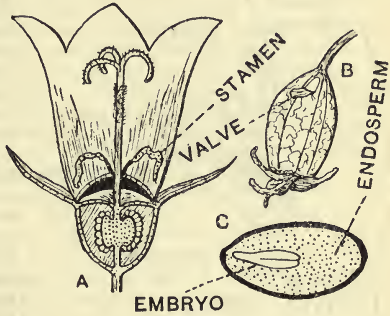

Fig. 82.—*Campanula.*
A, Vertical Section of Flower; B, Fruit; C, Longitudinal Section of Seed.

(*b*) Examine **Harebell** (or **Canterbury-bell**) flowers of different ages and note how the broad bases of the stamens cover the honey, how at first the anthers surround the style and shed the pollen on it and then fall outwards, and how the stigmas then separate (stage shown in Fig. 82). Make similar observations on the protandrous flowers of Cow Parsnip, Ivy, Willow-herb.

(*c*) Examine the flowers of **Woodrush,** and note the three large feathery stigmas which protrude from the flower before the stamens come out. Note the scaly perianth; the flowers are wind-pollinated.

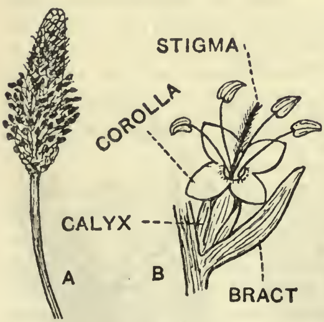

Fig. 83.
A, Spike; B, Flower of Plantain.

(*d*) Make careful observations on the life-history of a **Plantain** spike (Fig. 83). When the stamens of the lower (older) flowers hang out, after the withering of the stigmas, the stamens of the upper (younger) flowers are still in the bottom of the corolla-tube, and the stigmas projecting outwards and ready for pollination. Some species have brightly-coloured anthers, and are slightly scented; these are sometimes visited by insects for pollen. Otherwise the Plantains are wind-pollinated.

(*e*) Examine the flowers of a **Violet** and a **Pansy** (Figs. 84, 85). Note the five free green sepals, each prolonged below its insertion; the five free petals, of which the two upper pairs are lop-sided while the lowest petal is symmetrical and bears a spur; the five stamens, almost stalkless, the anthers forming a ring round the ovary and each bearing a triangular orange-coloured scale on top; the two nectaries, which grow from the backs of the two lowest stamens and project into the spur; the one-chambered ovary, containing numerous ovules on three parietal placentas; the style, with its free end thickened and produced into a beak which projects beyond the cone formed by the anther-scales and hangs over the entrance to the spur.

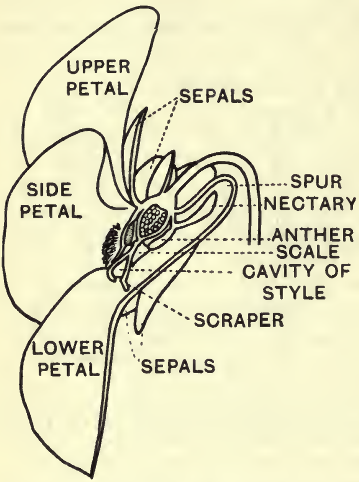

Fig. 84.—Longitudinal Section of Flower of Garden Pansy.

Sketch (1) the inner surfaces of an upper petal, a side petal, and the spurred front petal, detached; (2) the entrance to the spur, showing the parts above, below, and at each side, in their natural positions; (3) the spur cut open, displaying the nectaries; (4) one of the three upper stamens; (5) one of the lower stamens; (6) the pistil in side view; (7) the ovary cut across.

The flowers are pollinated by long-tongued bees. The anthers open by slits on their inner faces, and the pollen, which is loose and dry (not sticky as in most insect-pollinated flowers), falls into the cavity ("pollen-box"), which lies above the ovary and is roofed in by the five anther-scales. The pollen can only escape from the "box," through the space between the tips of the scales and the upper part of the style, when the projecting style-tip is moved about. A bee enters the flower, pokes its tongue into the spur in search of honey, rubs against the stigma, shakes the curved style, and causes the pollen to drop on to its head, at the same time placing on the stigma any pollen it has brought from a previously visited flower.

Fig. 85.—Floral Diagram of Violet.

If the flower-stalk were *erect*, not only would rain get in and spoil the pollen and honey, but the pollen would not fall into the "pollen-box." If the pollen were sticky, the grains would cling to the anthers and would not be touched by the bee.

The flowers are *homogamous*, since the style-tip is ready to receive pollen at the time the anthers open, but self-pollination is hindered by the projection of the style beyond the "pollen-box."

In Violets the anthers simply touch each other, edge to edge, so that some pollen may escape between them; but most of the pollen can only escape through the small circular slit between the style and the tips of the anther scales. In Pansies the anthers are firmly joined by the hairs on their edges, and the pollen escapes by an opening between the scales of the two lowest anthers, but this opening is separated from the stigmatic opening above it by the stigma-lip ("scraper").

In most *Viola* species plants protected against insects seldom fruit, but there is nothing which absolutely prevents self-pollination by insects visiting the flower in the proper way. The entrance of undesirable insects—small insects which would not be likely to effect cross-pollination—is hindered by the hairs on the side-petals and (in Pansies) on the sides of the stigma; the opening of the spur is further protected by the overhanging style-beak or the "scraper," the narrow groove on the spur-petal, the hairs lining the entrance and cavity of the spur (which species show one or more of these features most markedly?), and, of course, the length of the spur itself. On the other hand, the visits of long-tongued insects are encouraged by the conspicuous orange-coloured centre of the flower, heightened by the dark streaks ("honey-guides") which stand out vividly from the otherwise light-coloured bases of the spur-petals and side-petals (especially in Pansies) and which (since they follow the *veins*) converge to the spur-opening.

(*f*) Examine the yellow flowers of **Barberry**, noting the arrangement of the flower-parts in threes. What peculiarity is shown by the stamens? Push a pointed pencil or match-stick into the flower, imitating the action of a bee or wasp probing for the honey at the bases of the stamens, and notice what happens. The base of each stamen is sensitive to a touch, and the stamen responds by springing inwards.

264. Special Arrangements for Self-Pollination.—Many annual plants cannot afford to undertake the risks and sacrifices attendant on cross-pollination, and are commonly self-pollinated (*e.g.* Groundsel, Chickweed). They have small flowers, often without honey or smell, and are either **homogamous**—that is, their anthers and stigmas mature at the same time—or so slightly dichogamous that self-pollination is secure. Even in flowers evidently adapted for cross-pollination there is commonly the possibility of self-pollination as a last resort. Many of them are distinctly dichogamous, but not completely so, there being usually a short period during which self-pollination becomes possible. To effect this there are sometimes special contrivances, such as the curling back of the stigmas to reach the pollen, *e.g.* Love-in-a-Mist (*Nigella*), Composites, Campanulaceae.

A very special adaptation for self-pollination is the production of **cleistogamic flowers.** These are closed flowers produced late in the year by certain plants which had previously produced ordinary flowers—*e.g.* Sweet Violet, Wood Sorrel, Henbit Dead-nettle (*Lamium amplexicaule*). They are small and inconspicuous; the calyx never opens, and the stamens and pistil are developed in a closed case.

In our study of flower-mechanisms we are too apt to forget (1) that self-pollination occurs regularly in flowers which are neither unisexual, completely dichogamous, nor self-sterile, (2) that it is rarely *much* inferior to cross-pollination in its results, and (3) that it is always better than *no* pollination.

In Violets the flowering-period of the ordinary insect-pollinated flowers is short (rarely more than six weeks) and the number of flowers produced is small—especially in Sweet Violets, in which flowering only lasts for a month and a plant produces only about six flowers, each flower lasting about a week in a condition ready for pollination. Except in very bad weather these spring flowers are visited and pollinated by bees, but flowering does not stop when no more of the ordinary flowers are to be seen. The plant goes on producing flower-buds until autumn. Those which succeed the early (normal) flowers do not open but are self-pollinated, so that fruits are continually formed during summer. Finally in autumn a few buds are laid down for the normal insect-pollinated flowers which will open next spring.

In Sweet Violet these closed self-pollinating (*cleistogamic*) flowers have five very small petals and five stamens, but in Dog Violet there are only two stamens (the lowest ones). The anthers produce few pollen-grains (why few?) and do not open; the grains sprout inside the anther, and the pollen-tubes grow through the anther-wall and the style to reach the ovules. The formation of these flowers is partly dependent on shade; they are always shaded by the leaves of the plant itself. If a plant is kept in feeble light, it will usually produce only these cleistogamic flowers.

The Wood Sorrel also relies largely upon small and inconspicuous cleistogamic flowers for its propagation. In these flowers, produced in late summer or in autumn, the number of pollen-grains developed in the anthers is remarkably small (about a dozen in the smaller anthers, two dozen in the larger ones), but the capsules produced are much larger than those arising from the ordinary open flowers. The fruits produced by the cleistogamic flowers are thrust downwards into the soil, or at any rate brought close to it, by the downward curvature of the flower-stalk. The fruits produced by the ordinary flowers, however, show a remarkable mechanism for the scattering of the seeds (Art. 291).

265. Insects that visit Flowers.—The chief flower-visiting insects are beetles (Coleoptera), flies (Diptera), bees and wasps (Hymenoptera), butterflies and moths (Lepidoptera). For our purposes, the chief differences between these insects are the size of the body, the length of the tongue (proboscis), the time of year at which each kind is most plentiful, and their habits—*e.g.* whether they collect pollen or honey or both, whether they fly by day or in the evening.

By carefully studying the structure of a flower, and noting such points as the time of flowering, the order in which the anthers and stigmas mature, the relative positions of anthers and stigmas in the open flower and any changes in position that may occur, we can often tell what kind of insect is capable of effecting cross-pollination, and whether or not self-pollination is possible. We shall deal later with the characters of flowers which are mainly or entirely pollinated by the wind, and which lack the conspicuous colouring, scent, and nectar characteristic of insect-pollinated flowers (though not necessarily *all* present in the same flower).

There is only one way in which to study this fascinating subject—by going out and patiently watching the various insects which visit flowers. If you can get to know the names of the insects, do so; in any case it is usually easy to tell whether it is a butterfly or moth (four wings covered with scales, proboscis often long and coiled up, feelers or antennae with club-like ends in most butterflies, tapering and feathery in most moths), a bee or wasp (wings membranous, body usually banded with yellow and black, ovipositor at hinder end of female's body, used also as a sting), a fly (two clear wings with no scales or hairs and few veins—mostly longitudinal), or a beetle (front wings form two hard cases—elytra—covering the two soft hinder flying-wings, mouth-parts adapted for biting only). However, books on insect-study (Entomology) should be consulted; note especially the size of the insects, their habits and mode of life, and their mouth-parts (whether biting or sucking, etc.).

266. Flowers adapted for Short-tongued Insects.—Most flies and beetles have very short tongues, usually less than 3 mm. long (about one-eighth inch), and are only able

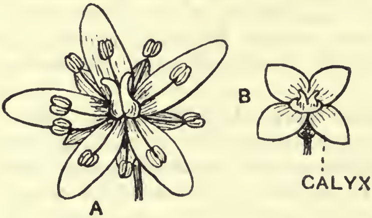

Fig. 86.—A, Flower of a Saxifrage; B, Flower of *Chrysosplenium* (Golden Saxifrage).

to lick honey which is freely exposed on the surface, as in Ivy, Umbellifers, Dogwood (Cornus), Bedstraw, Goosegrass, Golden Saxifrage (Fig. 86, B), or in flowers with a very short

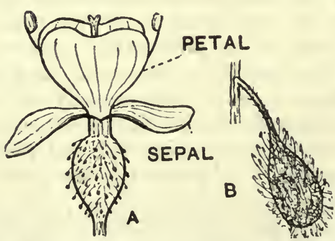

Fig. 87.—A, Flower; B, Fruit of Enchanter's Nightshade.

tube, *e.g.* Moschatel, Enchanter's Nightshade (Fig. 87), or in various shallow open flowers, *e.g.* Saxifrages (Fig. 86, A), Stonecrop. They can of course visit any shallow flowers, and at least get pollen from honeyless "pollen-flowers"—Poppy

Dog Rose, Rock Rose, St. John's Wort, etc. Some flowers show remarkable adaptations for pollination by flies, which are, as a rule, much lower in intelligence than the other classes of flower-visiting insects.

One of the commonest beetles seen visiting flowers is a small bronze-black one called *Meligethes*, but very few beetles have tongues over 3 mm. Most of the larger and longer-tongued flies (*e.g.* the Tabanids—Gad-flies, "Cleggs," Horse-flies) do not visit flowers, those just mentioned being blood-suckers, but some (with tongues sometimes as long as 12 mm.) are regular flower-visitors. These belong chiefly to two families—Hover-flies (Syrphids) and Bee-flies (Bombylids). The former (*Eristalis*, *Syrphis*, *Rhingia*, etc.) often resemble bees and wasps in having a banded body, and many flowers are adapted for their visits, *e.g.* Speedwell, in which the two stamens form an alighting-place for the fly. The Bombylids also visit flowers, and some are nearly as clever as the bees they resemble at finding concealed honey with their long tongues; of the few British forms, *Bombylius* (hairy body, humped thorax, slender legs) is of great importance in the pollination of spring flowers, *e.g.* Primrose (see Art. 379).

Among the smaller flies (tongues less than 3 mm. long) several visit flowers, e.g. *Lucilia* (small blue-bottle), *Anthomyia*, Dung-flies, Midges, Thrips; some of these feed on decaying matter, and some flowers appear to be specially adapted for their visits, having a peculiar odour, e.g. *Arum*, Hawthorn, Moschatel, Rowan.

Fig. 88.—Spadix of Arum.

Spathe removed to show the Flowers.

Examine the peculiar "flowers" of the **Cuckoo-pint** (*Arum*), so common in our hedgerows, where it blooms in April and May (Fig. 88). The whole "flower" is enclosed in a large green and purple leaf (the *spathe*). The upper portion of the spathe opens, exposing the bright purple club-shaped upper part of the spadix, while the lower bulbous portion remains closed except at the top, where it contracts to form a narrow throat. Cut open the lower part, and you see that the spadix is continued downwards, forming an axis, round which are situated two clusters of small flowers. The upper cluster is a dense mass of male flowers, each consisting of a single stamen; and the lower is a similar mass of female flowers, each consisting of a single carpel. Above each cluster are some abortive flowers that are reduced to hair-like structures, those above the stamens being longer, directed downwards, and lying in the contracted portion of the spathe.

If the flower under examination has recently opened, we find that the female flowers only are mature, but if it is one that has been open for some time, the female flowers are beginning to develop into fruits, and at the same time secrete a sweet fluid, while the male flowers are shedding their pollen. Thus the female flowers are not pollinated by the agency of the male flowers above them; how then are they pollinated?

On opening the lower part of the spathe we always find within it a number of little flies ("midges") which have been assisted in finding their present abode by the conspicuous nature of the spathe and spadix. All these flies are more or less dusted with pollen collected either here or from flowers previously visited. When the flies visit an Arum during its first or female stage, they find no food, and crawl about in their attempts to escape; but they are securely entrapped by the hairs at the neck of the spathe, which hairs, pointing downwards, allow easy access to the interior, but effectually prevent escape. However, in their movements the flies rub their bodies over the sticky stigmas, placing on them pollen previously obtained in other Arums.

The fertilised ovaries now begin to develop into fruits, while the anthers open, shedding their pollen over the bodies of the imprisoned flies. Then the hairs wither, setting free the flies after the work of pollination has been effected, and after they have become covered with pollen to prepare them for a repetition of the process in other Arums.

267. Flowers with partially Concealed Honey.—Many flowers have arrangements for concealing the honey from the shortest-tongued insects, so that the visiting insects must have tongues at least about 4 mm. in length to reach it. The honey may be slightly concealed by the stamens—*e.g.* Buttercup, Stitchwort; by the erect, stiff sepals in the smaller Crucifers; by the formation of a shallow receptacle-cup in many Rosaceae—*e.g.* Strawberry, Cinquefoil; or by a short corolla-tube—*e.g.* the shorter-tubed Composites and Labiates, Valerians, Viburnum, Guelder Rose, Speedwell. Such flowers are visited by the longer-tongued beetles and flies, as well as by insects of higher type.

268. Flowers with fully Concealed Honey.—This type of flower differs only in degree from the last. Here the honey is out of the reach of the short-tongued insects, and can only be obtained by those having tongues about 6 mm. long, including the longest-tongued flies (chiefly the Hover-flies and Bee-flies) and the shorter-tongued bees—*e.g.* burrowing bees (*Andrena*, tongue 2 or 3 mm.), hive-bees (*Apis*, tongue 5 or 6 mm.)—and wasps.

The concealment of the honey is effected by a further deepening of the flower, due to formation of a receptacle-tube, or to the sepals or petals (or both) growing out vertically from the receptacle (instead of spreading as in shallow flowers), and in many cases being joined below to a tube—*i.e.* being gamosepalous or gamopetalous.

Examples of medium-tubed flowers are seen in Blackberry, Currants, Gooseberry, Pasque Flower, Willow-herb, Geranium, Mint (compare these to see how the tube is formed in each case, and try to find other examples). Some flowers seem to be chiefly visited by wasps, *e.g.* Figwort (*Scrophularia*), Snowberry, *Epipactis*, Cotoneaster.

Some of the most interesting flowers belong to this type and the next, including the characteristic "bee-flowers," *i.e.* flowers adapted to, and extensively visited by, bees.

269. Long-tubed Flowers.—When the flower-tube becomes longer, all these shorter-tongued insects are more or less completely excluded, and the flower is adapted for, and chiefly visited by, the larger bees (especially the humble-bees), butterflies, and moths. Many flowers belonging to the Lily, Daffodil, and Iris families of Monocotyledons come under this type. In most long-tubed flowers the honey is found only in the lower part of the tube, but in Crocus it fills the space between the style and the long flower-tube, and is therefore easily reached by bees and butterflies.

Flowers like those of Papilionaceae, Snapdragon, and Toadflax can only be opened by large bees, and only the longest-tongued bees can reach the honey in such flowers as Monkshood and Larkspur. The humble-bees have longer tongues (about 10 mm. in *Bombus terrestris*, 20 mm. in *B. hortorum* and in *Anthophora*) than hive-bees. Moreover, the humble- and hive-bees have the most perfect mechanism (the "pollen-baskets" on the hind-legs) for collecting pollen to mix with honey and feed their brood. Humble-bees are particularly skilful in finding the way to well-concealed honey.

Blue, purple, and red colours are often associated with flowers visited by bees (especially blue and purple) and butterflies (especially red), while flowers visited by other insects are usually white, yellow, or variegated; but there are far too many exceptions to allow of a general rule.

270. Butterfly- and Moth-Flowers.—When the flower-tube (or at any rate the level of the honey) is more than about 12 mm. (about half an inch) deep, the honey is beyond the reach of bees, though they may visit the flower for pollen or the humble-bee may bite through the tube and thus rob the flower of its honey. Good examples of butterfly-flowers are seen in Red Campion and Ragged Robin, but butterflies also visit many flowers adapted for bees, *most* British butterflies and moths having tongues of about the same length as, or a little longer than, those of bees (about 15 mm.).

Some moths, however, have far longer tongues (30 mm. in a few British species),[1] which are (as in butterflies) carried coiled up in a spiral under the head when flying. These moths can reach honey even when it is at the bottom of a very long tube, as in the Honeysuckle, which is visited chiefly by the night-flying Privet Hawk-moth, and the White Convolvulus, which is said to be pollinated by another species of Hawk-moth (*Sphinx convolvuli*, tongue 80 mm. long), and to set seed very seldom in England owing to the rarity of this moth. Other flowers pollinated by night-flying moths are the White Campion (*Lychnis vespertina*), Evening Primrose, Tobacco Plant, Privet, Bladder Campion. Moth-pollinated flowers are white or pale-coloured, sweetly scented, and open in the evening, usually remaining closed and almost scentless during the day.

Examine the following moth-pollinated flowers:—Tobacco-plant, Honeysuckle, Evening Campion, Evening Primrose. Make and sketch a longitudinal section of each flower. Note the condition of the flowers at different times (day and evening), and try to follow all that happens in a single flower from the time it first opens until it finally closes (after being pollinated).

271. The Flower-Tube.—It is interesting to compare the various ways in which the flower becomes tubular in form, so as to protect the ovary, to conceal the honey, to shelter the pollen from rain, to exclude short-tongued insects, etc. The study of development shows that,

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[1] In some foreign moths the proboscis reaches the astonishing length of 300 mm. (about 12 inches).

starting from the simple "hypogynous" condition, the formation of a "perigynous" or "epigynous" flower, of a "gamophyllous" perianth, of a "gamosepalous" calyx, of a "gamopetalous" corolla, of "epipetalous" stamens, etc., in short, all the cases of "cohesion" and "adhesion" are due to the growth of the receptacle during the flower's development, and that all these conditions in the mature flower are due to differences in the extent of this growth. It is important to remember this, as the various terms in current use tend to obscure the facts of development, and even to imply that actual "fusion" occurs after the various flower-parts have been developed.

272. Protection against Rain.—The flowers already mentioned show examples of the various ways in which the pollen may be protected against rain. Pollen-grains, like seeds, are much less resistant to extremes of temperature and to drying when once they have been moistened and have begun in consequence to germinate. In some flowers, especially those whose pollen is exposed to rain when the flower opens, the pollen-grains are not readily wetted, having a covering of wax or of spines, etc. In most cases, however, the grains lose their power to germinate if wetted and then allowed to dry.

Many flowers protect the pollen by their horizontal or drooping position, *e.g.* Heaths, Bluebell, Lily of the Valley, Solomon's Seal, Violet, Daffodil. In some cases the flower closes up at night or in bad weather, *e.g.* Wood Sorrel, Tulip, Crocus, Lesser Celandine, Scarlet Pimpernel (in which self-pollination often occurs in the closed-up flower, by the stamens touching the stigma), and the same kind of closing is effected in the flower-heads of many Composites by the movements of the flowers and bracts. In Iris (Fig. 108) the large petaloid stigmas cover the stamens, while in Orchis (Art. 312) the single stamen is covered by a hood formed by one of the sepals and two of the petals. Find other examples.

273. Wind-Pollinated Flowers.—Many flowers which contain no honey are visited for pollen by insects, attracted by the colours or scents of these "pollen-flowers." Several examples have been mentioned. This leads to the consideration of flowers which have neither honey, scent, nor conspicuous colours, and which are seldom or never visited by insects. Such flowers are chiefly pollinated by the wind.

In a few water-plants the pollen is carried by water, and pollination occurs at or below the surface, but this is rare; most aquatic plants raise their flowers well out of the water, and are pollinated by wind (*e.g.* Pondweed) or by insects (*e.g.* Water Crowfoot, Water Lilies).

In wind-pollination it is obvious that the chances of a pollen-grain striking a stigma are very small, and that the plant must therefore produce a much larger amount of pollen than is the case in insect-pollination. In order to increase the chances of pollination the pollen is light, and can therefore float for a considerable time in the air and be carried to a great distance, while the stigmas are usually large and branched, to increase the amount of their surface.

The anthers are usually carried on long dangling filaments; all the stamens of a flower open simultaneously, instead of successively as in most insect-pollinated flowers; and they either open only in dry weather or are well protected (by catkin-scales, bracts, etc.) against rain.

In many wind-pollinated trees the inevitable waste of pollen is to some extent reduced by the flowers opening before the leaves have unfolded, or before they have grown large enough to form a serious obstacle to the wind-carried pollen. In most herbaceous plants with wind-pollinated flowers (*e.g.* Plantains, Grasses, Salad Burnet, Docks, Sorrels) the latter are carried up on a long stalk, well above the leaves, so as to expose them as freely as possible to the wind. It will be noticed that many wind-pollinated plants have the stamens and the pistil in separate flowers, either on the same plant or on separate plants, and that when they are both present in the same flower the stigma nearly always matures before the anthers open; most Grasses, however, are protandrous.

From these details and your own observations, draw up a tabular comparison of entomophilous (insect-pollinated) and anemophilous (wind-pollinated) flowers.

274. Comparison of Flowers of Willow and Poplar.—Examine and compare the flowers of Willow and of Poplar, which are very closely allied plants. In both cases the male and female flowers are on separate plants, and are carried on catkins, each catkin consisting of an axis bearing numerous flowers and each flower standing in the axil of a bract. In Willows the male catkins are bright yellow, the female ones green, when the flowers open. Each male flower consists of two (in some species more) stamens, with a honey-gland at their base; the female flower of a pistil with two stigma-lobes (each often forked at the end), ovary one-chambered with numerous ovules on two parietal placentas, and a honey-gland. The flowers are largely visited by bees seeking for honey and pollen among the scanty spring flowers.

In Poplars each male flower has a larger number of stamens (twenty to thirty), surrounded at the base by a cup-like outgrowth ("perianth"), and the female flower of a pistil (similar in structure to that of Willows) with branched stigmas forming a tuft; in neither case is there a honey-gland. The Poplars are wind-pollinated; their flowers have no honey to attract insects. More pollen is produced than in Willows, and the stigmas are more branched, exposing a larger surface; the catkins of Poplars hang down loosely and swing in the wind, and are longer than those of Willows, which usually stand out stiffly from the stem. Moreover, Poplars flower before the leaves appear, and their flowering is generally over by April, when most Willows are beginning to flower; many Willows flower at the same time that the leaves expand.

275. Birch, Hazel, Oak, etc.—Many forest-trees bear their flowers (or at least the male flowers) in catkins, or in clusters resembling catkins, but have the male and female flowers on the same plant. In Birch, Alder, and Hazel the male catkins hang down, so that the stamens are covered by the scales (bracts) to which they are attached (as in Poplar), and thus protected from rain. The female catkins are smaller, with stigmas projecting beyond the scales. In Hazel and Alder the catkins are formed from special buds, and are nearly mature in the autumn, ready to open early in spring, before the leaves. In Birch the female catkins are formed in the ordinary buds, and appear along with the leaves. This is also the case with both male and female flowers in Beech and Oak, in which the male flowers have a cup-like "calyx"; in Beech the male flowers are in a cluster at the end of a long drooping stalk, in Oak they are scattered along a similar stalk.

276. Other Wind-Pollinated Flowers.—Plants with wind-pollinated flowers occur in some families which are chiefly insect-pollinated—*e.g.* Meadow-rue (*Thalictrum*) in Ranunculaceae, Salad Burnet (*Poterium*) in Rosaceae. Compare their flowers with those of allied plants in the same family. Examine also the following flowers :—

Pine, Larch, Yew.—In these plants the stamens and carpels are on special branches (cones), the pollen is produced in enormous abundance, and the ovules are exposed, so that the pollen-grains reach the micropyle directly.

Stinging-Nettles.—Flowers small and green, male and female either on separate plants or on the same plant. In the male flower

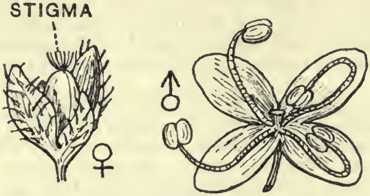


Fig. 89.—Male and Female Flowers of Nettle.

the stamens are at first folded inwards and downwards, but on warm, dry days they spring up violently and scatter the pollen in a cloud ;

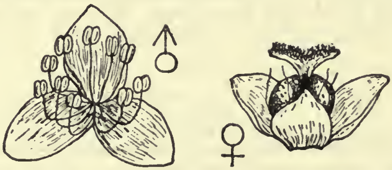


Fig. 90.—Male and Female Flowers of Dog's Mercury.

cut off a branch bearing male flowers, and observe this on touching the coiled-up stamens or warming the flowers. Female flower with a tufted stigma (Fig. 89).

Dog's Mercury.—Flowers small, green, dioecious ; stamens numerous ; two large stigmas (Fig. 90). Some honey is secreted, and the flowers are often visited by small insects.

Plantain.—Flowers in a spike, markedly protogynous; when the stamens of the lower (older) flowers hang out, after the withering of the stigmas, the stamens of the upper (younger) flowers are still in the bottom of the corolla-tube, and the stigmas projecting outwards and ready for pollination (Fig. 83). Some species have coloured anthers, and are slightly scented; these are sometimes visited by insects for pollen.

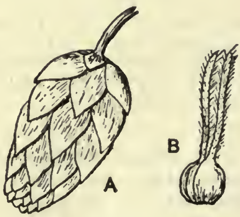


Fig. 91

Hop. A, Female inflorescence ; B, Female Flowers.

Other wind-pollinated flowers which you should examine are those of Hop (Fig. 91), Sedges, Rushes, Docks, Sheep's Sorrel, Crowberry, Walnut, Oriental Plane, Ash, Elm, Grasses.

QUESTIONS ON CHAPTER IX.

1. What is the usual function performed by the various parts of the flower? Have you observed any cases in which functions other than the usual ones are performed by floral structures? Show by several examples that the division of the flower into four whorls cannot always be rigidly maintained.

2. Give an account of the structure and function of a pollen-grain.

3. Describe the processes which lead to the conversion of an ovule into a seed, and state what is the difference between albuminous (endospermic) and exalbuminous (non-endospermic) seeds, giving examples.

4. Describe the situation in which honey is produced in any three flowers you have examined. How does it profit a plant to expend its substance in the production of honey? How is it that some plants dispense with the production of honey? Name three such plants.

5. Draw the flowers of any three of the following:—Figwort, Snapdragon, Foxglove, Salvia, Monkshood, Sweet Pea, Dead-nettle. What do you know of the method of pollination in the flowers you draw? Explain the connection, if any, between the methods of pollination and the time of year at which the flowers appear.

6. Mention a flower which is naturally self-fertilised, and another which is naturally cross-fertilised. What could you do to aid cross-fertilisation in the first, and self-fertilisation in the second case? Is the seed produced by cross-fertilisation better or worse than that produced by self-fertilisation?

7. Briefly describe, giving examples, the following forms of inflorescence, and point out the relationship which exists between them:—spike, spadix, raceme, head, panicle, umbel.

8. State what is the essential difference between *definite* and *indefinite* inflorescences, describing, with examples, the principal varieties of each (definite = cymose, indefinite = racemose).

9. What is meant by a floral receptacle? What part does it play in our conception of the structure of the flower?

10. Name any plants you know in which the flowers are massed in close, flat-topped inflorescences, and mention the advantages which you suppose are obtained by such an arrangement. Name any natural orders that are characterised by this type of inflorescence, and describe, with instances, the differentiation (modification) which the marginal flowers may undergo.

11. What flowers have you yourself observed being visited by wasps, by butterflies, by flies? What insects have you yourself seen at Sweet Pea, Primrose, Buttercup? Supplement this answer by information obtained in other ways, but distinguish carefully between observations and theories, facts and expectations.

12. Describe the inflorescence of a Daisy and of a Dead-nettle, pointing out the features of (*a*) resemblance, (*b*) difference, existing between them.

13. Describe the process of pollination in any *two* of the following :—Larkspur, Willowherb (*Epilobium*), Dead-nettle, Willow.

14. Describe the flowers of the Primrose, and explain the adaptations for pollination.

15. What is heterostylism, and what is its importance? Give examples of heterostyled British plants.

16. Mention any flowers you know which are pollinated by the wind. Describe the structures involved in pollination in each case, and show how they differ from the corresponding structures in insect-pollinated flowers. Have you noticed any other features of wind-pollinated flowers, such as habitat or time of flowering, which you can connect with wind-pollination? Give instances.

17. Name three flowers you have seen visited by flies and three by butterflies and moths. How did the insects behave in each case?

18. Name three flowers fertilised by bees in which the essential organs of the flower come into contact with the back of the bee, and three in which they come into contact with its underside. Why are bees on the whole better agents of pollination than other insects?

19. Describe fully the differences between insect-pollinated and wind-pollinated flowers, and mention six examples of each class. Are the seeds of wind-pollinated flowers generally distributed by the wind or not? Discuss examples.

20. What plants may be found flowering (either commonly or occasionally) in the winter months in England out of doors?

21. What *trees* occurring commonly in England have flowers which are visited by insects? You may take examples both from native and from introduced species.

22. Mention three examples of plants which possess dimorphic flowers. Give a short description of each illustrated with sketches.

23. Give a synoptic outline of a lesson on the structure of the gynaecium. State definitely what material you would select for illustration, explaining the special point of interest connected with each specimen.

24. Draw a flower of violet or pansy as seen in median vertical section. Distinguish between any three wild species of the genus *Viola* you know.

25. Give examples of flowers which produce honey, and explain exactly where the honey is produced. Of what use is it to the plant?

26. What do you understand by a "typical" flower? Compare briefly the arrangements of the parts in a floral and a vegetative shoot.

CHAPTER X.

FRUITS AND SEEDS.

277. How Fruits are Formed.—The influence of fertilisation extends from the developing seeds to the surrounding parts, causing a renewal of active growth not only in the carpels, but often in other parts of the flower as well. Usually, however, the stamens and corolla persist for a shorter time than they would have done had not fertilisation occurred.

The ultimate result of fertilisation is the formation of a fruit. The simplest definition of a fruit is that it consists of the parts of a single flower which persist and grow after fertilisation. This definition covers most fruits, which may be divided into *simple* and *aggregate.* A simple fruit is formed from one free carpel, as in the Bean, or from several united carpels (syncarpous pistil), as in the Poppy. An aggregate fruit is formed from several free carpels, as in Buttercup and Blackberry. The wall of the ovary becomes the **pericarp** or fruit-wall, which may, as the fruit ripens, either remain soft and fleshy or become dry and hard.

Whether the fruit is dry or fleshy depends on the amount of water it contains when ripe. Dry fruits which contain several seeds usually open so as to set the seeds free, the pericarp breaking apart to form an opening. Some dry, many-seeded fruits, however, split into pieces, each containing a single seed. These two types are distinguished as (1) Opening or Capsular fruits; (2) Splitting or Separating fruits. Dry one-seeded fruits, and practically all fleshy fruits, remain closed, and the seeds escape by the decay of the pericarp, or the latter may only be broken when the seed germinates. This third type may be called (3) Closed or Indehiscent fruits. Indehiscent fruits may be either dry, in which case they are usually one-seeded, or fleshy.

278. Opening or Capsular Fruits.—The **follicle** opens along the inner side (*ventral suture*) which bears the seeds, *e.g.* in Monkshood, Marsh Marigold, Winter Aconite, Christmas Rose, Columbine, Larkspur (all belonging to the Buttercup family), also in Magnolia, Stonecrop, etc. The **pod** separates into two valves by opening along both the dorsal and the ventral sutures. The **siliqua** (characteristic fruit of Crucifers) opens by two valves which separate from below upwards, leaving the seeds on the edges of a partition across the fruit (*e.g.* Wallflower). The **silicula** is a short and broad form of the siliqua (*e.g.* Shepherd's Purse).

A typical **capsule** usually consists of several carpels, and is dry. The capsules of Horse Chestnut are rather fleshy when ripe, and the fleshy capsules of the Balsam and Wood Sorrel are so much stretched when ripe that a touch is sufficient to cause them to split open and throw the seeds out violently.

Fig. 92.
Transverse Dehiscence of Capsule of Plantain.

Capsules usually open longitudinally, either along the dorsal sutures (midribs) of the carpels (*e.g.* Willow-herb, Blue-bell), or (more rarely) along the partitions between the chambers of the ovary (*e.g.* Foxglove, St. John's Wort). The capsule of Stitchwort and other Caryophyllaceae splits about half-way down into twice as many teeth as there are carpels. In all these cases the opening takes place along lines already marked out in the structure of the ovary; but in some plants it follows entirely new paths. Thus some capsules open transversely, a lid being separated, as in Plantain (Fig. 92), Pimpernel, Henbane. In the Poppy small pieces of the capsule-wall are detached, forming a series of holes around the top of the capsule, through which the seeds escape. The capsules of Snapdragon and of Campanula also open by pores, produced in the same way as in the Poppy.

Examine and make careful sketches of the fruits of Columbine-Monkshood, Larkspur, Winter Aconite, Christmas Rose, Gorse, Labur, num (seeds poisonous), Peas, Beans, Bird's-foot Trefoil, Wallflower, Candytuft, Shepherd's Purse, Charlock, Willow-herb, Bluebell, Iris, Foxglove, Snapdragon, St. John's Wort, Stitchwort, Campion, Chickweed, Plantain, Scarlet Pimpernel, Henbane, Poppy, Canterbury Bell.

279. Dry Closed Fruits or Akenial (Achenial) Fruits are given various names, but the chief types are (1) **akene** (or **achene**), with membranous or leathery pericarp—*e.g.* Buttercups, Little Celandine, Anemone, Cinquefoil; the akene of Composites (Daisy, Dandelion, etc.) only differs in being produced from an inferior ovary; (2) the **grain,** in which pericarp and seed-coat are firmly united—Grasses; (3) the **nut,** with hard pericarp (the term is usually applied to all large or hard-coated akenes)—*e.g.* Hazel, Oak, Beech, Sweet Chestnut, Hornbeam; (4) the **samara** or winged akene (or nut)—*e.g.* Elm, Birch, Ash. The akenes of Composites and Valerians often have a tuft of hairs, usually sessile but stalked in Dandelion and Goat's-beard, called the **pappus** (= calyx), at the top; those of Clematis have a long plume (= style), those of Avens a hooked style.

Examine and sketch the fruits of Buttercup, Lesser Celandine, Cinquefoil, Daisy, Yarrow, Dandelion, Groundsel, Thistle, Nipplewort, Goat's-beard, Wheat, Maize, Hazel, Oak, Beech, "Spanish" Chestnut, Elm, Birch, Ash, Valerian, Clematis, Avens.

280. Fleshy Fruits.—A few fleshy fruits open to let the seeds escape—*e.g.* Horse Chestnut, some Gourds, Balsam. Three chief types of closed fleshy fruits can be recognised: (1) the **berry,** in which the pericarp is soft and fleshy throughout except for the membranous or firm skin; (2) the **drupe,** in which the innermost portion of the pericarp forms a hard stone (endocarp) embedded in the fleshy middle portion (mesocarp), with a membranous skin (epicarp) on the outside; (3) the **pome,** in which the receptacle becomes fleshy, enclosing the ripe carpels.

281. Drupes ("stone fruits").—A simple drupe is formed from a single free carpel, and has one stone with one seed inside it—*e.g.* Plum, Cherry. Drupes may, however, be syncarpous, in which case each chamber of the ovary may form a distinct stone or drupe. The so-called "berries" of Holly, Dogwood, and Elder are really compound drupes of this kind. The Walnut is a drupe from which the mesocarp (flesh) peels off during ripening, and allows the stone, enclosing a single seed, to escape. The drupe of the Almond has a velvety skin and rather tough mesocarp, which splits along one side; the endocarp is pitted and brittle, and there are sometimes two seeds inside it.

The Coco-"nut" is a drupe in which the mesocarp (removed before exportation) is fibrous. The "shell" is the endocarp, and the flesh inside it is the endosperm in which lies a small embryo (below one of the three pits at the broader end of the "nut"); the fruit is formed from a three-chambered ovary, only one chamber being fertile; the space in the centre of the "nut," filled with sap, corresponds to the cavity (vacuole) in the young embryo-sac.

Examine, dissect, and sketch the fruits of Cherry, Plum, Almond, Holly, Elder, Walnut, Coco-nut.

282. Berries usually contain several seeds, but sometimes only one, as in Dogwood and Date. The Berry is distinguished from the drupe by the fact that the pericarp or "stone" has no hard part, whilst the stone in a drupe is the innermost part of the fruit-wall, and encloses the seed; the seeds ("pips") in a berry may have hard coats, but the fruit has no other hard parts.

The Banana, Currant, Cucumber, Grape, Gooseberry, Orange, Pomegranate, Bilberry, Bittersweet, and Tomato are all berries, although several of them exhibit special peculiarities. In the case of the Gooseberry and Pomegranate, the outer layer of the coat of each seed is succulent, and forms a large part of the fruit. The "quarters" of the Orange, Lemon, "Lime-fruit," and "Grape-fruit" correspond to the carpels, and the juicy part is composed of large hairs, which arise from the walls of the carpels and are filled with watery sap. The "Squirting Cucumber" (*Ecballium*) becomes highly turgid when ripe, so that when it breaks off its stalk the seeds are ejected along with a quantity of watery sap.

Examine, dissect, and sketch the fruits of Date, Banana, Gooseberry, Currants, Cucumber, Orange, Grape, Bilberry, Tomato, Bittersweet, Pomegranate.

283. Pomes.—The Apple or Pear affords the best example of a pome, being developed from an inferior ovary composed of five imperfectly syncarpous carpels. The outer fleshy part of an apple is really a portion of the receptacle, while the parchment-like membrane which forms around the wall of each chamber of the ovary is mainly carpellary in origin, the "pips" being of course the seeds. Pomes also occur in Rowan, Hawthorn, Quince, Medlar.

Examine, dissect, and sketch the fruits of Apple, Pear, Quince, Medlar, Rowan, Hawthorn, Cotoneaster.

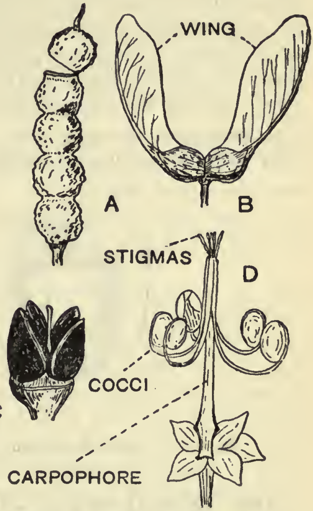


Fig. 93.—Schizocarps splitting into several Pieces.

A, of Hedysarum; B, of Maple; C, of Lamium; D, of Geranium.

284. Splitting or Separating Fruits (Schizocarps) are so called because they split into two or more one-seeded parts (akenes or nuts). Examples are seen in Sycamore and Maple (Fig. 93, B), Umbellifers (Fig. 136), Geranium (Fig. 93, D), the Labiate and Borage families (Fig. 93, C), Mallow (Fig. 94).

In some Leguminosae (*e.g. Hedysarum*, the "French Honeysuckle") and some Crucifers (*e.g.* Radish) the fruit splits across into one-seeded pieces, and is called a **lomentum** (more strictly, a lomentaceous pod, or siliqua, as the case may be), Fig. 93, A.

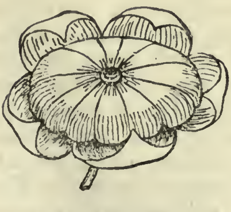


Fig. 94.—Schizocarp of Mallow.

The one-seeded parts into which a schizocarp splits do not usually open to let the seed out; but this does occur in some cases—*e.g.* Spurges, Geranium.

Examine and sketch the fruits of Sycamore, Maple, Cow Parsnip, Geranium, Mallow, Dead-nettle, Forget-me-not, Radish, "French Honeysuckle" (*Hedysarum*, cultd.), Spurge.

285. Aggregate Fruits may consist of a number of follicles, as in Christmas Rose, Marsh Marigold, Monkshood, etc., or of a number of akenes inserted on a convex receptacle, as in Anemone or Strawberry, or inside a concave receptacle, as in Rose, or they may consist of drupes on a convex receptacle, as in the Blackberry or Raspberry. Notice in each case whether the receptacle is dry or fleshy.

Examine and sketch the fruits of Strawberry, Rose, Blackberry, Raspberry, Buttercup, Columbine.

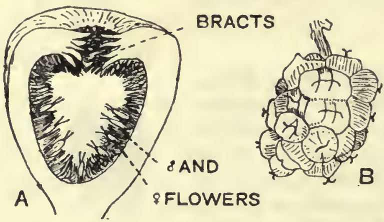


Fig. 95.—A, Fruit of Fig cut in half vertically; B, Fruit of Mulberry.

286. Special Types.—The fruits developed from a group of flowers or dense inflorescence are often aggregated in closely packed clusters, such as are formed by the fleshy red berries of the Honeysuckle and by the clustered fruits of the Mulberry, the perianths of whose flowers become fleshy and enclose the carpels (Fig. 95, B). The Pineapple is a spike-like inflorescence, in which the axis becomes fleshy during ripening, and the individual fruits fuse together. The Hop has an inflorescence consisting of an axis bearing membranous scales, in the axil of each of which there are two female flowers (Fig. 91); the scales are shed when ripe with the fruits attached to them. The Fig is formed by a hollow, pear-shaped capitulum bearing male and female flowers, the "seeds" being really akenes (Fig. 95, A). The Date is a berry, the hard stone being the seed. The Banana is a berry which, owing to cultivation, does not produce seeds.

Examine, dissect, and sketch the fruits of Honeysuckle, Mulberry, Pineapple, Hop, Fig, Banana, Date.

287. Dispersal of Seeds and Fruits.—Such a plant as a Cherry tree may produce thousands of fruits and fertile seeds in a single season, although none of the latter may succeed in establishing themselves as young seedlings beneath the shade of the parent tree. Even if the parent plant is cut down, or dies at the end of the season, it can hardly make room for more than one or two of its offspring. Hence it is of the utmost importance that the seeds should be afforded some chance of distributing themselves, and reaching localities suitable for the development of new trees. Birds act as the dispersing agents in this case, frequently carrying the fruit to a distance, and rejecting the hard stone which protects the seed.

Even in the case of annual plants, the dispersal of the seeds is of great importance, for it is evidently impossible that the thousand or so seeds which a single Sunflower may produce can germinate and become healthy seedlings on the same area that the adult plant occupied. The means of dispersal adopted by different plants vary widely, and are frequently such as to secure the almost ubiquitous distribution of some plants. The chief agencies by which dispersal is secured are: (1) **wind,** (2) **water,** (3) **animals,** and (4) **explosive** or **ejection mechanisms** in the fruit itself.

288. Dispersal by the Wind is facilitated by the minuteness or lightness of the seeds or fruits, and by the presence of tufts of hairs or wing-like membranes which increase the surface exposed to the wind without appreciably adding to the weight. It is only in the case of dehiscent fruits that mechanisms for wind-dispersal are borne by the seed; closed fruits and the segments of splitting fruits are themselves distributed and possess contrivances for dispersal, while the seeds have none and are carried inside the fruit. The seeds of Orchids are so small and light that, when they are set free by the dehiscence of the capsules, they are freely blown about by the wind, hence the epiphytic tropical Orchids establish themselves upon the trunks of trees.

When the seeds are larger and heavier, the fruit frequently opens in such a manner that the seeds can only escape a few at a time and are jerked out when strong winds rock the capsules to and fro. This **censer mechanism** is seen in follicles and many capsules, *e.g.* those of Poppy and Campanula (Harebell, Canterbury-bell), which open by pores; those of Campions, Stitchworts, Primroses, etc., which open by teeth at the top; besides in capsules opening by slits or a lid; also in the fruiting heads of some Composites which have no pappus on their akenes, *e.g.* Sunflower.

As an aid to wind-dispersal, seeds are frequently flattened (Wallflower, etc.), as also are the fruit-segments of Umbellifers and the akenes of Buttercups and Composites.

Very commonly, however, special structures are present which enable seeds, or more frequently akenes, to be more readily carried by the wind. The **plumed seeds** of the Willow, Poplar, Willow-herb (*Epilobium*), Bog Asphodel, and Cotton-plant have hairy outgrowths. **Winged seeds** occur in Pines, Yellow Rattle, Deutzia, and Bignonia ("Trumpet-flower").

The **winged akenes** (samaras) of the Ash, Elm, and Birch afford good examples of winged fruits in which the wing is an outgrowth of the pericarp. In the Maple and Sycamore each fruit splits into two or three winged samaras. The Hornbeam has persistent bracts which form a wing on the fruit; a similar bract-wing occurs in the Hop. In the Lime-tree (*Tilia*) the stalk bearing the cluster of nuts hangs down, and the large bract attached to it acts as a kite or aeroplane. Bracts also act as wings to the fruits of *Bougainvillea* and *Mirabilis* (Marvel of Peru) —two tropical but commonly cultivated plants. In Docks the fruit is covered by the "calyx," which bears three wings. In some cases the wing is funnel-shaped, or parachute-like, as in Thrift (persistent papery calyx) and Teasel (persistent bracts around the flower).

A few examples of **plumed fruits** (*i.e.* fruits bearing hairs or hairy appendages) may be given. In Clematis, Pasque-flower, and Dryas each akene has a persistent hairy style; in Cotton-sedge the fruit bears numerous long silky hairs, produced by the perianth; in Bulrushes hairs are produced by the stalk on which each fruit is carried. The most highly developed plumed fruits occur in Valerians and many Composites; in these plants the calyx grows after fertilisation, and forms a ring of hairs (the pappus) on the top of the fruit. Good examples are seen in the Dandelion and the Goat's-beard, where the pappus forms a parachute carried on a stalk. If the air becomes moist the parachute closes up, and the fruit falls to the earth, and is washed into the soil by the first shower of rain.

Dispersal by wind involves a greater loss of seeds than dispersal by animals, for the latter usually frequent fertile localities where the seeds have a chance of germinating, whereas wind-dispersed seeds may fall upon sterile or unsuitable localities, or may be carried out to sea. It is for this reason that winged and hairy seeds are usually absent from the plants of the seashore. Hence also arises the fact that wind-dispersed seeds are usually produced in relatively greater abundance than those dispersed by animals.

Examine and sketch, with special reference to their adaptations for wind-dispersal, the *fruits* of Poppy, Canterbury Bell, Campion, Stitchwort, Cow Parsnip, Buttercup, Ash, Elm, Birch, Maple, Sycamore, Hornbeam, Hop, Lime-tree, Marvel of Peru, Docks, Thrift, Clematis, Cotton-Sedge ("cotton-grass," in bogs), Valerian, Dandelion, Goat's-beard, Thistle, Groundsel; and the *seeds* of Willow, Poplar, Willow-herb, Pine, Yellow Rattle, Bignonia.

289. Dispersal by Water is uncommon, and occurs chiefly in aquatic plants. Seeds may also be carried on the mud adhering to the feet of aquatic birds. In plants which grow on the margin of streams, as well as in those aquatics whose leaves are aerial (*e.g.* Water Plantain, Arrow-head), the seeds may fall into the water. In some cases (*e.g.* Alder) the seeds are enabled to float to a distance by being provided with a spongy covering which contains air. This is also the case in Water Lilies, but in these—and in most submerged or floating water-plants—the fruits are developed under water, and are either achenes, nuts, or splitting fruits which separate into hard one-seeded parts.

290. Dispersal by Animals may be either passive or active, and the seeds may be carried either inside or outside of the animal's body. Animals assist in seed-dispersal in three ways. (1) Some plants have fruits bearing hooks, which catch on to the fur of animals and are then carried off. (2) Juicy fruits are eaten by animals, chiefly birds, the seeds being protected by a hard shell which can pass uninjured through the alimentary canal. (3) In the third method, animals carry the seeds off intentionally to their nests, and often drop them by the way, as squirrels do with acorns, for instance; ants play an important part in seed distribution in this way.

(1) Many fruits possess **hooks,** and hence may adhere to the wool or fur of passing animals. These adhesive contrivances are usually outgrowths of the fruit and not of the seed. Examples are afforded by Avens (hook = persistent style on each akene); Corn Buttercup; Goosegrass; Woodruff; Medick (pod coiled, bearing hooks); Hound's-tongue; Sanicle, Carrot, Chervils, and a few other Umbellifers; Agrimony (hooks on receptacle); Enchanter's Nightshade (Fig. 87). The flower-heads of Teasel and Burdock have hooked bracts so that a passing animal may catch the plant and drag it forward, the rebound causing the fruits to be jerked out; or, in Burdock, whole burs (fruit-heads) may thus catch on to the animal and be carried off.

In Burweed (*Xanthium*, a curious Composite, found in South England but not native, with small heads of unisexual flowers) the female flower-head is covered with hooked prickles and ends in two short conical beaks; and in Burmarigold (*Bidens*) each akene has a pappus of two or three stiff bristles covered with small downward-pointing prickles. The most formidable hooked fruits occur in tropical plants such as Martynia and Harpagophytum, which are usually shown in botanical museums. Hooks and spines also serve to protect fruits against animals which might otherwise eat them; this is probably the case with the spiny capsules of Horse Chestnut, the stiff bristles (awns) of Barley, etc.

(2) Active dispersal takes place when animals seek out **fleshy** fruits in order to devour them. The seeds are protected by hard stones in the case of drupes, or by thick leathery seedcoats in the case of most berries, by the pericarp in fruits such as those of the Strawberry or the Rose. In most cases the covering of the seed is hard and quite indigestible, and in not a few cases the seed itself is poisonous. Hence in many cases the seed can pass through the animal's body without being injured, and if deposited in suitable soil may succeed in germinating. Very often, however, the hard part of the fruit is never swallowed, but allowed to fall to the ground after the soft part has been pecked; for the animals concerned

in this mode of dispersal are usually birds, whose gizzards may crush small seeds and destroy them.

The surface of the fruit is usually conspicuously coloured. The pulp or flesh (often sweet and aromatic) may be produced from almost any part of the flower: from the ovary-wall (Cherry), the receptacle (Apple, Strawberry), the perianth (Mulberry), etc. Sometimes the seed has a coloured fleshy *aril* or extra seed-coat—*e.g.* Spindle-tree, Yew, Nutmeg ("Mace" = aril). Most, but by no means all, fleshy and bird-dispersed fruits occur on trees and shrubs (why?).

(3) Dry fruits (Acorns, etc.) may also be actively dispersed by such animals as squirrels, etc., for these animals often forget some of the hoards they lay up in autumn. This is, however, an accidental mode of dispersal, and, except in the presence of a hard pericarp, the structure of the fruit shows no special adaptations which might render this kind of dispersal more constant and profitable.

In most cases the seeds carried by **ants** are provided with an aril or other appendage which contains food, usually of an oily nature, and which is of no direct use to the seed itself, but forms an attraction for ants. Most of the plants which have this interesting means of dispersal grow where ants are most abundant—meadow and woodland plants. Experiments show that the ants take no notice of seeds which have been deprived of the attractive appendage, but carry off seeds of the same kind which have not been interfered with, and the seeds have been observed to be thrown out of the ant-nests after the appendage has been nibbled off.

In some localities it has been found that nearly half the plants growing in meadows and woods, where ants were plentiful, are dispersed by the aid of these insects. A few examples are Violet, Mignonette, Gorse, Fumitory, Spurges, Lesser Celandine. In some cases the plant has other means of scattering its seeds, but the ants help in carrying them to greater distances.

Collect, examine, and sketch fruits adapted for dispersal by adhering to animals, *e.g.* Corn, Buttercup, Avens, Goosegrass, Carrot, Medick, Sanicle, Hound's-tongue, Teasel, Agrimony, Enchanter's Nightshade, Burdock. In examining fleshy fruits, note which parts are (1) brightly coloured, (2) fleshy and edible, (3) hardened to protect the seeds.

291. Explosive Fruits.—Some fruits show active movements by which the seeds are scattered or flung out suddenly. These movements often depend upon extreme turgidity in some part of the fruit—*e.g.* in Squirting Cucumber and Balsams—or of the seed itself. In some Balsams the fleshy capsules have swollen and stretched walls, so that a slight disturbance causes the capsule to burst, and the seeds are thrown to a distance of several feet.

In some dry fruits the ejecting mechanism depends upon tensions set up by the drying of the fruit wall. In Pansies and most Violets the flower-stalk grows up erect after pollination has occurred, and the ripe capsule splits down, midway between the three lines of seeds, into three boat-shaped pieces, and as these dry they contract and squeeze the seeds together; the pressure causes the polished and slippery seeds to be flicked out forcibly and thrown to a considerable distance (sometimes as much as six feet in Garden Pansies).

In Geranium (Fig. 93, D) the carpels split apart, and the style splits off a slender thread attached to each carpel; these threads suddenly curl upwards and outwards, so as to throw the seeds out. The ripe pods of Gorse, Broom, Lupin, etc., suddenly burst open, the two valves becoming twisted and the seeds scattered. More or less similar explosive mechanisms occur in various other plants.

(*a*) In ripe fruits of Wood Sorrel notice that some of the chambers may be empty; if so, find the slit through which the seeds have escaped. This suggests that the seeds are in some way forced out of the chambers, the longitudinal slit running down the middle of the chamber-wall closing up again at once. How do the seeds escape? Try squeezing ripe fruits between the fingers until you succeed in causing seeds to spring out. How far may a seed be jerked away? By carefully examining (1) a ripe fruit with the seeds still inside, (2) a fruit from which the seeds have escaped, (3) the seed itself both before and after its escape, you should be able to discover that the seed has a thick fleshy extra coat (*aril*) covering it like a cup, and that this coat, by suddenly turning inside out, causes the seed to be shot out of the fruit through the slit in the chamber-wall.

(*b*) Examine and sketch the fruits of Violet, Pansy, Geranium, Gorse, Broom, Lupin, Box-tree, Spurge, Hairy Bittercress. Try to find out how the seeds are ejected in each case.

292. Practical Work on Fruits and Seeds.—Collect all kinds of fruits, belonging to both wild and cultivated plants, and arrange them according to (1) their structure, (2) their adaptations for seed-dispersal. Make sketches of all the fruits you examine; cut them across or open them up to make out the structure. Distinguish between one-seeded fruits (akenes, etc.) and true seeds, and notice which part of a fruit is fleshy, which part forms wings or tufts of hairs, etc. Carefully notice and compare the times taken for a winged or plumed fruit or seed to fall to the floor (1) with the wings or plumes still on it, (2) after removing them. Watch the scattering of flattened, winged, and plumed fruits and seeds on a windy day. Why do some winged fruits—*e.g.* Ash- and Sycamore-"keys"—whirl round while being blown away, and what are the advantages of this?

The structure of small seeds is best made out by the examination of thin sections. Rather puzzling appearances are, however, presented when the embryo is curved or twisted instead of being straight, or when the cotyledons are folded, or divided into lobes, for in such cases the same part may be cut twice in the one section.

In some seeds special outgrowths or **arils** are formed at the point of attachment of the seed and funicle, or from the surface of the seed. These assume the form of wartlike, fleshy excrescences in the seeds of the Pansy, Castor Oil plant (Fig. 27), and the Spurge. In the Willow and Poplar the aril is represented by a tuft of hairs which grow out from the funicle. Occasionally the aril forms an irregular fleshy investment to the seed, an example of which is afforded by the mace of Nutmegs. The succulent part of the red "berry" of the Yew is simply a special kind of aril, as is shown by its mode of development.

QUESTIONS ON CHAPTER X.

1. Distinguish between syncarpous and apocarpous fruits, and give examples of common table fruits under both heads.

2. Compare carefully the flower and fruit of a Rose with those of a Buttercup, and explain, by means of diagrams, the principal differences between them.

3. Show by comparative drawings of the flower and fruit of the Apple, the Rose, the Blackberry, the Plum, and the Strawberry just what parts of the flower and fruit correspond to one another in each case.

4. Mention two plants, each of which possesses a persistent calyx. Fully describe the calyx, and explain its use to the plant in both cases.

5. Describe and compare the fruits of the Rose, Fig, Strawberry, and Mulberry.

6. Give instances of seeds or fruits which are dispersed (*a*) through the agency of the wind, and (*b*) through the agency of animals. Of what advantage is it to plants that their seeds should be thus dispersed?

7. Describe examples of fruits or seeds which are dispersed by water, pointing out any adaptations for this method of dispersal.

8. Give an account of the various ways in which seeds are protected during the period of ripening.

9. Describe with the help of drawings five different devices by which seeds are scattered. Describe any experiments you have made on the scattering of seeds.

10. Mention any fruits or seeds you know which are distributed by the agency of animals. Describe the structures used in five cases. Have you made any personal observations on such distribution?

11. Write a short account of the structure of the more common dry dehiscent fruits, and explain how the seeds are scattered in those examples which you describe.

12. Describe examples of explosive fruits, and try to explain the mechanism in each case.

13. Describe the following fruits :—Plum, Strawberry, Raspberry, Apple, and Orange. What is the nature of the edible portion in each case?

14. How are the seeds of Cherry, Field Geranium, and Pine or Birch dispersed?

15 Describe in detail, with careful drawings, the parts of the plant used in the distribution of seed, in four cases observed by yourself, in which the seed is distributed by the agency of animals. How do the fruits whose seeds are thus distributed differ from those distributed by wind?

16. How do you know that a Strawberry "pip" is a fruit, while a Gooseberry "pip" is a seed? Mention any other "pips" you know, with drawings of three cases showing the surrounding structures, and say in each case whether the "pip" is a fruit or a seed. How are "pips" usually distributed?

17. Give a concise life-history of any one annual plant that you have grown throughout the year, with approximate dates at which the different organs appeared, stating at the same time the conditions under which it was grown. If possible, give sketches of the different phases of development.

18. Trace the life-history of any plant, living for more than a year, which you have carefully tended under cultivation from seed and back again to seed.

19. Name a fleshy fruit. Describe the structure of the flower of the plant to which it belongs and the development of the fruit, and point out any advantages derived by the species from its fleshy structure.

20. Describe the changes which an ovule undergoes in becoming a seed.

21. Mention two plants each of which possesses a persistent calyx. Fully describe the calyx, and explain its use to the plants in both cases.

22. What are the principal modes in which seeds are dispersed? Describe the mode of dispersal in Gorse, Violet, Willow, Blackberry.

CHAPTER XI.

THE BEAN FAMILY.

293. The Study of Typical Plants.—In the following chapters we shall study various common plants as "types" of certain orders or families. **Each of these plants should be studied throughout its life history.** The best way is, of course, to make repeated visits to the growing plants at short intervals, day by day (and at different times of the day in some cases), week by week, month by month, throughout the year. In any case—more especially if these frequent visits cannot conveniently be made—dig up the smaller plants and keep them under continuous observation, indoors or in a garden, making notes and sketches of the various stages in the progress of the plant's growth and development. Sow the ripe seeds of each plant and study the stages of germination and the growth of the seedling into the mature plant. Carry out all the experiments mentioned in connection with each plant and any others which suggest themselves as being likely to yield answers to the questions arising from the study of the plant itself.

Many plants which do not grow wild in Britain, or are rarely met with as wild plants, are grown in gardens, or can be bought from nurserymen. If possible get the "roots" or bulbs and grow the plants, or sow their seeds.

294. Among the many points to be attended to, the following may be mentioned:—

(1) The habit (form and general appearance) of the plant—*e.g.* tree, shrub, climbing, creeping, rosette-form, erect herb, bulb-forming—and the advantages and disadvantages of the habit.

(2) The habitat (place of growth)—*e.g.* hedge-row, field, marsh, ditch, pond, stream, wood—and the adaptations to the habitat.

(3) The conditions of growth as regards soil—*e.g.* sand, clay, loam, chalk, moistness or dryness of soil, presence or absence of humus.

(4) The light-conditions—whether deeply or partially shaded or in full light.

(5) The associated plants and *their* habits and adaptations.

(6) The characters of the vegetative organs of the plant—*e.g.* methods for reaching light and air, for spreading by runners, etc., for perennating, storage of food, form and texture of stem and of leaf, hairiness or smoothness, buds (structure, form of young leaves, unfolding), arrangement of leaves, form of blade, lengths of leaf-stalks, movements of young or adult leaves, abundance or scarcity of stomates on upper and lower surfaces of leaf, methods by which young or adult leaves are protected against excessive transpiration, etc., leaf-mosaics.

(7) The characters of the reproductive organs (note any means of vegetative propagation apart from the production of seeds)—*e.g.* time of flowering, colour, scent, honey, mechanisms for promoting cross-pollination, kinds of insects seen visiting the flower if insect-pollinated, adaptations for insect-visits or for wind-pollination, movements of flower-parts or of flower-stalks and the reasons for the movements, structure of flower (dissect, cut longitudinal section, and draw these and also the ground-plan or "floral diagram" of the flower), stages in development of fruit, growth of ovary-wall after fertilisation and any changes in its texture and colour, growth of other parts (calyx, receptacle), structure of ripe fruit (sketch whole fruit and sections), time when fruit ripens, number and size of seeds, proportion of seeds to ovules, adaptations for seed-dispersal by birds or other animals, by wind, by mechanisms for ejection ; whether the plants grow singly or in colonies.

For various special points in the biology of trees and shrubs see Chapter XVI. Where small-type descriptions are enclosed in square brackets [ ], it means that the plant is not a native of Britain.

The following abbreviations are used in the Notes on Common Plants in the succeeding Chapters :—

A, andrecium (stamens).
alt., alternate.
Brit., British Isles.
C, corolla.
cf., compare with.
comp., compound.
cpl., carpel.
cultd., cultivated.
distd., distinguished.
esp., especially.
exc., except.
flr., flower.
G, gynecium (pistil).
inf., inferior.
infl., inflorescence.
K, calyx.
loc., loculus (of ovary).
-loc., locular.
opp., opposite.
P, perianth.
per., ,,
rec., receptacle.
reg., regular.
repd., represented.
sta., stamen, stamens.
zygom., zygomorphic (irregular).
♂, male.
♀, female.
☿, hermaphrodite.

295. Classification of Seed Plants.—Seed plants (see Art. 1) are divided into two main groups—**Gymnosperms** and **Angiosperms.** In Gymnosperms the ovules (and therefore the seeds) are not enclosed in an ovary, or seed-vessel; in most (though not all) cases they are carried on the surface of the flat carpel-leaves. In Angiosperms, on the other hand, there is an ovary or seed-vessel formed of united carpels, or of a single carpel with united margins.

Angiosperms are divided into two classes—a lower class (**Monocotyledons**) and a higher class (**Dicotyledons**), the former having an embryo with one cotyledon, the latter an embryo with two cotyledons. Even this distinction is not an absolute one, and the other distinguishing marks are even more liable to exceptions if taken singly, but on the whole it is always easy to tell a Monocotyledon from a Dicotyledon.

Monocotyledons generally have the stem-bundles scattered in cross-section, the individual bundles are "closed" (without a cambium-layer), the main leaf-bundles (veins) are parallel and connected by delicate cross-veins, and the flower-parts are in threes. In Dicotyledons the stem-bundles are generally arranged in a single ring as seen in cross-section, the bundles are "open" (with cambium between bast and wood), the finer leaf-veins form an irregular network, and the flower-parts are in twos, fours, or fives. Very few plants "break" more than two of these rules, and no plant breaks them all; in exceptional cases the plant's position is usually easy to define on its general affinities, instead of by applying more or less arbitrary laws.

296. Characters used in Classification.—The general rule with regard to the kind of characters used in the classifying of plants is that *the less any part of the plant is concerned with special habits the more important is it for classification.* For instance, the vegetative organs (roots, stems, leaves) are of little value in characterising the larger groups, because they are on the whole more liable to variation and modification than are the flowers and fruits, though some vegetative characters (*e.g.* the alternate or opposite arrangement and the veining of the leaves) are less liable to modification than others and can be used in classification. Of the floral characters, the most generally useful is cohesion (Art. 257), but other characters (adhesion, form of receptacle, symmetry, number of parts in a whorl, placentation, etc.) are also used, as are also the characters of the fruit and seed (*e.g.* number of cotyledons, form of embryo, presence or absence of endosperm).

297. Variety, Species, Genus.—The object of classification is to arrange plants in a scheme which shall as nearly as possible express their actual affinities or relationships by Descent, or Evolution, from common ancestors. A really natural scheme can never be more than an ideal to be aimed at, and any scheme adopted is only an expression of our views concerning these "blood relationships," but as knowledge grows by further research the scheme will become more and more a true reflection of the affinities of plants.

There is always a certain amount of **variation** among the offspring of plants, no two individuals being exactly alike. In most cases variation is **continuous**, or **fluctuating,** *i.e.* the varying forms are connected by a continuous series of intermediate forms. In some cases, however, it is **discontinuous,** *i.e.* we find on examining a large number of individuals that they group themselves in two or more sets, races, or **varieties,** which are hardly connected, if at all, by intermediate forms. Many examples of both kinds of variations are found in cultivated plants. Varieties differ from each other in relatively small and variable characters, often only in the vegetative organs or in floral or seed characters, of slight importance.

Species are groups which differ in more important and more constant characters of the vegetative organs, or of the flowers and fruits, or both. When the differences become still more pronounced, important, and constant, we agree to recognise distinct genera—a **genus** being of higher rank than a species just as a species ranks above a variety. A number of related genera, agreeing in certain broad features, though differing (often considerably) in others, constitute a **Natural Order.**

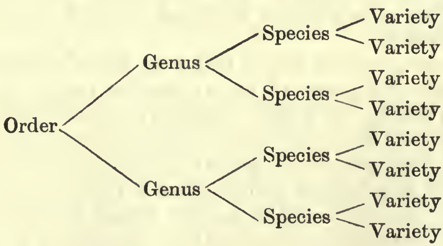
Moreover, though different Natural Orders differ from one another in important features, we can often trace a general likeness in a few characters, enabling us to group the Orders into **Cohorts.**

The relative values of the characters which distinguish what we call varieties, species, and genera can be illustrated by comparing, for example, the resemblances and differences existing between the varieties of Sweet Pea, Garden Pea, Broad Bean; those existing between the different species of the genera *Lathyrus*, *Vicia*, *Trifolium*, etc.; and those between the different genera of Leguminosae.

The Order Leguminosae is united with several others to form the Cohort Rosales, which includes the Orders Rosaceae, Saxifragaceae, Crassulaceae, and a few more. If only the native British genera of Leguminosae are taken into account, it is hard to see why this order is grouped with those just named, but the *Mimosa*-tribe of Leguminosae has flowers which differ very little in structure from those of certain Rosaceae.

As you proceed with the work of classifying plants, you will realise that the boundaries between varieties and species, between species and genera, and so on, cannot be precisely and sharply defined; the same applies even to the boundary between the lowest plants and animals. This is, of course, just what one might expect from what has been said about variation and evolution. Hence an absolutely natural system of classification can never be realised. The nearest approach to such a classification of Angiosperms is that of Engler and Prantl, adopted in this book, which should be compared with the Bentham-Hooker arrangement given in British Floras.

The relations between a variety, a species, a genus, and an order may be shown as below:—



Of course, there are many species which, though variable (as all species are), have no distinct varieties—that is, they show continuous but not discontinuous variation. A species may have many or few varieties, a genus many or few species, and an order many or few genera. In fact some genera have only one species—that is, a species may be so distinct from other plants that it is raised to the rank of a genus. And a single genus may be regarded as forming an order by itself—there are several such cases known. In the scheme given above, each species is represented as having two varieties, each genus as having two species, and the order as consisting of two genera.

298. The Bean and Pea Family, so far as the native British and the commonly cultivated foreign plants belonging to it are concerned, can be readily recognised by the characteristic structure of the flowers, especially the corolla. It is therefore taken first in our study of the chief families of Dicotyledons. All the commoner British wild plants in which the flower has a corolla resembling that of the Broad Bean (*i.e.* consisting of standard, wings, and keel) are described in this chapter.

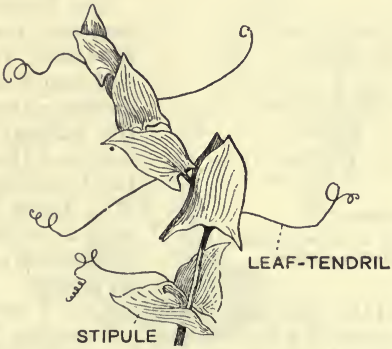


Fig. 96.—Yellow Vetchling (*Lathyrus aphaca*).

In studying all the available plants belonging to this family, note carefully their resemblances and differences, as a basis for a knowledge of the general principles upon which the classification of plants is founded.

The Bean Family is one of the largest, and also one of the most useful, among flowering plants. The family as a whole is characterised by the fruit being, with rare exceptions, a pod (legume), whence its name Leguminosae.

In the great majority of the species, forming the sub-family **Papilionaceae**, the flower has the same general structure as that of the Broad Bean. There are two other sub-families, not represented in Britain; one of these includes the Acacias and the Sensitive Plant (*Mimosa*). The family includes trees, shrubs, creeping plants, climbing plants, erect herbs, annuals, and perennials; the leaves vary greatly in form, etc. Examine all the plants of this type that you find growing wild or in cultivation.

Fig. 97.—Part of a Garden (Culinary) Pea Plant (*Pisum sativum*).

The British Papilionaceae may be divided into five tribes. I. Gorse tribe: leaf simple or of 2 or 3 leaflets, no tendrils, leaves (or leaflets) with entire margin. II. Clover tribe: like I., but leaflets serrate. III. Lotus tribe: leaf with 2 or more pairs of leaflets and an end-leaflet, no tendrils. IV. Sainfoin tribe: like III., but pod consisting of 1 or more indehiscent one-seeded joints instead of opening by 2 valves. V. Vetch tribe: leaf with the stalk ending in a tendril or point.

299. Gorse Tribe.

A. Calyx deeply 2-lipped, coloured: *Ulex* (Gorse).

B. Calyx shortly 2-lipped, green.

1. Each calyx-lip deeply toothed: *Genista* (Petty Whin, Dyer's-weed).
2. Each calyx-lip minutely toothed: *Cytisus* (Broom, Laburnum).

300. Clover Tribe.

A. Stamens monadelphous (all joined): *Ononis* (Rest-harrow).

B. Stamens diadelphous (upper one free).

1. Flowers in heads, pod straight: *Trifolium* (Clovers).
2. Flowers in racemes, pod coiled: *Medicago* (Medicks).

301. Lotus Tribe.

A. Calyx shorter than corolla.

1. Pod constricted between seeds: *Lotus* (Bird's-foot Trefoil).
2. Pod divided by a longitudinal partition: *Astragalus* (Milk Vetch).

B. Calyx longer than corolla: *Anthyllis* (Lady's-fingers).

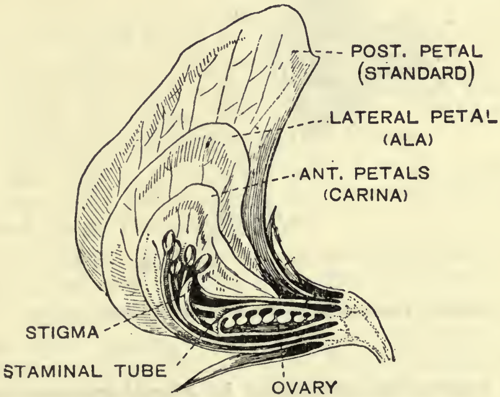


Fig. 98.—Median Section, Flower of Culinary Pea.
Ala = wing-petal, carina = keel.

302. Sainfoin Tribe.

A. Pod cylindrical, many-jointed: *Ornithopus* (Bird's-foot).

B. Pod flat, of several curved joints: *Hippocrepis* (Horse-shoe Vetch).

C. Pod hard, one-seeded: *Onobrychis* (Sainfoin).

303. Vetch Tribe.

In *Vicia* (the **Vetch** genus, to which the Broad Bean belongs) there are usually at least 4 pairs of leaves, and there is a tuft of hairs on the style, below the stigma. In *Lathyrus* (**Vetchling** or **Pea** genus, including the Sweet Pea) the leaflets are few (usually 1 or 2 pairs) and the style has hairs scattered over it, not in a little tuft.

Fig. 99.—Longitudinal Section of Flower of Scarlet Runner.

304. Flower Mechanisms in Papilionaceae.—In examining the flowers note any differences in the calyx (lobes equal or unequal in length, smooth or hairy, etc.); the corolla (how are the wings jointed with the keel?); the ten stamens (is the stamen joined with the others so as to form a complete stamen-tube, or is it free, and are the filaments equal or unequal in length?); the pistil (length of style, its position with the keel, presence or absence of hairs). In each case sketch all the parts carefully (sketch the separate parts and a longitudinal section of the flower), and find out what happens when the keel is pressed down; if possible, watch bees at work on the flowers. The following notes on the chief types of **flower-mechanism** may be useful:—

(*a*) Stamens and stigma emerge from keel when it is depressed, and return inside it again when the bee flies away; the same flower may therefore be visited several times: Clover, Sainfoin, Laburnum, etc.

(*b*) Keel-petals joined above as well as below, leaving a small opening at the tip; pollen shed into upper end of keel before flower opens; five of the stamens have filaments thickened below the anthers, and the piston thus formed pushes out some of the pollen each time the keel is depressed: Bird's foot Trefoil (*Lotus*). The other five stamens are shorter and shrivel up after they have shed the pollen, which is carried by the long stamens (those with the thickened ends) into the tip of the keel. A somewhat similar mechanism is found in the Lupin and in Lady's-fingers (*Anthyllis*).

(*c*) Upper edges of keel-petals at first joined, and pollen forced out at tip, as in *b*, but later on the keel splits open, and stamens and stigma emerge as in *a*: Rest-harrow (no honey in flower, therefore stamens all united).

(*d*) Like Broad Bean, with tuft of hairs on the style which sweeps the pollen out of the keel when the latter is depressed: most Vetches and Peas.

(*e*) Mechanism as in *d*, but stamens long and coiled up within a coiled keel: Kidney Bean, Scarlet Runner.

(*f*) Stamens and style tightly held, more or less coiled up, in the keel under tension, and springing out violently when keel is depressed: Gorse, Broom, Petty Whin (*Genista Anglica*), Dyer's-weed (*G. tinctoria*), Lucerne and other Medicks (*Medicago*).

Recent observations on the flowers of Papilionaceae have led to the generalisation that while many *perennial* kinds have *self-sterile* flowers (see Art. 263), *all the self-fertile kinds are annuals.* Some of the latter, in fact, are self-pollinated before the flower-bud opens (*e.g.* Sweet Pea, Garden Pea). The annuals cannot afford to be self-sterile, because they depend on each year's crop of seeds for their very existence, whereas perennial plants can safely run the risk of not being pollinated at all on the chance of securing cross-pollination now and then.

QUESTIONS ON CHAPTER XI.

1. Describe the leaf of a Sweet Pea, with a careful sketch. Why is the stem of the Sweet Pea "winged"?

2. Describe the appearance of (1) a young Sweet Pea tendril before it has met with a support, (2) a tendril which has just caught a support, (3) the same at a later stage, (4) an old tendril which has not grasped any support.

3. Describe, from your own observations and experiments, how a tendril acts.

4. Describe the vegetative parts (shoot and root) of the Everlasting Pea, and compare it throughout with the ordinary Sweet Pea.

5. Describe, with sketches, the flower of a Sweet Pea and its method of pollination.

6. Describe a common Vetch (*Vicia*) and compare it (as to shoot, leaves, flowers) with Sweet Pea and with Broad Bean.

7. Why is the Broad Bean placed with the Vetch (*Vicia*) genus, and not with other "Beans," *e.g.* French Bean or Scarlet Runner?

8. Describe the mode of growth of White Clover and compare it with that of Red Clover, pointing out how the vegetative organs of each adapt it to its surroundings.

9. Describe the sleep-movements of a Clover leaf as they occur in nature, and explain their causes and their utility. Give an account of experiments you have yourself made on these movements.

10. Compare the habit, habitat, leaf-structure, and leaf-movements of Clover and Wood Sorrel.

11. Describe and compare the flowers of Red Clover and White Clover, pointing out any differences in structure and mode of pollination.

12. Describe the way in which the Scarlet Runner climbs, and compare its climbing with that of Sweet Pea or Garden Pea.

13. Can you explain why a Scarlet Runner can only climb vertical or inclined supports, while a Sweet Pea can climb round even horizontal supports?

14. Describe the flower-structure and pollination-mechanism of a Scarlet Runner, with sketches.

15. How can you cause a Sweet Pea plant, or a cut branch, to go on flowering for a longer time than it would if left alone?

16. Sketch part of a Gorse plant, marking clearly which structures are leaves and which are stems. How are these organs distinguished?

17. Point out the structural features by which a Gorse plant is adapted to its usual habitat. What other plants are often found growing along with Gorse?

18. Describe observations and experiments which show that the peculiar features of the Gorse plant are adaptations for enduring drought.

19. Describe the seedling of Gorse, and discuss its structure and its relation to the structure of the mature plant.

20. Describe the structure of the Gorse flower. What happens when a bee alights on the flower? How often can a Gorse flower be visited by bees?

21. Describe the appearance of a Laburnum tree (1) in winter, (2) in spring, (3) in late summer or in autumn.

22. Describe the inflorescence of Laburnum, and compare it with the inflorescences of the other plants of the Bean family which you have studied.

23. In what respect does the nutrition of plants of the Bean family differ from that of most flowering-plants?

24. Name eight papilionaceous flowers, of which six must be British. Describe carefully, from observations you have made, the pollination of any one of these and draw its floral diagram.

CHAPTER XII.

MONOCOTYLEDONS.

305. Crocus.—The life-history of the Crocus should be carefully studied by continuous observation, according to the following detailed instructions.

Note that a dry resting-corm is almost entirely covered by brown **scales**, thin and dry. What can you see of the structure of the scales? Pull off a bit of this scaly covering: which surface (outer or inner) is rough and dull, and which is smooth and shiny? In which direction can the scales be torn easily, and why? Do the strings or fibres, of which the scales are almost entirely made up, run parallel, or do they diverge and form a network, or do they show both of these arrangements? What do you think the strings are, or at any rate were at one time?

Now look at the flat or concave lower end of the "bulb" (how can you tell which is the lower end?) and notice the roughly circular patch. Unless you have examined Crocuses after they have been dug up when the growth of flowers and leaves had finished for the season, you cannot tell how this patch was formed. What can you see on the lower end of the "bulb," just outside of this patch? Sometimes one can plainly see numerous short slender white pointed projections in this part, arranged in a ring. If you can see these, you should be able to guess that they are young roots.

Now remove the scales carefully one by one, starting from the lowest. Notice that each scale goes right round the "bulb," and that on removing it you can see a brown line where the scale was attached (Fig. 101). What name might be given to each of these lines? What name is given to the place where a seed breaks from its stalk, or a leaf from the stem? Would you call the hard white solid mass to which these scales are attached a **stem?** We know that a stem bears leaves and buds. As you remove the scales, notice that they become more crowded at the top, so that the scars are closer together here. What do you see projecting from this upper end? Can you find any similar projections lower down? In most cases you will find one between any two neighbouring scars. What are these projecting bodies?

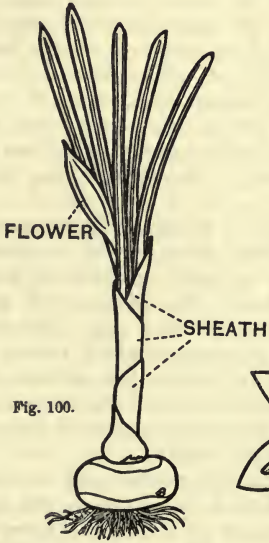


Fig. 100.

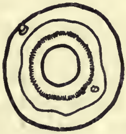


Fig. 101.

Fig. 102.

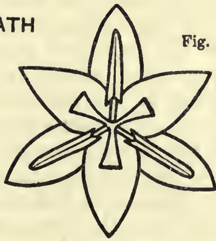


Fig. 103.

Figs. 100-103.—Crocus. 100, Entire Plant just before the Flower has opened; 101, Corm from below; 102, Side view of Corm; 103, Flower as seen from above.

From these observations you should be able to infer that the "bulb" is a short thick stem bearing **buds,** and is therefore a form of shoot. It is distinguished from most bulbs (Onion, Tulip, etc.) by having a large thick stem and thin dry scales instead of a very small disc-like stem and thick fleshy scales; it is therefore called a "solid bulb" or **corm.**

Now pick off one of the large buds from the top of the corm, and very carefully dissect it, making a sketch of the entire bud and of each part you remove from it. Notice first the **scales**: how many are there, how are they inserted (trace each one carefully to its base), how do they resemble the scales you picked off the corm itself, and how do they differ from these? Next notice the young yellowish or green **foliage-leaves,** each having a broad base inserted like a ring around the lower part of the bud; this part is not easy to make out clearly, so you may have to try several buds.

What do you find in the centre of the bud? In most cases you will find one or (in some Crocuses) several tapering, pear-shaped bodies covered by a papery sheath, and tapering to a point above and into a stalk below. Each of these bodies is a **flower-bud,** containing a young flower. Notice the long tube ending above in six pointed oval lobes; the stamens (how many?), which are already very large as compared with the "petals"; the style, ending in the three fan-like stigmas.

Now examine some Crocus plants in flower and in earlier stages of growth, or plant some corms in moist sawdust or soil and watch their growth. Notice the swelling and upward growth of the buds; the roots which spring from the base of the corm, arranged in a ring; the sheath, consisting of the enlarged bud-scales, which covers the young shoot until it has grown well above the surface of the soil; the bursting of the scaly sheath and the appearance of the foliage-leaves, which are now bright green in colour; and the escape of the flower from its sheath.

Examine the flower carefully, noting and comparing what you see in flowers in different stages, or in the same flower day by day from the time of its emergence from its sheath. Note the six coloured lobes, three outer and three inner, which form the most conspicuous portion of the flower, and which arise from a funnel-like structure, prolonged below into a long narrow tube. The tube, funnel, and lobes together form the *perianth.*

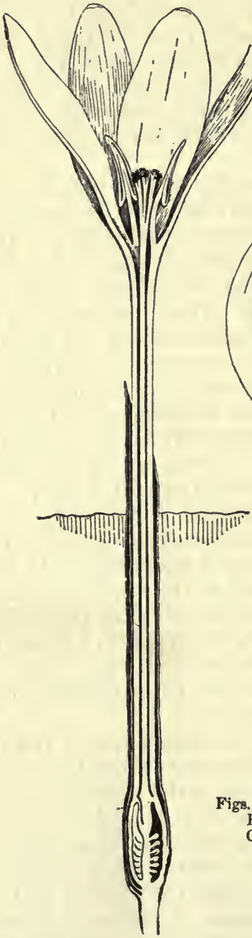
Note the three stamens, each consisting of a long anther (showing the four pollen-sacs very distinctly) and a short filament: the latter is inserted on the mouth of the flower-tube, opposite a "sepal," and the stamen is spear-shaped owing to the anther being produced into a sharp point on each side of its base (where the filament is attached). Note the three fan-like stigmas, with more or less toothed or frilled edges, continued below into the style; cut open the flower-tube and trace the slender style right down. Both the style and the flower-tube arise from the top of a swelling, the ovary; cut the ovary across and notice the numerous "young seeds" arranged in two longitudinal rows on the inner side of each of the three ovary-chambers. Below the ovary is the flower-stalk; the bracts spring from this stalk, just below the ovary.

Close observation of a flower day by day will show that the lobes spread out in the daytime and move inwards at night, thus causing the opening or closing of the flower. The flower opens when exposed to light, sufficient warmth, and dry air, whilst its closing may be caused by coldness or dampness of the air as well as by darkness. The movements of opening and closing can, by careful measurement, be shown to be caused by the outer sides of the perianth-lobes growing faster (closing movement) or more slowly (opening movement) than the inner sides. What are the advantages to the flower of this power of opening or closing? What other plants, growing wild or in gardens, have flowers which open on bright days and close on dull or wet days and at night? For how many days does a Crocus flower last?

It is easy to discover that the anthers open by two slits, shedding the pollen outwards, *i.e.* away from the centre of the flower, that this happens while the stigmas are in contact with each other, and that a day or two after the anthers have opened the three stigmas separate and spread out, one opposite each *inner* perianth-lobe. Do you see how this helps in promoting cross-pollination? The Crocus flowers are visited by bees, butterflies, and moths.

The Crocus contains honey in abundance, as can easily be seen by opening up the perianth-tube; the honey, produced by glands in the partitions between the three ovary-chambers, rises up the tube and can be sipped by bees entering the flower. The bee stands on the perianth-lobes and pushes its head into the funnel-like mouth of the tube, seeking for the honey, and in doing this it touches the stigmas (if these have spread out) and then the stamens. If, however, cross-pollination fails to occur, the stigmas may curl over and touch the anthers, bringing about self-pollination.

After the flowering period the perianth, stamens, stigmas,



Figs. 104, 105.—Vertical Section of Flower and Floral Diagram of Crocus. (After Church.)

and style wither; if fertilisation has occurred the ovary grows larger and forms the fruit, which later on is carried upwards by the lengthening of the flower-stalk. The fruit (capsule) ripens in June (in Spring Crocuses) and splits down the middle of each chamber, setting the seeds free.

Long after the flowers have withered the foliage-leaves persist, carrying on photosynthesis and storing up food. Where, and in what form, is this food stored? Examine a Crocus plant in May or June, noting the swollen base of each shoot that has grown from a bud on the corm. The latter is now withered and shrunken, while the swollen shoot-bases

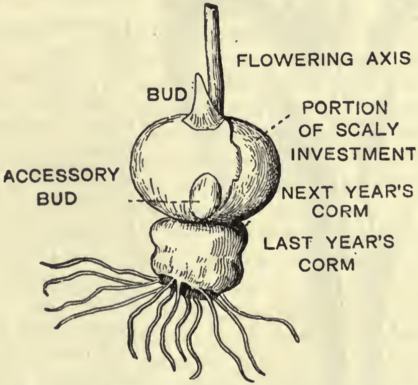


Fig. 106.—Corm of Gladiolus after removal of enveloping scales. The Bud forms the Corm of next year; the Accessory Bud separates and forms a new plant.

are fresh and plump. Cut vertically through one of these swollen bases and note the solid white mass, which is obviously a *young corm*. The young corm is formed by the swelling of the base of the stem, and its cells contain food which has been made by the leaves and has travelled downwards for storage in the young corm. Of what nature is the stored food in the Crocus corm?

The new corms continue to grow in size until the foliage leaves die and wither, when they will be found to have become as large as the parent corm (to which they are attached) was

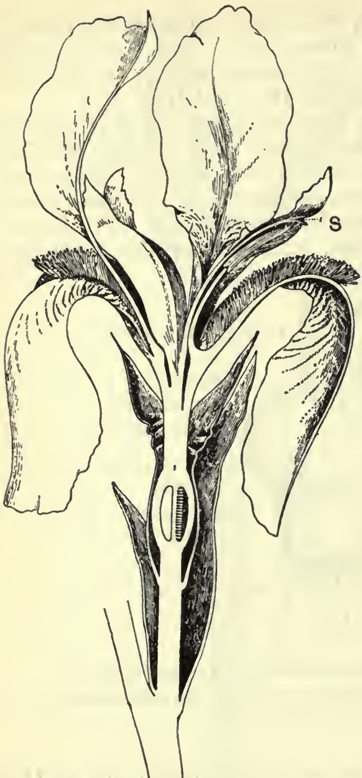


Fig. 107.—Vertical Section of Flower of Iris. (After Church.)

On the left are shown an outer perianth segment, a petaloid style entire, and an inner posterior perianth segment cut in half. On the right an outer anterior perianth segment and a style are cut in half showing a stamen lying between them; at the back is a lateral inner perianth segment (petal); s = stigma.

when planted. Three or four, or even more, new corms may be developed in this way on the parent corm. Gardeners usually dig up Crocuses after the leaves have withered, and the young corms, which readily break off from the old withered corm, are stored in a dry place until the time comes for planting them. In this way the number of corms is multiplied, and in most cases gardeners do not trouble to raise Crocuses from seed. Hence by the formation of corms the Crocus is not only enabled to last from year to year, *i.e.* to become a *perennial* plant; the production of several new corms on each old one is a method of *vegetative multiplication*, *i.e.* increase apart from seeds. In Gladiolus (Fig. 106) the corms remain connected in chains.

Now we can explain certain features of the dry Crocus corm. The patch at the base of the corm is the *scar* where it separated from its parent corm. The brown stringy scales are the withered bases of the bud-scales and the foliage-leaves. Compare carefully the parts of the fresh young corm with those of (1) a dry corm, (2) a bud on a dry corm, (3) a shoot which has grown from a bud.

306. The Crocus and Iris Family (Iridaceae) is easily distinguished from other Monocotyledons by the petaloid 6-lobed perianth, the 3-chambered inferior ovary, and the 3 stamens.

Examine the two common British species of *Iris*—**Yellow Flag** (*I. pseudacorus*) and **Roastbeef Plant** (*I. foetidissima*)—or one of the cultivated Irises. Note the very large petaloid stigmas (Fig. 107).

307. Bluebell or **Wild Hyacinth** (*Scilla nutans*) is one of the most familiar of spring-flowering plants. It grows best in woods which are not *too* deeply shaded, but it sends up its leaves and flowers early in the year, thus gaining the benefit of the light and of insect-visits before too many other plants have joined in the competition. By the end of May, when the wood has become darker with the full foliage of the trees, the Bluebell has ceased flowering.

Note the long (9 to 18 ins.) and narrow (about ½ in.) leaves; the flowering shoot which grows, as a rule, beyond the leaves; the bell-shaped perianth, the six parts of which are free, or joined only at the bases; the stamens, one inserted on the base of each perianth-leaf. Below each flower there are paired bracts, which help to pack up and protect the flowers in the bud-condition. Note the blue colour of bracts, perianth, filaments, and pistil. The latter consists of a ribbed ovary (cut it across and note the structure), style, and three-lobed stigma (the lobes are often very faintly marked). Honey is found along the grooves which run down the outside of the ovary; the nectaries or honey-producing glands are in the partitions between the three chambers of the ovary.

The flowers are sometimes pink or even white, instead of having the typical blue-purple colour. The flower-stalk is erect until the flower opens; then it bends down and the drooping flower is protected against rain, which would spoil the pollen and honey; finally, when the fruit is ripe the stalk curves upwards again, so that the seeds are shaken out gradually from the three slits into which the capsule opens.

Visit plants at intervals, so as to observe all the changes which occur from the time the leaves and flowers emerge from the soil until the ripe capsule opens to let the seeds be scattered by the wind. Dig up a few plants each time you visit a place where Bluebells grow; a useful plan is to thrust sticks into the soil to mark the positions of the plants, so that you can get the underground parts after the leaves and

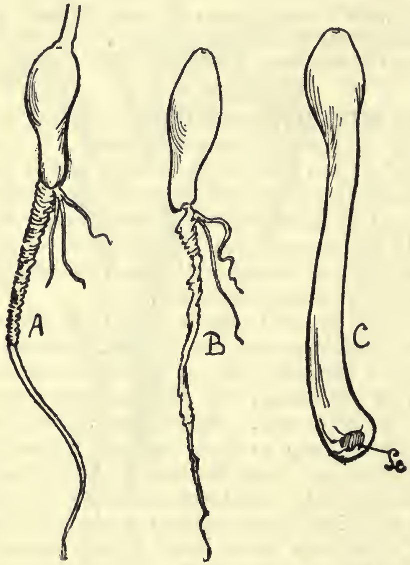


Fig. 108.—Bluebell Bulbs.

A and B show the wrinkled contractile root which pulls the bulb down into the soil.

flowering shoots have died down. "The Bluebell is a plant which carries on a considerable part of its activity underground. At all times of the year some work is going on, and although much of it is hidden from view, a study of this underground history constitutes one of the most interesting phases in the life-cycle of the plant."[1]

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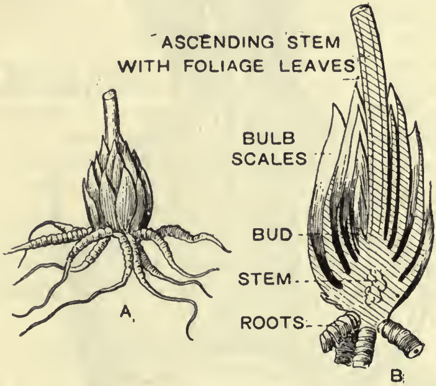
[1] Woodhead, "Notes on the Bluebell," *Naturalist*, 1904.

Examine the swollen lower portion of the shoot, which often lies about a foot below the surface of the soil. Tear off the thin outer scales (leaf-bases) which surround it, and note the white, sticky, fleshy scales which make up the greater part of the swollen mass. Cut (1) transverse and (2) longitudinal slices through this mass, and notice in the latter the small disc-like stem from which all the scales arise, and which bears roots on its lower surface and



Figs. 109, 110.—Scaly Bulb of Turk's Cap Lily.
109 (A), Entire; 110 (B), Median Longitudinal Section.

buds on its upper surface. This structure is a **bulb** (Figs. 109, 110). It differs from the corm of the Crocus chiefly in the relatively smaller size of the stem, and in its investment by thick fleshy scales, which contain large stores of reserve food. In *scaly* bulbs (Lilies, Fig. 111) the food-containing scales simply overlap at their margins, whereas in *tunicated* bulbs (Bluebell, Onion, Hyacinth) the outer leaves are large and completely ensheath the inner portions of the bulb.

The coloured membranous covering on the outside of such bulbs is formed by the shrivelled remains of the food-scales of a previous season.

The bulb of a Garden Hyacinth, a Daffodil, and an Onion should be examined, since the parts are more easily observed than in the Bluebell. The bulb is largely composed of the enlarged persistent bases of foliage-leaves, but it also includes a certain number of scale-leaves. A bud

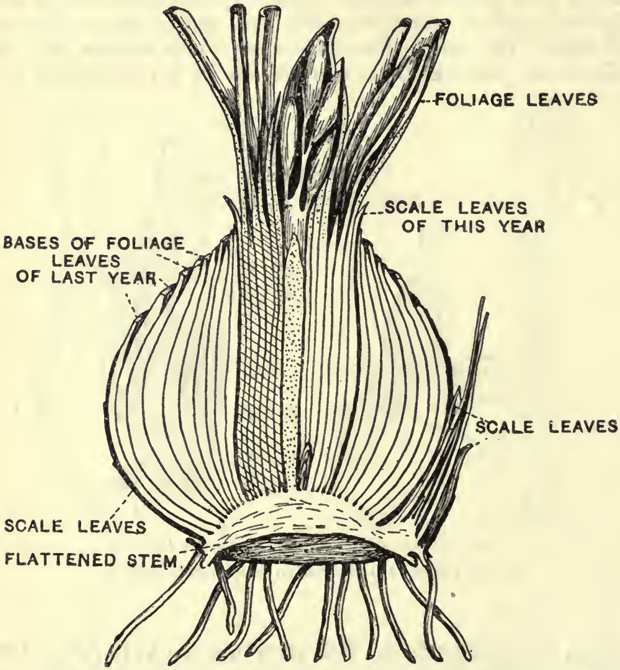


Fig. 111.—Vertical Section of Flowering Bulb of Hyacinth in Spring, with a lateral bud enclosed by a pair of scale-leaves.

The shaded portion on the left marks this year's growth on that side. On the right the bud of next year is shown.

arises in the axil of the innermost leaf, and next spring this will develop into a flowering axis, surrounded by a number of foliage-leaves, and outside of these a few scale-leaves. The outermost scales of the previous year shrivel, the inner ones persist, together with the bases of the foliage-leaves, and the enlarged axillary bud now forms the central portion of the new bulb. This may continue for several years, but ultimately two or more buds develop in the axils of the upper leaves. As they grow they rupture the parent bulb, and are set free, after having absorbed a large amount of nourishment from it. This is especially well seen in a Narcissus bulb. Buds, composed of scale-leaves enclosing foliage-leaves, may also develop in the axils of the outer scale-leaves. See Fig. 110.

We saw that the Crocus corm contains abundant starch: what reserve food is present in the Bluebell and these other bulbs? On testing a sliced bulb with iodine we find that the Bluebell contains very little starch, the Onion none at all. The chief food stored in the Onion is *sugar*, as can be proved by means of Fehling's test, while the Bluebell bulb contains chiefly a carbohydrate substance called *inulin*, which resembles starch in composition but is soluble in water (less so than most sugars, however).

The underground life-history of the Bluebell is very interesting, and the main points, as regards external features at any rate, are fairly easy to make out. Young seedlings can be dug up in October or November, older ones in May and June, but if you cannot find the seedlings in the soil bring some capsules home and sow the black globular seeds. The germination is similar to that of the Onion (Art. 87).

308. The Lily Family (Liliaceae) consists chiefly of perennial herbs with bulbs (Lily, Onion, Hyacinth), rhizomes (Solomon's Seal, Lily of the Valley), or corms (Meadow Saffron), but the order also includes a few shrubs (Butcher's Broom) or even trees (*Yucca*, *Dracaena*). The Butcher's Broom has flat green branches (cladodes), and the true leaves are represented by small scales; it flowers throughout the colder months of the year, the flowers (borne on the cladodes) usually being *dioecious* (some with stamens only, others with pistil only). Asparagus also has small scaly leaves and tufts of green (generally needle-like) branches which carry on the functions of foliage-leaves; sometimes these cladodes are flattened. That the cladodes of Butcher's Broom and Asparagus are really branches is shown by the fact that they bear flowers, and that they arise in the axils of scales (the true leaves) on the stem.

The flowers are regular and hypogynous. The flower-parts outside of the stamens are all coloured, and do not differ much, if at all, in form; they are therefore said to form a *perianth*. The perianth nearly always consists of six parts, rarely of eight parts (*e.g.* Herb Paris, Aspidistra), and usually there is a division into three inner and three outer parts. There are usually six stamens, arranged in two series (whorls), outer and inner. The pistil usually consists of a three-chambered ovary with numerous ovules in each chamber, a single style, and a 3-lobed stigma. Note that in Bluebell

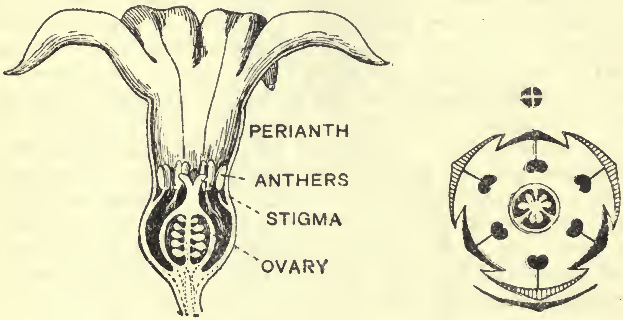


Fig. 112.—Longitudinal Section and Floral Diagram of Flower of Garden Hyacinth.

and Tulip the perianth-parts are free from each other, whilst in the majority of Liliaceae (Fig. 112) they are carried up as lobes on the margin of a tube, the stamens being inserted on the inner side of the tube.

Both self- and cross-pollination occur, most of the flowers being adapted for long-tongued insects. In most Liliaceae honey is produced by glandular tissue in the partitions between the chambers of the ovary. In *Colchicum* honey is secreted on the outer side of the filaments of the stamens, at the bases of their free parts, not in the long perianth-tube. In Tulip and Garlic there is no honey, but the flowers are visited for pollen. In Herb Paris the dusky colour and fetid smell of the flower attract carrion-loving flies, which alight on the stigma and then crawl over the anthers, becoming dusted with pollen.

The fruit is either a capsule or a berry, and the seeds are endospermic; the endosperm generally contains oil and proteids and the cell-walls are thickened (cellulose).

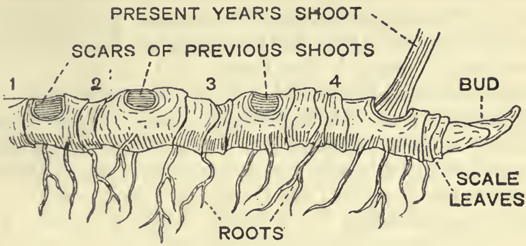


Fig. 113.—Rhizome of Solomon's Seal.
The numbers represent increments of successive years.

309. Daffodil (*Narcissus pseudonarcissus*) grows wild in various localities, but has often been introduced and "naturalised." Its bulb has much the same structure as that of the Hyacinth, and its long narrow leaves are covered with bloom and blunt-tipped.

The large flowers (March, April) are carried singly on a long and rather flattened flowering stem. The young flower is protected by a scale (bract or **spathe**), and is at first erect, but before opening becomes horizontal or nearly so, while its short stalk also turns towards the light. The bract becomes withered and wrinkled as the flower opens, but still clasps the ovary, which is inferior. The perianth-tube is funnel-shaped, about 18 mm. long, 15 mm. wide at mouth, 4 mm. wide at base; the perianth-lobes (three outer and three inner, but inserted close together in a ring) are pale yellow and ovate with acute tip. Beyond the perianth-tube is the **corona**, a cylindrical outgrowth 30 mm. long and 15 mm. in diameter, deeper yellow than the rest of the perianth; its mouth is frilled and its inner surface wrinkled.

The six stamens have long filaments, inserted a little above the base of the flower-tube; the long anthers are close together around the style, a little below the three-lobed stigma which stands rather more than half-way up the corona; the anthers open inwards by slits. A little honey is secreted by the partitions separating the chambers of the ovary, near the top;

the small honey-pores at the base of the style can be seen with a lens.

Since the flower-tube is very wide, except at the very base, insects of all kinds can enter and take away pollen and honey; the pollen from the burst anthers falls on the lower side of the horizontal corona. The flower is, however, adapted for pollination by large bees, which in entering rub first against the stigma and probe for the honey which collects below the insertion of the six flat filaments. Each flower remains open and ready for insect-visits for about three weeks; the stigma and anthers are protected by the large corona, which makes the flower conspicuous.

310. The **Snowdrop** (*Galanthus nivalis*), though not a native British plant, occurs as a garden escape in various places. It has a small bulb, which each year produces a scale-leaf, two foliage-leaves, and a flowering stem bearing a single flower. The scale-leaf forms a protective sheath; the swollen bases of the foliage-leaves and the flowering stem form the fleshy scales of the new bulb; the flowering stem arises in the axil of the upper foliage-leaf, and the axis ends in a flowering bud for next year. A new bulb may arise as a bud in the axil of the sheathing scale-leaf or that of the lower foliage-leaf, and ultimately separate from the main axis, which grows on year after year.

The flower is at first erect and enclosed in a sheathing bract, which has two thick green side portions and a colourless middle portion and is prolonged above into two claws. The ovary is inferior, three-chambered, and contains numerous ovules. The perianth consists of six free parts, of which the outer three are white, elliptical, with narrow base, and the inner three are shorter, broader, and notched at the top. The outer perianth-leaves are spreading, while the inner ones are nearly vertical and have on the outer side a green V-shaped patch following the notch, and on the inner side about eight green lines. The six stamens arise from the top of the ovary, within the perianth-leaves; the filaments are short and slender, the anthers long and tapering and ending each in a thread-like process at the tip. The anthers are close together and form a cone around the style; each opens by a pore on the inner side at the top, but each pore extends as a slit to the base of the anther. Within the six filaments and around the base of the style there is a ring-like nectary; the style projects beyond the anthers and ends in a pointed tip which bears stigmatic hairs.

The flower performs opening and closing movements, confined to the three outer perianth-leaves. These movements are, as in the Crocus, dependent on temperature; warmth causes these segments to grow more rapidly on the inner side and thus to curve outwards, exposing the conspicuous inner segments. The flowers are adapted for pollination by bees, and in gardens they are chiefly visited by hive-bees. The bee, landing on the outer perianth-leaves and grasping the inner ones, rubs against the outwardly-curved tips of the anthers and brings a shower of the dry dusty pollen on its head, having previously rubbed against the stigma. Self-pollination occurs frequently, especially when the weather is very cold and no bees are about.

311. The **Daffodil Family** (*Amaryllidaceae*) differs from Liliaceae in having an inferior ovary, and from Iridaceae in having six stamens. It includes many showy garden plants.

312. Early Purple Orchid (*Orchis mascula*).—This is the commonest and best known of British wild Orchids. It grows in various situations, most luxuriantly in low-lying or

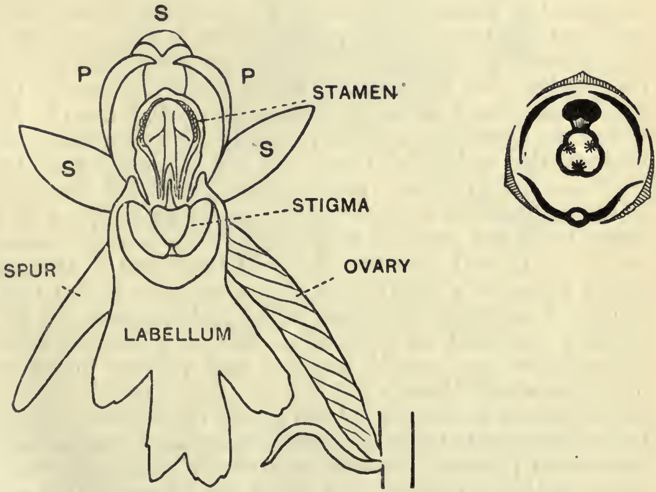


Fig. 114.—Flower (front view) and Floral Diagram of Orchis.

sheltered and moist meadows, where its flowering shoot may reach a height of over a foot, while on exposed downs it is only a few inches high.

Note the strap-shaped leaves, which come up in a rosette along with, and surrounding, the inflorescence about the middle or end of April; each leaf clasps the stem at the base and usually has dark purplish spots or blotches.

Examine the flowers, noting their spiral arrangement on the stem, the youngest ones being at the top. Note the bract below each flower (Fig. 114); the three sepals, alike in form and size; the three petals, one of which is larger than and different in shape from the other two. This large petal, the *labellum*, consists of a broad lip and a curved spur; it is rather like the spurred petal in a Violet, but it contains no liquid honey. The thick wall of the spur, however, consists of sweet tissue, as can be perceived by chewing it, and an insect can only get the sweet juice by scraping the inside of the spur.

The structure of the inner parts of the flower is rather complex, but the essential points for our purpose are easily made out. Do you see, above the mouth of the spur, a projecting mass consisting of two club-like structures, side by side, arched over by the two small petals and one of the sepals, and below these structures a rounded knob? By slicing the flower longitudinally, so that the slice passes down through the middle of this mass and the middle of the labellum, and by careful inspection, you will find that each of the club-shaped structures is a pocket which opens by a vertical slit and contains a greenish club-like body with a slender stalk, and that the stalks of these two bodies are joined below to a sticky disc resting on the rounded knob below. The green clubs are called *pollinia*, and the two together represent an anther, in each of whose lobes the pollen-grains are massed together into packets joined by branching elastic threads.

The stamen and the style have grown up together, so that the stamen stands above the knob-like stigma. The rounded sticky disc (*glandula*) at the base of the pollinia lies in a small cup-like structure, just above the stigma. This cup (*rostellum*) splits readily on the slightest touch—perhaps spontaneously—so as to expose the disc. A bee visiting the flower pushes its head against the disc as it pokes its tongue into the spur, and when it leaves the flower it carries off the pollinia planted on its head by means of the sticky disc. Then the disc contracts in such a way as to bring the pollinia downwards and pointing forwards, and the thick end of a pollinium touches the stigma of the next flower visited (Fig. 115 B, C), and the sticky stigma drags off some of the packets of pollen.

The pollinia remain fixed on the bee's head, as the sticky disc soon hardens, so that a single pollinium may be carried about and pollinate several flowers before all the pollen is pulled off by the stigmas. One often sees a bee, which has been visiting Orchids, carrying a dozen pollinia stuck on its head, base of tongue, and thorax.

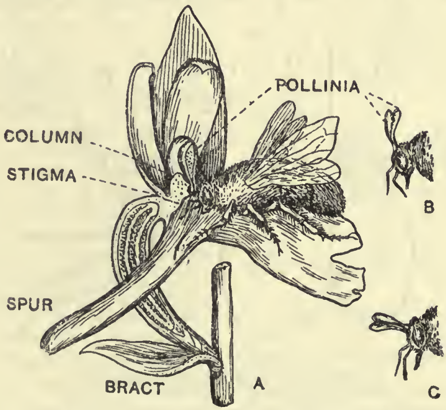


Fig. 115.—Pollination of Orchid by a Bee.
At C the pollinia have bent forward and will touch the stigma of the next flower visited.

Poke a pointed pencil into the spur of the labellum (to imitate the action of a bee thrusting in its tongue to scrape the honeyed walls of the spur). Notice the two club-shaped masses of pollen which are withdrawn from their pockets and remain attached to the pencil by the sticky mass at the base of their stalks. What change in position do the pollinia undergo after being removed, and how does this help in bringing about cross-pollination?

Where is the ovary? Examine the apparent stalk of the flower, opening it up with a pin or the point of a knife. Note the three ovule-bearing strips (placentas) on the inner wall of the one-chambered ovary. The real stalk, at the base of the ovary, is very short; the long inferior ovary makes a long flower-stalk unnecessary, as it pushes out the flower and exposes it to visiting insects. A curious point is that the ovules are not formed until after pollination has taken place. Compare young and mature flowers to see the twisting of the ovary, which brings the labellum to the front.

Trace the shoot down, below the inflorescence and the leaves, to the basal swelling, which is a root-tuber. Cut the tuber across and test the cut surface for starch. Besides the tuber in which the present year's shoot ends, notice the

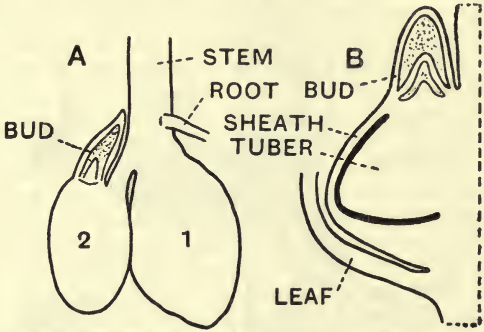


Fig. 116.—Orchis. A, Base of a Plant (dug up in summer), with old (1) and new (2) Tubers; B, Section of a developing Tuber.

brown and shrunken tuber formed last year, and the new tuber being formed for next year. To see these tubers of different ages and to trace their life-history you must of course examine plants at different times of year.

Each year one root (sometimes two), instead of growing out like the other roots, becomes swollen up and packed with food (made by the green leaves and transported downwards through the stem); this root is formed at the base of a bud, from which next year's leaf- and flower-bearing shoot will develop (Fig. 116). When the shoot dies, the root-tuber, with the bud above it, remains in the soil during winter, and the early growth of the shoot takes place at the expense of the food stored in the tuber, while ordinary roots grow out to absorb water and salts from the soil.

The fruit, a capsule, opens by three longitudinal slits; the seeds are very small (easily dispersed by wind), the embryo is minute and only slightly developed in the ripe seed.

313. Four species of *Orchis*, beside *O. mascula*, are fairly common in Britain. **Spotted Orchis** (*O. maculata*) resembles the Early Purple in having spotted leaves and in the general structure of the flower, but the tubers are lobed (Fig. 117), the spike of flrs. (May-July) is shorter and denser, the flowers paler purple, the labellum broader and its middle lobe narrow and not lobed, and the spur is shorter than the ovary. **Marsh Orchis** (*O. latifolia*) also has lobed tubers and spotted leaves, dense spike, and grows in moist places, but the flrs. are larger and more deeply purple, and the labellum toothed rather than lobed. **Green-winged Orchis** (*O. morio*) has rather small unspotted leaves, a globular tuber, sepals green-veined and arching over the two small upper petals so as to form a hood or helmet; not so common as the preceding three species, and chiefly found in South England. **Pyramidal Orchis** (*O. pyramidalis*) is easily known by its pyramidal spike of small rosy flrs., which have a long slender spur; tubers globular, leaves narrow and long.

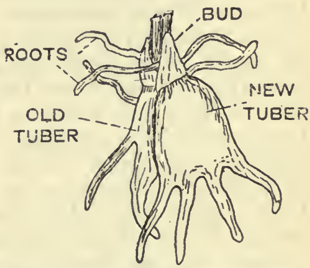


Fig. 117.—Palmate Tuber of an Orchid.

314. The **Orchid Family** (**Orchidaceae**) contains over 400 genera, with 5000 species. Orchids are most abundant in the tropics, and most of the tropical species are epiphytes, while the temperate species are mostly ordinary land-plants, and all are perennial herbs. It would be impossible here to describe the wonderful adaptations shown by tropical Orchids, both in their vegetative organs and their flowers. The student should read Darwin's book on the *Fertilisation of Orchids*, and if possible visit hot-houses containing these plants, *e.g.* the Orchid House at Kew.

Some British Wild Orchids grow by means of a rhizome, but in most species tubers are developed, as in the Early Purple, the bud for next year's growth being formed at the base of the stem and giving rise to a thick tuberous root. Some of the British genera are rare and local in occurrence, especially those found in the South of England and on chalk.

315. Wheat (*Triticum vulgare*).—The origin of the cultivated varieties of Wheat is very uncertain, as in the case of the Broad Bean and other plants which have long been in cultivation. The closest relative of Wheat among British Grasses is Couch-grass, but Wheat is annual while Couch-grass (like the great majority of Grasses) is perennial.

We have already studied the germination of the Wheat grain (Art. 80). In a young plant showing four or five leaves note the arrangement of the leaves in two opposite rows, each leaf arising from a slight thickening ("node") on the stem. Note the narrow green leaf-blade, bearing green ridges, separated by white grooves, on its upper surface; in the early leaves there are about a dozen of these ridges. Note that the blade has no stalk, but passes into a sheath covered with soft hairs on the outside but smooth within; the sheath clasps the stem, but is split down on the side opposite the blade. Note the stem-clasping outgrowth, or upward continuation, of the sheath at the base of the blade; this outgrowth, here long and either rounded or toothed on its margin, is called the *ligule*.

Trace the leaf-sheath downwards to its insertion on the stem, noting the firm thickened basal part of the sheath, which produces the swelling at the "node," and the softness of the stem in this region. Examine plants at different stages of growth. In seedlings with only four or five spread-out leaves, on carefully pulling down each leaf-sheath, also on slicing the whole shoot longitudinally, you will notice (1) a bud in the axil of each leaf, (2) a small swelling at the tip of the stem. Later on, note that the buds have grown out of the leaf-sheaths and given rise to branches, which may repeat the process. By this branching or "tillering" as many as fifty shoots may be produced from the basal part of a single Wheat plant. The swelling at the end of the stem will now show two opposite rows of projections—the young spikelets or "ears."

In the ordinary kind of Wheat flowering occurs in June. At the beginning of May the "nodes" are still close together, so that although the leaf-blades are long and well developed the sheaths overlap each other. But now the "internodes" of the stem begin to lengthen, spacing out the leaves and carrying the shoot upwards. This elongation, which is most marked in the upper "internodes," is largely due to the active growth of the soft parts of stem just above each node—the parts enclosed in the leaf-sheaths — though elongation also occurs in all parts of each "internode." Since the stem grows in width as well as in length, the inner tissue is torn and the stem becomes hollow, except at each node, where a solid partition remains. The growth in length is greatest in the uppermost "internode" (above the highest leaf), which carries up the inflorescence or "spike."

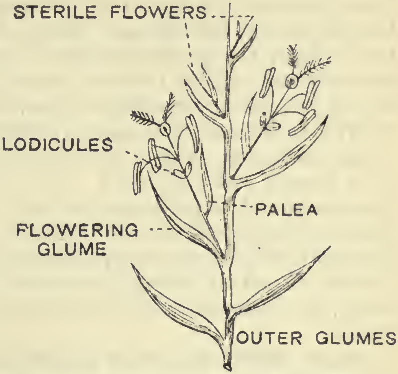


Fig. 118.—Diagram of a Grass Spikelet.

About the beginning of June the sheath of the highest leaf swells up, owing to the growth of the "spike" which it encloses, and in about a fortnight the flowers are mature and the spike emerges from the sheath. The "ears" are arranged in two opposite rows; each ear is flat and is attached to the axis of the spike by its side, so that the whole spike is four-sided (the flat ears of Rye are attached by their *edges*, hence the Rye spike is flattened).

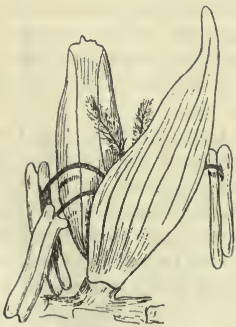


Fig. 119.—Flower of Wheat enclosed in its two Scaly Bracts or Glumes.

Examine a single ear and, beginning at the base, note the two lowest scales, nearly opposite each other, hard, dry; these **outer glumes** enclose from three to five flowers (usually three) arranged alternately on opposite sides of the ear (Fig. 118). In each flower (Fig. 119) note the two enclosing scales—an outer scale (*flowering glume*) which is similar to the outer glumes but sometimes bears a bristle (*awn*) at its tip, and an inner scale (*palea*) which is thinner. Within the palea come the three stamens and the pistil. The stamens when ripe have long filaments, the filament being attached to the middle of the anther; the pistil consists of a rounded ovary bearing two stigmas. Note the two very small white scales, each with a fringed upper margin; these are called **lodicules.**

Wheat, like other Grasses, shows several adaptations to wind-pollination, though (like most other cultivated cereals) it is largely self-pollinated. The spike is carried well up into the air; the pollen-grains are small and dry; the ripe anthers are pushed out of the flower by the elongation of the filaments and dangle about freely owing to their "versatile" (easily turned or swung) insertion on the end of the filament; the hairy styles expose a large surface to catch pollen-grains.

Before flowering occurs plenty of food has been manufactured by the green leaves and stored up in all parts of the plant—leaves, stem, roots. The enormous extent of the root-system of a single Wheat plant makes it easy to understand what a large amount of food can be stored in them, to be drawn upon for the maturing of the grains. The roots penetrate deeply into the soil, and since each of the "tillers"—branches arising from the base of the shoot—produces scores of roots (especially from the lower "nodes") the aggregate length of the roots of a single Wheat plant runs to hundreds of yards.

When the Wheat is in full bloom the active life of the plant as a manufacturer of food has reached its climax. It has attained its full size, all its leaves are spread out in the air, the roots have gained their greatest dimensions in the soil, and the building up of new tissues has ceased. The activity of the plant is now directed to utilising the surplus food (stored in leaves, stem, and roots) in the production of the seed.

This will be more apparent if we consider the actual increase in weight of the dry matter of the plant, excluding the roots, at three stages in its life—the end of March, the end of June, and at harvest. Of the dry matter of the ripe plant 20 per cent. was present by the end of

March, when some four leaves were visible; 45 per cent. was added by the time it was in full flower at the end of June; and the remaining 35 per cent. before harvest. This 35 per cent. is not, however, an addition to the weight of the plant by the production of new food; the greater part of it had already been prepared and had been sent down into the roots to be in store there until it was needed. When the flowering is finished the food is transferred from the underground parts of the plant to be finally stored in the seed, and necessarily increases the weight of dry matter in the plant above ground.

The stem or "straw" of the Wheat plant is hardened by the fibrous tissue surrounding the bundles, which form a hollow cylinder, and additional strength is gained by the presence of flinty matter (silica) in the epidermis. The stem has alternate green and white lines, like the leaf, the green lines bearing stomates.

It is interesting to compare the strength of the "straw," which has to bear the weight of the heavy ripe spike, with that of other materials. Cut off ripe spikes and attach them (tie with thread, or stick with sealing-wax) to wires of steel, iron, copper, of about the same length and weight as the Wheat-stalk. The latter is a fine example of strength combined with lightness and economy of material. The "nodes" —more strictly, the swollen bases of the leaf-sheaths—are of great importance. The actual node forms a solid partition across the otherwise hollow stem and thus gives it greater rigidity; the swollen base of the leaf-sheath, just above the "node" itself, remains capable of growth, and, in the lower parts of the plant especially, if the stem is laid horizontally (*e.g.* by wind), the lower side of the "node" grows rapidly and thus brings the shoot into the vertical position again; the lower "nodes" also give out roots.

Examine young ears and study the stages in the ripening of the fruit; the stigmas and stamens fall off after fertilisation, and the ovary grows into the grain.

316. Oat (*Avena sativa*) is probably derived by cultivation from the Wild Oat-grass (*A. fatua*). It can be cultivated above the limits of height and of latitude at which the cultivation of Wheat stops. In this country Wheat ceases to be a regular crop if the rainfall exceeds about 33 inches a year, and if the average July temperature is below about 13° C. On upland farms the chief cereal crop is Oat, which is cultivated in Europe to latitude 69° N.

The ears of Oat are not arranged in a close spike as in Wheat, but in a loosely branching system ("panicle"), in which the main axis gives off branches, which may again branch, each branch ending in an ear, which hangs downwards.

Examine an ear and compare its structure with that of Wheat. Note the two large boat-like outer glumes, enclosing (usually) three pairs of smaller scales (each pair = a flowering-glume and a palea, as in Wheat), but usually only the two lower pairs contain a flower, the small uppermost pair enclos-

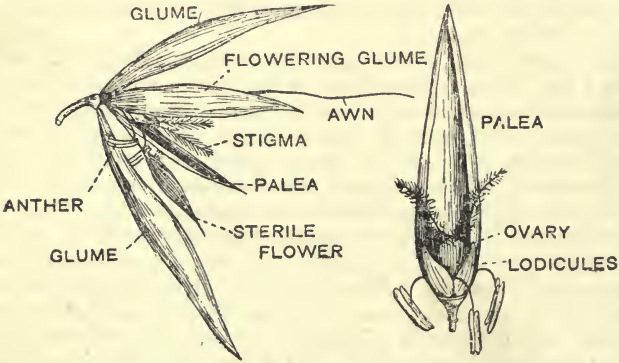


Fig. 120.—Spikelet and Flower of the Oat.
(In the right-hand figure the flowering glume has been removed.)

ing merely the barren end of the axis of the ear. Each flowering-glume bears on its outer side, just below the tip, a long bristle called the **awn**, which is sharply bent at its middle. The flower itself resembles that of Wheat, consisting of two lodicules, three stamens, and an ovary with two feathery stigmas (Fig. 120).

Oat differs from Wheat in having a short toothed ligule to the leaf; a smoother and less hairy leaf-sheath; in having awned flowering-glumes;[1] and in having the flowering-glume and the palea joined to the ripe grain, forming the "husk" which has to be removed by grinding; in addition to the differences already noted in the inflorescence.

317. The Grass Family (*Graminaceae*) is excelled in number of species by the Orchid, Bean, and Composite families; the known species in these four families number 4,000, 5,000, 7,000, and 11,000 respectively. Its success in the struggle for existence, however, is shown by the fact that Grasses vastly exceed all other families as regards the number of individuals, and in their world-wide distribution.

Grasses are mostly herbaceous plants, though a few tropical types are woody and tree-like (*e.g.* Bamboos), but even the latter show no secondary thickening of the stem. They are easily distinguished from other grass-like plants—*e.g.* Sedges and some Rushes—by their two-rowed leaves and circular or flat (in cross-section) stems; the leaves very rarely (Bamboos) have stalks, and the stems are rarely solid (Maize, etc.) and rarely branch in the upper parts. Most Grasses are perennial, though several (besides Wheat and Oat) are annual—*e.g.* Sea and Wall Barley, Darnel, *Poa annua.* Annuals are easily recognised as such by all the shoots bearing inflorescences. Perennial Grasses grow by means of buds which arise from the lowest nodes of the shoot, within the leaf-sheaths.

The general habit of the plant depends largely on the way in which these buds grow out. (1) The new shoots grow up inside the leaf-sheaths and the plant then forms only tufts or tussocks—*e.g.* Sheep's Fescue, Cock's-foot, Timothy, Dog's-tail; (2) the shoots grow up in the sheaths, but some or all of them later grow along the soil as runners; (3) the buds break through the leaf-sheaths and either form runners (*above ground*) or creeping *underground* stems ("stolons"). Some Grasses vary in habit; for instance, the common Bent-grass (*Agrostis alba*) is tufted when growing on dry heaths, but has runners or stolons when in rich moist soil, while there are several varieties of Sheep's Fescue with stolons. Other examples of tufted (tussock-forming) Grasses are Hair-grass (*Aira*), Mat-grass (*Nardus*), Bromes, Rye-grasses. Yorkshire Fog and Marsh Foxtail are examples of Grasses with runners. Common and easily-recognised stolon-forming Grasses are Couch-grass, Lyme-grass, and Marram-grass (*Psamma*).

In most Grasses the leaf-sheath is split down the side opposite the blade and rolled round the stem so that one edge overlaps the other, but in a few cases the sheath is entire—*e.g.* the Water-grass (*Glyceria*). In Yorkshire Fog the prominent keel of the blade runs down as a

[1] Some varieties of Wheat ("bearded" varieties) have an awn, especially in dry climates.

ridge on the sheath; in some Fescues, Rye-grasses, and Yorkshire Fog the sheath is red. Most Grasses have a membranous ligule, as in Wheat and Oat, but sometimes it is represented only by hairs—*e.g.* Purple Bent (*Molinia*), or may be very small or absent—*e.g.* most Fescues. The leaf-blade is flat, thin, and soft in most Grasses; it has large air-chambers in the floating Water-grass (*Glyceria*); it is dry and harsh, with a spiny tip in Wall Barley; firm, hard, and leathery in coast-grasses (*Nardus*, Fescues, Hair-grasses in which the leaf is narrow, bristle like, and permanently rolled up).

The margin is even in most Grasses, but rough with minute teeth in Millet-grass, Oat-grass, Timothy, Quake-grass, etc. The upper surface usually has ridges, one over each vein; the ridges sometimes bear small teeth, giving the leaf a rough feel. The surface is, however, usually smooth, though in several Grasses it is hairy, the hairs often being found chiefly on the ridges; some common hairy-leaved Grasses are Yorkshire Fog, Bromes (*Bromus mollis* and *B. asper*), Oat-grasses, and Sweet Vernal Grass.

The rolling and folding of many Grass leaves are due to the presence of special epidermis-cells ("motor-cells") on the upper side of the leaf. These cells on losing water (when the air is dry and the transpiration current is flagging) contract and draw together the adjacent parts of the leaf. In the simplest cases there are two rows of motor-cells, one on either side of the midrib (*e.g. Poa*), or a single band extending over the midrib (*e.g.* Cock's-foot), so that the leaf is merely folded (becoming V-shaped in cross-section) by their contraction. In most cases, however, there is a row of these cells at the bottom of each groove, between the ridges, so that the leaf can be rolled up to form a tube when the air is dry or hot; this rolling-up is easily observed in Meadow Fescue or in Tufted Hair-grass, the leaf rolling up when allowed to dry, and unrolling again when set in water. The common coast-grasses *Elymus* (Lyme-grass) and *Psamma* (Marram)[1] also show the rolling and unrolling very plainly. In Sheep's Fescue, Wavy Hair-grass, *Nardus*, and some other moor-grasses, the motor-cells are not well developed and the leaf is permanently rolled up.

The flowers of Grasses are arranged in spikelets. We have already examined the spikelets or "ears" of Wheat and Oat, with which other grass-spikelets agree in general structure, each spikelet consisting of an axis bearing two opposite rows of scales which vary in size, shape, and texture, and some of which enclose flowers. Since the composition of the spikelet and the form of the inflorescence afford a good method for distinguishing the Grasses, we shall note some of the chief points here, for comparison with Wheat and Oat, and then give the characters of the commoner British Grasses.

In some cases the spikelet contains a single flower (*Psamma*, *Nardus*, *Milium*, *Alopecurus*, *Phleum*, Barley, *Agrostis*), or a single perfect flower with one or more male flowers (Sweet Vernal Grass, *Holcus*, False Oat). In *Nardus* and *Lolium* the spikelet has only one outer

[1] See preparation of *Psamma* (*Ammophila*) leaf in *Plant Biology Collection of Microscopic Slides.*

glume instead of two, while in Sweet Vernal Grass there are four. The outer glumes are rarely awned (*Nardus*, *Phleum*, Couch-grass); in Barley they are narrow, pointed, and stiff, but in most Grasses they are boat-like. The flowering-glume and the palea are often awned, especially the former (Oat-grass, False Oat, Barley, Bromes, Darnel, etc.); the palea is usually smaller and more delicate than the flowering-glume, and it usually has two side-veins but no midrib.

The awn carried by the flowering-glume (or by the empty glumes, or by all the glumes) grows from the midrib and may be terminal or inserted on the back of the glume. Awns act as a protection against birds and browsing animals; in some cases they aid in dispersal by wind or by animals. Besides these uses the awn has a vein, green tissue, and stomates, so that it can assimilate and transpire, and it doubtless helps in the nutrition of the developing grain. The awn probably corresponds to the reduced leaf-blade, the basal part of the glume to the leaf-sheath, and the free portion beyond the awn to the ligule of a leaf. The two lodicules (absent in Sweet Vernal Grass, *Nardus*, Foxtail, etc.) of most Grasses (three or even more occur in some foreign Grasses, *e.g.* Bamboo) are probably mere extra scales, *not* representing a perianth.

In all British Grasses there are three stamens (except Sweet Vernal Grass, which has two), and the pistil has two feathery styles, right and left (except *Nardus*, which has a single style). In some foreign Grasses there is only one stamen, in others six, while some have as many as forty; while there may be three styles (some Bamboos) or a single long style (*e.g.* Maize). Hence the typical Grass flower consists simply of two stigmas and a single carpel, with no perianth. The "styles" do *not* correspond to two carpels in this family. The lodicules, when present, are said to swell up and push apart the scales enclosing the flower, so that the stamens and styles may more easily project from between them.

In most Grasses the pollen is shed before the stigmas are ready to receive pollen, but in some Grasses—*e.g.* Sweet Vernal Grass, Foxtail—the opposite is the case, *i.e.* the flower is protogynous. In some foreign Grasses the flowers are unisexual—*e.g.* Maize, where the feather-like male inflorescences occupy the top of the plant, while the female ones ("cobs") are near the base.

In most cases there is a chance of cross-pollination, but most cereals are largely self-pollinated; in Rye the flowering-glume and palea do not separate at all, hence the flowers are self-pollinated. Grasses are wind-pollinated (what are their adaptations for wind-pollination?), but some, *e.g.* Sweet Vernal Grass, are frequently visited by flies.

In most British Grasses the grain remains within the flowering-glume and palea, as in Oat, and becomes detached along with these and the part of the axis of the spikelet which bears them. There are several adaptations for dispersal of the grains by wind or by animals. In Hair-grass (*Aira*) there are silky hairs below the flowering-glume, and in many cases the glumes expand and act as wings; some Grasses have small light grains, easily carried by the wind. The awns, especially when bent, catch on to animals; a familiar example is seen in Barley, the awn of which twists and untwists when one breathes on it, and causes the grain to creep up one's sleeve. The awns of some foreign Grasses have arrangements for becoming attached to animals, for burying the grain in the soil, and in some cases for wind-dispersal as well (e.g. *Stipa*).

QUESTIONS ON CHAPTER XII.

1. Describe, with sketches, the structure of a resting Crocus corm.

2. Give a clear account, from your own observations, of the events which occur from the time a resting Crocus corm is placed in moist soil or sawdust, up to the time when the leaves die down. Include the changes that occur below as well as above the soil, and give a series of sketches.

3. For how many days does a Crocus flower last, from the time when it first opens?

4. Describe observations and experiments you have made on the opening and closing of the Crocus flower.

5. What other flowers with which you are familiar open and close like the Crocus flower?

6. Draw a floral diagram of any flower belonging to the Order Iridaceae, and describe fully its pollination. Name the chief points of difference in the structure of such a flower and a tulip flower.

7. Describe the structure of the flower of Bluebell, and compare it with that of a Garden Hyacinth.

8. What other flowers besides those of Bluebell droop when they open? How is the drooping caused? Can you explain why so many spring flowers either droop or have the power to open and close? Give a list of spring flowers which droop and of those which perform opening and closing movements.

9. Describe, from your own observations and dissections, the structure of a Garden Hyacinth bulb. Sketch, on a large scale (about twice the natural size), a longitudinal section made through the centre of a bulb, marking all the parts shown.

10. Describe and explain the structure of a Narcissus bulb, with the smaller bulbs attached to it. How is it that some scales go round the whole set of bulbs?

11. Describe carefully all you saw when growing a Hyacinth bulb in soil, sawdust, or water, and explain the things you saw. Give sketches.

12. Describe the whole of an Early Purple Orchid plant as seen when in flower in early summer, omitting the flowers themselves.

13. Describe, from your own observations, the growth of an Early Purple Orchid from the time when its leaves first come above ground until they die down. When did you first see the leaves, and when do they die down?

14. Describe, with sketches from actual specimens examined, the flower of the Early Orchid, and explain its adaptations for pollination. Describe experiments you have made with the flowers.

15. Compare the following plants with regard to the nature of their reserve food and that of the food-storing organs:—Crocus, Bluebell, Garden Hyacinth, White Lily, Orchid, Onion.

16. Describe the structure of a Wheat grain, as seen with a lens. Give sketches.

17. Describe the growth of a Wheat seedling up to the time when four or five foliage-leaves are visible. What structure can usually be found at this stage, on opening up the shoot?

18. Describe the shoot- and root-systems of a growing Wheat plant, about the end of May, omitting the flowers. What is meant by "tillers"? Give sketches.

19. Describe carefully the structure of a "node" of the Wheat plant. How do the nodes differ from the rest of the shoot, and what is the importance of this difference?

20. Describe the spike of Wheat, and give a careful account, with sketches, of the structure of a single "ear" (spikelet").

21. Describe a few of the weeds found growing in a cornfield (1) when the Wheat is young, (2) when it has reached its full height. How are these weeds adapted to their mode of life?

22. Describe the structure of the flower and the mode of pollination of any common wild Grass you have examined. Give sketches.

23. Show by means of floral diagrams how the flowers of *Orchis* and Wheat (or other grass) may be considered to have been derived from such a flower as that of a Lily. How do you account for the striking differences of structure between the flowers of *Orchis* and Wheat?

24. To what Orders do the Hyacinth, the Snowdrop, and the Crocus belong? Give in tabular form the distinguishing characters of these Orders, showing the resemblances and differences between them.

CHAPTER XIII.

THE LOWER DICOTYLEDONS.

318. The Bentham-Hooker System.—The classification of the Lower Dicotyledons differs considerably in different systems which have been proposed. The Higher Dicotyledons (Gamopetalae) form a more sharply defined series, and their classification varies in detail only in different schemes.

In the Bentham-Hooker System the Lower Dicotyledons are divided into (1) "**Incompletae,**" in which the flowers have a simple and usually sepaloid perianth, or none, and are often unisexual, and (2) "**Polypetalae,**" in which the perianth is double, the inner whorl being petaloid and free (polypetalous). But the "Incompletae" include many Orders which are clearly related to certain Orders of "Polypetalae," though sometimes it is difficult to say whether the "Incompletae" are primitive (*i.e.* on the upgrade of evolution) or reduced (*i.e.* on the downgrade).

The "Polypetalae" are divided, in this system, into three groups: (1) "**Thalamiflorae,**" with strictly hypogynous flowers; (2) "**Disciflorae,**" hypogynous but with a "disc" (forming a ring or cushion spread over the base of the calyx-tube, or fused with base of ovary, or represented by a series of separate glands) on which the stamens are inserted; (3) "**Calyciflorae,**" with perigynous or epigynous flowers.

319. The **Engler-Prantl System**, adopted in the great German encyclopaedia *Die natürlichen Pflanzenfamilien*, does away with many of the defects and artificialities of the Bentham-Hooker and other systems. The Gamopetalae remain much the same, on the whole, but the "Incompletae" are placed with the "Polypetalae" in a single series distinguished by having a relatively simple perianth. We shall study in detail some typical Orders, not adhering rigidly, however, to the sequence set out in the Engler-Prantl scheme.

320. Little Celandine (*Ranunculus ficaria*).—This familiar plant, easily recognised by its glossy heart-shaped leaves and its bright-yellow star-like flowers, grows chiefly in moist places, whether open or shaded.

Dig up entire plants and notice that there is no tap-root and that some of the roots are long, thin, and branched, while others are short, thick, swollen, and unbranched. Do the swollen roots contain reserve-food? How do the two kinds of roots differ in function? Cut across a swollen root and test with iodine solution: is starch present? Look for young shoots early in February, before the flowers have appeared, and note that above the swollen roots the young shoot has given off a number of ordinary roots; the latter serve for absorbing water and salts, while the growth of the shoot takes place at the expense of the food stored in the thick (often club-shaped) *root-tubers*. Note the large membranous sheathing scales (how many?) which protect the young shoot. Try to find earlier stages, with the young shoot still enclosed in its sheathing scales, before the leaves and the slender roots have grown out; when were the *tuberous* roots formed?

Examine plants in different stages of growth and at different times of the year, keeping some under observation in pots or boxes, and make out as much as possible of their life-history. How do the root-tubers change as the leaves grow larger and the flowers appear? Note that the leaves are stalked, arise from the stem in opposite pairs (as a rule), and that the base of the stalk is broad and sheathing.

Examine the flowers (February to May), each on a stalk arising in a leaf-axil. In most cases the flower has three green sepals, and usually eight or nine petals. Each petal has a small scale-like nectary at the base of its inner (upper) surface: why is this surface bright yellow and shiny, while the outer (lower) surface of each petal is dull and dark-coloured?

What difference is observed if you visit the flowers on fine sunny days and on dull or wet days? What advantages does the flower gain by closing in bad weather (wet, cold, or overcast)? In what kind of weather are most insects seen on the wing, visiting flowers? Note the numerous stamens, which ripen successively towards the centre of the flower, and the numerous carpels, which are not ready for pollination (*i.e.* the stigmas do not become expanded and sticky) until most of the anthers have opened (what is the advantage in this arrangement?). Examine the carpels carefully, noting the small stigma on each. Sketch (1) an entire flower, open, (2) the same, closed, (3) a sepal, (4) a petal, (5) a stamen, (6) a carpel, (7) a longitudinal section of the flower.

The flowers are visited by various insects, the pollen being quite accessible and the honey only slightly hidden, so that flies as well as bees and wasps help in pollination. After pollination the flower-stalk curls over while the fruits are ripening. What other changes occur in an old flower, after it has been pollinated, or at least has had its chance of pollination? How do the petals change in colour, and why do they lose their power of closing up? It might be suggested that the bleaching of the old petals saves the time of intelligent insects, *e.g.* bees, by showing them that the flower is no longer worth visiting.

You will generally find that plants growing in deeply shaded places—in woods or under dense hedges—produce few fruits (why?), but to atone for this the plants produce small tuberous bodies (bulbils) in the axils of the leaves. Each bulbil contains starch and has a resting-bud; the bulbils eventually become detached and give rise to new plants. The shoots die down soon after the fruits have ripened, food being stored for the following spring in the tuberous roots and the bulbils.

321. Buttercups (Fig. 121) belong to the same genus (*Ranunculus*) as the Little Celandine. They differ from it in having lobed (often deeply divided) leaves, five sepals, and five petals.

In a Buttercup flower note the five green sepals; the five petals alternating with these, each with a honey-scale at the base; the numerous stamens; the numerous carpels, each having a small thickened or hook-like stigma. Each of these parts is inserted independently on the receptacle, which is merely the expanded knob-like end of the flower-stalk. There is no *cohesion*—*i.e.* the receptacle-tissue does not grow up and raise the members of a series of flower-leaves on a basal outgrowth (compare sepals and stamens of

Bean); the carpels contain each a single ovule, attached to the bottom of the ovary.

The flower is shallow, accessible to all kinds of insects, which visit it for the abundant pollen as well as for the honey (only slightly concealed by the outer stamens). Examine flowers of different ages; the outer stamens have shed their pollen (the anthers open at the sides), while the inner ones are still bent over the carpels, covering the

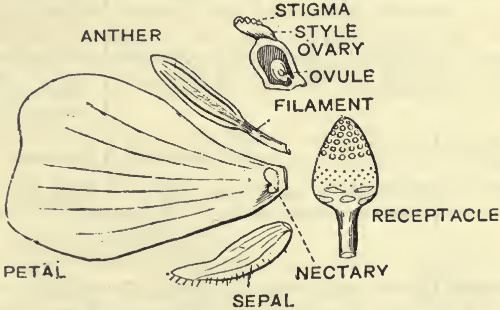


Fig. 121.—The Parts of a Buttercup Flower.
The points of insertion of the different parts are diagrammatically represented on the receptacle.

stigmas, which are not exposed until most of the stamens have moved outwards and have set the pollen free to be carried away by insects. The "male stage" and the "female stage" thus overlap for some time, during which self-pollination is possible, either because the innermost stamens touch the stigmas or by means of small insects crawling over the flowers.

322. The **Bulbous Buttercup** (*R. bulbosus*) is easily distinguished when in flower; the sepals curve outwards and downwards. The stem is swollen at the base, forming a kind of corm; the lower leaves are broad and many-lobed, the upper ones have only a few narrow lobes. The **Creeping Buttercup** (*R. repens*) has long creeping branches (runners) which grow along the soil and at the "nodes" send roots downwards and shoots upwards. The **Meadow Buttercup** (*R. acris*) has neither runners nor a thickened stem-base, its flower-stalks are not grooved (as are those of the other two species), and it is the tallest of British Buttercups, being sometimes more than a yard in height; the sepals are, like those of *R. repens*, spreading, not reflexed as in *R. bulbosus*.

R. bulbosus flowers chiefly in early summer (May-July); *R. repens* from May to September; *R. acris* from April to November (all the year round in sheltered places).

The three commonest species of Buttercup agree in many respects—*e.g.* in having five sepals and five petals, etc.—but are distinguished by the following, amongst other, characters:—

	Bulbous Buttercup (*Ranunculus bulbosus*)	Meadow Buttercup (*Ranunculus acris*)	Creeping Buttercup (*Ranunculus repens*)
Stem	Swollen at base, for storage of food	Not swollen at base; no runners	Gives off runners, which root at nodes, producing new plants
Flower-stalk	Furrowed	Not furrowed	Furrowed
Sepals	Reflexed, *i.e.* bent downwards	Spreading	Spreading

The **Celery-leaved Buttercup** (*R. sceleratus*) is a more decidedly moisture-loving plant than the other Buttercups (given above), growing chiefly in ditches, and it is annual. It differs from the three commonest species in having no scale on the nectary at the base of the petals, and its akenes are raised on an oblong receptacle (owing to growth of the latter after fertilisation). The flowers are small (5 mm.), with pale yellow petals, hardly longer than the sepals—which are reflected as in *R. bulbosus*. **Goldilocks** (*R. auricomus*), in woods, is like *R. acris* but is less hairy and not so tall, and lower leaves have fewer, shallower, and blunter lobes; its flowers (March-May) often have, instead of the 5 normal petals, numerous imperfect ones passing gradually into stamens, and there is no scale over the nectar-pit.

Of the remaining Buttercups, the commonest species is the **Corn B.** (*R. arvensis*), a troublesome cornfield weed, with tall (1 to 2 ft.) stem, growing with the corn and ripening its fruits at harvest-time, the flowers (May-July) small (12 mm. across) and pale yellow, akenes few but large, covered with hooked spines, the style also forming a stout hook. What are the advantages to the Corn Buttercup of (1) the *unbranched* stem, (2) the *hooked* akenes? These two species are annuals; *R. hirsutus* is rare in Scotland and not found in Ireland, while *R. arvensis* is very rare in Ireland.

The ordinary Buttercups are sometimes called "Crowfoots" from the shape of the leaves in most species, but the two "Spearworts," which grow in marshy places, are easily distinguished by their long and narrow tapering leaves. Like ordinary Buttercups they have yellow flowers. The **Lesser Spearwort** (*R. flammula*) is the more widely distributed in wet places, marshes, bogs, etc.; it is rarely over 1 foot high, its lower leaves are stalked, and its flowers (June-Aug.) about 1 cm. in diameter. The **Greater Spearwort** (*R. lingua*) is 2 to 3 feet high, its leaves are all sessile, and its flowers (July-Sept.) about 4 cms. in diameter; it is not nearly so common.

323. Water Crowfoot (Fig. 122).—Under this name are comprised various forms of Buttercup or Crowfoot which live in marshes or streams and have white flowers.

The Water Crowfoots are very variable and the varieties are connected by intermediate forms, so that systematic botanists are not agreed as to the number of species that can be distinguished.

(1) Those which grow in fast streams have most or all of their leaves submerged and divided into numerous fine threads—the form best adapted to resist tearing by the running water, besides increasing the surface for absorption of water with dissolved salts and gases.

(2) In those forms which grow in slow streams, ditches, or ponds, there are usually floating leaves (on the surface of the water) as well as submerged leaves. The former are rounded or lobed, not much divided, and bear stomates on their upper surface. The submerged leaves are finely cut, with numerous segments spreading in a circle.

(3) In forms which grow in shallow water, in marshes and muddy places, all or most of the leaves are of the entire, rounded or lobed, "floating" type.

Fig. 122.—Part of a Water Crowfoot, showing a floating leaf and two submerged leaves.

We thus get every transition from plants with all or most of the leaves submerged and dissected, to plants with all the leaves broad and either floating on the water or raised above it. The intermediate forms are "amphibious"; when the stream or pond dries up, they grow quite well in the mud, bearing only aerial leaves and no finely divided ones. On the other hand, if flooded or transplanted into water in an aquarium, they will grow and produce only the divided submerged leaves. Experiments of this kind should be made: sow in damp soil the seeds of submerged forms, sow in water those of mud-inhabiting forms.

In all cases the flowers are carried above the surface of the water; they resemble the flowers of ordinary Buttercups in general structure. The flower-buds are developed below the surface, but do not open until they reach the air.

Some botanists distinguish nearly 20 British species of Water Crowfoot, but they are probably all varieties of one species (*R. aquatilis*). The commonest form has the lower leaves submerged and finely cut and the upper ones floating with broad lobes. The commonest mud-inhabiting form is often called Ivy-leaved Crowfoot (*R. hederaceus*); it has no submerged leaves, its stems root at nearly every node, and the flrs. are very small, the petals being scarcely longer than the sepals; two others are often regarded as distinct species—*R. tripartitus*, with 3-lobed leaves and long narrow 3-veined petals, and *R. lenormandi*, with kidney-shaped leaves and longer 5-veined petals.

Examine Water Crowfoots, sketching the leaves and flowers. Compare the forms of the leaves in plants growing in fast streams, in ditches, in deep water, in shallow water, in mud, etc. Try to account for the differences and to find out how they are connected with the different habitats of the plants.

The Water Crowfoots serve admirably to illustrate many points in the biology of aquatic plants (see chapter on Ecology).

324. Marsh Marigold or **Kingcup** (*Caltha palustris*).—This plant, which grows in low-lying meadows, marshes, banks of streams, ponds, ditches, and other wet places, has a tufted habit.

The thick perennial rhizome bears annual shoots, about a foot long, which either grow erect or creep and root at intervals. Most of the leaves arise from the base of the stem and are long-stalked; the sheathing leaf-base has large membranous stipules which enclose the young buds. The upper leaves, carried on the flowering branches, are smaller than the lower ("radical") leaves and have very short stalks. Cut across stems and leaf-stalks, noting their hollow structure. Blow through a leaf, with (1) the stalk, (2) the blade, dipping into water; plunge a leaf into hot water.

Note the large flowers (often 2 inches in diameter), with golden-yellow flower-leaves (*sepals*),[1] numerous stamens, and

[1] How do these apparent petals differ from the petals of Celandine and Buttercup? Honey is produced at the bases of the carpels; the flowers are visited by beetles, flies, bees, etc.

from 5 to 10 carpels. Note the resemblance of each carpel to the single carpel ("pistil") of Bean or Gorse. Open up a carpel and note the arrangement of the seeds: how many rows are there, and on what side of the carpel, inner (towards centre of flower) or outer, are they carried? When ripe it becomes a dry fruit (follicle) which splits open along the seed-bearing inner edge; the seeds are gradually shaken out as the wind rocks the fruit to and fro.

325. The Buttercup Family (Ranunculaceae) is distinguished by the complete absence of cohesion or adhesion between the parts of the flower; the sepals, petals, stamens, and carpels are always free [except in *Nigella*, where the carpels are joined together and the fruit is a capsule]. The stamens are indefinite in number, *i.e.* they are numerous and bear no definite numerical relation to the petals or sepals.

The only really common genera in Britain are *Ranunculus*, *Anemone*, *Clematis*, and *Caltha*, but many are cultivated in gardens for their showy flowers.

326. Flower Mechanisms in Ranunculaceae.—This family shows a wide and interesting range in flower structure, and includes some of the most beautiful examples of adaptation to visits of particular insects. The perianth is generally petaloid and rarely shows a "typical" calyx and corolla, though this does occur in the largest genus (the one with most species)—*Ranunculus*. In nearly all cases the "petals" either bear nectaries or are represented by more or less elaborate honey-organs. These nectaries, which so often occur between the perianth leaves and the stamens, are commonly regarded as modified petals, but more probably they have been derived from the outer stamens and have never been petals at all.

Which genera have flowers whose structure seems to suggest (1) that the flower has not yet developed petals, whose attractive function is assumed by the coloured (petaloid) sepals, or (2) that petals may have been derived from the outermost stamens, or (3) that sepals may have evolved from foliage-leaves or bracts growing just below the flower? Perhaps the flowers of this family are still in course of evolution; at any rate, very few show the distinct sepals and petals of a "typical flower." "Sepals" are always present (primarily as a green protective envelope), and should the "petals" develop as honey-tubes or remain undeveloped the "sepals" usually become white or coloured when the flower opens, rarely remaining green (Wild Hellebore), so that it is at least convenient to limit the term "petals" in this family to the honey-leaves.

The flowers are usually protandrous, with the anthers extrorse (opening on their outer faces), but those of *Thalictrum* (Meadow-rue), *Helleborus* (Christmas Rose), and *Eranthis* (Winter Aconite) are protogynous, and those of Wood Anemone and *Trollius* (Globe-flower) are homogamous.

Wood Anemone and Traveller's Joy are honeyless flowers, visited chiefly by small insects (flies, etc.) for pollen, but in

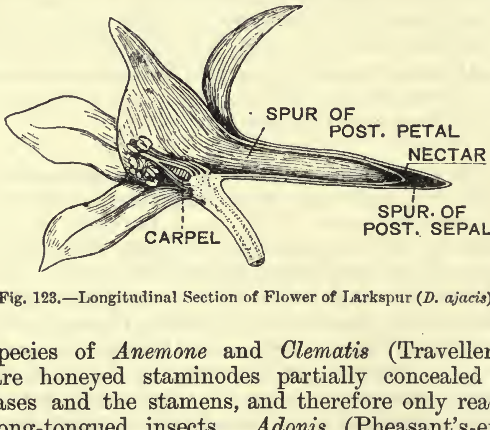


Fig. 123.—Longitudinal Section of Flower of Larkspur (*D. ajacis*).

some species of *Anemone* and *Clematis* (Traveller's Joy) there are honeyed staminodes partially concealed by the sepal-bases and the stamens, and therefore only reached by fairly long-tongued insects. *Adonis* (Pheasant's-eye) and *Thalictrum* are also "pollen-flowers"; some species of *Thalictrum* have *polygamous* flowers (some with stamens or with carpels only, others with both, on same plant) and are largely wind-pollinated, though the kinds with pretty anthers are visited by insects.

The flowers of *Trollius* and Wood Anemone are often self-pollinated, and in most of the other genera self-pollination may occur as a last resort, but in *Helleborus* it is precluded by the absolute protogyny of the flower. In *Nigella* (Love-in-a-mist) the long styles are at first erect, out of reach of the stamens (the flower is protogynous), but before all the anthers have opened the styles (unless already pollinated) bend down and thus bring about self-pollination.

Eranthis and Paeony show closing movements to protect the pollen and honey (cf. Little Celandine), and *Trollius* has the flowers nearly closed all the time; similar protection is given by the inclined or drooping position of the flower in *Helleborus* and in *Aquilegia* (Columbine—the hooked end of the petal-spurs prevents the honey from dropping out), by the arched hood in Monkshood, and the horizontal position of the flower in Larkspur. The nectaries of Columbine, Larkspur, and Monkshood can only be reached by long-tongued bees; the flowers open in summer, when bees are plentiful, are visited chiefly by humble-bees, and usually have the rich blue colour characteristic of so many "bee-flowers."

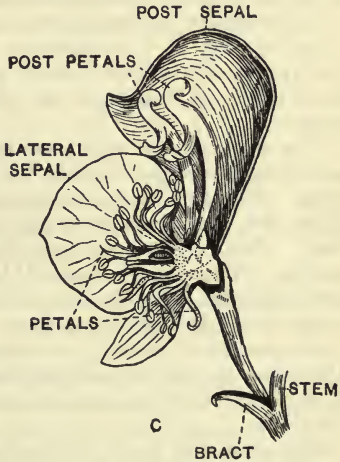


Fig. 124.—Longitudinal Section of Flower of Monkshood.

The flowers of Larkspur (Fig. 123) and Monkshood (Fig. 124) are the most highly specialised in the family, and the visiting insects can only enter in one particular way to reach the well-concealed nectaries; the stamens move upwards or inwards in turn, as they ripen, so as to block the way to the nectaries, each stamen moving away again when its pollen is shed. In Larkspur the entrance to the spur is further narrowed by the two side-petals, present in most species, which also act as "honey-guides."

The humble-bee often bites through the petal-spurs of Columbine and the hood-sepal of Monkshood, but the thick double-walled spur of Larkspur seems to prevent this. These three flowers are fine examples of adaptation to a special insect-visitor; the pollen and honey are sheltered from rain, and the honey can only be reached by a large and long-tongued bee. All three flower in midsummer, when humble-bees are most abundant. The limit of distribution of the Monkshoods (*Aconitum*) over the earth closely follows, and is just within, that of the humble-bee (*Bombus*).

327. Greater Stitchwort (*Stellaria holostea*).—This well-known plant, whose white star-like flowers are produced so abundantly in hedgerows in spring and early summer (April-June), is a herbaceous perennial, the shoots dying back in winter. The branches produced in spring arise from buds in the axils of last year's leaves on the old parts of the stem.

The weak slender stems are four-angled, and easily broken across at the swollen "nodes," which bear the leaves in crossed pairs. The stems are not strong enough to grow erect, except when the plants are crowded and support each other, but they often climb or scramble over the hedge-forming shrubs. The narrow leaves (1 to 4 ins. long) are at first erect (parallel with the stem), but as the stem with its long internodes (due partly at least to the plant being *shaded*) insinuates itself among the branches of the hawthorns, etc., the leaves spread out and thus hook on to the supports, the four rough ridges of the stem also helping in this method of climbing.

The grass-like form of the leaves is also well adapted to enable the Stitchwort to grow among long grasses and to get its share of air and light in the struggle which is so keen in crowded hedgerows. The leaves are rigid and sessile, their long narrow shape making a stalk unnecessary, and the bases of each pair are joined around the stem, forming a sort of cup in which water can be caught and absorbed by the stem "nodes." Note the hairs covering the younger parts of the stem and the edges of the leaves, and the single well-marked vein (midrib), with indistinct side-veins, of the leaf.

Most of the shoots end in an inflorescence, which is a good example of the *dichasium* or biparous cyme, characteristic of this family though found in several others. The stem ends in a flower which grows out on a long thin stalk, then a branch arises in the axil of each of the two leaves, this branch bearing a pair of leaves and ending in a flower, and so on. This branching may occur quite regularly as often as six times, but as a rule the full number of flowers is not formed every time of branching.

The flower (1 to 2 cms. diam.) has five free sepals, five petals twice as long as the sepals and each deeply notched, ten stamens in two circles, and a rounded ovary with three styles. The numerous ovules are on a free central axis. The cup-like flower contains honey, secreted by glands at the bases of the stamens on the receptacle and available to short-tongued insects.

The flower is protandrous, the two circles of stamens successively rising and shedding their pollen before the styles diverge. The inner surface of each style is covered with stigmatic hairs, so that pollination does not occur until the styles spread out and expose their stigma-surfaces. The flowers are usually cross-pollinated by the various insect-visitors, but self-pollination may occur as a last resort by the spreading styles touching the anthers.

The fruit is a thin-walled globular capsule, which splits at the top into six teeth, the seeds being shaken out when the wind rocks the plant about (censer mechanism).

328. Common Chickweed (*Stellaria media*) is one of the commonest and most variable plants, but is easily recognised by the line of hair on the cylindrical stem, changing in position at each "node." Water poured on the leaves runs down these lines, which evidently serve to dry the plant after rain and to convey water to the root, some of it probably being absorbed at the "nodes," where it collects in a drop between the bases of the opposite leaves. The leaves are ovate and pointed, but variable in size; the lower ones are stalked, but the upper (those coming off above the first flower of the infl.) are sessile. The flowers are much smaller than in Stitchwort; the petals are generally shorter than sepals; stamens generally only three to five, rarely as many as ten. The plant is a polycarpic annual, flowering all the year round; in winter the flowers are often cleistogamic, sometimes without petals, and in any case are homogamous and self-pollinated in the absence of insect-visitors (flies chiefly).

329. The other Brit. species of *Stellaria* are perennials. **Lesser Stitchwort** (*S. graminea*), in dry fields and hedgerows, resembles Greater Stitchwort in most respects, but has narrower leaves, sepals joined at bases, and perigynous stamens; the capsule is egg-shaped; the flowers (May-Aug.) are rather smaller and not so markedly protandrous. **Bog Stitchwort** (*S. uliginosa*) also has the stem 4-angled and the sepals joined, but the cyme has very few flowers (May-July), and these are small ($\frac{1}{4}$ in. diam.), with petals shorter than sepals. **Marsh Stitchwort** (*S. palustris*) also has 4-angled stem, united sepals, and egg-shaped capsules, but petals longer than sepals; while **Water Stitchwort** (*S. aquatica*) has broad leaves, flowers $\frac{1}{2}$ in. across, and large (1 in. long) ovoid capsules surrounded by the free sepals, which enlarge after flowering, and differs from the other species in having 5 styles and 10 capsule-valves; these two species are not so common as the other three.

330. Red Campion (*Lychnis diurna*) is very common in hedgerows and damp, shaded places. It has a thin branching rhizome, giving off erect (1 to 3 ft. high) flowering shoots, with stalked obovate "radical" leaves (3 to 6 ins. long) and narrower sessile upper leaves; the whole shoot is covered with soft hairs and the cylindrical stem has swollen nodes.

The flowers (May-Sept.) are unisexual, and the male and female plants are easily distinguished, as a rule, even before flowering. The female plants are usually more robust, with thicker stems and larger leaves. The flowers (about 2 cms. across) have a hairy, reddish, gamosepalous calyx, with five pointed teeth, corresponding to five ridges on the long ($\frac{1}{2}$ in.) calyx-tube; in the female flower the calyx is more globular than in the male. The five petals are free; each has a narrow vertical stalk (claw) and a broad spreading, horizontal, deeply cleft blade, with a two-lobed scale at junction of stalk and blade. The five claws, held together by the tubular calyx, form a deep flower-tube, so that only long-tongued insects (bees, butterflies) can reach the honey, the five spreading blades serving as a platform, while the scales form a collar or "corona" and keep out small insects, besides helping to protect the honey and pollen.

The male flower has ten stamens, five being longer than the alternate five (are the long ones opposite petals or calyx-teeth?). Sometimes the anthers contain, instead of pollen, a powdery brown or black mass—the spores of a smut-fungus, which are carried from flower to flower, like pollen, by visiting insects. There is often a rudiment of the pistil in the centre of the male flower. The female flower has an egg-shaped ovary with five long spreading styles, and sometimes contains rudimentary stamens.

The capsule, nearly globular, opens by ten teeth, which curve outwards, leaving a wide opening; the short flower-stalk remains erect, and the censer mechanism is more efficient than in the Stellarias.

331. The **White** or **Evening Campion** (*L. vespertina*) resembles Red Campion in structure, but grows in drier and more exposed places, often in fields as well as hedgerows; its flrs. (May-Oct.) are white and only open in the evening, and are visited by moths.

Two other species of *Lychnis* are common; both differ from Red and White Campions in having protandrous ☿ flowers. **Ragged Robin** (*L. flos-cuculi*), perennial, in moist fields and beside streams, has hairless shoots with lanceolate leaves; the blade of each petal is divided into four narrow lobes, giving the drooping rosy flrs. a characteristic look; the capsule is egg-shaped and opens by 5 teeth only. The **Corn Cockle** (*L. githago*), annual, is a beautiful cornfield weed; stem 1 to 2 ft. high, only slightly branched; the branches and the long (2 to 5 ins.) lanceolate leaves are nearly erect, making a small angle with the stem (why is this habit advantageous to a plant growing among tall corn?); stem, leaves, and calyx covered with long hairs; flrs. few, large, pale purple, scentless; calyx-tube ribbed, teeth large and projecting beyond corolla; petals without scales and with blade only slightly notched or entire.

332. The Campion Family (Caryophyllaceae) is easily recognised by the opposite (decussate) simple, generally entire, leaves; stem usually with swollen nodes; regular flowers in dichasia (biparous cymes, in which one side generally outgrows the other and branches more freely); ovary generally with free central placenta bearing numerous ovules in double rows corresponding to the number of carpels (indicated by number of styles), and sometimes showing at the base traces of partitions.

333. Flower Mechanisms in Caryophyllaceae.—There are two distinct types of flower structure in this family. In the lower type **(Alsineae)** the flower is wide open, the sepals being free or (Knawel, Lesser and Bog Stitchworts) joined at the base only, and the petals sessile or having only short stalks (claws). The flowers of *Stellaria* are more or less perigynous. The honey, secreted by a narrow ring, or by 5 or 10 glands, at the bases of the stamens, is accessible to short-tongued insects, though those with rather large flowers (*e.g.* Greater Stitchwort) are also visited by bees.

Knawel (*Scleranthus*), Pearlwort, and Chickweed are homogamous and largely self-pollinated, Chickweed having in winter cleistogamic flowers. These, as well as the Sandworts and Spurreys, are visited by flies. *Sagina nodosa* (Pearlwort), *Cerastium* (Mouse-ear Chickweed), Lesser Stitchwort, and the Spurreys (*Spergula* and *Spergularia*) are more or less protandrous but capable of final self-pollination, while Greater Stitchwort is almost completely protandrous with but little self-pollination. *Arenaria trinervia* is exceptional in being protogynous, while *Arenaria peploides* (Sea Purslane) is polygamous.

In the **Sileneae** the flower is made tubular by the gamosepalous calyx, the petal-claws and stamens partly filling the tube and making the honey (secreted by a nectary on the receptacle at the base of corolla, Fig. 125) inaccessible to any but long-tongued insects (bees, butterflies, moths), small insects being further excluded by the "corona" of scales on the petals in *Silene* and *Lychnis* (exc. *L. githago*). The Sileneae are generally very protandrous; the Red and the White (Evening) Campions are dioecious, while Bladder Campion is polygamous.

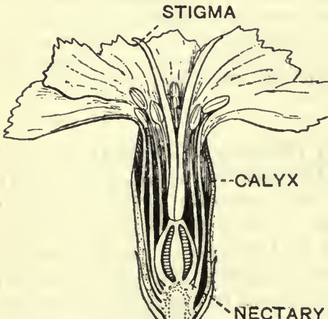


Fig. 125.—Longitudinal Section of Flower of Clove Pink.

In most cases butterflies are probably the chief visitors, but Evening Campion and several kinds of Catchfly are moth-pollinated, the flowers opening and becoming heavily scented only at night and having conspicuous white or pale corollas. In *Silene nutans* the flower opens during three successive nights, five stamens shedding their pollen on each of the first two nights and the styles protruding on the third. In the night-flowering Catchflies the petals remain curved inwards during the daytime.

334. Wallflower (*Cheiranthus cheiri*) can be obtained in flower at almost any time of year. Various other plants of this easily recognised family should also be examined.

Note the perennial erect stem, woody and cork-clad below, green and five-angled above; the crowded sessile lance-shaped

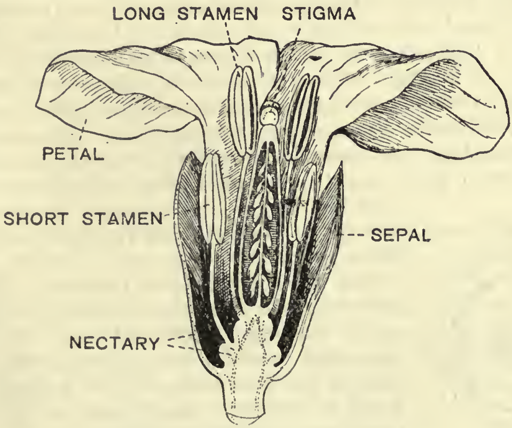


Fig. 126.—Vertical Section of Wallflower.

leaves, entire or slightly toothed, arranged in five rows; the numerous branches, often ending in a bractless raceme of flowers (rich red or purplish brown in garden plants, yellow in the wild form which grows chiefly on old walls). The younger parts, including the sepals (outer side) and the ovary of the flower, bear curious hairs, not easily seen but plainly felt on drawing a leaf (underside) across one's lips. These hairs are pointed at each end and lie parallel with the surface of the stem or leaf, attached by a short stalk at the middle, like a compass-needle; they are well adapted for preventing slugs and snails from crawling over the plant. Tear off a strip of skin (epidermis) from stem or leaf, mount in water, and draw some of the hairs seen with the microscope.

In a raceme note that all the flowers are at first kept nearly at the same level, owing to the longer stalks of the lower flowers, but as the lowest flowers wither (after pollination) the raceme-axis grows on and the next flowers to open take their places, until all the flowers have opened and been pollinated, then the axis keeps on lengthening and spaces out the fruits. Note the position of each part of a flower with reference to the stem or raceme-axis (Fig. 126).

Note the four free erect purplish sepals, in two pairs, one pair (right and left) a little below (outside) the other (front and back) pair; the two lower (outer) sepals are bulged at the base. Note the four free petals, each with a narrow erect lower part (claw) and a broad spreading upper part (limb); the two outer short stamens (one opposite each of the bulged sepals) and the four inner long ones (in two pairs, a pair opposite each inner sepal); the cylindrical ovary with two rounded stigma-lobes on a very short style; the green nectaries at the bases of the outer stamens.

Fig. 127.—Floral Diagram of a Crucifer.

The honey can only be reached by fairly long-tongued bees and butterflies; they stand on the platform made by the spreading petal-limbs. In probing for the honey, which collects in the pocket-like bases of the outer sepals (each of the two outer stamens stands out, leaving a space between it and the pistil), a bee will rub against an anther with one side of its head and against the stigma with the other side. The fragrant flowers are much visited by bees and butterflies, but are self-pollinated in the absence of insect-visits.

The structure of the ovary is best seen by examining the fruit or "pod" into which it grows; it can, however, be made out with a lens. The ovules are attached to the inner wall of the ovary at opposite sides (front and back), but from each placenta a plate of tissue grows (when the flower is developing) to meet a corresponding plate from the opposite placenta, so that the ovary becomes two-chambered, though the ovules are on *parietal* placentas.

When the "pod" ripens, the wall splits off into two valves (right and left) from below upwards, leaving a frame consisting of the thickened placentas (each bearing two rows of seeds) with the thin partition ("false septum") stretched between them (Fig. 128); the "pod" opens in dry weather and the thin flat seeds may be carried by the wind. This kind of capsule is termed a *siliqua*; it is very characteristic of the Wallflower Family, though occurring in a few other families besides.

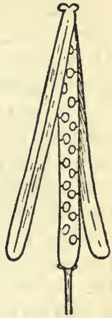


Fig. 128.—Fruit of Wallflower.

335. The Wallflower Family (Cruciferae) is easily recognised by the cross-like arrangement of the four petals, the general similarity of the other flower-parts to those of Wallflower, and by the fruit, which is nearly always a siliqua or a silicula (short broad siliqua).

336. Flower Mechanisms in Cruciferae.—The flowers are generally homogamous, though often protandrous but with a relatively long overlapping period during which self-pollination may occur. The flowers are visited by flies when the sepals are short or spreading and the petals short-clawed, and some of the small-flowered types (*e.g.* Shepherd's Purse, whose flowers often have only 2-4 stamens when produced in the colder months) are regularly self-pollinated. The larger flowers, in which the sepals are erect and hold the clawed petals together so as to form a sort of flower-tube, are visited by bees and butterflies, the honey being partially concealed and protected from rain. The large light-coloured evening-scented flowers of *Hesperis* (Dame's Violet) and some Stocks, etc., are visited by moths.

Note the general tendency of the raceme to form a round- or flat-topped inflorescence while the flowers are opening—the raceme is nearly always *corymbose*—so as to make a conspicuous mass of flowers. This is especially marked in Candytuft, where the flowers, especially the outer ones, have a zygomorphic corolla. After flowering, the raceme-axis lengthens out, carrying up the fruits for more effective seed-dispersal.

337. The **Field Poppy** (*Papaver rhoeas*), so common in cornfields, is the largest of the red Poppies growing in Britain. It is annual, and its leaves are cut up pinnately into toothed pointed lobes, covered with rough spreading hairs.

The flowers (May to August) are large (3 to 4 inches across) and are carried on long stalks covered with bristly hairs like those on the rest of the shoot. The young flower nods on its stalk, not simply on account of its own weight but because one side of the stalk grows more rapidly than the other; when the flower is about to open, the concave side of the stalk grows more and thus brings the flower erect. When the stalk has straightened, the two thick hairy concave sepals, which have covered and protected the young flower, drop off, so that unobservant students are apt to think the Poppy has no calyx.

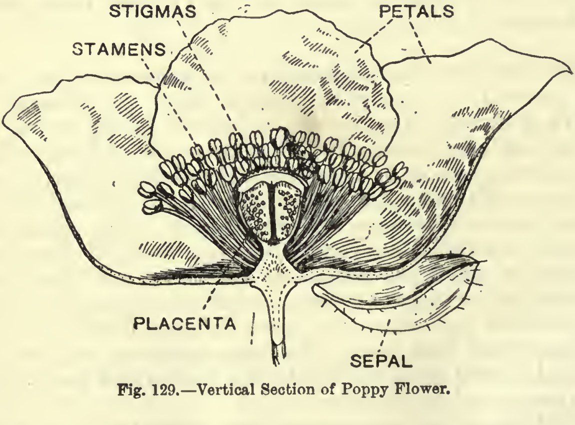


Fig. 129.—Vertical Section of Poppy Flower.

Note the curious crumpled appearance of the petals in the young flower; as the latter opens the folds are smoothed out. The four petals are in two pairs, and each petal has a black patch on its lower part, so that the centre of the scarlet flower is made more conspicuous. The stamens are numerous and have curved filaments, arching over the pistil. The outer stamens open first, moving outwards as they shed their pollen. See Figs. 129, 130.

The pistil has a peculiar structure. It consists of a rounded top-shaped ovary, crowned by a radiating series of stigmas (8 to 12), forming ridges on the convex roof of the ovary. This roof projects over the ovary at the edges, and on cutting across the ovary just below the "eaves" of this roof you will see that the cavity of the ovary appears to be partitioned up by a series of radiating plates corresponding in number and in position with the stigmatic ridges. The plates, or placentas, covered with numerous ovules, are ingrowths of the ovary wall, but they do not meet at the centre of the ovary cavity, hence the ovary is one-chambered with parietal placentation (Fig. 131).

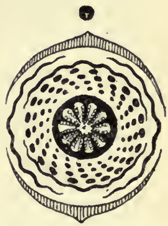


Fig. 130.—Floral Diagram of a Poppy.

In most of the flowers which have this kind of ovary each stigma stands directly over the midrib of a carpel and therefore between two placentas; the exceptional arrangement seen in the Poppy is explained by regarding each stigmatic ridge as corresponding to the fused halves of two adjacent stigmas. When pollen-grains are placed on a stigmatic ridge, the pollen-tubes grow down in the loose conducting tissue of the placenta and emerge on reaching the ovules.

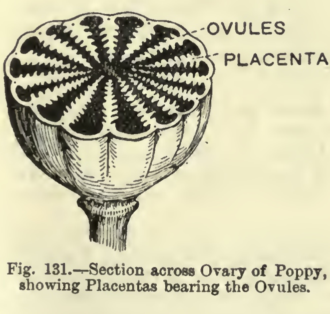


Fig. 131.—Section across Ovary of Poppy, showing Placentas bearing the Ovules.

The Poppy flower contains no honey, and is a good example of a pollen-flower, being visited by all sorts of insects for pollen. In crawling about the stamens and stigmas, the insects may effect either cross- or self-pollination. The pollen-grains are, contrary to the general rule in insect-pollinated flowers, little damaged by rain, to which the erect open flower is freely exposed, and appear to be unwettable by water.

After pollination, the petals and stamens fall off, and as the capsule grows larger you can see, just below the eaves of the stigmatic roof, a number of openings being formed by bits of the wall splitting off (Fig. 132). The flower-stalk remains erect, the roof of the capsule protects the seeds against rain, and the seeds gradually escape through the holes when the plant is shaken by high winds. This is a fine example of a censer mechanism.

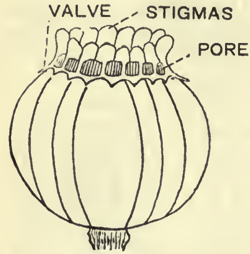


Fig. 132.—Capsule of Poppy with Poral Dehiscence.

338. The **Poppy Family** (**Papaveraceae**) is a small one, closely allied to the Cruciferae and, like it, consists almost entirely of herbaceous plants, chiefly found in the North Temperate regions. The Fumitory Family is now merged in the Poppy Family, because, though differing from the latter in some respects, it agrees in having two sepals, four petals, and a superior one-chambered ovary. The Poppy Family in the wider sense has therefore two sections or sub-orders: (1) the Poppy Sub-Order (flowers regular, petals not spurred, stamens numerous) and (2) the Fumitory Sub-Order (petals spurred, stamens two).

Poppy Sub-Order.—Besides *Papaver* itself, there are two genera common in Britain, and each represented by a single native species; both have long narrow ovaries and fruits, the latter opening by two valves, in somewhat the same way as the siliqua of a Crucifer. The plants of the Poppy Sub-Order usually contain milky or yellow juice.

The **Greater Celandine** (*Chelidonium majus*), common in England, on roadsides and in waste places, but chiefly near houses, has leafy shoots 1-2 feet high, containing orange juice, thin leaves divided into 3-7 toothed lobes; yellow flrs. with umbel, long ovary, short style, with 2-lobed stigma; fruit opening by two valves which separate from below upwards, seeds with a small appendage (for dispersal by ants). The **Horned Sea Poppy** (*Glaucium luteum*) is a large annual common on sandy shores, with spreading branches and thick leaves covered with waxy bloom; flrs. large (2-4 inches across), golden yellow; ovary divided into two chambers by a partition (as in Crucifers); fruit about a foot long.

339. Dog Rose (*Rosa canina*).—There are many kinds of Wild Roses in Britain, the Dog Rose being the commonest.

The plant has a woody "stock" which produces suckers; these are also given off by the roots in some cases. During the first year of growth each shoot usually grows erect to a height of three or four feet and does not branch; later on the shoot may branch freely and reach a length of ten feet or more in a single season.

How do the long arched shoots scramble over other plants in a hedge? Sketch a piece of the shoot, showing the shape of the prickles and the direction in which they curve.

Fig. 133.—Longitudinal Section of Flower of Dog Rose.

Are the prickles deeply embedded in the stem, or can they be pushed off easily? Each prickle is evidently part of the rind or outer tissue of the stem.

Sketch a leaf, showing the narrow pointed stipules which adhere to the base of the leaf-stalk; pull a leaf down and notice the bud, which is protected by the stipules.

Do all the shoots bear flowers? Do the flowers grow singly or in clusters? Are the flowers found in the thick parts of the hedge, or only at the top and along the sides, where there is plenty of air and sunlight? How does the arrangement seem advantageous with regard to (1) the pollination of the flowers, (2) the ripening of the fruits, (3) the dispersal of the fruits?

Examine a flower (Fig. 133), noting the green urn-like tube from the edge of which arise the five green sepals, the five white or reddish petals, and the numerous stamens; the petals are attached by a narrow base, as in Buttercups, while the sepals have broad bases. Examine the sepals carefully, noting the appendages which fringe the edges; are all the sepals fringed on *both* sides, or are any of them fringed on one side only, or not fringed at all? Examine a flower-bud and see whether the relative positions of the sepals throw light on the distribution of the fringes.

The Dog Rose has no honey, but the flowers (June to August) are visited by various insects for pollen. Note the numerous styles, each with a slightly dilated stigma, which project a little from the mouth of the flower-tube. Cut a flower down through the middle of the tube and trace the styles down to the ovaries which are inserted all over the lower part of the tube. The stigmas become receptive practically at the same time that the anthers open, but insects generally alight on the stigmas first, and thus bring to them pollen from previously visited flowers.

Examine twigs showing various stages in the formation of the fruits ("hips"), noting that the sepals become bent downwards but do not fall off before the fruit ripens and turns red. Note the shape of the fruit (from what part of the flower is the red fleshy "hip" formed?), the narrow mouth of which is blocked with woolly material; on the rim of the urn notice the five scars where the sepals have fallen. Cut the "hip" in two longitudinally, noting its thick wall and the numerous seed-like bodies (really fruits, *akenes*, since each is formed from an ovary) within it, and the white threads (bundles) passing from the flower-stalk into the wall of the "hip." Why is one side of each akene curved and the other two sides flat? Note the slender thread (style) at the top of each akene, also the stiff brittle hairs covering the akenes and the inner surface of the "hip." The akenes are dispersed by birds, which are attracted by the bright colour of the fleshy "hip."

340. Some of the commoner Wild Roses are easily identified. The **Burnet Rose** or **Scotch Rose** (*R. spinosissima*) is a small erect bushy plant (1 to 3 ft. high), chiefly found on sand or shingle at the coast, with crowded prickles varying in size and shape, but mostly straight, and passing into mere bristles and glandular hairs; seven to nine small leaflets; flowers small, solitary; fruit nearly black; sepals persistent and erect on top of "hip." The **Sweet Briar** (*R. rubiginosa*) is more closely allied to Dog Rose, but its leaves have a pleasant smell when rubbed owing to an aromatic substance produced by numerous small reddish gland hairs on leaf-stalks and lower side of leaflets; the prickles are hooked but mixed with bristles and hairs; flowers usually solitary. The **Field Rose** (*R. arvensis*) has leaves and prickles as in Dog Rose, but is a more trailing plant; the flowers are white, scentless, in clusters (3 or 4); "hip" globular; sepals not fringed; styles united into a column which projects from mouth of "hip"; this species keeps on flowering later than the Dog Rose. The **Downy Rose** (*R. villosa*) is distinguished from the downy varieties of Dog Rose by the globular fruit, which bears small prickles; the stem-prickles are straight or only slightly curved, the leaflets downy on both sides.

341. The Rose Family.—One of the chief features distinguishing this large family (*Rosaceae*) from the Buttercup family is the presence of what is often wrongly called a "calyx-tube." If you imagine a Buttercup flower in which the receptacle, during the development of the flower-parts, grows up at the sides as a ring which carries on its edge the sepals, petals, and stamens, leaving the carpels on the central knob, you would have a flower like that of a Cinquefoil, Strawberry, or Blackberry. The cup-like outgrowth involves the sepals more than the other parts, which can easily be detached from the cup. This upgrowth of the receptacle not only tends to enclose and protect the carpels, but also makes the flower tubular and conceals the honey to some extent (there is usually a honey-disc within the bases of the stamens). In Apple, Pear, Hawthorn, Quince, Medlar, etc., the receptacle-cup grows up closely around the carpels, and later on becomes joined to them.

The great variety of fruits (akenes, drupes, drupelets, follicles, and pomes) found in this family is due to various causes—the degree of perigyny shown by the flower, persistence or non-persistence of receptacle ("calyx-tube"), dryness or fleshiness of pericarp or receptacle, number and form of ripe carpels, etc.

Note the following interesting features in the vegetative organs:—the runners of Strawberry and of some Potentillas; the suckers of Raspberry; the long shoots of some Brambles which grow into the soil at the tips, producing roots which contract and pull the tip down, and the formation of new plants in this way; the prickles of Roses, Brambles, Raspberry; the spines of Sloe and Hawthorn; the curious glands on the petiole of Cherry, just below the leaf-blade; the evergreen leaves of the introduced but commonly cultivated Cherry Laurel and Portugal Laurel, both belonging to the Cherry genus (*Prunus*).

342. Flower Mechanisms in Rosaceae.—In most Rosaceae the flowers, which are regular and show all degrees of perigyny, are insect-pollinated (except Salad Burnet) and

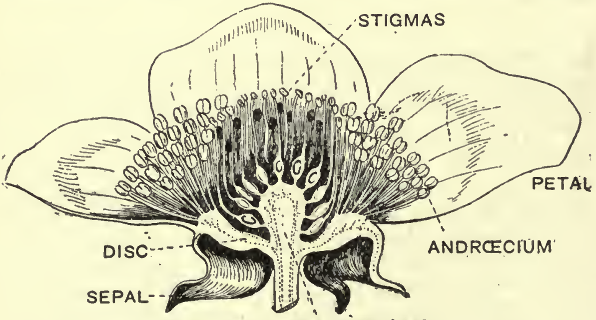


Fig. 134.—Longitudinal Section of Flower of Blackberry (Bramble).

mostly visited by all sorts of insects. In most cases honey is produced by the whole inner surface of the receptacle, or there is a ring-like nectary (disc, Fig. 134) round the receptacle mouth within the insertion of the stamens; Dog Rose, Agrimony, Meadowsweet, and Dropwort are honeyless pollen-flowers. Lady's Mantle and the smaller Potentillas are visited by flies, Cotoneaster chiefly by wasps.

In *Prunus* (Cherry, etc.) and the larger-flowered Pyrus-types (Apple, etc.) the stamens form a sort of palisade, which keeps out short-tongued insects; this is especially marked in flowers like those of Quince, which are largely visited by bees (the shorter-tongued ones only getting pollen) and whose receptacle is often bored by the bees. The flowers are often more or less protogynous (Hawthorn, Sloe, Avens, Bird Cherry, Japanese Quince, etc.), though (often in allied forms) sometimes homogamous (Common Cherry, Gean, Dropwort, etc.) or protandrous (Roses, Potentillas, Meadowsweet, etc.). Self-pollination is apparently possible in all cases.

343. The **Cow Parsnip** or **Hogweed** (*Heracleum sphondylium*) is one of the commonest, largest, and most easily recognised of British Umbellifers. It grows in moist fields and hedgerows, often beside streams, and in favourable places reaches a height of 5 or even 6 feet.

The erect annual shoots arise from a short thick rhizome which is perennial, though lasting only a few years. The stem is hollow, furrowed, and branched a few times in the upper part. The whole plant is more or less rough with short stiff hairs. The leaves are large (often a foot long) and pinnate, with 3, 5, or 7 large broad leaflets which are toothed and lobed; there is a good deal of variation in the number, size, and lobing of the leaflets. The base of the leaf-stalk is broad and forms a concave sheath.

The umbels are compound (Fig. 80), as in most Umbellifers, and often measure 4 or 5 inches across. Each has about 20 rays (branches), each ending in an umbel. In many Umbellifers there are bracts below the whole compound umbel, forming the involucre, and bracts below each of the small umbels, forming the involucel, but the Cow Parsnip either has none in either place or else small ones which soon fall off. The whole inflorescence is flat-topped; when young, it is protected by the sheathing base of the leaf-stalk.

The flowers (June to September) have an inferior ovary, crowned by a very narrow rim (calyx) with 5 small lobes; 5 white, cream, or pinkish petals, each notched on the outer margin, with a small process arising from the notch and curving inwards; 5 stamens, alternating with the petals; and 2 short stigmas, surrounded by a honey-disc on the roof of the ovary (Fig. 135). The ovary is 2-chambered, with a single ovule hanging from the top of each chamber. The young flower-bud is protected by the petals, which are at first curved inwards. When the flower opens, by the outward curving of the petals, each stamen curves outwards and sheds its pollen; later, the stigmas separate and spread out, ready to receive pollen; finally, the stamens bend inwards again. Thus, though the flower is protandrous, self-pollination may occur as a last resort if the flower has not been pollinated while the stamens were bent outwards.

The flowers are visited by insects of all kinds, the honey being freely accessible to flies and beetles with short tongues. The large flat-topped inflorescence is very conspicuous, though the individual flowers are small, and the massed effect is heightened by the fact that the outermost flowers—those around the edge of the whole inflorescence—have their 3 outer petals larger than the 2 inner ones, and are therefore zygomorphic (cf. Candytuft and some other Crucifers).

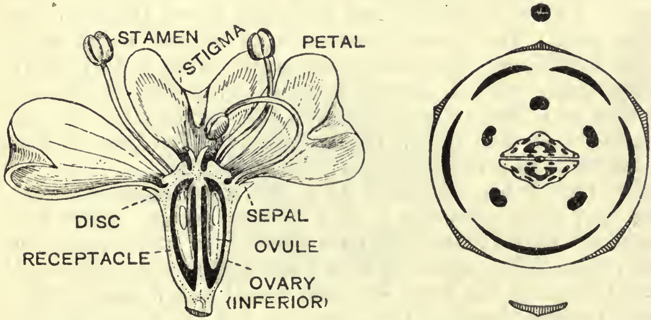


Fig. 135.—Vertical Section and Floral Diagram of Flower of Cow Parsnip.

After pollination, the petals and stamens drop off, and the ovary develops into a flat dry fruit, which eventually splits into 2 parts (mericarps, *i.e.* "divided fruits"), which are suspended on the 2 branches of a Y-shaped stalk (*carpophore*, *i.e.* "fruit-carrier"). Each half-fruit shows 3 or 5 vertical ridges and a thin membranous margin. In the space between every two ridges there is a dark mark which does not reach the base of the half-fruit and is thickened at the lower end. These marks are due to oil-containing cavities in the wall of the fruit; each is called a *vitta* (Fig. 136). The ripe mericarps dangle on the slender stalks and are readily detached and carried away by wind. Their flat form, giving a large surface without increase of weight, is an admirable adaptation for wind dispersal. The seed is endospermic, the endosperm being hard and oily.

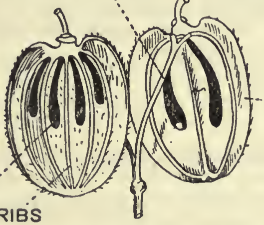


Fig. 136.—Schizocarp of Heracleum (Cow Parsnip).

344. The **Umbellifer Family (Umbelliferae)** is a fairly large one, chiefly found in the North Temperate region and well represented in Britain. Most Umbellifers can be recognised by the hollow stems, alternate sheathing pinnate leaves, compound umbels, and characteristic splitting fruit. In a few cases, *e.g.* Hydrocotyle, there is a simple umbel; in Sanicle there is a cymose grouping of simple umbels; in Eryngium the flowers are in a head.

The general flower structure is practically the same throughout the Order, and the Umbellifers are classified chiefly on the structure of the fruit, so that except in the case of such readily recognised plants as Cow Parsnip, Hydrocotyle, Sanicle, Eryngium, etc., it is necessary to have ripe fruits in order to identify an Umbellifer species in a "Flora." The outer surface of each half-fruit usually has 5 projecting ridges, in some cases with secondary ridges, 4 to each half-fruit, between the primary ones. It is important also to note the appearance of the vittas, and the breadth of the surface of junction between the two half-fruits.

345. Water Pennywort (*Hydrocotyle*), a small creeping plant in wet places, has round peltate leaves and simple umbels of small greenish or pinkish white flrs. (May-July). **Wood Sanicle** (*Sani-*

cula) has long-stalked "radical" leaves with 5-lobed palmate blade, erect flowering stems bearing only a few 3-lobed leaves below the infl. (usually = 3 small terminal heads of flrs. and below these branches each bearing 3 small heads), K-teeth nearly as large as petals, stamens and stigmas long, fruits covered with hooks for animal dispersal. **Sea Holly** (*Eryngium*), on sandy shores, has spiny leaves covered with bloom and globular heads of blue flrs. **Samphire** (*Crithmum*), on rocks by the sea, has each leaf divided into stiff thick fleshy lobes, and flat-topped umbels of greenish-yellow flrs.

In all the other Umbellifers commonly found in Britain, the leaves are pinnately divided, often very much like fern leaves, and the umbels are nearly always compound.

QUESTIONS ON CHAPTER XIII.

1. How does the Little Celandine hibernate, and at the same time multiply apart from seed-production?

2. Describe, with sketch, the appearance of a Little Celandine plant when its leaves first appear (end of January or in February).

3. Describe the flower of Little Celandine and compare it with that of an ordinary Buttercup. What property has the Celandine flower that is not possessed by a Buttercup flower, and why?

4. Describe, from your own observations, the movements shown by the flower and the flower-stalk of Little Celandine.

5. Name the three commonest English species of Buttercup. Describe any one of them as fully as possible, and point out exactly the characters in which the other two differ from it and from one another. How do they differ as regards the situations in which they usually grow, and the time of year in which they flower most freely?

6. Describe the adaptations which the flowers of Celandine, Buttercups, and Water Crowfoot have for securing pollination. Which of these will be likely to receive most insect-visits, and why? Which will get fewest visitors, and why?

7. Describe a Water Crowfoot and compare it with an ordinary Buttercup.

8. Describe the adaptations shown by a water plant, with floating leaves or submerged leaves or both kinds, to its mode of life.

9. Why are aquatic Flowering Plants believed to have descended from land plants?

10. Describe and compare the leaves, flowers, fruits, and mode of life of Marsh Marigold and Little Celandine. Why are the yellow leaves of the flower of Marsh Marigold regarded as being sepals and not petals?

11. Describe the flowers and fruits of Clematis, and point out the resemblances and differences between this plant and a Buttercup. By what organs does Clematis climb? In what respects does Clematis differ from the other British members of the Buttercup family?

12. Describe the flowers of Larkspur and Monkshood, and compare them with a Buttercup flower.

13. Distinguish between a species, a variety, a natural order, and a genus, illustrating your answer by reference to three examples of each. Can you exhibit the relations of the four in a diagrammatic form?

14. Describe, with drawings, the appearance and structure (not microscopical) of the fruits of five different members of the Ranunculaceae; and also of any five of the following seeds: Maize, Bean, Almond, Castor Oil, Pine, Sunflower, Gourd.

15. Describe the typical inflorescence of caryophyllaceae. In what other families does a similar inflorescence occur, and how would you distinguish their flowers from those of Caryophyllaceae?

16. Give an account of the vegetative organs of the Caryophyllaceae (excluding flowers and fruits), noting any adaptations to special habitats.

17. Which members of the Caryophyllaceae grow in (*a*) hedges, (*b*) woods, (*c*) cornfields, (*d*) seaside localities, (*e*) sandy soil away from the sea?

18. Write an account of the structure and mode of pollination of the flowers in the British Caryophyllaceae.

19. Describe the typical fruit of Caryophyllaceae. In what other family does a similar fruit occur, and how is it distinguished from Caryophyllaceae?

20. Describe fully the carpels of the Pea and of the Wallflower, and state the uses of the various parts.

21. Describe the flower structure and pollination of Wallflower, with sketches.

22. Describe the parts of the plant which are eaten in the following: Turnip, Cabbage, Brussels Sprouts, Cauliflower, Sea Kale, Radish, Mustard, Watercress, Common Cress, Horse Radish, Kohl-rabi.

23. Describe the Cruciferae which grow at the sea-coast. How do they differ from most plants which grow inland?

24. Write an account of the fruits of Cruciferae, noting any peculiar forms or methods of seed-dispersal, with sketches.

25. Note any points of interest connected with the following plants: Shepherd's Purse, Candytuft, Hairy Bittercress, Sea Rocket, Honesty, Dame's Violet, Garlic Mustard, Vernal Whitlow-grass.

26. Describe the flower of a Poppy and its adaptations for pollination.

27. Describe the Horned Sea Poppy and the Greater Celandine. In what habitats do these plants grow, and how do they differ from the Field Poppy?

28. Describe the fruits of Poppy and Greater Celandine, pointing out the adaptations for seed dispersal.

29. Describe carefully the structure of a Rose flower. Why is the Dog Rose called a "pollen-flower"?

30. Explain clearly the differences between the prickles of Roses or Brambles and the spines of Hawthorn or Sloe.

31. Describe and compare, giving sketches, the fruits of Rose and Strawberry.

32. Describe the different kinds of leaves on a Strawberry plant. In what respects does a cultivated Strawberry differ from the Wild Strawberry?

33. Compare, by means of a series of sketches with the parts labelled, the fruits of Cherry, Bramble, Strawberry, Potentilla, Avens, Agrimony, Rose, Hawthorn, Rowan, and Apple. Deal only with fruits you have actually examined.

34. Mention the commonest species of Potentilla, noting the distinctive characters of each, the months when each is most abundant in flower, and the habitat in which each occurs.

35. Give diagrams with brief descriptions, showing the variation in the form of the ovary and receptacle in the *Rosaceae*. Give examples of each case. Name the chief British genera of this order.

36. Describe the inflorescence and flower of Cow Parsnip. How are the flowers pollinated?

37. Describe examples of Umbellifers (two in each case) which grow (*a*) in woods, (*b*) in hedgerows, (*c*) beside streams, (*d*) at the seaside.

38. How do the following Umbellifers differ from the rest of the family?—Wood Sanicle, Water Pennywort, Sea Holly.

CHAPTER XIV.

THE HIGHER DICOTYLEDONS.

346. In the **Primrose** (*Primula vulgaris*) note the thick stem which grows in the soil bears crowded bases of former leaves, together with numerous roots, and stores up reserve

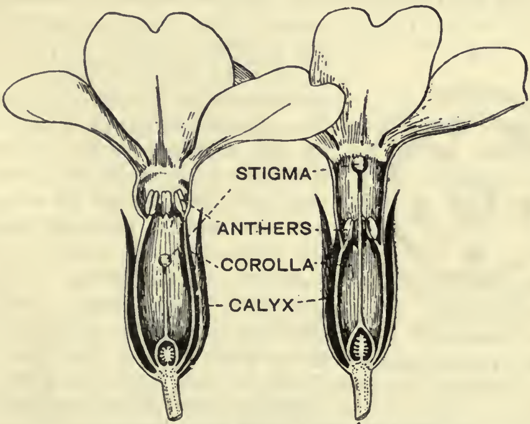


Fig. 137.—Vertical Sections of Short-styled and Long-styled Flowers of Primrose.

food; the pale green leaves, arranged in a rosette at the growing end of the stem, each being 3 to 6 inches long, obovate, toothed, wrinkled, with a broad midrib, veins very prominent on the lower side, which is hairy.

The flowers (Figs. 137, 138), each carried on a hairy pinkish stalk, appear to arise singly from the stem, but close inspection shows that they really form an umbel, since all the stalks are joined at the base to a short outgrowth from the stem. Note the bract on the flower-stalk; the inflated and five-angled calyx with five narrow pointed lobes; the corolla, consisting of a *tube* and a flat broad upper portion, the *limb* with five notched lobes. The corolla-lobes are pale yellow, but round the mouth of the tube there is an orange-coloured ring with thickened folds; this ring is sometimes represented by five patches (one to each lobe) darker in colour than the rest of the expanded limb. The limb serves as a platform on which the insect-visitors (chiefly bees) stand, and the orange ring acts as a honey-guide, enabling the insect to reach the centre of the flower more quickly and certainly.

Note the five stamens, which are, in some flowers, at the mouth of the tube, and can then be seen to stand opposite to the lobes; it is characteristic of the Primrose family (Primulaceae) to have the stamens equal in number to the corolla-lobes and opposite to (not alternate with) the lobes. Open up the corolla-tube of a flower of this kind ("thrum-eyed"): the filaments of the stamens are very short and are inserted near the mouth of the tube, while the stigma is about half-way up the tube. Note the structure of the ovary: it is one-chambered, and the numerous ovules are attached to a rod (placenta), which projects from the floor of the chamber upwards but does not reach the roof, so that the ovary-wall may be removed leaving the ovules attached to the free central placenta.

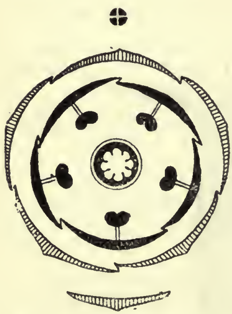


Fig. 138.—Floral Diagram of Primrose.

Now examine other flowers on (1) the same plant which bears the kind of flower just described, (2) other plants. Do you find that (1) *all* the flowers on the first plant are "thrum-eyed" (short-styled), (2) some plants have a different type of flower in which the *stigma* is at the mouth of the tube, while the stamens are inserted half-way up?—this is the "pin-eyed" or long-styled form. The two kinds of flower appear to be always on distinct plants, and the plant apparently produces flowers of the same kind year after year. So that there are evidently two varieties of Primrose, differing only in the relative lengths of stamens and style; in the two types the positions of anthers and stigma are simply reversed. In which case does self-pollination seem to be possible or likely to occur, and in which does it appear to be hindered?

Cover flowers of each kind with muslin, and find out whether self-pollination does occur in either kind. With the microscope examine the pollen-grains and the stigma of each kind of flower, noting that the higher anthers (*i.e.* those of short-styled flower) produce larger pollen-grains (about $\frac{1}{700}$ inch diameter) than those of the long-styled flower (about $\frac{1}{1000}$ inch diameter); the long style is globular and rough with small projecting hairs, while the short style is rather flat-topped and smooth (with very short projections). Possibly the difference in size of the pollen-grains may be due to the fact that the larger grains have to send a longer pollen-tube down the long style to reach the ovary. Perhaps also the longer stigmatic hairs are required to catch and hold the larger grains, which would tend to roll off the nearly smooth stigma of the short-styled flower.

The fruit (capsule) of Primrose opens by five teeth (one opposite each sepal) at the top, each tooth being notched in the middle. This, together with the occasional production of "monstrous" flowers in which the pistil is represented by five leaves, affords evidence that the Primrose pistil is made up of five carpels.

347. In the **Cowslip** (*Primula veris*) the leaf-stalk is "winged" below the blade, not forming a bare midrib at the base of the blade as in Primrose. The flowers are carried up on a general stalk or inflorescence-axis and are arranged in an umbel, each flower having a stalk of its own. The corolla is smaller than in Primrose; the tube is shorter and its "throat" is dilated below the mouth, which is more funnel-shaped than in Primrose. The orange-coloured honey-guides are very conspicuous, forming a patch opposite each of the five lobes. The flowers are heterostyled, as in the Primrose.

348. Note on Pollination of Primrose and Cowslip.—In both of these plants honey is produced at the bottom of the corolla-tube, and the flowers are visited largely, in fine weather, by bees, butterflies, and moths, whose tongues are long enough to reach the honey. It has been found by experiment that, on the whole, "legitimate" cross-pollination (transference of pollen from long-styled flower to stigma of short-styled flower, and *vice versa*) yields better results (more seeds germinate and stronger seedlings are produced) than "illegitimate" cross-pollination, while both kinds of cross-pollination are better than self-pollination. However, the manner in which the pollination of the Primrose actually occurs in nature has been for many years the subject of conflicting statements by various observers.

The following extracts from a paper by Professor Weiss (*New Phytologist*, 1903), based on observations made in Shropshire during the Easter vacation of 1903, are given not merely because they are of interest, but in the hope that they may induce observers in various parts of the country to take up the subject.

The chief insects seen visiting the flowers were species of short-tongued burrowing-bees (*Andrena*), hive-bees (*Apis*), small humble-bees (*Anthophora*), large humble-bees (*Bombus*), and a fly called *Bombylius* (see Art. 266). "Considering the regularity of the visits of *Bombylius* and the relatively large number observed in really fine weather, I have no doubt that this insect is an active agent in the pollination of the Primrose. It seems admirably adapted to obtain nectar from the depths of the tubular corolla with its long proboscis, and it seemed at this time of year to confine its attention to the Primrose. Only on one occasion did I observe a *Bombylius* sucking nectar from the Celandine, which is so largely visited by the bees. . . .

"On five different occasions I have observed *Bombus* visiting Primroses, and generally in such a manner as to ensure the pollination of the flowers. In two cases, however, I noticed the humble-bee not sucking at the flower, but moving all over the corolla, apparently endeavouring to obtain the honey by illegitimate means, just as Darwin observed them at times biting through the corolla in the case of the Cowslip, of which they are regular visitors. I ought to state clearly that *Bombus* was a more frequent visitor of other flowers than the Primrose, and was more commonly seen on the Willow, the Dandelion, the Violet, and the Barren Strawberry. A smaller humble-bee, however, *Anthophora*, though less plentiful in the district, was more often seen on the Primrose, to which it seemed to confine its attention. There can be no doubt that this insect is both able to gather honey from the Primrose flower and also to effect its pollination.

"The honey-bee, *Apis mellifica*, appeared to be less hardy than the humble-bee or *Bombylius*, for it only gathered honey on warm days and was not observed at all on several days when *Bombylius*, *Bombus*, and *Anthophora* were about. The bees visited chiefly the Celandine, Barren Strawberry, Wood Anemone, Violet, and Dandelion. Occasionally a stray one would visit a number of Primroses, but did not spend much time on each. They were evidently endeavouring to obtain the nectar, which however they were unable to reach. They stayed a little longer on the short-styled flowers, from which they collected a little pollen. They were obviously not the regular visitors of the flowers, although they could no doubt bring about cross-fertilisation of the long-styled forms.

"This object would also be effected by the visits of *Andrena gwynana*, but this insect must be placed in a different category from the bee, for it is a regular and busy visitor of the Primrose and more often seen by me on its flowers than on those of other plants. It was only observed towards the close of my visit when the weather was much milder, but then it was present in considerable numbers. It gathered the pollen greedily and in getting at it poked its head deep into the mouth of the corolla.

"From the instances given above, therefore, there is no doubt in my mind that Primroses are efficiently cross-pollinated in the district under observation by *Bombylius*, *Anthophora*, and *Andrena*, with the addition of occasional though by no means isolated visits of *Bombus*.

"That self-pollination may occur fairly often in the Primrose cannot be denied, and, indeed, Darwin observed the frequent occurrence in both Cowslip and Primrose of Thrips, which he considered aided the self-fertilisation of both forms. In many Primroses which I examined numbers of Thrips were present, and in these flowers it was very common to find pollen-grains scattered throughout the tube of the corolla and it seemed likely that it had been carried about there by these small insects. Another agency for self-pollination is no doubt the wind, taken in conjunction with alterations in the position of the flower.

"In the absence of cross-pollination, which must frequently fail in flowering plants in early spring, the strong winds of that season are probably of considerable use. In the Primrose the flowers open at first in a vertical position, and if the flower is short-styled the pollen from the opening anthers can readily be shaken by the wind on to the lower-standing stigma. But towards the end of flowering the flower-stalk has grown considerably in length and the flower passes into a horizontal and often a pendant position, so that the long-styled forms have a chance of self-pollination too when the flowers are agitated by the wind.

"It may be thought that this movement is mainly for the concealment of the fruits, which in the Primrose are ripened beneath the foliage, but though this may be to a certain extent the case, I cannot but believe that the self-pollination is also a determining factor in this movement. For in the Cowslip the very opposite occurs. The flowers, at first pendant, offer greater facilities as far as self-pollination is concerned to the long-styled forms, but later on the flowers become erect and thus in the absence of cross-pollination the short-styled forms will have ample opportunity to be self-pollinated.

"From the observations I have made on the Primrose I feel convinced that it is both regularly visited and cross-pollinated by insects under favourable climatic conditions, but that like most flowers adapted to the visits of insects it is provided with efficient means for self-pollination, and these are important to a plant flowering at so early a period of the year, when the visits of insects may be precarious."

Watch insects visiting the flowers of Primrose and Cowslip: in the former case the flat top of the erect corolla serves as a platform, in the latter the insect enters the drooping flower from below. Why is the top of the corolla narrow and cup-like in Cowslip, instead of being broad and flat as in Primrose?

Why do Primroses usually grow in woods or on slopes and banks, while Cowslips grow mostly in open and level meadows, often among long grasses? Does the possession of a long flowering-axis in Cowslip, carrying up the flowers in a tuft, as compared with the arrangement in Primrose, seem to be connected with the different situations in which the two plants grow?

349. The Primrose Family (*Primulaceae*) is easily recognised by the regular flowers with stamens opposite to the corolla-lobes and the one-chambered ovary with free central placenta.

350. Flower Mechanisms in Primulaceae.—The pollination of Primrose and Cowslip has been dealt with. The flowers are usually homogamous and honeyed. Heterostyled dimorphic flowers occur in many species of *Primula* (though in *P. scotica* and various garden Auriculas, etc., stamens and style are of same length), also in *Hottonia* (Water Violet), Yellow Loosestrife (*Lysimachia vulgaris*), and *Glaux* (Sea Milkwort, which also has cleistogamic flowers). In many cases, especially when the flower-tube is shallow or open, the flowers droop so that pollen and honey are protected.

The flowers of Scarlet Pimpernel open on bright days, usually from about 9 to 3, closing at night and in bad weather; if not cross-pollinated (by flies, etc.) during the warm hours of the day, the flower is self-pollinated at evening when it closes and the stigma is rubbed against the stamens. The long-tubed forms are largely visited by bees and butterflies; the honey is secreted by a ring round the base of the ovary.

351. Scorpion-grass or **Forget-me-not** (*Myosotis*), though not a good "typical" genus of the Borage Order, is the most abundant and familiar to all. Any of the species found wild, or cultivated in gardens, will serve as an example for study, but in order to make our description definite we shall take

Field Scorpion-grass (*M. arvensis*), which grows on hedge-banks, in waste and cultivated fields, and on the edges of woods, and flowers from May to August. It is usually annual, but sometimes biennial, and has a straggling stem, usually branched at the base and often a foot long, and hairy oblong leaves of which only the lowest are stalked. Each branch usually ends in a long inflorescence, bearing stalked flowers; the stems and flower-stalks are covered with hairs, like the leaves.

The inflorescence is coiled, but as the flowers open it uncoils, and all the flowers on opening face in the same direction. The flower is regular, pale blue, and about 4 mm. in diameter. The calyx is bell-shaped, cleft halfway down into five narrow lobes, bearing hooked hairs. The corolla has a short tube and a spreading and rather concave limb with five rounded lobes; at the mouth of the tube there are five notched scales, one opposite each lobe, which nearly closes the mouth. The stamens are inside the corolla-tube, just below the ring of scales; they have very short filaments. The ovary is four-lobed, like that of the Dead-nettle, but the short style ends in a small spherical stigma, which just reaches the mouth of the corolla-tube.

The flowers are pollinated by flies and bees. The honey, secreted by a gland at the base of the ovary, is protected from rain by the scales which narrow the entrance and also protect the pollen, so that the shortest-tongued insects are excluded. The ring of scales also serves as a honey-guide.

The fruit splits into four akenes, and while these are ripening the calyx-lobes curve inwards. The akenes are shaken out by wind, and the hooked hairs covering the calyx probably bring about dispersal by animals as well.

There are three other common species of *Myosotis* in Britain, of which two grow in dry places and one in wet places; the former are hairy and the latter hairless—a general rule among plants, though with some exceptions. The **Changing** or **Yellow-and-blue Scorpion-grass** (*M. versicolor*) is a common annual in fields and waste places, with a rosette of sessile radical leaves and a few erect ones along the stem; flrs. (April-June) about 3 mm. diameter, at first yellow then changing to blue, corolla-tube relatively long, akenes black. **Early Scorpion-grass** (*M. collina*) is a low and much-branched annual, flowering in early summer and soon dying; flrs. bright blue with short C-tube; calyx wide open in fruit, akenes brown. **Water**

Scorpion-Grass or **True Forget-me-not** (*M. palustris*), in wet places, especially on edges of streams and ponds, is perennial, with creeping rhizome and runners; erect stems 1-2 feet, stout; leaves 1-3 inches long, bright green; flrs. usually large (8-12 mm. diameter), bright blue with yellow centre; a very variable plant.

352. The Borage Family (Boraginaceae) is represented in Britain by eleven genera, all of which except *Echium* (Viper's Bugloss) have regular flowers, and is easily distinguished by the alternate simple leaves, the general covering of stiff hairs, the curved one-sided inflorescence, and the structure of ovary and fruit.

353. Flower Mechanisms in Boraginaceae.—The inflorescence of this family is rather difficult to explain, and it is perhaps enough to notice that the flowers in most cases all point in one direction, either upwards or downwards, which increases their conspicuousness to insects. The lower forms, with short corolla-tube, e.g. *Myosotis*, are visited by flies (chiefly hover-flies), while the higher types are adapted for bees and butterflies and show some interesting floral mechanisms. The pollination of *Myosotis* has been dealt with.

Viper's Bugloss (*Echium*) has, on separate plants, female flowers and perfect flowers, and is therefore termed *gynodioecious*. The perfect flowers are protandrous. The flowers are protected against rain by the leaves and by the zygomorphic corolla, though there are no scales in the throat of the tube. After the stamens have shed their pollen they curve backwards and the style moves forwards so that the stigma stands where the stamens were previously. It is visited chiefly by bees and butterflies.

The Borage (*Borago*) is a typical bee-flower, and is largely cultivated for feeding bees. Though the flower (Fig. 139) hangs downwards, the honey is prevented from dripping out by the scales which nearly close the corolla-tube. The pollen collects within the conical chamber formed by the anthers; at first the style lies inside this chamber. A bee hanging on to the flower thrusts its tongue between the bases of the stamens and brings a shower of pollen on to its head. After the pollen has been shed, the style grows out of the anther-cone and developes its stigma.

In Comfrey (*Symphytum*) the mechanism is somewhat similar to that of Borage, for the flowers droop and the pollen is shaken out of a cone formed by the anthers and the scales which alternate with them. The bee gets at the honey by poking its tongue between the scales and anthers; the scales, with their hairy edges, prevent small insects from entering the flower.

Many other plants of this family have blue bee-flowers, e.g. *Anchusa* [*A. italica* is commonly grown in gardens]; Lungwort has heterostyled flowers; [Heliotrope, with sweetly scented flowers, etc., are also cultivated.]

"Many species in the course of their individual development seem to recapitulate to us the evolution of their colours —white, rosy, blue in several species of *Myosotis*; yellow,

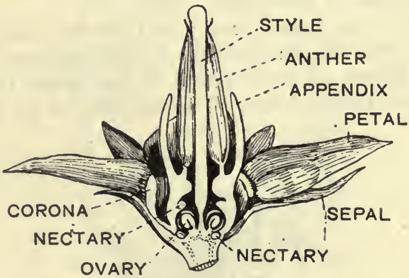


Fig. 139.—Borage (*Borago officinalis*). Vertical Section of Flower.

bluish, violet in *M. versicolor*; and red, violet, blue in *Pulmonaria*, *Echium*, etc. Here white and yellow seem to have been the primitive colours; and, at least in many cases, violet and blue seem to have been preceded by red—an assumption which is strengthened by the fact that many blue and violet species (*Myosotis*, *Anchusa*, *Symphytum*) give us white and rose-red varieties, apparently by revers to more primitive characters." (Müller.)

354. White Dead-nettle (*Lamium album*) is common on roadsides, especially near houses, farms, and refuse heaps. It is a rather hairy plant, with a perennial creeping rhizome, which gives off (1) branches which grow horizontally in the soil, (2) branches which soon turn upwards and come above ground.

The stems are square and hollow; the leaves arise from the flat sides of the stem in crossed pairs, those on the underground parts being small white scales. The aerial shoots are rooted and branched at the base, and then grow erect (6 to 18 inches high). The leaves are all stalked and heart-shaped, the lower ones having longer stalks and broader blades than the upper ones (why is this advantageous to a plant whose leaves are in superposed rows?).

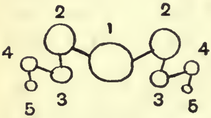


Fig. 140.—Diagram indicating the relation of Flowers in half of a cluster ("Verticillaster").

The flowers, produced nearly all the year round, but chiefly in summer, are in ring-like clusters round the stem just above a pair of leaves, on the upper part of the shoot.

Examine several clusters and note that each consists of two groups of flowers, one group in the axil of each leaf; also that the central flower of each group is the oldest (the first to open), the next oldest being at either side of it, and so on.

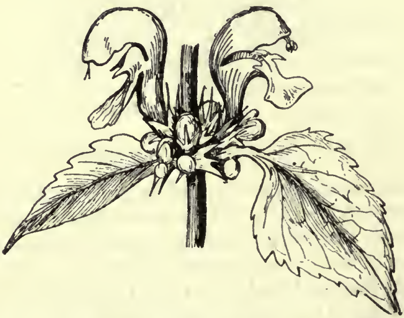


Fig. 141.—Dead-nettle, showing two Clusters of Flowers.

Each group is a biparous cyme which becomes uniparous after the first branching. This is obscured by the fact that the flowers are practically sessile, but it can be made out in Labiates whose flowers have distinct stalks, *e.g.* Calamint, Black Horehound. Fig. 140 is a diagram of a cyme (half-cluster); the main axis (1) ends in a flower and gives rise to two lateral axes (2), each of which ends in a flower and then gives rise to a single axis (3), and so on. How many flowers are there in each "ring"? How do the upper "rings" differ from the lower ones as to number of flowers?

In a flower (Fig. 141) note the almost regular calyx and the very irregular (zygomorphic) corolla. The funnel-shaped calyx-tube has 5 nearly equal teeth, narrow and tapering, longer than the tube itself; it persists around the fruit. The corolla-tube is curved; its lowest part is cylindrical, but

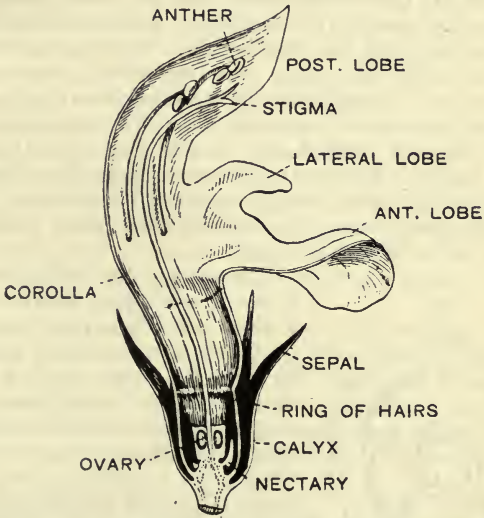


Fig. 142.—Sectional Elevation of Flower of White Dead-nettle.

higher up it is dilated and also flattened from side to side, while its mouth has an arched upper lip, two side-lobes, and a notched lower lip which spreads out. It is obvious that one of the calyx-teeth (sepals) is at the top or back of the flower, and since the 5 petals alternate with the 5 sepals, the lower corolla-lip represents a single petal, while the upper lip, though not divided, represents the two upper petals (some Labiates show this clearly).

The four stamens have long filaments attached to the corolla-tube, while the anthers lie under the hood-like upper lip. The two lower (anterior) stamens cross the upper pair, so that their anthers lie behind and above them. Note the hairy anthers, each with two lobes which, instead of lying side by side, are separated (owing to growth of the connective) and lie in a straight line one above the other. Note the long style which runs up the back of the corolla-tube and is divided at the top into two fine stigmatic lobes.

Pull off (1) the corolla of a flower, (2) a whole flower, and carefully slit open the corolla-tube. Note the ring of hairs near the bottom of the corolla tube; the constriction of the tube just below this ring; the four-lobed ovary with flat upper surface; the style arising from between the four lobes, which are separated from each other by deep grooves; the ring-like nectary around the base of the ovary, better developed on the lower than on the upper side (Fig. 142). The ovary consists of two carpels, upper and lower, but early in its development the ovary divides into four parts; each chamber contains a single ovule.

Fig. 143.—Floral Diagram of Labiatae.

The upper lip of the corolla forms a protecting hood over the anthers and style (why is this advantageous?), the lower lip a platform for the humble-bees which are the chief visitors to the flowers. The ring of hairs inside the corolla-tube above the ovary stops small insects from crawling down to the nectary, besides keeping rain from trickling down and spoiling the honey. The flower is homogamous, and capable of self-pollination, but the forked style-tip hangs down and touches the bee's back before the anthers do, so that cross-pollination occurs regularly.

The corolla (with the epipetalous stamens) and the style fall off very soon after pollination has taken place, and the four ovary-chambers grow into smooth black akenes ("nutlets") with hard coats; each nutlet is three-sided and flat-topped. As they ripen they become loose and fall out of the persistent calyx-tube, or are shaken out by the wind.

355. Red Dead-nettle (*Lamium purpureum*) is far more abundant and widely distributed than the White, often occurring in extensive patches in cultivated soil (fields, gardens) as well as on waste ground. It is a smaller plant and is annual, flowering throughout the year (chiefly from March to October), and may pass through several generations in a single year. Its leaves are broader in proportion to their length, with a more heart-shaped blade, and are more crowded towards the top of the stem. The upper leaves are often densely covered with silky hairs, and have a purplish-red colour.

In open places the plant is branched at the base, giving it a spreading habit, rarely over 6 inches high, and the whole plant (stem, leaves, flowers) is deeply coloured. When growing among rank and crowded vegetation the plant is less branched and taller, with dull-green leaves and stems. In hedgerows the plant is "drawn" up to a height of 18 inches or more, the stem having long internodes, and having nearly all the leaves at the top.

The flowers are smaller than those of *L. album*, but similar in structure. The corolla is about ½ inch long, so that short-tongued bees, and even flies, can reach the honey and effect cross-pollination; the tube is not constricted below the ring of hairs, which is often poorly developed, and the throat of the tube is very wide from back to front.

Two other Brit. species of Dead-nettle are fairly common. *L. galeobdolon* **(Yellow Archangel)**, perennial, in woods and shaded hedgerows, apart from being a shade-loving plant and having yellow flowers (April-June), resembles *L. album* in habit and structure. Its leaves are relatively longer and narrower, the calyx has short teeth, the lower lip of the corolla has red or brown spots (making the flr. more conspicuous to bees), and the anthers are hairless.

Hen-bit Dead-nettle (*L. amplexicaule*), annual, in waste places and cultd. fields, is like *L. purpureum* in general habit, but its leaves are gen. distinctly lobed, and the upper ones are stalkless and clasp the stem; it rarely grows in such crowded patches, and flowers freely from April to Oct., the pale-rose flrs. varying in size; in spring and autumn small flrs. are produced which have a small imperfect corolla and do not open but are self-pollinated (cleistogamic flrs.), the ordinary flrs. being pollinated by bees.

356. The Dead-nettle Family (*Labiatae*) is one of the most easily recognised, all the Labiates having square stems, simple decussate leaves without stipules, corolla generally two-lipped with no clear indication of the separate petals, stamens generally in two pairs owing to suppression of the upper one (sometimes only two stamens present), ovary of 2 carpels, but with four one-seeded chambers.

By the ovary and fruit (four akenes) Labiates are distinguished from those plants of the Foxglove Family which have square stems, decussate leaves, and bilabiate flowers with two pairs of stamens. By the decussate leaves, bilabiate corolla, and the presence of four stamens Labiates are distinguished from the Borage Family, in which the ovary and fruit are similar in structure.

357. Flower Mechanisms in Labiatae.—In most Labiates the flower is protandrous, and in many cases the stamens move outwards or downwards (well seen in Wood Sage) after the anthers have opened, when the style moves into their place and the stigmas spread apart to receive pollen. When the flower is homogamous, the style projects below the anthers so as to be touched first by the visiting insect. In the short-tubed flowers of Mint, Gipsywort, Thyme, and Marjoram, with more or less regular corolla and spreading stamens, all sorts of insects crawl over the flowers and touch the anthers and stigmas with any part of their bodies.

Most British Labiates, however, are definitely "bee-flowers" and have a conspicuous lower corolla-lip to attract insects and to act as a landing-place, and usually an arched upper-lip to shelter the stamens and style, which are generally placed so as to touch the bee's back as it enters the flower.

In Sage (*Salvia*) the two stamens (the other pair is represented by small staminodes) have a peculiar structure ; they are T-shaped, the filament being short and jointed to the long connective. In the lower types of *Salvia* each end of the connective bears a half-anther, but in the higher types (*e.g.* Garden Sage, which should be examined) the lower end of the connective is barren and flattened and the outer (upper) part of the connective is longer than the inner (lower) part, the whole forming a delicate lever. A bee on entering the flower (Fig. 144) pushes against the united lower ends of the two connectives, in poking for the honey, and causes the curved connectives to swing on the filaments as on hinges, so that the two fertile anther-lobes (*a*) come down and strike the bee's back, dusting it with pollen. As the bee retires, the stamens return to their former place under the corolla-hood.

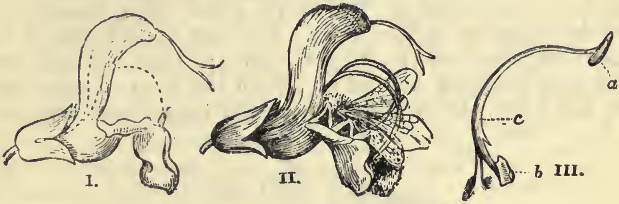


Fig. 144.

I., Flower of Sage from side; II., With Humble-bee extracting Nectar, and the Anthers rubbing against his back; III., Single Stamen.

In an older flower the style bends down and the stigma is touched first by a bee entering the flower.

[The long-tubed red flowers of *Monarda* are largely visited by butterflies, and some tropical species of *Salvia* are pollinated by humming-birds.]

Cross-pollination is promoted by the occurrence, often on different plants, of pistillate flowers besides the ordinary flowers, as in Thyme, Ground Ivy, Corn Mint, Self-heal.

358. Foxglove (*Digitalis purpurea*), the most familiar and most conspicuous British plant of this family, is abundant in sandy or rocky soils in open places or the edges and less shaded parts of woods. It is usually biennial, forming in its first year a rosette or broad-stalked "radical" leaves with prominent veins and wrinkled surface, 6 to 12 ins. long; in the second year the stem grows up to form a flowering shoot, 1 to 5 ft. high, with spaced-out leaves gradually becoming smaller and sessile. In sheltered places especially the plant becomes perennial, as do also the garden varieties.

The plant may send up branches when the flowers of the main shoot are nearly over, or in cases where the main stem has been damaged; these branches are quickly formed if the main stem is cut off either near the base or below the flowers.

Note the arrangement of the flowers in a long raceme, with a small leaf (bract) below each flower. The young flower is erect, but before opening it begins to droop owing to the bending downwards of the short stalk. The flowers are arranged spirally on the stem. Do they spread out in all directions when open? If not, how are they brought into their final position, and why? Note the calyx, deeply cleft into five lobes, the uppermost narrower than the others.

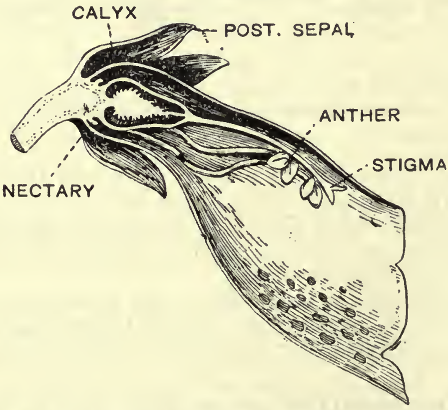


Fig. 145.—Longitudinal Section of Flower of Foxglove.

Sketch (1) a complete flower in side view, (2) the parts seen on looking into the mouth of the corolla, (3) the isolated corolla (pulled away from flower) in side view, (4) isolated corolla slit open along the middle line above, (5) the pistil and nectary, with calyx removed, (6) a section of the entire flower (Fig. 145). Note the peculiar form of the corolla: why is the tube dilated at the base, then narrowed, then widened out? Why is the mouth of the corolla longer below than above? Note the two lobes of the upper lip (= 2 petals) and the less distinct lobing of the longer lower lip (= 3 petals).

If you watch humble-bees visiting the flower, you should be able to answer the following questions. What are the uses of (1) the drooping position of the flower, (2) the curious "eye-spots" on the corolla, (3) the hairs inside the corolla? Examine flowers of different ages; the anthers of the upper pair of stamens shed their pollen before those of the lower pair, then the stigma-lobes separate and are ready to receive pollen; how does this sequence of events promote cross-pollination? Note how the two anther-lobes diverge when the anther ripens. Cut across the ovary and note the two chambers, with numerous ovules on the axile placenta, which resembles a dumb-bell in cross-section (Fig. 146).

Fig. 146.—Floral Diagram of Foxglove.

The egg-shaped capsule opens by splitting on each side; the partition splits into two layers, and at the same time separates from the placenta, so that the two valves are formed and the numerous small seeds are left on the placenta and are gradually shaken off when the wind rocks the plant (censer-mechanism). Note that the upper valve of the capsule splits down the middle; sketch the ripe capsule before and after opening.

359. Speedwell (*Veronica*).—There are 16 British species of *Veronica*, of which 10 are common and widely distributed. In certain respects they all agree: the leaves, or only the upper ones, are opposite; the flowers small and blue, with 4-lobed calyx and corolla, the corolla-tube being very short and the lobes flat; stamens 2, projecting from the corolla along with the style which ends in a small stigma.

Germander Speedwell or "Bird's-eye" (*V. chamaedrys*), one of the commonest species and earliest to flower (April to September, but chiefly in May and June) has rather large flowers ($\frac{1}{2}$ in. across) and will serve as a type. It is perennial and has slender branches, 8 to 24 ins. long, prostrate at the base but soon becoming erect.

Note the two opposite lines of hairs on the stem (cf. Chickweed); the opposite leaves, sessile or nearly so, $\frac{1}{2}$ to $1\frac{1}{2}$ ins. long, cordate (heart-shaped), with deeply toothed margin and wrinkled hairy surface.

The flowers are in racemes, each of which arises in the axil of one of the upper leaves, and is carried well up on a slender axis; the raceme with its stalk is 2 to 6 ins. long. Each flower arises in the axil of a narrow pointed bract; these are arranged spirally on the raceme axis, not in crossed pairs like the foliage-leaves.

Note the calyx, deeply divided into four narrow green pointed lobes. The short flower-stalk is slightly curved, so that the flat spreading lobes of the corolla lie in a vertical plane; what advantage do you see in this? The plant commonly grows on hedgebanks, in which case the flowers all tend to face outwards (why?); when in open places, the flowers face in different directions all round. Note the four lobes spreading from the short tube of the bright-blue corolla; the two side lobes, which lie behind (below) the upper lobes, are similar in size and shape—the upper lobe is the largest, the lower lobe is the narrowest.

Note the white rim (honey-guide) at the mouth of the corolla-tube and the hairs which protect and partly conceal the honey, secreted by a ring-like nectary round the base of the ovary.

The position of the lobes of the calyx and corolla suggests that the uppermost (posterior) sepal of the calyx is missing, and that the upper petal represents the two upper petals usually found in this family; occasionally one finds Speedwell flowers with five sepals and five petals. The two stamens present belong to the upper pair; each is inserted on the corolla-tube between the upper petal and one of the side petals. The ovary is two-celled, each cell having numerous ovules on an axile placenta, and is broader than long (flattened from side to side), covered with hairs, and notched at the top, the style arising from the notch.

The flowers are largely visited by hoverflies (Art. 292), and appear to be specially adapted for cross-pollination by these insects. The two stamens project horizontally and diverge a little at each side; the filament of each stamen has at its base a small bend which forms a kind of hinge; the style hangs out over the lowest petal. A fly coming to the flower first rubs its under side against the stigma, and then grasps the stamens with its legs and draws them together to form a support as it probes for honey in the corolla-tube, thus causing the anthers to dust its body with pollen. When the insect leaves, the stamens spring back to their former position, and the flower can be visited several times. Do you see why the corolla has no "platform" lower lip?

The sepals persist around the short flattened capsule and grow a little longer after pollination. The ripe capsule, which contains rather few seeds in each chamber, opens by two slits, but the valves remain attached to the seed-bearing axis. The seeds are thin, flat on one side and convex on the other; they escape gradually through the narrow slits; the sepals also help in this censer-mechanism and prevent too many seeds from falling out together except when a strong wind is blowing. After flowering the racemes lengthen considerably; this aids in the dispersal of the seeds by wind (how?); the flower-stalks stand erect, close to the raceme axis, while the flowers are young, spread out when the flowers open, and become erect again when the flowers have been pollinated.

360. The Foxglove Family (*Scrophulariaceae*) shows a fairly wide range of flower structure, as we have seen from our study of Foxglove and the Speedwells, but all agree in having the flower zygomorphic (in some cases nearly regular), with gamosepalous calyx (sometimes almost polysepalous), a gamosepalous and typically two-lipped corolla; stamens generally in two pairs, epipetalous; a honey-disc at base of ovary; a two-chambered ovary (chambers in vertical plane of flower) with numerous ovules (few in *Veronica*) on axile placentas.

361. Flower Mechanisms in Scrophulariaceae.—The flowers of most Scrophulariaceae are adapted for pollination by bees, though the short-tubed open flowers of *Veronica* and *Verbascum* are visited chiefly by flies. In most cases the entering bee rubs the anthers and style with its upper side, and the flower is protected against rain by the hood-like upper corolla-lip. In Toadflax and Snapdragon, however, the flowers stand erect, instead of being horizontal or pendulous, and the corolla-mouth is closed by the bulge or "palate" of the lower lip, so that it can only be opened by a heavy and strong insect; these flowers are visited by humble-bees, which often bite holes at the bulging base of the corolla-tube in Snapdragon. In the Musk or Monkey-flower (*Mimulus*) notice the curious stigma, with two flat lobes: what happens if the stigma is touched on the inner surface, and how will this help as regards pollination?

Figwort (*Scrophularia*), which is largely visited by wasps, is *protogynous*. In the newly opened flower (Fig. 147) the style lies in the mouth of the corolla above the lower lip, but the anthers are still closed and hidden in the corolla-tube, the filaments being curved; next day, or a little later, the

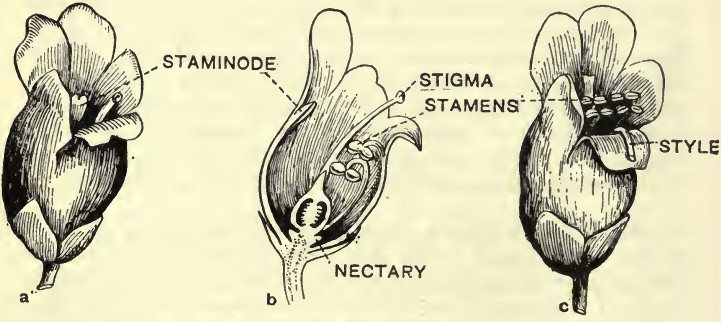


Fig. 147.—Figwort (*Scrophularia*).

a, Flower when first opened; b, Longitudinal section of same; c, Flower day or two later. In c the style and stigma are now withering, while the anthers are exposed and about to open.

style withers and falls on the front of the corolla, the visiting insect rubs the stigma and anthers with its under side in this case. The female stage is now over, and, unless cross-pollination has occurred, no seeds are formed. Then the filaments unbend, bringing the anthers up to the position formerly occupied by the stigma, and a bee probing for the honey at the base of the corolla-tube is dusted with pollen.

which it may then carry to the stigma of a younger flower.

In *Rhinanthus* (Yellow Rattle), *Pedicularis* (Lousewort), *Melampyrum* (Cow-wheat), and *Euphrasia* (Eyebright) we get a "loose-pollen mechanism." The stamens lie under the upper corolla-lip, and the four anthers are close together and usually connected by interlocking hairs in this fashion:

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so as to form a "pollen-box." The pollen is dry and powdery (like that of wind-pollinated flowers), and when a bee enters the flower it rubs against the lower side of the "pollen-box" and receives a shower of pollen on its head.

362. Potato (*Solanum tuberosum*).—Examine tubers and also whole plants (freshly dug up); plant tubers in soil and in sawdust, keeping some in darkness and others in the light.

Since the tubers themselves can be at once obtained at any time of year, we will take them first. Do any of the tubers show at one end a stalk or the withered portion of a stalk? Notice the "eyes": each eye is a small outgrowth sunk in a pit on the surface of the tuber. Carefully examine one of the larger eyes: is it a solid body, or does it bear any appendages? What do you think the eye *is*? Are the eyes scattered all over the tuber uniformly, or are they more numerous at one end of the tuber? Can you make out that the eyes are crowded at the end furthest from the remains of the stalk which attached the tuber to the parent plant? If so, we may call one end the "eye end" or "bud end" or "growing end," the other the "stalk end" or "barren end." Have the eyes any definite arrangement on the tuber, or are they scattered anyhow over its surface?

Try to determine the position of the eyes on a Potato tuber by fixing a pin in each eye and joining the pins by a piece of thread. The eyes are arranged in a spiral, the sixth eye being in a straight line with the first; the thread in going from the first to the sixth eye goes around the tuber twice. Compare this arrangement with that of the buds on an Oak twig and of the leaves on a Wallflower.

Plant tubers in the garden or in pots, some in moist sawdust, some in moist soil; some in water, some in damp air in covered vessels; some with the bud end upwards, some with this end downwards; some cut in two, separating bud end from stalk end, some cut into several pieces with an eye or without an eye. After a week or two, when the buds begin to sprout, it will be easy to tell the bud end from the stalk end. Will the buds sprout if a tuber is kept in darkness? Do all the specimens gain in weight? Which do not? In the case of specimens that gain in weight, where does the

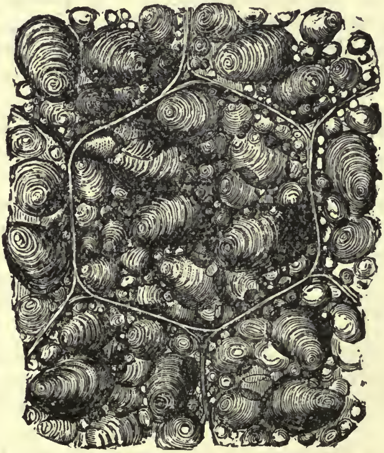

Fig. 148.—Cells of Potato, showing Starch Grains, greatly magnified.

extra material come from? In the case of specimens grown in darkness, at what stage do they die? In what other respects do specimens grown in darkness differ from those grown in the light? Why do tubers with sprouting buds turn soft? Chop up some sprouted tubers, shake up the pieces in water; then filter, and test the filtrate for (1) starch, (2) sugar.

In examining plants grown from tubers, note that the new tubers are simply the swollen ends of branches, which can be traced back to the lower part of the stem and arise from it in the axils of small leaves. In seedlings it is easy to make out that the tuber-bearing branches come off above the cotyledons, so that the tubers are not roots, being developed above the root-system. Why are potato-fields ridged with the plants occupying the ridges? Why is the soil heaped up around the plants? What happens if you do not "ridge" a Potato-plant in the garden? Have you ever seen tubers growing in the *air*, in the axils of foliage-leaves? What happens if you cut off the underground tuber-bearing branches?

Cut across a tuber, and test for starch with iodine solution. Put a drop of water on a glass slide and dip a cut piece of tuber into the water: notice the small white starch-grains which escape from the opened-up cells of the tuber and become suspended in the water. If you have a microscope, examine the grains, some of which will show delicate lines corresponding to thin layers built up around the first-formed portion of the grain (Fig. 148). Do the lines run evenly around the centre of the grain, or are they closer together at one end?

These starch-grains are formed from sugar by the activity of small colourless protoplasmic bodies called leucoplasts, distinguished from the *chloroplasts* found in green parts by containing no chlorophyll and by being unable to build up sugar and starch from carbonic acid. Compare the results given with the iodine test in very young and small tubers with the starch-content of larger tubers. Compare the taste of (1) very young tubers, (2) fully developed tubers, (3) tubers which have sprouted and given out well-grown shoots. Test tubers in these different stages for sugar with Fehling's solution. Does the tuber contain any other kind of reserve-food besides starch? Shave off a very thin slice from the outer portion of a tuber and test it with iodine: the outer layer contains *proteids*. Note the layer of *cork* which forms a skin over the tuber; if this is shaved off, a new layer is formed. What is the use of the corky skin?

Note the arrangement of the leaves on the stem of the Potato-plant. Are the leaves simple or compound, with stipules or without? What peculiarity do you notice in the sizes of the leaflets in each leaf? The branching of the shoot, especially in the upper part, is rather complex; in most plants of the Potato family the branches and inflorescences do not arise strictly in the leaf-axils.

Examine the flowers (Fig. 149), arranged in more or less "flat-topped" inflorescences; the short calyx-tube with five sepals; the five-lobed funnel-like corolla; the five stamens with very short stalks and long yellow anthers, which taper and are joined above and open by pores at the top; the two-chambered ovary with numerous ovules, slender style, blunt stigma. There is no honey, but the flowers, by their coloured or white corolla, attract various kinds of insects, which come for pollen. Note the drooping of the flowers: do you see how this is advantageous in protecting the pollen from rain and in sprinkling the pollen over the bodies of insect-visitors?

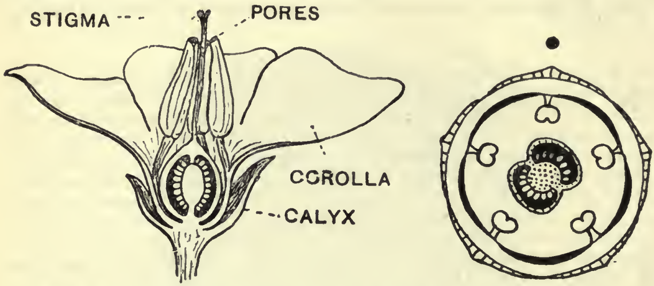

Fig. 149.—Longitudinal Section and Floral Diagram of Flower of Potato.

Examine fruits of different ages. Does the fruit change in colour as it ripens? What other part of the flower remains after the fruit has formed? Cut across the fruit and note its structure. It is a true berry, for the whole of the ovary-wall becomes juicy except the firm outer skin; the only hard parts are the seed-coats.

363. Bittersweet Nightshade (*Solanum dulcamara*) is a woody perennial plant, forming a bush which usually straggles or climbs over other plants, especially in moist or shaded places. It is often many feet long, but it dies far back in winter.

The twigs are yellowish-grey in colour and bear conspicuous lenticels. The resting-buds have no special bud-scales; only two or three of the young leaves are visible from the outside. The rind (cortex) is bitter, the wood sweet. The leaves are stalked, the leaf-blade usually entire and egg-like or heart-like in outline, with a pointed tip, but the shape varies a good deal on the same plant, some of the leaves being lobed at the base, or even divided into three leaflets.

The flowers (June, July) have much the same arrangement and structure as those of Potato. Each flower has a slender drooping stalk ; a short calyx-tube with five broad blunt lobes ; a short corolla-tube with five horizontally-spreading lobes (each lobe purple, with two green spots at the base) ; stamens and pistil as in Potato. How does the fruit (ripe in September) agree with, and differ from, that of Potato ?

Note the way in which the Bittersweet climbs. Does it twine its stems round the supporting plants, or does it merely insinuate its branches among them ? Is the stem twisted ? If twining occurs, is it always right-handed or left-handed, or in either direction indifferently ? The Bittersweet is a feeble climber, as a rule. It is worth while to plant cuttings or grow seedlings and make experiments like those given for Scarlet Runner (Art. 230). Several foreign shrubby Solanums are often grown, some being erect plants, while others—e.g. *S. jasminoides*—climb by twisting their petioles around the support ; other plants with "petiole-tendrils" are Clematis and Garden Nasturtium (Tropaeolum).

364. The **Potato Family (Solanaceae)** is very poorly represented in Britain and in Europe generally ; of the 72 genera in the family exactly half are confined to Central and South America—the native home of the Potato itself. The family includes herbs and shrubs and a few small trees. The leaves are usually alternate, but in some cases they are opposite in the flowering upper part of the plant. The flowers are regular in most cases, with a 5-lobed persistent calyx, a 5-lobed corolla, 5 stamens, and a 2-chambered ovary ; the carpels are obliquely placed, the posterior one to the right, the anterior one to the left (Fig. 149). There are numerous ovules, and the fruit is a berry or a capsule, with endospermic seeds.

365. Flower Mechanisms in Solanaceae.—The flowers of all the Solanaceae are conspicuous and insect-pollinated, chiefly by long-tongued flies and bees ; *Nicotiana* (Tobacco Plant) is a beautiful example of a moth-pollinated flower. The flowers of *Solanum* show much the same mechanism as those of Borage, while those of some foreign genera (e.g. *Schizanthus*) have practically a "Papilionaceous" mechanism, in some cases exploding (as in Gorse, etc.) when a bee alights on the lower corolla lip.

366. Honeysuckle or **Woodbine** (*Lonicera periclymenum*), though exceptional among its relatives in being a climber, is

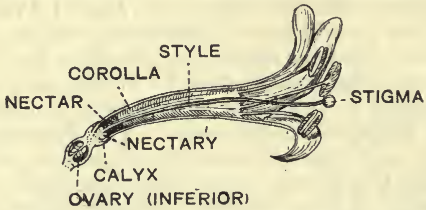

Fig. 150.—Longitudinal Section of Flower of Honeysuckle.

the most familiar representative of its family in Britain. Its stems twine round those of other plants in hedgerows and woods; its leaves are in pairs, and are ovate with entire or sometimes slightly lobed margin and a downy under side. The leaf-buds open early in spring; the flowers appear in May and are usually at the ends of the branches, in rounded clusters. The cluster resembles a Composite flower-head, but is cymose, the central flowers being the first to open. Below the cluster there are some small bracts.

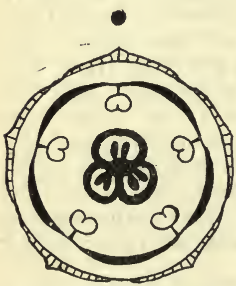
Fig. 151.—Floral Diagram of Honeysuckle.

The flower (Figs. 150, 151) has a small rounded inferior ovary (three-chambered, with several ovules in each), crowned by the short calyx, which has five small teeth. The corolla, about 4 cms. long, has a narrow tube, and its mouth is two-lipped, the lower lip (consisting of the lowest petal) being strap-shaped and the upper broad and four-lobed; it is reddish and covered with hairs outside, but yellow within.

The five stamens have fairly long filaments, inserted on the corolla-tube, and long narrow anthers, each attached at the middle to the filaments, *i.e.* the anthers are versatile. The stamens reach just beyond the mouth of the tube, but the style is longer and ends in a spherical stigma.

The flowers are specially adapted for pollination by moths with long tongues, *e.g.* the hawk-moths. Each remains open and in a state of readiness for pollination for two days. During the first day the anthers split so as to be ready to shed the pollen, then the flower moves into the horizontal position, and towards evening the corolla, whose tube is now about half filled with honey, opens and the style, projecting beyond the anthers, is at first bent downwards, so that an entering moth rubs against the anthers. If the evening is warm and calm so many moths may visit the flower, attracted by its whiteness and heavy perfume, that the whole of the pollen may be removed. Next day, the style moves up so as to become horizontal, the withered stamens bend down, and by evening the flower, which has become yellow, is in its female stage, so that an entering moth rubs against the stigma and brings pollen from another flower.

If the first evening has been windy, wet, or cool, so that no moths have come, the flower may be visited next day by bees and flies which carry away pollen though they cannot reach the honey, and on visiting younger flowers may bring about cross-pollination.

The fruit is a red berry, containing a few seeds or only one.

367. The **Honeysuckle Family** (**Caprifoliaceae**) is a small one, consisting of 11 genera of shrubs and trees, with the exception of the Moschatel, which is now usually set apart in a special family by itself. All have decussate leaves, flowers in cymes, flower-parts in fives (except the pistil in most cases), ovary inferior, fruit usually a berry or drupe, seed endospermic.

368. Flower Mechanisms in Caprifoliaceae.—This small family shows some interesting mechanisms, that of Honeysuckle, already dealt with, being the most remarkable.

The flowers of Elder and the Viburnums have a short corolla-tube and are visited by flies as well as bees. These flowers are made conspicuous by being massed in more or less flat-topped inflorescences. The scented flowers of Elder have no honey, but are visited mainly by flies and beetles for honey; though the anthers open on their outer sides, self-pollination is possible since the anthers and stigmas are ready at the same time. Wayfaring Tree and Guelder Rose also have homogamous flowers, but they produce honey, accessible to flies and beetles. The inflorescence of Guelder Rose is made conspicuous by the large corollas of the sterile outer flowers. [Diervilla, having a fairly long corolla-tube, is visited by bees and butterflies for the abundant honey.]

[The flowers of Snowberry are visited chiefly by wasps; the hairs inside the corolla prevent the honey from running out of the drooping flower, and the wasp, being short-tongued, has to thrust its whole head into the flower, touching the stigma and the anthers and carrying away pollen as it withdraws its honey-covered head.]

The Moschatel, though its flowers are small and inconspicuous, is pollinated by flies, which are attracted by the musky smell.

369. Dandelion (*Taraxacum dens-leonis*) is one of the commonest and most familiar of plants. It is apt to be confused with Hawkweeds and other allied plants of the same family, but is distinguished by the lobing of its leaves, and by its solitary head of flowers being carried on a soft hollow stalk which arises from the centre of the leaf-rosette.

Examine and compare plants growing in different situations, *e.g.* in exposed and in sheltered places, among short grass on a lawn, among longer grass in meadows, neglected lawns, or garden borders, in hard or gravelly soil and in soft damp soil. Note that the leaves have a strong tendency to spread out in a rosette and press themselves to the soil (what happens if you carefully dig up a plant growing at the bottom of a wall and put it into level soil?), but that among long grass the leaves grow up in a nearly vertical position.

Note the peculiar form of the leaves, which vary in the extent of the lobing and the shape of the lobes. Why is the possession of lobed leaves an advantage to a short-stemmed rosette-forming plant? Note how the lobes of the different leaves fit together with very little overlapping. Note also how rain-water falling on the leaves runs down the midrib to the tap-root, in which is stored the food that enables the plant to live from year to year. The Dandelion is really an evergreen plant, since it is never without leaves.

In a dug-up plant note the long tap-root, which is usually blackish outside and white inside; cut across the root of a plant and note that soon a healing-tissue ("callus") forms over the cut surface, from which arise new shoots. It is not easy to tell, by inspection, where root ends and stem begins; the stem remains very short, covered by the leaf-bases, and each year it produces a bud for the shoot's further growth, while the root contracts (as in so many other "ground-hugging" plants, *e.g.* plants with runners, rosette-forming short stems, underground stems, bulbs, corms, or thick food-storing tap-roots) and draws the stem down so that it never comes above the soil. What do you suppose is the use of the bitter juice contained in the Dandelion tap-root along with the reserve-food?

The flowers, which appear in early summer but may be found (in south England and in sheltered places elsewhere) all the year round, are in solitary heads, each head on a long or short stalk. The stalk is smooth and hollow; when cut it gives milky bitter juice (also found in other parts of the plant) which turns brown on exposure to the air. Note the numerous (100 to 300) small flowers crowded on the flat expanded circular top of the flowering stem, each flower being inserted in a small pit. Where are the youngest flowers—at the centre or at the outside of the disc? By comparing heads of different ages you will find that the flowers open successively from outside to centre, so that the head resembles an umbel (*e.g.* Cowslip, Ivy) in which the flowers have no stalks (or very short ones) and are seated on the disc-like end of the flowering axis. Note the double circle (*involucre*) of narrow green leaves (*bracts*) around the head.

How do the outer bracts differ from the inner ones in form, position, and function? Does either series appear to perform any function *besides* that of protecting the very young flower-head before any of the flowers open or the flowering axis grows up? Why does the inner series remain erect, though the outer bracts bend downwards?

In an open flower (Fig. 152) note the narrow strap-like outgrowth from the outer side of the mouth of the corolla-tube. How many teeth are there at the top of the strap? Now examine the flower carefully with your lens. Note the slender style, divided at the top into two curled branches (stigmatic arms), each about 2 mm. ($\frac{1}{12}$ inch) long, with short hairs (in about 12 rows) on the inner (stigmatic) surface; note the long hairs on the style a little below the point of branching. Slit down the corolla-tube and trace the style down to the bottom of the tube; on its way down, the style passes through a tube about $\frac{1}{8}$ inch long; holding the top of the style, pull it out of this narrow tube.

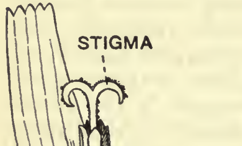

Fig. 152.—Flower of Dandelion, lower part (corolla-tube and ovary) cut open.

What *is* this tube around the style? Can you see five slender threads joining the lower edge of this tube to the inner surface of the corolla-tube? If so, you should be able to see that the tube consists of the five anthers joined together by their sides; their outlines can, however, be seen on careful inspection.

What is the swelling below the base of the corolla-tube? Note the hairs which form a circle just above this swelling. Can you see a slender neck-like part between the swelling (ovary) and the ring of hairs (*pappus*, representing the calyx)? Can you see the small ring-like cushion (nectary) at the bottom of the corolla-tube, around the base of the style? If you cannot make out all these points in the structure of the flower at the first try, examine more flowers until you succeed in seeing all the parts. The honey rises in the narrow corolla-tube, so that even short-tongued insects can reach it. The heads are visited by an unusually large variety of insects, including hive-bees, humble-bees, flies, beetles, and butterflies.

The Dandelion is a very suitable plant on which to make daily observations with a view to learning the complete life-story of the flower-head and of the individual flowers. By watching the same head at frequent intervals day by day, and by examining flowers of different ages, you can make out a good deal of the story for yourself. Is the head always expanded? Under what conditions does it close? Note how the straps of the outer flowers close over the inner flowers, and how the closing is completed by the inner circle of bracts. Does it close at night only? For how many hours does it remain open each day in fine weather? Do *all* the flowers in a head open on the first day that the head itself is expanded? How often must the head open in order that all the flowers in it may have a chance of being pollinated by insects?

In watching Dandelion-heads in a garden I have noticed that, as an average, the heads are only open for about eight hours on fine days and that a head rarely opens more than thrice. In fine weather nearly all the flowers in a head are open by the end of the third day, and on the fourth or fifth day the head is closed and the corollas are beginning to wither, while on cold and wet days the heads remain closed. How do these observations agree with yours?

Open up flowers of different ages, and note that at first the style is low down in the tube formed by the united anthers, the two stigmatic arms being in close contact by their inner (stigmatic) surfaces; the pollen is shed inside the tube, and is swept out of the top by the hairs on the style as the latter grows up. During this "male" stage, insects visiting the head remove the pollen-mass from the top of the anther-tube as it is pushed up by the piston-like style, and since the stigmatic surfaces are not exposed, only cross-pollination is possible. Then the style emerges and its two lobes diverge, exposing the stigmas; if cross-pollination does not occur during this second or "female" stage, the arms curve back until the stigmas touch the pollen still adhering to the style, thus bringing about self-pollination.

After the corollas have withered and the head has closed up for the ripening of the fruits, the head-stalk usually bends down towards the ground, and an interesting series of changes takes place. What changes do you observe in (1) the length of the head-stalk, (2) the shape of the expanded top of the stalk (which is at first *flat*), (3) the size of the ovary, (4) the length of the slender stalk (at first *very* short) just above the ovary, (5) the ring of hairs at the base of the (now withered) corolla-tube? What becomes of the upper parts of the flower (corolla, stamens, style)? When the fruits are ripe, the stalk becomes erect again. Does the head still open on fine days, or does it remain closed and for how many days? How is the change in form of the stalk-top connected with the change in form of the whole head? The "disc" is now becoming rounded (convex) instead of flat, while the fruiting head becomes a globular mass about two inches in diameter; the flat fruits require, therefore, to be spaced out on the "disc."

Do *all* the flowers in a head grow into fruits? Do you notice any difference in this respect between plants growing in sunny places and plants growing in shaded places? Why do the latter usually produce a smaller proportion of fruits than the former? Why are most of the unfertilised flowers usually found at the *outside* of the head? Probably the last three questions can be answered after considering the facts that efficient insect-visits are far more frequent (1) in sunny places and (2) in the more fully expanded and therefore more conspicuous heads, *i.e.* after the first day on which the heads are open.

These observations raise the question, is self-pollination an effective substitute for cross-pollination? I have tried experiments, designed to prevent insect-visits, with rather variable results, but on the whole the output of normal fruits has been much smaller than in neighbouring heads left untouched. Tie small bags of muslin or, better, paper over young unopened heads, and see how many fully developed fruits are produced. In watching Dandelion-heads and noting all that happened day by day I have found that the average time from the first opening of the flowering head to the final opening of the fruiting head (with fruits ready for dispersal) is about eighteen days; it is lengthened a little by rainy days, shortened when the weather is fine. However, in this, as in all other readily verified matters, make your own observations instead of merely accepting those of other people.

Note the structure of the ripe fruit (akene), opening up the fruit-wall to see the single seed. Note how the parachute-like pappus (ring of hairs) closes up on wet days (why ?) and expands on dry days (why ?). By what agency is the seed dispersed ? Try the effect of picking off the parachute from the fruit; note the times taken for (1) a complete fruit with expanded pappus, (2) the same fruit deprived of the pappus, to fall from the same height. Try the comparison under different conditions, *e.g.* indoors and outdoors, on a still day and on a windy day. Note the small stiff hairs (straight or hooked ?) on the akene itself. How do these hairs help the akene to become attached to the soil after the parachute comes down ? What are the advantages of having the pappus carried up on a long stalk ? When is this stalk above the ovary developed ? Is there any trace of it in the *flower* ?

370. Daisy (*Bellis perennis*).—This familiar plant flowers from spring to autumn; even in winter a few days of sunshine will often cause the flower-buds to open. It is practically evergreen as well as perennial, producing leaves throughout the year. In general habit it resembles the Dandelion, but the stem is longer and it sends out runners all round, giving rise to numerous new plants; apart from seeds, therefore, the Daisy has a very efficient method of spreading and multiplying.

Carefully examine patches of Daisies at frequent intervals during the year, making notes (with sketches) of your observations. At what time of year are the "runners" given off by the parent plant most copiously ? How many young plants may be formed in this way ? How long are the runners ?

Note the arrangement of the leaves in a rosette. Sketch a plant from above, showing the shapes of all the leaves. Where is each leaf broadest ? What are the advantages of the peculiar shape of a Daisy leaf ? Which leaves (upper or lower) have the longest basal parts and the largest blades, and why ? Why is it a good plan for a rosette-forming plant to have its leaves broadest towards their free ends ?

Examine the flower-heads (Fig. 153) and the individual flowers very carefully, on the lines indicated in the preceding article on the Dandelion. How long are the flowering-axes ?

How broad are the heads? Note the shape of the expanded top of the head (slice it down longitudinally) and the structure of the involucre (number of bracts? in how many circles? shape and colour of bracts?).

You will notice that the outer flowers, forming a single series, resemble those of the Dandelion in having a strap-like outgrowth from the mouth of the corolla, while all the inner flowers have a tubular corolla; the strap-like (*ligulate*) flowers are often called the ray-flowers, the small tubular ones the disc-flowers. Compare a ray-flower of Daisy with a Dandelion flower: note the shape of the strap, the narrow but short stigmatic arms, the absence of stamens. In a disc-flower note the regular tubular corolla, with five (some-

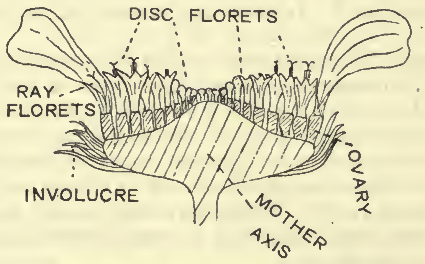

Fig. 153.—Vertical Section of Capitulum.

times only four) equal lobes round its edge, the thick short stigmatic arms, the presence of stamens. The ray-flowers thus differ from the disc-flowers in having no stamens, as well as in the shape of the corolla. In what respect do *all* the flowers differ from those of Dandelion?

Note the closing of the head at night and in bad weather. On a bright day the straps of the ray-flowers spread out horizontally, at night they move inwards and meet at the tops so as to cover and protect the young central flowers.

Is it possible to make the head close in the daytime? Cover a plant with a flower-pot or box, excluding all light by sprinkling soil round the edges where the pot or box rests on the ground. Keep a Daisy in darkness for two or three days, then bring it to the light, or remove the pot or box covering it; note that the head does not open completely, but remains half closed, as is also the case on dull days. Regular *alternation* of light and darkness is essential for the regular opening and closing of the heads.

How are the opening and closing movements affected by changes in temperature? Pick a head which has closed for the night, set it in a bottle of water, and bring into a warm room: a temperature of 15° C. or even more will fail to cause opening. A Daisy head when closed in the evening does not readily open with even a considerable rise of temperature; when open in the morning it does not close unless the temperature is greatly lowered. If a closed head is warmed in the morning it readily opens; if an open head is cooled in the evening it readily closes.

Note the elongation of the convex top of the flowering-axis after the flowers have been fertilised, and the flat akenes without a pappus. The compressed akenes are doubtless carried by the wind, though very poorly adapted for wind-dispersal as compared with Dandelion fruits. However, in comparing the equipment of plants for the struggle for existence, one must not fix on any single biological advantage, but take into consideration the whole equipment. The akenes of Daisy cannot be so often carried to a distance as those of Dandelion, but once a Daisy plant establishes itself in a suitable place it may, by its runners, give rise to hundreds of plants in a few years.

371. Coltsfoot (*Tussilago farfara*) is a well-known plant whose flowering shoots appear early in spring (sometimes as early as December), long before the large leaves. The plants grow chiefly in damp heavy soils, in waste places or roadsides, in clayey fields—usually in well-exposed situations.

Note the yellow flower-heads (1 to $1\frac{1}{2}$ ins. diameter), each carried on a stem (4 ins. to 1 ft. high) which arises direct from the ground and at first droops but later becomes straight. The flowering-stem bears numerous scales which are, like the stem itself, covered with woolly hairs. At the top of the stem, just below the head, there are several short scales, then a series of long narrow bracts surrounding the flowers. Are the flowers all alike, with tubular or strap-shaped corollas? How many ray-flowers are there? How do they (1) resemble, (2) differ from, those of the Daisy and Dandelion? Is there any pappus? How many disc-flowers are there in the head? Does the style bear diverging stigmatic arms, or not? By careful observation try to make out the life-history of the flower-head.

The central (disc) flowers appear to resemble those of the Daisy, but close inspection shows that they are really *male* flowers, for the style acts merely as a piston to push the pollen out of the anther-tube; the style does not divide into two stigmatic arms. The outer (ray) flowers are *female* flowers, as in Daisy; both kinds of flower have a pappus, but it remains small in the male flowers, though it enlarges to form a parachute on the fertilised ovary of the female flower. Only the male flowers produce honey; insects visiting a newly opened head must (if cross-pollination occurs) bring pollen from an *older* flower (why?). When the head closes in the evening the pollen pushed out of the anther-tubes of the male (disc) flowers may be transferred to the straps of the female (ray) flowers, and when the head opens again the pollen may slide down the straps to the stigmas situated at the base, bringing about pollination.

Examine the leaves, which come up in a tuft, a few weeks after the flower-heads. The leaves are upright and rolled up at first, but when the blade begins to unfold it turns over so as to be horizontal, and then rapidly spreads out and becomes from three inches to nearly a foot broad. The leaf is covered, especially on the lower side of the heart-shaped angular blade, with a cotton-like mass of hairs (formerly soaked in saltpetre and used as tinder); the stalk is long and stout, and the fully grown leaf spreads out like an umbrella and stops the growth of other smaller plants below it.

Dig up a plant in early summer and note that each flowering shoot comes off independently from the stem, which bears the scars of the leaves of former years. In plants dug up in autumn note the young leaves for next year, also the egg-shaped buds of the flowering shoots, in which the young flowers can be plainly seen on making a longitudinal section. Note also the long white tough branches which arise from the underground stem and which enable the plant to spread over a large area. The Coltsfoot is a rampant and troublesome weed when once it gets a footing in fields, owing to its rapid spread by means of the underground branches and to its very effective method of choking off competing plants by its large leaves.

372. The Composite Family (Compositae) is the largest among flowering plants, and one of the most successful and widely distributed. There are about 800 genera (40 in Britain) and 11,000 species (115 in Britain), *i.e.* over 10 per cent. of the total number of species of Flowering Plants! There are nearly 1300 species of one genus (*Senecio*) alone. It is easy to see why this family is such an aggressive and successful one. What are the advantages of having (1) numerous small flowers grouped together in a compact flat-topped head, (2) the outer flowers often more conspicuous than the inner ones, (3) honey in most cases accessible to even short-tongued insects, (4) in most cases small light fruits provided with a pappus?

Examine all the Composites you meet with and find out all you can about the arrangement and structure of the heads and of the individual flowers. How do the heads and flowers of Cornflower and Knapweed ("Hard-heads") differ from those of our three types? What other Composites resemble (1) the Dandelion in having all the flowers ligulate, (2) the Daisy in having the outer flowers ligulate and the inner ones tubular, (3) the Cornflower ("Bluebottle") and Knapweed in having all the flowers tubular? How do the outer flowers of the Cornflower-head differ from the inner ones? What common Composites have small heads densely massed together to form a flat-topped corymb of heads, and what are the advantages of this arrangement? In each case study the biology of the inflorescence and of the individual flower, in the way we have studied the Dandelion and Daisy.

373. Mechanisms in Compositae.—The general structure of the flower is remarkably uniform throughout this huge family. As regards the number of flowers in a head, we get every transition from the single-flowered heads of Globe Thistle (*Echinops*, cultd.), through the few-flowered ones of Hemp Agrimony, etc., to the huge heads of Sunflowers with hundreds of flowers.

In all cases the head is surrounded by an envelope (involucre) of bracts, which may be in one or two circles, or spirally arranged and numerous, generally free but sometimes joined, and which in some cases perform "sleep"-movements or close up on being moistened. The inv.-bracts are usually green and therefore carry on assimilation, but they serve mainly to protect the young flowers and, later, the developing fruits, so that they perform for the Composite flower-head the same functions that in most other plants are performed by the calyx of the individual flower. When spiny, the involucre protects the flowers against browsing animals, and when the spines are hooked (*e.g.* Burdock), it serves for animal dispersal of the "seeds" (akenes).

Since the ordinary functions of the calyx are transferred to the involucre, the sepals of the individual flowers are rendered unnecessary in this respect, and are often represented only by a few small scales (free, or joined to form a collar) or bristles, but in many cases it forms a pappus of long hairs which may be sessile or raised, after fertilisation of the flower, on a long stalk. The pappus-hairs are either rigid or silky, and either simple (unbranched) or bearing minute knobs or secondary hairs (feathery pappus); they are usually hygroscopic, spreading out like a parachute in dry air and forming a most effective means of wind-dispersal, and also helping to loosen the fruits and detach them from the receptacle.

In some cases, e.g. *Bidens* (Bur Marigold), the pappus consists of barbed bristles, serving for animal-dispersal. In Composites without a pappus the receptacle often contracts in drying, so as to loosen and even jerk out the fruits (Sunflower, etc.), or becomes conical (Daisy, etc.), so that the fruits may be more readily carried away by wind.

The common receptacle which carries the flowers—the enlarged end of the flowering axis—is generally flat or rather convex, and is either naked or bears bracts corresponding to the individual flowers. The corolla is either tubular (generally having a narrow lower part and an expanded upper part with five lobes) or zygomorphic (the tubular corolla is generally symmetrical, but sometimes not strictly so—*e.g.* in Cornflower). Of the zygomorphic corolla there are several types. *Mutisia.* In Dandelion and its allies (Hawkweeds, etc.) the mouth of the corolla is drawn out, on the outer side of the flower, into a strap with five teeth at the end; this is the true ligulate type. In most heads of the Daisy type the strap-like lower lip of the ray-flowers is either entire or divided into three lobes at the end. Other "falsely ligulate" types are seen in the numerous "double" varieties of Dahlia, etc.

The Composites are practically all insect-pollinated, and have a beautiful and effective mechanism of a comparatively simple type, already described for Dandelion (Art. 369). The grouping of the small flowers into heads—an arrangement not peculiar to Composites but found in many other

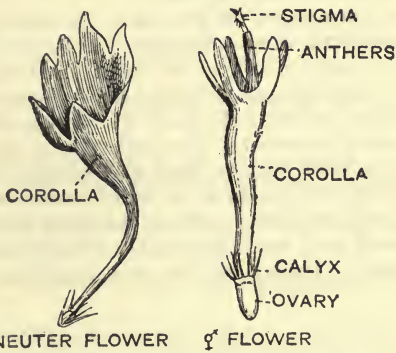

Fig. 154.—Cornflower (Centaurea).

I., Outer neuter flower (× 3); II., Tubular hermaphrodite flower (× 6).

families, *e.g.* Scabious, Sheep's-bit, Sea-Holly, Clovers—brings about a saving in corolla-material, besides enabling a single insect-visitor to pollinate several flowers in a short time and causing the flowers to form a conspicuous mass (this is heightened by the frequent arrangement of the heads, when small, in corymbs or racemes, or even—in Globe Thistle—compound heads, *i.e.* heads of heads).

Most species of *Centaurea* (Fig. 154) have irritable stamens, sensitive to contact. When an insect touches the stamens, the filaments contract and force a mass of pollen out from the top of the anther-tube. The mechanism is easily observed in the Cornflower. With a camel-hair brush or a pointed match-stick remove the pollen projecting from the anther-tube of a newly-opened flower (in which the style has not yet grown out), and note the thread of pollen which emerges.

Next carefully slit open the corollas of a few young flowers removed from the flower-head, set the flowers in a watch-glass or on a glass slide under a bell-jar for a few minutes (to let them recover), then touch the filaments and note their writhing contraction. Each filament can be made to contract independently, pulling the anther-tube over to the corresponding side, as well as drawing it downwards, so that the pollen-mass present above the style is squeezed out and carried away on the insect's head.

Artemisia (Mugwort, Wormwood) is peculiar in having flowers adapted to wind-pollination. The pollen-grains are smooth (not spiny or ridged, as in other Composites), dry, and powdery, and the small dingy flower-heads are on long flowering stems carried well above the large leaves; the heads droop in Sea Wormwood. The anther-tube projects a little beyond the tubular corolla, and has bristles on its upper edge which hold the pollen in a sort of basket, so that it may be gradually blown away. Then the style emerges and the stigmas spread out; each stigma has a large fanlike fringed end, presenting a large surface to receive pollen.

QUESTIONS ON CHAPTER XIV.

1. Draw up a comparison between Primrose and Cowslip as to habitat, leaf, inflorescence, and flower.

2. Describe the structure of a Primrose flower, pointing out the differences between the two types of flower.

3. Describe and discuss the pollination of the Primrose. Do you consider heterostyly plays an important part in promoting cross-pollination? Give reasons for your answer.

4. Describe the pollination of the Cowslip, and point out how it differs from the Primrose.

5. Describe the fruit of Primrose and Cowslip.

6. Draw the floral diagram of a Primrose, and sketch in longitudinal section the two forms of the flower. How do you account for the unusual position of the stamens in relation to the lobes of the corolla? How do you infer the number of the carpels?

7. Write notes on points of interest presented by Red Pimpernel, Sea Milkwort, Brookweed, Cyclamen.

8. Describe the inflorescence and flowers of a Scorpion-grass or Forget-me-not, and the mode of pollination.

9. Describe the flowers of Lungwort, Comfrey, and Borage, with special reference to their pollination.

10. Write notes on any points of interest presented by the flowers and fruits of Viper's Bugloss, Alkanet, Hound's-tongue, and Gromwell.

11. Describe the typical inflorescence of Labiates, as seen in Dead-nettles.

12. In what places would you expect to find White Dead-nettle, Red Dead-nettle, Yellow Dead-nettle, Thyme, Bugle?

13. Point out as many differences as you can between White and Red Dead-nettles.

14. Draw a floral diagram of the Dead-nettle flower. Does the hood consist of one or of more petals? Give reasons for your answer.

15. Describe the pollination of Dead-nettle or of any other Labiate flower you have observed.

16. Describe the structure and mode of pollination of the flower of Sage (*Salvia*).

17. Describe the flowers of Mint, Self-heal (*Prunella*), and Wood-Sage (*Teucrium*), pointing out in each case how they differ from a Dead-nettle flower.

18. Mention Labiates whose flowers are pollinated by (*a*) flies, (*b*) short-tongued bees, (*c*) long-tongued bees.

19. Describe the structure of the Foxglove flower, with sketches, and point out its adaptation for pollination.

20. Mention three British species of the genus *Veronica* (Speedwell) and give the characters by which you would know them one from another, including the months when each is in fullest flower. Have you noticed any difference in the places where they usually grow?

21. Describe the flower of Mullein (*Verbascum*), pointing out how it resembles, and differs from, that of Foxglove.

22. For what reasons are Foxglove, Snapdragon, Toadflax, Figwort, Mullein, and Speedwell all placed in the same family? How do their flowers differ in structure?

23. How are all Scrophulariaceae distinguished from all Labiates? Which plants of both families might at first sight be confused, and how could you tell, from the flower, which family a plant with a two-lipped gamopetalous corolla and four stamens belonged to?

24. Mention Scrophulariaceae which are pollinated by (*a*) flies, (*b*) short-tongued bees, (*c*) humble-bees, (*d*) wasps.

25. Describe the life-history of a single Figwort flower, from the time when its corolla opens.

26. In what habitats would you look for Mullein, Ivy-leaved Toad-flax, Brooklime, Cow-wheat, Lousewort, Bartsia, Yellow Rattle?

27. Describe the flower of Potato and its method of pollination.

28. Describe the Bittersweet (stem, leaves, flowers, fruit). Where does this plant usually grow?

29. Describe the flower of the Tobacco-plant and its mode of pollination.

30. How is the Potato family distinguished from (*a*) the Foxglove family, (*b*) the Borage family? Mention plants belonging to these families which show some resemblances in general flower-structure.

31. Describe the fruits of a few Solanaceae, British and cultivated.

32. Describe the inflorescence and flower of the Honeysuckle, giving an account of the biology of the flower and its mode of pollination.

33. Describe the vegetative organs (root, stem, leaves) of a Dandelion. Why is this plant a troublesome weed in lawns?

34. Describe the arrangement and shape of the leaves of a Dandelion. What differences in the leaves have you noticed in plants growing in diverse habitats, and how may these differences be explained?

35. Describe the structure of the flower-head of a Dandelion. Why is it wrong to call the head a flower?

36. Describe the structure of a single Dandelion flower, and relate any observations and experiments you have made on its biology, stage by stage.

37. Give a general account of the life history of a Dandelion flower-head as seen by watching the same plant day by day from the time it is first visible. How often did the head open and close? For how long did it remain open during a single day? Did it open every day—if not, on what sort of day did it (*a*) open, (*b*) remain closed?

38. Describe, from your own work, the adaptations of the flowers of Dandelion for cross-pollination by insects. Is there any provision for self-pollination? If so, explain the mechanism, with a series of sketches (from the actual plant).

39. Describe the way in which a Daisy spreads over a lawn. Compare it in this respect with the Dandelion. How many young plants have you observed in course of formation by the parent plant? Why do you suppose the Daisy resorts to this method of spreading apart from seeds?

40. Compare the flower-heads and flowers of Daisy with those of Dandelion. Which plant seems, from your own observations, to propagate itself most freely by *seed*?

41. In how far may a Daisy flower-head be compared with a flower?

42. In what sort of locality, and in what sort of soil, have you seen Coltsfoot growing? How does Coltsfoot spread (apart from seeds) and what makes it a tiresome weed in fields?

43. Describe carefully the appearances presented by a Coltsfoot plant month by month throughout the year: that is, give a brief "diary" of its year's life, noting such points as the time when the flower-head is first formed, when it emerges from the soil, when it opens, how long it remains open, when it closes again, when it reopens to let the fruits escape, when the leaves emerge, how they expand, etc.

44. Describe fully the flower-head and flowers of Coltsfoot, and compare the pollination arrangements with those seen in Dandelion and Daisy.

45. Why are the Composites called "an aggressive and successful family"?

46. Write an account of the "division of labour" seen in the flower-heads of Daisy and Coltsfoot.

CHAPTER XV.

TREES AND SHRUBS.

374. Trees and Shrubs.—There is no sharp distinction between herbaceous and arboreous plants, though the terms herb, shrub, and tree are convenient for general use. It is perhaps sufficient to define a tree or shrub as a woody plant whose stem persists above the soil year after year—as compared with a plant which dies down to the level of the soil, though the "root-stock" or rhizome is hard and woody.

A **tree** usually possesses a stout, main trunk from which smaller and more slender lateral branches arise. Frequently, however, the main stem is short, and is exceeded in length by the branches. A **shrub,** on the other hand, is simply a miniature tree, the stem being usually short, and soon breaking up into numerous more or less erect branches.

Various plants which form large trees when growing in sheltered or low-lying places are reduced to stunted shrubs when they occur on high mountains or wind-swept ridges. On Dartmoor, for instance, there are several patches of gnarled and stunted oak trees, doubtless of great age, growing among granite boulders along river valleys, at a height of about 1,500 ft. On several of the "tors" (granite-caps on hills) there grow Rowan (Mountain Ash) plants reduced to low creeping shrubs a few inches high; in one case the flat top of a tor, about 1,800 feet above sea-level, was covered with this dwarf Rowan.

375. Hints on Tree Study.—In studying trees, the following points should be specially attended to, full notes and sketches being made in each case:—

(1) The general form and appearance as determined by the mode of branching, the direction of the main branches and finer twigs, and the character of the foliage.

(2) The general effect of each kind of tree on the landscape in winter, spring, summer, and autumn.

(3) The situation and soil in which each kind of tree apparently thrives with the greatest luxuriance.

(4) The thickness of the trunk as compared with the size of the tree; the characters of the bark; the arrangement, direction, and surface of the main branches and finer twigs.

(5) The arrangement, orientation, shape, size, and colour of the resting-buds, their structure, the mode of folding-up of the young leaves, the nature of the bud-scales.

(6) The time of appearance of the leaves; stages in opening of the resting-bud; the leaf-scars; erect or drooping position of the opening-buds; arrangement, composition, shape, margin, and venation of the leaf; presence or absence of stipules and petiole.

(7) The time of flowering; nature of inflorescence; structure and mode of protection of flower-buds; structure of the flowers and their mode of pollination; floral formula; floral diagram.

(8) Structure of fruit and seed; mode of dispersal.

(9) Germination of seed, form of seedling, nature of reserve food, behaviour of cotyledons, etc. Look for seedlings under or near the tree; gather ripe seeds and study their germination.

(10) Kinds of insects, if any, that feed on the foliage or which produce galls; insects, if any, that visit the flowers; fungus parasites.

(11) Name of tree (scientific and common names), and the Natural Order it belongs to. Comparison with allied plants.

These are merely a few suggestions, to help you in making an orderly and thorough study of each tree.

Note whether the main trunk persists and runs up through to the top of the tree ("excurrent" or "spire-forming" habit, *e.g.* Larch) or whether it soon becomes lost in a complex of strong branches ("deliquescent" or "diffuse" habit, *e.g.* Beech); the form of the tree's crown, whether pointed, rounded, or umbrella-like ; the arrangement of the branches, the angles at which they come off, their direction of growth; why branches at the top of a tree are usually more straight than the lower branches; why branches turn up at the ends in many trees; why branches rise upwards, or bend in towards the centre of the tree in winter (in deciduous trees). All these points, which, together with others, unite to give trees their general form, should be carefully studied. In many cases this is more easily done in winter, when deciduous trees show their bare branches.

Note also the depth of the shade cast by the tree when in full foliage, and the effect this has on the nature and habit of the plants forming the undergrowth ; the mode of branching shown by the tree when growing with others in a clump or in a wood, and that shown by the same kind of tree when growing by itself in an open situation ; the differences in size and in texture of the leaves well exposed to light, and of those growing in shade ; the tendency of the leaves on each twig to form a "leaf-mosaic" (*i.e.* to vary in size, shape, etc., so as not to shade each other).

Some further points relating to the biology of trees may be mentioned here. One often sees on high exposed places inland, as well as near the coast, trees which have grown obliquely, sometimes almost horizontally, after reaching a certain height ; in other cases the trees growing in such situations are erect, but growth has occurred almost entirely on one side. If you see examples of such trees, try to discover the causes of their bent or one-sided growth. Note the direction of the bend or that of the well-grown side of the tree, then find out the directions and characters (whether dry or moist, cold or warm) of the prevailing winds. At what time of year will the prevailing wind have most influence on the tree's growth, and in what way?

376. How Wounds Heal.—You will often notice on the trunks of trees curious ring-like cushions. It is easy to find out the meaning of these cushions and to trace their history, especially if you have seen foresters at work cutting off branches. Under whatever circumstances and for whatever reasons (find out all you can on these points) this "tree surgery" has been practised, the amputation-wound soon begins to heal up, under proper conditions. The cambium (Art. 212), which has been exposed by the cutting, produces a mass of growing tissue, known as **callus**, which in time rolls over and covers the wounded wood (which cannot heal of itself). If the wound is a small one, the callus-cells soon meet at the centre and form a continuous tissue which produces cork at the surface and (being continuous with the ordinary cambium) wood internally, covering up the stump.

The callus protects the exposed wood by excluding water, bacteria, and fungi, which set up decay ; all exposed surfaces, whether caused by pruning-knife or saw or by the breaking-off of branches, offer a foothold for disease and decay, and once a wood-rot fungus enters it may grow inside the tree after the wound is quite covered. Hence, for the wound to heal properly and as quickly as possible, the limb to be removed should be cut off close to and perfectly even with the parent trunk or branch, so that no portion of the amputated branch may remain.

An exposed stump or stub left when a branch breaks off cannot possibly heal over of itself, and if it project far from the trunk or branch, the cambium or inner bark cannot produce enough callus to cover and protect it, so that decay of necessity sets in, and the stump dies back, possibly to communicate disease to the trunk; even if it does heal up at the base, a bad knot is formed in the timber. A clean-cut, smooth and hard surface, such as is produced by a sharp pruning-saw, is much preferable to a rough and jagged one, since it affords less lodgment for water or germs, avoids crushing or tearing of the cambium, and assists the progress of the protecting and healing callus.

In the case of a *large* wound, cork and new cambium are produced by the callus at the edges of the wound, which does not close up until cushion after cushion of callus has grown over it, and this may take several years. Though the growth of the callus cannot be hastened by "dressing" the wound, the latter can be protected from moisture and fungus-spores by applying tar or lead-paint.

The old wood exposed by the wound, which generally becomes dark in colour, does not grow with the new wood formed by the callus, hence a deep cut—*e.g.* an inscription—made in the wood of a tree can be found years afterwards, covered by annual layers of new wood. Any hard body, *e.g.* a nail or the stem of another tree, may be enclosed in a tree by causing the cortex to split and a callus-layer to be formed which grows over the body and covers it with new wood.

Wounds made in herbaceous stems, roots, tubers, leaves, fruits, etc., are healed in a much simpler way. In general, whenever the inner tissues are laid bare by injury a layer of cork is formed by the exposed cells which are living and capable of growth; the wounds covered in this way are easily recognised by the brownish patches of cork. A potato-tuber, for instance, is covered by a layer of cork, and a similar layer is soon formed on a piece cut out of the tuber and kept under a bell-jar or tumbler; try this simple experiment, and if you have a microscope cut sections to see the cork-layer in (1) an uninjured tuber, (2) a piece cut out and allowed to heal.

Familiar operations which depend upon callus formation are pruning, grafting, budding, and propagation by cuttings.

377. Scots Pine or **"Scotch Fir"** (*Pinus sylvestris*) is usually easy to distinguish from other Pines by the bluish-green foliage-leaves ("needles") arranged in pairs; the bark, orange-coloured except at base of trunk, where it is dark; the pointed cone, with a dull surface.

The tree rarely exceeds a hundred feet in height. In plantations or forests it shows a tall branchless stem (any signs of branches formerly present?) with an umbrella-like crown, but in the open it keeps the lower branches for many years. The bark on the upper part of the trunk peels off in thin scales, leaving the surface orange-coloured, but near the base the scales remain attached for a long time, so that the bark here is thicker, rougher, and darker. The structure of the buds, their mode of expansion, and the growth of the branches, have already been dealt with (Art. 180).

The stiff needle-like foliage-leaves are borne in pairs, each pair on a short or dwarf shoot. Each leaf is slightly twisted; the upper side is flat, the lower curved, and the two sharp edges bear small teeth (how can one perceive these without using a lens?). The leaves live for three or four years, their duration depending on the amount of light they receive. Each dwarf shoot bears about a dozen small scales, forming a sort of sheath at the base of the two needles. The whole dwarf shoot is cast off when the leaves are dead, giving the old twigs a rough scarred surface.

Fig. 155.—The Pine, showing Cones. (Sketch made in June.)

Each year a circle of long shoots is formed, so that the age of the tree (after the first three years of its life) can be told at once from the number of these circles of branches, or their remains if they have broken off. When the end shoot is damaged, one (sometimes more) of the side shoots grows out so as to replace it; in fact, one sometimes finds that one of the side buds does not expand along with the others, but remains as an "emergency bud."

The flowers (May, June) are of very simple structure; the male and female flowers are on the same tree. The male flowers (Fig. 155) are yellow egg-shaped bodies, about $\frac{1}{4}$ inch long; they represent dwarf shoots, and are crowded together at the bases of the year's long shoots. Each male flower is in the axil of a scale, and has about four scales at its base; it consists of a slender axis bearing numerous spirally-arranged stamens. Each stamen has a very short filament and a scale-like anther with a small crest at the free end; on the lower side are two pollen-sacs which open by longitudinal slits and let out the dusty sulphur-like pollen. Shake a branch, or hit it with a stick, when the male flowers are ripe. Each pollen-grain has two air-bladders, which make the grain more buoyant by giving it a much larger surface without much extra weight.

The male flowers fall off after the pollen is shed, so that if the stem goes on producing male flowers year after year it shows a tufted arrangement of the needle-bearing dwarf shoots, the tufts being separated by bare parts marking the former positions of the clusters of male flowers.

Each female flower or "cone" (Fig. 155) arises in the position of a lateral long shoot. Its bud grows rapidly in the first year and is then nearly spherical and stands erect on a short stalk. At the base of the cone there are some small scales, and above these come the scale-like carpels. Each carpel consists of a lower scale bearing on its upper surface a larger and thicker scale; the latter has two ovules on its upper side near the base.

While the pollen is being blown about, the axis of the cone lengthens so as to separate the scales and allow the pollen grains to reach the ovules. Then the stalk of the cone bends down, while the scales grow larger and thicker and become tightly packed together. Next year the cone begins again to grow bigger and becomes egg-shaped and pointed (about 2 inches long). In the third year the cone dries up, the scales gape apart (starting at the top of the cone), and the seeds escape. Examine cones of different years. Do all the scales of a ripe cone bear seeds? How many seeds are on each scale? Note the long thin wing attached to the seed, enabling it to be carried far by the wind.

The early germination of the seed has already been described (Art. 88). After the cotyledons have absorbed the endosperm and escaped from the seed, long needle-like leaves are produced, which *stand singly and directly on the stem.* In the second year single needles are produced at first, but they gradually dwindle upwards into scales; in the axils of the upper scales there arise the two-leaved dwarf shoots. Thus the *young* Pine resembles *adult* Firs in having the foliage-leaves borne singly and directly on the stem.

378. The **Poplars** (*Populus*) and the **Willows** (*Salix*) are closely allied, forming a family (**Salicaceae**) which is sharply marked off from all other catkin-bearing plants. A catkin is simply an inflorescence consisting of a main stem or axis which bears either male flowers or female flowers, each flower arising in the axil of a leaf (bract) and having a very simple structure. The male and female catkins are on separate plants.

379. The best known Poplar is the **Black Poplar,** which we shall take as a type for first study. The main part of the root system grows deep into the soil, but some of the roots run along, more or less horizontally, a little below the surface. The shallow roots often send up leafy shoots (" suckers "). The tree is rarely over a hundred feet high; most of the branches bend upwards, and the tree has a loose appearance and a "lopsided" crown.

The leaves (Fig. 156) have long stalks and the upper part of the stalk flattened at right angles to the blade, so that the leaf hangs loosely and quivers in the gentlest wind. It has been suggested that two advantages arise from the tremulous character of the leaves in this and several (not all) other Poplars :—(1) the resistance offered to the wind is lessened, so that the thin twigs can better withstand the strain; (2) the evaporation of water from the leaf is increased, an advantage in rapidly-growing trees with a good water-supply from below. The first suggestion is supported by the fact that in Poplars with *thick* twigs, *e.g.* Lombardy Poplar, the leaf-stalks are not flattened; the second by the fact that Poplars "prefer," *i.e.* thrive best in, deep moist soils.

Fig. 156.—Twig and Male Catkin of a Poplar.

The buds are long, pointed, smooth ; each has four scales—an outer concave scale on the side away from the stem and three inner ones. In spring these scales fall off, together with the stipules of the sticky young foliage-leaves. The side buds generally grow into dwarf shoots or into catkins, while the end bud grows into a long shoot. The highest bud is not really the end bud ; as in many other trees, the real end bud does not develop at all, the highest axillary or side bud replacing it in growth.

The long hanging catkins open before the leaves unfold. Each catkin is produced from a special bud, which resembles an ordinary bud in having four scales. The bracts are fringed at the free (outer) edge, but are not hairy. Each flower has a short stalk bearing a shallow lop-sided cup-like organ.

In a male catkin we find within this cup a tuft of stamens (about forty), each with a red anther. At first the male catkin is erect or horizontal and the filaments are very short, but soon the catkin-axis lengthens, the catkin droops, the bracts fall off, and the filaments rapidly grow longer and push out the anthers. Then the anthers open and shed the pollen, which is carried by the wind, and very soon the whole catkin falls off the tree.

In the female catkin the cup surrounds the base of the pistil ; above the ovary (one-chambered, with numerous ovules in two lines on the wall) are two large yellow branched stigmas. After pollination the axis of the catkin lengthens and the ovary grows into the fruit (capsule), which splits down along two lines halfway between the two lines of seeds, then the two valves roll outwards and the seeds escape. Each seed has a tuft of hairs serving for wind-dispersal.

For a comparison of the flowers of Poplars and Willows see Art. 274.

380. The **Lombardy Poplar** is simply a "pyramidal" variety of the Black Poplar, distinguished by its deeply furrowed bark and especially by the strong tendency shown by the branches to bend upwards and grow erect. Connected with this peculiar habit, which enables one to recognise the tree from a great distance, is the fact that only the buds on the *outer* side of the tree, *i.e.* those which are most exposed to light, grow out to form shoots.

381. The **Aspen**, the smallest of the common Poplars, is rarely over fifty feet high, with a slender trunk (about 1 ft. diameter). The bark remains smooth and light-coloured for many years ; the leaves are rounded and not pointed. The buds and flowers resemble those of Black Poplar, but the flowering buds are more distinct from the ordinary buds, being larger and less pointed ; the bracts bear numerous long hairs on their edges ; the stamens are fewer (about ten) ; the stigmas are red, not yellow.

382. The **White Poplar** resembles the Aspen in many respects, but is easily distinguished by (1) the white down on its leaves (lower side) and young twigs, (2) the dry and hairy buds, (3) the frequently lobed leaves, (4) the less marked flattening of the leaf-stalk, (5) the slight hairiness of the bracts, (6) the four slender yellow stigmas. It grows very quickly and may become a hundred feet high in forty years, with a massive trunk. The White Poplar, like the Black, has a "pyramidal" variety.

383. There are many different **Willows**, including varieties and hybrids, in Britain, but the commoner kinds are fairly easy to identify, and there are many points on which most of our Willows agree pretty closely. The leaves are alternate, with stipules, and usually have prominent cushions which run down the stem for some distance. The buds, which are generally pressed against the stem, may either produce long shoots bearing leaves, or short shoots which end each in a catkin; the short shoot sometimes bears a few leaves below the catkin (*e.g.* Crack Willow). Each bud shows on the outside only one large rolled-up scale; sometimes there are two small buds inside this scale, one on each side of the ordinary bud.

The catkin-bracts have silky hairs on the outer surface, and each flower has a green or yellow nectary, or two nectaries, at the base of the stamens or pistil on the side nearest the axis of the catkin. The male flower has few stamens (two to five), the number (though not constant) serving to distinguish some of the species; the anthers are yellow, the filaments long. The female flower has a pear-shaped ovary, generally carried on a stalk; the tapering upper end runs into a style with two stigmas which are sometimes branched, and the ovary has the same structure as in Poplars. Bees visit the flowers for honey and pollen. The capsule opens by two valves, as in Poplars, and the seeds have a tuft of hairs arising from the seed-stalk.

Willows may be roughly divided according to the presence or absence of long slender quickly-growing shoots (osiers) which often grow about nine feet long in a single season, or according to the breadth or narrowness of the leaves.

384. Hazel (*Corylus avellana*) is a small tree, rarely over 15 ft. high. There is usually no main trunk, but several branches starting at the base of the tree. From the base of the shoot arise numerous erect quickly-growing branches ("stool-shoots"), and similar branches ("suckers") are often given off by the root; the stool-shoots and suckers differ from the ordinary branches in having the leaves arranged in three rows instead of two. The bark remains smooth for many years, and has narrow transverse lenticels; in the older parts it becomes rough and scaly.

The leaves are stalked and simple. The blade varies in form and amount of lobing, but has irregular pointed teeth on the edge, a pointed tip, a rough surface, and is usually larger on one side of the midrib than on the other, especially at the base.

The twigs of the current year are hairy and have a zigzag appearance, the leaves (and buds) coming off singly at each bend. The buds are egg-shaped but rather flat, and are covered with brown scales; within these come pairs of silky stipules without leaf-blades, then stipules with young blades between them, each leaf being folded along the midrib.

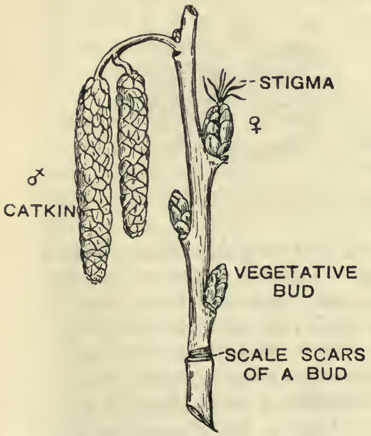

Fig. 157.—Male and Female Inflorescences of the Hazel.

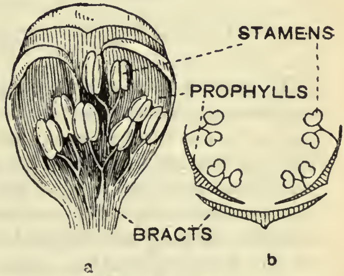

Fig. 158.—Hazel.
A, Male Flower; B, Diagram of same.

The uppermost bud on each twig grows out and forms a long shoot, but in summer the end of the shoot dries up, then the place of the lost end bud is taken by the uppermost side bud. Most of the side buds, however, grow into dwarf shoots, which may either bear a few leaves or may produce a male or a female inflorescence.

The "male bud" differs from the ordinary buds and the female buds in the fact that it grows at once, in the year it is formed, and produces first a few buds (which next year will become ordinary shoots or else female catkins) and then ends in from two to five male catkins. The cylindrical male catkins, therefore, are visible in late summer, and by February (sometimes after a few fine days in January or even December) they open.

The drooping male catkin (Fig. 157) has numerous concave green scales, each bearing on its downward face (its true upper face) two small scales and a number of stamens (Fig. 158); each stamen has a short filament ending in a one-lobed anther (a half-anther). There are usually eight of these half-anthers, and (in some cases at least) their filaments are joined in pairs at the base, so that in reality there are only four stamens.

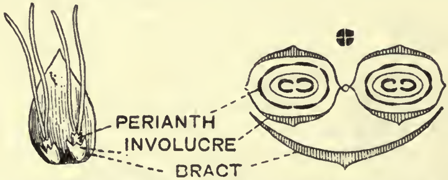

Fig. 159.—Two Female Flowers of Hazel in Axil of a Bract, each with two long Stigmas, and Diagram of same.

When the female bud opens, a tuft of about twenty scarlet stigmas projects from the top. Carefully dissect the bud and note the brown outer scales, then several pairs of stipules, then a few small leaves, and finally about five bracts each with two female flowers (Fig. 159). The flower consists of an ovary surrounded by a double cup at the base and bearing on top two long red styles, but the lower parts are very small at the time pollination occurs. Only a few flowers in each catkin develop into nuts; the ovary has two chambers, each with an ovule, but the nut has only one seed. The cup becomes leafy and very conspicuous as the nut ripens. What changes in colour, texture, taste, and size does the nut undergo while ripening? Note the embryo which fills the nut and has two large cotyledons containing starch and oil. Sow ripe nuts, first soaking them in water: do the cotyledons remain below ground or come above it?

385. Alder (*Alnus glutinosa*) grows chiefly in moist places, beside streams and pools, in marshes and bogs, but will thrive in drier places which are sheltered or in which the air is moist enough. It is generally a small tree, but may reach a height of sixty feet ; the trunk, however, rarely exceeds a foot in diameter.

The Alder is rather like the Hazel in general mode of growth, being often shrubby owing to the production of numerous stool-shoots, but the roots rarely produce suckers. On the older parts of the shoot the bark is black and scaly; on younger parts it is brown, with very distinct lenticels.

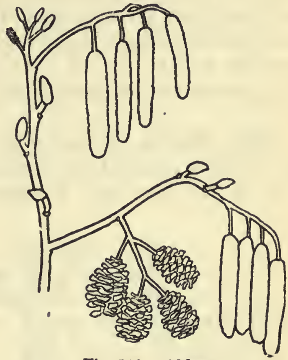

Fig. 160.—Alder.
Twig with male catkins, young female catkins (above), fruiting catkins (below), and resting buds.

The young leaves have stipules which soon fall off; the blade is broad and usually notched at the end, and except at the base its edge is doubly toothed, the teeth being short. The large egg-shaped brown resting buds are peculiar in that each is on a stalk. The young leaves are pleated (Fig. 48, *plicate*), and both they and the twigs are sticky at first. The buds are covered by two or three scales, which are rather difficult to separate and have a waxy coating.

The catkins open in February before the leaves appear. Both kinds of catkins can be seen in the previous autumn, and in winter they are conspicuous on the bare twigs. The ordinary resting buds of Alder contain only foliage-leaves.

The male catkins are cylindrical and are nearer the end of the shoot than the shorter female ones. Each scale is thickened at the outer edge and bears, on its (true) upper surface, three flowers, each with a green four-lobed " calyx " and four stamens. In the female catkin, which usually turns upwards and does not droop like the open male catkin, each scale bears two flowers resembling those of Hazel in structure but having no " calyx."

After fertilisation the ovary grows into a dry akene; the scales become stalked, hard, and woody, giving the old female catkin the appearance of a Pine cone. The cone ripens in autumn, but remains closed until the following spring, when the scales become separated and the akenes (which have a spongy coat) may be blown away by the wind or may fall into water and be carried by it.

386. Birch (*Betula alba*) is easily recognised by its thin main stem (sometimes forty feet high), which runs up to the top of the tree and is rarely over a foot in diameter; its slender twigs, drooping at the ends, and the light foliage, which together give the tree its graceful appearance; and its smooth thin white papery bark with long, dark transverse lenticels.

Fig. 161.—Birch. Twig showing male and female catkins.

There are two varieties in Britain, "White" Birch and "Common" Birch; they are connected by variations and hybrids, but the "Common" Birch is distinguished by its branches being more spreading and rarely drooping at the ends, its twigs *not* being covered with hairs, its bark being, at the base of the trunk, rough, dark, and furrowed, and by its hairless and longer-tipped leaves with the blade placed horizontally. The young bark is brown in both cases, becoming white later on.

The leaves are arranged all round the stem, but sometimes tend to form two rows; the stalk is thin, the blade variable in outline (heart-shaped, diamond-shaped, etc.), doubly toothed, with pointed tip. Since the leaves are relatively small, well spaced on the slender twigs, long-stalked, and hang vertically on the drooping twigs, they cast little shade. Hence the Birch catches but little light, as compared with trees which spread out their leaves and form a mosaic. It is, in fact, the most exacting tree in its demand for light, and conversely it grows worse in shaded places than any other tree in Britain.

Between an extreme light-demanding tree like the Birch and an extreme shade-enduring tree like the Beech we get various intermediate trees. The buds are small, pointed, dark brown; some produce long shoots, others dwarf shoots. Each year the end of the long shoot dies and its growth is continued by the uppermost side bud.

The catkins open along with the leaves in March or April (Fig. 161). Both kinds are cylindrical; the female catkins are at first erect and more slender than the male catkins, but later (in fruit) become much larger. The male catkins are visible during autumn and winter (as in Hazel) at the ends of twigs in twos or threes. In spring the male catkin lengthens and droops, the scales separate, and the pollen is blown out. Each scale (bract) bears (on its true upper surface) several small scales and three groups of stamens, each group consisting of two stamens each split into two half-stamens (Fig. 162, c).

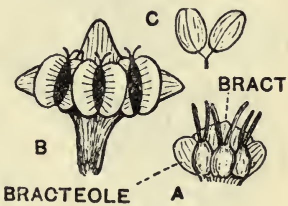

Fig. 162.—Birch.
A Female flowers in axil of bract; B, Fruiting scale, with three samaras; C, stamen from male flower.

Each female catkin is produced inside a resting-bud; in spring this bud grows out, produces a few foliage-leaves, and ends in a slender catkin (Fig. 161). Each scale bears on its upper side two small scales (*bracteoles*, Fig. 162, A) and three flowers. Each flower consists of a pistil (like that of Hazel in structure), without any cup. The akene is flat and produced at each side into a thin wing. In autumn the scales fall off and the light-winged fruits are dispersed by the wind.

Examine twigs in autumn, noting the ripe female catkins of this year, and the male catkins and the buds for next year; rub, or pick to bits, a fruiting catkin and note the scales and the winged akenes (Fig. 162, B). The seedling has two small green cotyledons, carried up; the first foliage-leaves are less toothed and more hairy than the later ones.

387. The **Hornbeam** (*Carpinus betulus*) is sometimes mistaken for Elm or even Beech, but with a little care it is easily distinguished, especially if its characteristic fruits are seen. In Britain, it is native only in Wales and the southern half of England, and rarely grows over seventy feet high or has a trunk over a yard in diameter. It is commonly seen in hedges.

Fig. 163.—The Hornbeam, with Cluster of Fruits.

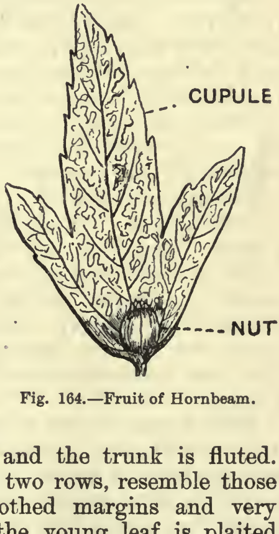

Fig. 164.—Fruit of Hornbeam.

The bark is thin and smooth, and the trunk is fluted. The leaves, which are arranged in two rows, resemble those of Beech in outline, but have toothed margins and very marked side veins, along which the young leaf is plaited while in the bud. The resting-buds are rather like those of Beech, but are shorter, and the lateral ones are pressed against the stem; the stipules soon fall off when the bud opens.

The male and female catkins, which come out with the leaves in early summer, are terminal on short shoots arising from buds on the previous year's twigs. The male bud, on opening, develops a short stem bearing at its base a few scales and occasionally two small leaves, and ending in a loose drooping catkin. The catkin-scales are large and concave; each bears from four to twelve stamens, and each stamen has a forked filament with a half-anther on each fork. The female catkins, which usually stand higher up the twig, develop from a bud which produces at its base foliage-leaves as well as scales. They are narrower than the male catkins, and in the axil of each catkin-scale there are two female flowers resembling those of Hazel; at the base of each flower there is a small three-lobed scale.

The fruits (Fig. 163) are ribbed nuts, each showing at the top the five lobes of the perianth, while the small scale around the flower grows into a large three-lobed structure (corresponding to the cupule of Hazel) which clasps the fruit below and acts as a wing, helping in wind-dispersal; the narrow catkin-scales fall off after pollination.

388. Oak (*Quercus robur*), the largest of British trees, sometimes 150 feet high, with massive trunk, is easily recognised at all times of year. Even when without its wavy-lobed leaves or its acorns, it differs from other trees in its gnarled and contorted main branches and in having its buds crowded round the ends of the twigs (see Art. 179).

Fig. 165.—The Stalked Oak, with Flowers.

In the commoner variety of the Common Oak (Stalked Oak) each group of acorns is carried on a stalk; in the other variety (Sessile Oak) the acorn-group has no stalk. The Oak leaf has small stipules which soon fall off. In Stalked Oak there is no leaf-stalk or a very short one, in Sessile Oak the leaf-stalk is long; in Sessile Oak the blade is firmer, more tapering at the base, and has hairs on its lower side.

The flowers appear with the leaves in April or May. The male catkin bears numerous flowers scattered singly or in groups on the axis; each flower (Fig. 166, C) has a deeply 5- to 7-lobed "calyx" and from 5 to 12 stamens. The female catkin has fewer flowers (1 to 5); each flower has a shallow cup covered with triangular overlapping scales, and inside this, the future acorn-cup, there is a 6-toothed

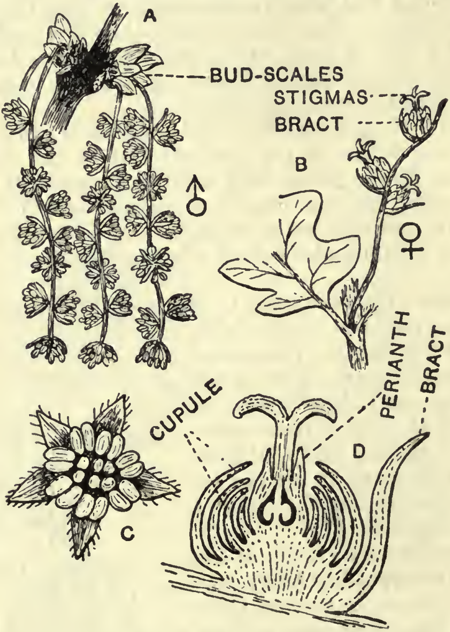

Fig. 166.—Oak.
A, Male; B, Female inflorescences; C, Male flower; D, Female flower in section.

"calyx" (Fig. 166, D, *perianth*) inserted above the small ovary, which has a style with three stigmas. The ovary has three chambers; the ovules (two in each chamber) are not even developed until after pollination. As a rule only one seed is present in the ripe acorn; still one often finds three or more, especially in looking for seedlings. The seed is filled up by the embryo, whose thick cotyledons contain starch, together with tannin, oil, sugar, etc. (Art. 79).

389. Beech (*Fagus sylvatica*), which is so easily distinguished by its smooth grey bark, its ovate leaves, fringed with hairs when young, its long brown tapering buds, and its three-sided nuts in pairs within a four-lobed spiny cup, is one of our largest trees, often over a hundred feet high. It usually has very characteristic ridges or buttresses at the base of the trunk, which run out to the shallow roots.

The leaves are arranged in two rows, and on horizontal or inclined branches their insertion is nearer the lower than the upper side of the branches; by twisting of the stalks the blades all present their upper faces to the light. The blades vary in shape, but are usually symmetrical and taper above and below. On young trees the dead leaves often remain attached during the winter.

Fig. 167.—The Beech, with a Fruit.

Besides the ordinary long branches there are dwarf shoots which grow very slowly and bear few leaves each year; inspection of the "girdle-scars" (close-set scars of bud-scales of former end buds) will often show that a dwarf shoot has grown less in length in about twenty years than a long shoot in about a month. The dwarf shoots do not branch, and bear crowded leaf-scars and annual girdle-scars. Sometimes a dwarf shoot grows out, after several years, to form a long shoot, owing to the fall of a branch above it or some other cause which gives it plenty of light.

Carefully examine a branch of Beech and note how beautifully the long and short shoots are arranged and mixed and how the sizes of the leaf-blades are varied, so that the leaves form a close mosaic and catch a large amount of light. Hold the branch against the light, and you will understand one reason why the Beech casts such a dense shade and why so few plants can grow under Beeches; when growing in a wood the main trunk runs up nearly to the thick crown of the tree, but in the open the stem branches low down into several strong cylindrical trunks, while the leafy "crown" comes nearly to the ground. From these observations you will understand why Beech is called a "shade-enduring" tree (more so than any other tree in Britain), while Birch is called a "light-demanding" tree.

The long zigzag twigs have the buds standing off at an angle of about 60°; the end bud may either persist or be replaced by the uppermost side bud. Each bud stands at the side (upper side) of the leaf-scar (small, oval, with three bundle-scars). In autumn the tips of the shoots cease to form leaves, but keep on forming stipules which act as bud-scales. The scales are pale brown, arranged in four rows; the outermost scales are broad, short, pointed, but those further in are longer, narrower, and more delicate in texture. The first seven or eight pairs of scales have no leaves, but the innermost pairs have a small leaf-blade between them, then come the pleated foliage-leaves with their stipules densely covered with silky hairs.

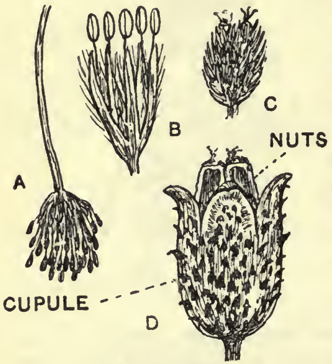

Fig. 168.—Beech.

A, Male inflorescence; B, Male flower; C, Female inflorescence; D, Cupule with nuts.

As a rule the highest buds on a twig grow into long shoots, those lower down into dwarf shoots, and the lowest ones remain dormant; the dormant buds do not, however, remain alive and capable of growth for nearly so many years in Beech (rarely 20 years) as in other trees, hence one does not see young shoots growing from the old trunks of Beeches, like those on Oak, Elm, Hornbeam, etc.

The flowers, which come out with the leaves in spring, are in clusters at the ends of slender branches which arise singly in the axils of the leaves, the female clusters being higher up on the twig than the male. The male branch has a long hanging stalk; that of the female branch is shorter, thicker, and erect. The numerous male flowers (Fig. 168, B) have each a bell-shaped "calyx" with five to seven teeth, covered with hairs, and about ten stamens. The female branch has only two flowers (Fig. 168, c) surrounded by a four-lobed cup covered with soft outgrowths; each flower has a four- to eight-toothed perianth above the three-chambered ovary (two ovules in each chamber), and the style has three stigmas.

After fertilisation the cup becomes woody and its outgrowths stiff or even spiny; about October the four lobes spread out and let the nuts escape (Fig. 168, D). The nut is filled by the embryo, which has two folded cotyledons. On germination the cotyledons are carried up and spread out as broad green leaves. For several years the young plant grows very slowly; each year the end of the stem bends over so that the leaves (set in two rows) shall not shade each other, then the upward growth for the next year is carried on by a bud on the top of the bend.

[The **Copper Beech** is a variety of Common Beech in which the epidermis of the leaf contains a red pigment (dissolved in the sap of the epidermal cells); the mesophyll consists of green tissue, as in the ordinary Beech.]

[**390.** The **Sweet** or **Spanish Chestnut** has long, oval, toothed leaves, which remain on the tree till late autumn, when they assume a rich golden colour. The flowers are produced in long spikes during July, the male flowers being situated on the upper parts of the spike, and the female flowers near the base. The former soon wither and fall, while the latter develop into tiny husks, lined by silky hairs, and each containing from two to five pointed nuts, some of which do not fully develop. The fruit is ripe in September, and falls in October, when the cupule splits and exposes the nuts. The seeds ripen in Britain only in warm seasons or favourable localities.]

391. Elm (Figs. 169, 170).—There are two kinds of Elm in Britain, the **Common** or **English Elm** (*Ulmus campestris*) and the **Wych, Scots,** or **Mountain Elm** (*Ulmus montana*); roughly speaking, most Elms growing south of the Trent belong to the former species, while most Elms north of the Trent belong to the latter.

In both Elms the bark is rough and shoots are often produced from the lower part of the trunk. Both grow into tall trees (up to about 120 feet), and have short-stalked simple entire doubly-toothed leaves arranged alternately in two side-rows on the stem. The blade is roughly heart-shaped in outline, but one half (that nearest the tip of the twig, or that farthest from it?) comes off the leaf-stalk lower down than the other half and bulges out, so that the blade is lopsided.

Fig. 169.—The Elm, with Clusters of Fruits.

The advantage of this lopsidedness is easy to observe if you hold a leaf-bearing twig up to the light and notice how the larger half of each blade tends to fill up what would be a space (if the leaf were symmetrical) between the leaf, the stem, and the leaf above. This peculiarity of the leaf-blade, enabling the leaves on a twig to catch more light without too much overlapping of each other, is a simple method of producing a leaf-mosaic; it is more pronounced in the Wych Elm (leaf 3 to 6 ins. long, up to 3 ins. across broadest part, taper-pointed) than in Common Elm (leaf about 2 ins. long, not so pointed).

In Wych Elm the crown is broader and the main branches more spreading than in Common Elm; the latter has its bark more deeply furrowed. There are two kinds of buds; the higher ones are pointed and grow into leafy shoots (either long shoots or dwarf shoots), while the globular lower buds produce clusters of flowers. The buds have much the same structure as in Hazel; the young leaves have stipules which soon fall off; the branches, like the leaves, are in two side rows; the true end bud dies off each year, and the uppermost side bud replaces it.

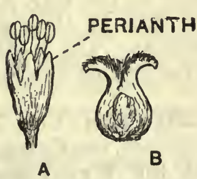

Fig. 170.—Elm. A, Flower; B, Pistil.

The flower-buds open first, in March or April, each producing a dense tuft of small brownish-green flowers; each flower has a bell-shaped "calyx" with four to eight lobes, a stamen opposite each lobe, and a two-chambered ovary with two spreading stigmas (Fig. 170). At first the stigmas project beyond the stamens and are receptive, but after a time the filaments lengthen and carry out the anthers, which then open. The pollen is carried by the wind; it is obvious that self-pollination is prevented during the female stage of the flower, but it may occur when the anthers of the flower open if cross-pollination has failed.

The ovary becomes an akene, with a thin wing around the seed-containing part; the fruits (oval, notched above) are at first green, but become brown and ripe by May. In Wych Elm the seed is at the centre of the fruit (about 1 in. long); in the smaller fruit of Common Elm (about ½ in. long) it is above the centre. The seeds of Common Elm are said never to germinate in this country, but this is largely atoned for by the fact that this species of Elm sends up numerous suckers from its roots, so that one often sees a long stretch of hedge on each side of an old Elm, or a thicket of young Elms around the parent tree. The Common Elm is not regarded as a native British tree, but as having been introduced within historic times. The Wych Elm, regarded as native, does not produce suckers, as a rule, unless the tree is cut down; its winged akenes (samaras) are well adapted for wind-dispersal, and in germination the green cotyledons are carried into the air.

Common Elm differs from Wych Elm chiefly in having smaller leaves, flowers, and samaras; fewer "calyx"-lobes and stamens; in the non-germination of its seeds in Britain, and its production of suckers in large numbers from the roots; in the direction of growth of its main branches and the shape of the crown.

392. Sycamore Maple or **False Plane** (*Acer pseudoplatanus*), usually called simply Sycamore (though this name was originally given to a wild Fig, *Ficus sycomorus*, growing in the East), is not a native of Britain, though so common here; its home is in central Europe and western Asia. The Sycamore is really a species of Maple; the only native British species of *Acer* is the **Field** or **Hedge Maple** (*A. campestris*), but two other species are commonly grown—**Norway Maple**

(*A. platanoides*) and **Ash-leaved Maple** (*A. negundo*). They all have the leaves in crossed pairs (therefore in four rows, *decussate* arrangement) and a fruit which splits into two (sometimes three) winged akenes.

Fig. 171.—The Sycamore, with Flowers.

The **Sycamore Maple** (Fig. 171) is a fairly tall tree (up to 60 ft.); the bark long remains smooth, but eventually becomes rough and scaly. Each leaf has a stalk whose broad base extends about half round the stem; the blade (4 to 8 ins. broad) has five pointed toothed lobes and is shiny and dark-green above, dull and light-green below. The main veins spread out from the top of the stalk, one running to each lobe and giving off side veins; in the young leaf the veins are fringed below with hairs, but in the old leaf the hairs are confined to tufts at the points where the secondary veins join the five main veins.

On a horizontal branch the leaves are arranged so that the blades may get as much light as possible; the leaf stalks vary in length, and those of the upper and lower rows of leaves become twisted, while the blades vary in size, in amount of lobing and sizes of the lobes, so as to produce an effective leaf-mosaic. On a more or less horizontal branch the buds (Art. 177) on the upper and lower sides either remain dormant or grow into very short shoots, so that on an old branch of this kind the long twigs are confined to the flanks; but on more erect branches there are strong twigs on all sides, especially on the side farthest from the middle of the tree. How may these facts be explained?

A flowering shoot (how can you tell in winter which buds contain an inflorescence?) bears one or two pairs of leaves and ends in a long hanging bunch of stalked green flowers. At the base of the inflorescence branches bearing each about three flowers arise from the axis, but higher up it gives off single flowers. Note the five sepals, the five petals (narrower than the sepals), the stamens (8 to 12) inserted on a yellow ring-like cushion (nectary), the hairy flattened ovary (two chambers each with two ovules), and the short style with two curved stigmas. As a rule the central flower in each group has a fully developed pistil, and eight stamens with short filaments, but the anthers (though containing pollen) do not open, so that the flower is practically female. The other flowers are male, having eight to twelve stamens with long filaments, and a small sterile pistil. Sometimes a whole inflorescence consists of these male flowers; in all cases the male flowers appear to mature before the female flowers. The flowers are visited by insects, chiefly bees and flies.

The fruit has two spreading and diverging wings, one produced from the outside of each chamber or half-fruit. Each chamber contains a large rounded seed (Art. 79).

[**393. Horse Chestnut** (*Aesculus hippocastanum*) is a large tree (about 60 ft.), with erect trunk and pyramidal head; it is a native of Asia and North America and was introduced into Britain about 1630. The name is derived from the resemblance of its seeds (too bitter for human food, though eaten by various animals) to the edible fruits of Sweet Chestnut, "horse" being a contemptuous prefix meaning coarse, as in Horse Radish, or as "dog" in Dog Violet, etc.

The twigs are thick, the buds (Art. 178) large, brown, and sticky; the branches ascend at first, then bend downwards and often curve up again at the ends. The bark is smooth for many years, but later becomes grooved and scaly. The leaves are in crossed pairs. As in Sycamore, the leaves differ according to their position on the branches, the lower ones having larger blades and larger stalks, but the mosaic is made more perfect by the fact that the leaves are compound, so that the individual leaflets can vary in shape and thus catch the light more fully.

The leaf-stalk has a broad base and is also broadened at the top where the leaflets (5 to 9, typically 7) come off. The leaflets themselves have no stalks; each has a sharp tip, just below which the leaflet is broadest, and a toothed edge. On a horizontal branch the lower buds either remain dormant or grow into small and short-lived twigs. When the inflorescence eventually falls off from the end of a flowering twig, a saddle-shaped scar is left, and the onward growth is usually continued by one of the uppermost side buds.

The flowering branches (Fig. 172), whose buds are much larger than the ordinary buds, resemble those of Sycamore in general structure, but are erect; they open in April or May, as a rule, sometimes not until June. The thick erect axis bears clusters of flowers below, single flowers at the top. Each cluster contains (1) male flowers, with stamens but no pistil; (2) complete flowers, of which some are really female, since the stamens fall off before the anthers open; (3) flower-buds, which do not open but wither and fall off.

Each flower is stalked, stands out horizontally, and is irregular (*zygomorphic*); there are five united green sepals forming a bell-shaped calyx, four free petals (an upper pair and a lower pair, sometimes with a fifth odd petal below). Each petal is white, with a yellow blotch (larger in the two upper petals) which later turns red, and jagged edges. Within the petals there is a ring-like nectary, thickest at the upper side of the flower, and within this the stamens (usually seven) are inserted. Each stamen has a long filament which turns up at the end and bears a red anther. The pistil has a three-chambered ovary and a long pointed style bearing stigmatic hairs.

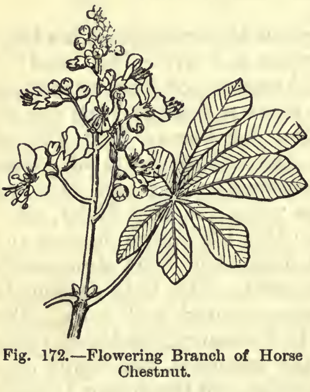

Fig. 172.—Flowering Branch of Horse Chestnut.

The flowers are visited by insects, especially bees. In a perfect flower the style is ready to receive pollen before the anthers open. When a bee visits a newly opened flower the style, which projects forwards and upwards, touches the bee's abdomen, while the unripe stamens are bent down. Later the stamens ripen and turn forwards and upwards, so that the anthers are brought into the position formerly occupied by the style. Cross-pollination is further aided by the fact that the male flowers in an inflorescence are the first to open, also by the presence of the "female" flowers, *i.e.* those whose anthers fall off without having opened.

The ovary grows into a brown globular spiny fruit (a *capsule*, though differing from most capsules in having a rather fleshy wall), which opens (about October) by three valves and usually contains two seeds.]

[**394. The Lime.**—This tree (Fig. 173) grows "wild" in a few of the southern counties, and is sometimes supposed to be a native; but this is doubtful, since the seeds do not germinate in uncultivated soil. The leaves are heart-shaped, with serrated edges.

Fig. 173.—The Lime—Leaves and Flowers.

Its flowers, which bloom in June and July, have five sepals, five petals, many stamens, and a five-celled ovary with two ovules in each. They are of a greenish yellow colour, and have a long leaf-like bract attached to the axis of the inflorescence (a cyme). They are also very fragrant, and produce abundance of nectar, and are consequently very attractive to insects. The fruits are nuts, and the persistent bract forms a wing which aids in their dispersal by wind.]

[**395. Common Lilac** (*Syringa vulgaris*), a native of Persia and Central Europe (introduced into Britain about 1600), forms a shrub or small tree (up to 20 feet), which grows rapidly (as much as a yard per year for the first three or four years), but does not last very long—about 20 years in rich soils, but 40 or 50 in dry poor soils (why this difference in duration?); it is well known for its handsome appearance when in leaf and its abundant and beautiful flowers. It sends up suckers profusely in all directions; why do gardeners clear these away as they appear, when a fine tree is desired?

The leaf has a long stalk; the blade, usually heart-shaped but rather variable in outline, is thin and has its surface smooth and its edge entire. The leaves are in crossed pairs.

The buds are large and green; the bud-scales are smooth and green, in crossed pairs. As a rule the end bud has either died off or produced an inflorescence, so that the end of a twig usually has two buds side by side. The buds are somewhat sunk in the base of the leaf-stalk in whose axil it stands, and each has four or five pairs of hard scales, then about ten pairs of young leaves which just touch each other at the edges, so that the bud is a very easy one to dissect. Some of the buds contain only leaves, others (larger) both leaves and an inflorescence.

The flowers (blue, purple, red, or white, in different varieties) are in large loose clusters, the main axis bearing groups of stalked flowers on its branches. The calyx is short and four-lobed; the corolla has the same general shape as that of a Primrose, consisting of a long trumpet-like tube and four horizontal lobes. There are two stamens inserted by short filaments on the inner surface of the corolla-tube. The ovary is two-chambered, the style long and ending in two small stigmas. Besides being fragrant, the flowers have honey, produced at the bottom of the tube; they are visited by bees and butterflies. The capsule opens by two valves; the calyx is persistent.]

396. Common Ash (*Fraxinus excelsior*) is a fairly tall tree, often 80 feet high; it is a native of Britain, but has generally been planted. It is easily distinguished by its stout grey twigs, usually turned up at the ends, its compound leaves in crossed pairs, and its stumpy black buds, also by its characteristic "keys." See Fig. 174.

Note that the base of each leaf runs down on the stem as a projecting cushion, so that the stem is flattened below each pair of leaves; this gives the twigs a knotted appearance when the leaves have fallen. The leaves have about five pairs of side leaflets and an end leaflet; the leaflets are stalkless, narrow, pointed, and slightly toothed.

The buds have 4 to 6 pairs of scales, of which only the outermost ones (2 to 4 scales) are visible on the outside; these outer scales are covered with black hairs. When the bud opens, one generally sees transitions between the bud-scales and the foliage-leaves. The large end buds grow into leafy shoots, but in April, before the leaves appear, clusters of flowers grow out from the side buds.

The inflorescence shows the same branching as in Lilac; the main axis gives off branches which branch again, and the last branches end in flowers. The flowers may be either male, female, or perfect; the three kinds may be present on the same tree or on separate trees, being grouped in various ways. There are always two stamens in a male or perfect flower (filaments joined below in male flower), while the pistil is bottle-shaped and consists of a two-chambered ovary, tapering style, and two stigmas. The flowers are mostly wind-pollinated, though apparently sometimes visited by insects.

Fig. 174.—The Ash, with Cluster of Fruits.

The fruits are winged akenes (samaras); the long and often twisted wing is formed from the top of the ovary and shows at first the remains of style and stigmas on its tip. Note the thickened basal part of the key, forming a cavity which contains the single long flat seed. When the seed germinates, the whole key is carried up; the cotyledons remain inside it at first to absorb the food stored in the endosperm, then come out and form oval green leaves. The first foliage-leaves are three-lobed.

[**397.** In the **Manna Ash** (*Fraxinus ornus*) of South Europe the flowers have sepals and petals, so that the Common Ash has evidently lost these parts through becoming wind-pollinated. The Ash belongs to the same family (Oleaceae) as Lilac, Jasmine, Forsythia—commonly cultivated shrubs—Privet (in Britain), and the Olive.]

QUESTIONS ON CHAPTER XV.

1. Name three English trees with which you are thoroughly familiar. Describe the habit, branching, buds, bark, leaves, flowers, and fruit of each. In what sort of situation would you expect to find each growing? Make your descriptions so clear that the trees could be easily distinguished and identified.

2. Mention ten woody plants, either native or introduced into this country, which have evergreen leaves, distinguishing between the native and the introduced species. What is the general difference between the leaves of evergreen and deciduous woody plants? Can you give a reason for the difference?

3. Give the names and distinguishing characters of *two* evergreen shrubs selected from each of the following groups:—(1) Conifers; (2) Monocotyledons; (3) Dicotyledons with free petals; (4) Dicotyledons with united petals.

4. Why does the normal branching of a tree follow its leaf arrangement? What is the arrangement in Apple, Gooseberry, Lime, Birch, and Lilac respectively? What influence has the formation of a terminal flower bud upon the subsequent growth of a shoot?

5. Explain as clearly as you can how plants heal their wounds. What are the conditions that favour the healthy healing of cut surfaces?

6. How are pruning-wounds healed? How can the act of healing be encouraged and materially helped by the operator?

7. Make diagrams of the relation of "leaf-buds" and "fruit-buds" in any fruit-tree with which you are familiar, and also of the shoots produced by each. How can you distinguish the two kinds of bud before they open?

8. What is the object and what do you suppose is the physiological effect of "pruning" fruit-trees? What are the conditions that favour the production of flowers in trees?

9. It is necessary, in order to be successful in any grafting operation, to bring together (at least at some part of the junction) a particular kind of tissue found in the stem, both of the stock and the scion. What particular tissue is this, and why is it of so much importance in grafts?

10. What are the essential conditions of success in the progress of grafting? Give reasons for your answer.

11. What are the conditions that favour the successful striking of a cutting, and why? There are certain differences in treatment between woody cuttings and herbaceous ones. Mention these differences and give reasons for same.

12. Why is it that herbaceous cuttings require light, while woody cuttings may be grown, at least for a considerable time, in darkness?

13. Why is a moist atmosphere for the first few days helpful, and after that harmful, to most herbaceous cuttings?

14. In what way does overwatering affect the health of the cuttings?

15. Why does warmth, in most cases, cause starvation of the roots in woody cuttings, while it encourages root growth in herbaceous cuttings?

16. Mention some plants which are commonly propagated by (1) cuttings of their roots, (2) isolated pieces of their leaves.

17. How are the following plants propagated (multiplied) apart from seeds?—Dahlia, Rose, Carnation, Aspidistra ("Parlour Palm"), Begonia, Pelargonium (Garden Geranium), Anemone, Lily of the Valley.

18. In removing a bud from (say) a tuber for purposes of propagation why is it necessary to include in the cutting part of the substance of the tuber itself?

19. Draw and describe the appearance during winter of the buds of either Beech, Horse Chestnut, or some other tree. Show by drawings the stages through which these buds pass in spring. How can you hasten the natural opening of a bud on a cut branch?

20. Describe the general habit, leaves, and catkins of any kind of Willow (*Salix*) you know. Make drawings to illustrate the structure of the flowers and explain how pollination occurs.

21. How can you tell a Poplar from a Willow in winter?

22. Describe and explain the process of "pollarding" Poplars and Willows.

23. Which Willows are used for basket-making? Where do these Willows grow?

24. Describe and compare the flowers of Willow and Poplar, giving sketches of their structure. How are the flowers pollinated? Compare the pollination adaptations of Willows and Poplars.

25. Describe the winter buds of a Willow or Poplar, with sketches.

26. How can you distinguish from a distance (*a*) the Lombardy Poplar, (*b*) the Aspen?

27. How could you distinguish an Alder in winter? Where do Alders usually grow?

28. Describe, with sketches, the buds, young twigs, and leaves of Alder.

29. Describe the male and female catkins and flowers of Alder. Give sketches. At what time of year are the catkins formed? In what other catkin-bearing trees can both kinds of catkin be seen in winter?

30. Describe the fruit of Alder. In what respect do the fruiting catkins of Alder differ from those of other catkin-bearing trees? How could you distinguish an Alder "cone" from a Pine cone? Give sketches.

31. Describe the appearance of a Hazel in winter. How can you tell the Hazel (*a*) by its twigs and buds alone, (*b*) by its leaves alone, (*c*) by its fruits? Give sketches.

32. Describe the male and female catkins and flowers of Hazel. Give sketches.

33. Describe the appearance of a Birch in winter. How can you tell a Birch easily from a distance (*a*) in winter, (*b*) in summer? Why is the Birch called a "light-loving" tree?

34. Describe the catkins and flowers of Birch. Which kind of catkin can be seen on the tree during the winter? Give sketches.

35. Describe the ripe fruiting catkin of Birch. How are the fruits dispersed? Give sketches.

36. How can you tell an Oak in winter by its twigs and buds? Give sketches. Why are the buds crowded at the tips of the twigs?

37. Describe the catkins and flowers of Oak. When do the catkins first appear? Compare Oak with Birch, Hazel, and Alder in this respect. Give sketches.

38. Describe the fruit of Oak and compare it with that of Hazel.

39. Describe the general appearance of a Beech (*a*) in winter, (*b*) in summer. What makes the Beech cast such a dense shade? Why is Beech called a "shade-enduring" tree?

40. Describe the inflorescences and flowers of Beech, with sketches. How do the inflorescences of Beech and Oak differ from those of Birch, Hazel, and Alder?

41. Describe the fruit of Beech, and compare it with that of Oak. How are Beech and Oak fruits dispersed?

42. How would you distinguish an Elm *in winter* from a Beech, a Lime, or a Sycamore? Describe the leaves and flowers of the Common Elm, and compare with those of the Wych Elm.

43. Describe the fruits of Common Elm and Wych Elm, with sketches. How are Elm fruits dispersed? At what time of year do they ripen?

44. How is the Common Elm chiefly propagated, and how does it differ in this respect from the Wych Elm?

45. Describe all the external features seen on a Sycamore twig showing several years' growth. Give sketches, and explain all the marks and structures you have drawn.

46. Describe the flowers of Sycamore, and compare with those of Hedge Maple. Give sketches.

47. Describe the fruits of Sycamore, and compare with those of Maple. How can you distinguish between Sycamore and the true Plane-tree (*a*) in winter by bark and buds, (*b*) in summer by leaves and flowers?

48. Describe the leaves of Horse Chestnut, and compare with those of Sycamore. Give sketches to show the relation between the two types of leaf.

49. Describe the flowers of Horse Chestnut, and compare with those of Sycamore. Note the adaptations for pollination.

50. Describe the fruit of Horse Chestnut, and compare it with that of Sweet Chestnut. How may the latter plant be distinguished by its leaves and flowers?

51. Compare the external features of the shoot (excluding flowers and fruits) of Sycamore and Horse Chestnut.

52. Describe the mode of growth and the external features of the Lilac. How is the Lilac usually propagated in gardens?

53. Describe the flowers and fruits of Lilac, with sketches.

54. Describe the winter features of the Common Ash. What other common trees resemble it in some respects (state these), and how can the Ash be distinguished from them?

55. Describe the leaves and buds of the Ash, with sketches. What distinctive features are shown by the twigs?

56. Describe the flowers and fruits of Ash, with sketches, and mention the adaptations for pollination and for dispersal.

57. How would you distinguish the following trees in winter:—Oak, Beech, Lime, Horse Chestnut, Elm, Lombardy Poplar, Ash, Alder? State how you can tell the annual segment of growth in a shoot.

CHAPTER XVI.

THE ECOLOGY OF PLANTS.

398. Plant Ecology.—Having now gained some practical knowledge of the structure and life-processes of plants, you should proceed to study the vegetation of your own district and that of any district you may visit. The main object of this study should be to find out as much as possible about the various ways in which plants are influenced by, and adapted to, their surroundings or "environment." The term **Plant Ecology** simply means "the study of plants in their homes." Much can be done in this direction even with limited knowledge of the classification of plants; but the more you know of structure, physiology, and classification, the better will you be equipped for the study of plants from the ecological point of view. It is an easy task to learn how to distinguish the commoner plants, especially those which show striking adaptations to some special locality or "habitat."

There are various books which enable one to identify any flowering plant met with in this country. The most complete of these "Floras" are Bentham and Hooker's *British Flora* and Hooker's *Student's Flora*; the former is illustrated, and is the more expensive of the two. Smaller books, less complete and less expensive, are Hayward's *Pocket Flora* and Watts's *School Flora*.

399. Terms used in Plant Ecology.—You must often have noticed that various plants grow together, in a sort of society or community, in certain localities—*e.g.* in water or in marshes, on moors and in bogs—evidently because they "like" or "prefer" (that is, are adapted to) the same kind of soil, the same conditions of dryness or wetness, the same amount of light or of shade, etc. Such groups of plants, growing together in a sort of community, may be called Plant Associations.

There are four main ecological plant-types. At one extreme we have plants adapted to life in ponds, rivers, ditches, growing partly or entirely submerged in water. These true water-plants are said to be *hydrophilous* (*i.e.* "water-loving"), and are termed **Hydrophytes.** Plants which grow in marshes or swampy ground, on river-banks or on ditch-sides, or in damp shady woods, are said to be *hygrophilous* ("moisture-loving") plants, or **Hygrophytes.**

At the other extreme we have plants which are adapted for life under conditions of "physiological" drought—that is, under such conditions that it is necessary to check or greatly reduce the rate of transpiration, or to store up water, or to do both, because the water supply is scanty or runs through the soil too quickly for the roots to absorb much of it, or because the water cannot be absorbed freely on account of the presence of excessive amounts of dissolved salts or of peaty matter, or because the plant grows in places exposed to high drying winds, or in cold soil, etc.

A little reflection will show that any of these causes will lead to the development of adaptations for reducing transpiration or for storing the scanty or precarious supply of water which the plant can absorb. In other words, such plants will be *xerophilous* ("drought-loving") plants, or **Xerophytes.** Xerophytes occur on heaths and moors, also in the boggy places which accompany them; on high mountains with an Alpine flora; in sandy and gravelly places; on chalk downs; on the sea-coast (cliffs, rocks, sandy beaches, sand-dunes, salt-marshes); and in dry woods or plantations.

Between xerophytes and hygrophytes we find a great many intermediate forms (**Mesophytes**), comprising, in fact, the majority of British plants, which grow in meadows, pastures, cultivated fields, and in damp woods and plantations of deciduous trees (Beech, Oak, Birch, etc.). These plants show no decided xerophilous or hygrophilous characters, though some approach xerophytes in form and structure and others approach hygrophytes.

Woody perennials (trees and shrubs) with deciduous leaves show distinctly xerophilous characters in winter (the protected winter buds, cork-covering of stems and of leaf-scars, cork-layer closing up the lenticels), while in summer they bear thin leaves like those of mesophytes or hygrophytes. It has been proposed to call such plants, which are more or less hygrophilous in summer and xerophilous in winter, **Tropophytes** (*i.e.* "changing plants"). This applies only to deciduous plants; evergreen land-plants are more or less strongly xerophilous in character, their leaves being usually tough, thick, and leathery (*e.g.* Holly), or needle-like (*e.g.* Pine), with thick cuticle.

It must be remembered that no hard-and-fast lines can be drawn between these types. For instance, some aquatic plants can, when the stream or pond dries up, continue to live and grow, sometimes even more vigorously, in the air, thus changing from hydrophytes to mesophytes. The same species of plant may be found growing under hygrophilous or xerophilous conditions in different localities. In each case the structure of stem and leaf, as well as the form of the leaves and the general habit of the plant, become modified to suit these different modes of life. Coast-plants can, in many cases, be grown in ordinary soil, and develop thin instead of fleshy leaves.

400. Environment.—In the study of Plant Biology you should always be on the alert to ascertain whether the differences in form and structure presented by different plants can be accounted for by differences in their mode of life and habitat. This study requires a sound practical knowledge of the morphology and physiology of plants. All the factors that make up the environment must also be taken into account. These factors fall into four main groups: (1) the **physiographic** factors, including altitude, exposure, slope; (2) the **climatic** factors, including temperature, rainfall, light; (3) the **edaphic** factors, including the physical and chemical characters of the substratum, *i.e.* in most cases the soil; (4) the **biological** factors, including other plants, animals, and man.

In dealing with a comparatively small area, like that of Britain, we find that the plant-societies are determined much more by the edaphic factors than by the climatic conditions, and of the edaphic factors the most important are the physical properties (especially the porosity) of the soil and the presence in it of humus.

401. Water-Plants.—The submerged leaves of a water-plant are usually either long and strap-like, as in *Glyceria fluitans*, a water-grass; or narrow and arranged in whorls, as in Water Starwort (*Callitriche*); or divided into numerous fine threads, as in Water Buttercups. These submerged leaves have chlorophyll in the epidermis, which bears no cuticle, so that water containing dissolved salts and gases can pass in freely. Since the submerged parts get their salts, oxygen, and carbon dioxide directly from the water, there are no stomates, nor does the stem contain many wood-vessels, and the roots serve chiefly to fix the plants to the bottom, having few or no root-hairs, since root-absorption is not required.

As we have seen, a land-plant requires to have its stem and leaves strengthened by hard tissue, arranged so as to resist the strains caused by weight and by wind. In a water-plant the weight is, of course, supported by the water, and the only strain to which fixed submerged plants are subject is a pulling-strain due to movement of the water, especially in fast streams. For these reasons there is little or no special mechanical tissue outside of the vascular bundles, and the latter are placed in the centre of the submerged stem, as in the *root* of a land-plant.

Leaves which float on the surface of the water are entire and rounded or slightly lobed (Water-lilies, Pondweeds, Duck-weed, and some Water Buttercups), and bear stomates on their upper surface, which is covered with cuticle or wax so as to prevent wetting. These floating leaves have the same general structure as those of land-plants, but the air-spaces are very large and are continuous, with air-passages running down the leaf-stalk to the submerged stem and roots. Air-spaces are also present in the stems of plants which grow with only their lower parts in water, *e.g.* Rushes, Sedges, Mare's-tail, Horsetails. Besides helping to make the plant buoyant, the air-spaces store up air absorbed from the water and aerate the lower parts of the plant which grow in deep water or in mud where very little oxygen is present for respiration.

Water plants are subject to less extremes of heat and cold than are land plants, since, owing to its high specific and latent heats, water takes longer to be heated and longer to cool than soil does. As regards nutrition, water plants are well provided with carbon dioxide, since this gas dissolves very readily in water; water at 15° C. dissolves about its own volume of this gas, which is present in such a small proportion (about 4 parts by volume in 10,000) in the atmosphere.

On the other hand, the proportion of oxygen dissolved in water (it need hardly be pointed out that aquatic plants and animals do not get their oxygen for respiration by the splitting-up of water into its elements) is much smaller than that present in the atmosphere. The lower parts of an ordinary rooted water plant is poorly supplied with oxygen, and the same is true of a marsh plant, *i.e.* a plant having its leaves in the air but its roots and shoot-bases in water or mud. The water or mud at the bottom is poor in oxygen as compared with the surface water, and still or sluggish water contains less oxygen than running water. The air-spaces in the leaves, leaf-stalks, stems, and roots serve to convey air to the badly aerated lower parts, and their primary importance for aeration is shown by their large development in marsh plants.

Since a submerged plant gets salts and carbon dioxide so easily, and lives in very favourable circumstances generally, it grows rapidly, branches freely (the branches are usually about as thick as the main axis itself), and reproduces itself largely by vegetative means, chiefly by the decay of the older parts and the setting-free of the younger branches.

The water plants of tropical regions grow continuously all the year round, not being hampered by a cold season, but in the temperate regions, where growth is interrupted by the winter, the water plants usually have some method of perennation (nearly all water plants are perennial). In some cases the plant remains unaltered and sinks to the bottom (e.g. *Callitriche*); in Water-lilies food is stored in the thick rhizome; in Arrowhead tubers are formed. A very common method of perennation is the formation of winter buds, which are produced at the ends of the branches. These buds are large and their leaves contain reserve food; they drop off and remain at the bottom until spring. Buds of this kind occur in Water Milfoil, *Hottonia*, Frog-bit, Bladderwort, and various species of *Potamogeton* (Pondweed).

What we may term "typical" aquatics grow with the whole shoot (except, in most cases, the flowers) under water and the leaves submerged or floating. Some plants can grow either submerged or on muddy soil with their shoots in the air; in these amphibious plants the leaves of the land form are broader and the stem and leaf structure resembles that found in marsh plants. Many water-loving plants can be grown on land, either by transplanting them to soil or by sowing the seeds in soil: in the former case the new shoots formed differ from the water form with regard to leaf shape and leaf and stem structure, in the latter case the seedlings usually produce at first some leaves of the aquatic type and later bear broader land-leaves. This change occurs frequently in nature, when a pond becomes more or less dried up in summer; observations should be made on these "amphibious" plants.

Experiments should be made on the lines suggested, and also the reverse kind of experiment, *i.e.* transplanting, or germinating the seeds of, land plants in mud, very wet soil, or in water. In some cases the change from land form to water form can readily be brought about, especially with plants which grow ordinarily in damp places.

Since water plants reproduce themselves extensively by vegetative methods, they flower, on the whole, less freely than land plants—often only when the water has sunk low or the plants have got on to muddy soil. In a few cases the flowers are adapted for pollination at the surface, or even under water. In *Vallisneria* (not a British plant, but often grown in aquaria) the male flowers break off when mature, as buds, and float up to the surface, where they open and expose the anthers. The female flowers, which are on separate plants, open about the same time and have long stalks which bring them to the surface, where the stigmas frequently come into contact with the floating male flowers (Fig. 175).

In the Eel-grass or Grass-wrack (*Zostera*), the pollen-grains are threadlike and have the same specific gravity as the sea-water in which they float until they drift on to the stigmas of the female flowers. In most water plants, however, the flowers are formed above the water and are adapted for pollination by wind or by insects; in the former case much of the pollen falls into the water and is wasted, in the latter the scarcity of insects makes the chance of cross-pollination rather small.

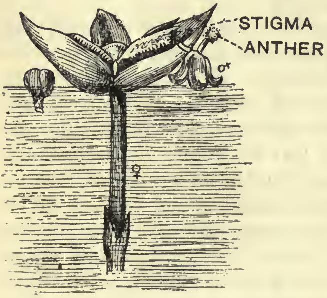

Fig. 175.—Female Flower of Vallisneria Spiralis.

With the anther of an open male flower touching one of its fimbriated stigmas, and an unopened male flower on the left.

A few submerged water plants have short stems with a "radical" rosette of more or less **cylindrical leaves**: **Quillwort** (*Isoetes lacustris*, allied to the ferns and not a flowering plant), with long awl-shaped leaves (2-6 inches) which contain four rows of air-chambers and have broad bases usually bearing a spore-case; **Awlwort** (*Subularia*, a Crucifer), in shallow edges of mountain lakes, rather exceptional among aquatics in being an annual, a small plant with a tuft of leaves about an inch long; **Water Lobelia** (*Lobelia dortmanna*), in mountain lakes, with cylindrical leaves 2 or 3 inches long containing two rows of air-chambers; **Shoreweed** (*Littorella*, allied to the Plantains), in sandy or gravelly edges of lakes, when submerged has narrow erect semi-cylindrical leaves and multiplies by runners, but when on mud has shorter and more flattened leaves spreading out; **Water Soldier** (*Stratiotes*, chiefly in E. England), with thick toothed leaves and conspicuous flowers carried on long stalks above the water.

Some submerged aquatics have **ribbon-shaped leaves**, which may float on the surface or remain submerged: *Vallisneria*; **Water Sweet-grass** (*Glyceria fluitans*); **Grass-wrack** (*Zostera*), on shores and especially in estuaries, with leaves 1-4 feet long; **Horned Pondweed** (*Zannichellia*), in fresh or brackish pools and ditches, with opposite leaves 1-3 inches long; and several species of **Pondweed** (*Potamogeton*). [The **Canadian Waterweed** (*Elodea*, or *Anacharis*), in streams, has narrow pointed leaves about 2 cms. long, arranged in threes on the stems.] **Water Starwort** (*Callitriche*) grows very commonly in still waters and is erect, 3-12 inches high; lower leaves submerged, about 1 inch long, narrow, in spaced-out pairs; upper leaves broader, forming a rosette at the surface and bearing the small flowers in their axils.

In the large and variable genus *Potamogeton* we get species showing all transitions from broad floating leaves (e.g. *P. natans*, the commonest species) to long narrow submerged ones. *P. natans* is the species least adapted for aquatic life (and therefore the nearest to the ancestral land type from which the Pondweeds arose); its upper leaves are oblong, stalked, and floating, while the lower ones are smaller or reduced to a mere stalk. In *P. heterophyllus* the upper leaves float but are narrower than in *P. natans*, and the lower ones are submerged, very narrow, and 2-7 inches long. In *P. lucens* all the leaves are narrow and submerged, or there may be a few floating upper leaves. All the other British species have all the leaves submerged and either oblong (e.g. *P. crispus*) or ribbon-like (e.g. *P. pusillus*, *P. pectinatus*). The flowers, which come above the water, are in a spike, each flower having 4 stamens, each with a sepal-like scale growing from the outer side of the anther.

Several plants resemble the Common Pondweed (*P. natans*) in having **broad floating leaves**, usually entire and rounded in outline. In the **Water-lilies** the large leaves are kidney-shaped or almost circular and have long stalks springing from a stout rhizome which sends roots into the mud; the blade is leathery, with unwettable cuticle, stomates, and palisade tissue on the upper side; air-chambers are present in all parts of the plant, and the large flowers are on a long flexible stalk. Examine the common **Yellow Water-lily** or **Brandy-bottle** (*Nuphar luteum*) and the **White Water-lily** (*Nymphaea alba*), or some of the cultivated species; note the numerous stamens and carpels, and the transitional structures between petals and stamens found in the Nymphaeas.

Frog-bit (*Hydrocharis*), found in ditches and ponds, has slender stems floating in the water and bearing at intervals tufted shoots, each tuft consisting of several stalked leaves with nearly circular blades, white flowers carried above the surface (male and female on separate plants), and usually a few roots hanging into the water; resting-buds are formed on the stems, drop to the bottom in autumn, and float up in spring to produce new shoots. **Duckweed** (*Lemna*), which often completely covers the surface of ponds, has flat green floating shoots, not distinguished into stem and leaf except that the branches and the minute flowers arise from lateral pockets at the narrow end of the "leaf," which bears long roots below, dangling in the water; in autumn resting buds are formed in the pockets and the whole plant falls to the bottom. [Other free-floating aquatics, not British but often cultivated, are **Water-nut** (*Trapa*), *Eichhornia*, and *Salvinia* (a fern).]

Several British aquatics have all their **leaves submerged and finely divided** into hair-like segments, like the submerged leaves of the Water Crowfoot. **Water Milfoil** (*Myriophyllum*) has a creeping fixed rhizome giving off shoots which float in the water and vary in length according to the depth and current, only the inflorescences coming to the surface; the leaves are in circles of 3-5, each leaf being pinnately divided, *i.e.* consisting of an axis bearing a row of narrow segments on either side. **Water Hornwort** (*Ceratophyllum*) resembles Water Milfoil in habit, but the leaves are twice or thrice forked into narrow segments, which have small teeth on their edges. **Water Violet** and **Bladderwort** are free-floating plants.

402. Marsh Plants.—Under this heading we include those plants whose roots and rhizomes, or shoot-bases, are in water or mud, while their leaves, or foliage-bearing shoots, and of course the flowers, grow in the air. Between typical aquatics, marsh plants, moisture-loving plants, and land plants there is every stage of transition. We may, however, distinguish between associations of permanently submerged water plants and those characteristic of marshes and bogs in which the substratum alternates between long periods of wetness and shorter periods of more or less complete drying-up. The characteristic feature of marsh and bog plants is that their lower parts, buried in the mud, are adapted to aquatic life, while their upper parts, exposed to the air, either resemble those of land plants or are adapted to withstand drought.

The reduced leaf-surface and thick cuticle of Rushes, Sedges, Horsetails, etc., have often been attributed to the existence in stagnant mud, especially in peat-bogs, of acids produced by the decaying organic matter, this acidity making it difficult for the roots to absorb water and necessitating a reduction in the transpiring surface of the plant. But actual analyses show that in some cases at any rate the pond-mud in which Rushes and Sedges grow contains no acids or only traces of acidity, and moreover the presence of acids, in certain quantities, actually increases the rate of water absorption by plants.

In order to meet these objections it has been suggested that these "marsh xerophytes" owe their mixed characters to the persistence of ancestral features in spite of a striking change of habitat, and that they are now "hydrophytes wearing a xerophytic mask." Perhaps the bad aeration of the roots, which usually show marked hydrophytic characters, especially in the existence of abundant air-spaces, has something to do with the xerophytic structure of the shoot in both bog and marsh plants, and the "physiological drought" theory (*i.e.* the view that the acidity of the substratum prevents absorption and acts in the same way as actual lack of water) may hold good for bog plants. At any rate, the biology of marsh and bog plants appears to be somewhat complex.

The following list comprises the commoner British marsh plants, which grow on the muddy margins of ponds and streams and in marshy ground, or which have their lower parts in water but all or most of their leaves above water.

The **Horsetails** (*Equisetum*) and the **Pillwort** (*Pilularia*) are flowerless plants, allied to ferns. The former have green cylindrical ribbed hollow aerial stems, with whorls of united scaly leaf collars and of green branches; the latter is a rather local plant, with creeping stem and tufts of long cylindrical leaves.

Monocotyledonous marsh plants include **Reedmace** (*Typha latifolia*), 3-7 feet high, leaves (3-6 feet long and 2-6 cms. broad) in two rows flower spike 6-10 inches long; **Bur-reed** (*Sparganium*), 1-4 feet high, leaves 1-4 feet by 1 inch, flrs. in globular heads; **Arrow-grass** (*Triglochin palustre*), 6-12 inches high, leaves ("radical") semi-cylindrical and 3-9 inches long, flrs. green in racemes; **Water Plantain** (*Alisma*), 1-3 feet high, leaves "radical," stalked, and arrow-shaped, white flowers in several spaced-out whorls; **Flowering Rush** (*Butomus*), with narrow "radical" leaves 2-4 feet long, large pink flrs. in an umbel; **Yellow Iris; March Orchis** (*O. latifolia*); and several Rushes, Sedges, and Grasses.

Rushes and Sedges are chiefly marsh plants. The **Bulrush** (*Scirpus lacustris*, 1-8 feet high, stem cylindrical, leaves practically reduced to sheaths around stem, flrs. in oblong spikelets in a lateral cluster) and **Lake Clubrush** (*Scirpus palustris*, with creeping rhizome, numerous erect leafless stems 6-18 inches high, terminal inflorescence 3 cms. long) belong to the great Sedge family (*Cyperaceae*); most of the **Sedges** (*Carex*) have a three-angled stem, leaf with basal sheath complete and not split as in the Grasses; **Rushes** (*Juncus*) have cylindrical leaves or green leaf-like stems. The most conspicuous marsh Grasses are the Reed-grasses (*Phragmites* and *Digraphis*).

Dicotyledonous marsh plants include the following: various **Willows; Alder; Water Docks** (species of *Rumex* and *Polygonum*, both easily known by the fused stipules forming a sheath around the stem at base of leaf—*Rumex* has large leaves, dingy flrs. in clusters, 6 perianth-leaves, while *Polygonum* has smaller leaves, pink flrs. in spikes, and 5 perianth-leaves); **Marsh** and **Water Stitchworts; Ragged Robin; Blinks** (*Montia*, a small tufted or straggling annual with opposite obovate leaves 6-12 mm. long, small white axillary flrs., K 2, C 5, A 3, $\underline{G}$ (3), allied to *Caryophyllaceae*); **Spearworts; Marsh Marigold; Cuckoo-flower** (*Cardamine pratensis*); **Golden Saxifrage** (*Chrysosplenium*, with opp. short-stalked circular leaves, small yellow flrs. in cymes); **Water Avens; Meadowsweet;** two species of **St. John's Wort** (*Hypericum*, with leaves opposite, regular yellow flrs. in cymes, stamens numerous and joined in bundles—

H. elodes is hairy, with stem-clasping rounded leaves, about an inch diameter and woolly on both sides, flrs. pale yellow 2 cms. diameter, while *H. quadrangulum* has four-angled stem, 1-3 feet high, ovate leaves, bright yellow flowers an inch across); **Purple Loosestrife** (*Lythrum salicaria*, 2-5 feet, opp. lanceolate leaves, red-purple flrs. in spikes, heterostyled with three forms of flower); **Water Purslane** (*Peplis*, a small annual rather like *Montia*, with opp. oblong leaves 2 cms. long, small white flrs. in the leaf-axils, K 6, C minute or absent, A 6 or 12; three species of **Willow-herb** (*Epilobium*, with epigynous polypetalous flrs., parts in fours)—Marsh W. (*E. palustre*, 1-2 feet, leaves opp. sessile lanceolate, rose or lilac flrs. 4 mm. across), Square-stemmed W. (*E. tetragonum*, like *E. palustre* but stem four-angled, leaves serrate, flrs. 6-8 mm. across), Codlins-and-cream (*E. hirsutum*, 3-5 feet, leaves stem-clasping serrate 3-5 inches long, flrs. rose-purple 1-2 cms. across); **Marestail** (*Hippuris*, 1-2 feet, stem cylindrical unbranched, leaves linear entire 2-6 cms. long in whorls of 6-10, flrs. small, green in leaf-axils); several Umbellifers (**Water Dropworts, Water Parsnips**, etc.); **Yellow Loosestrife**; **Moneywort**; **Brookweed**; **Bogbean** (*Menyanthes*, with stout rhizome, erect shoots 6-10 inches, long-stalked leaves with 3 leaflets, white or pink flrs. in raceme, K (5), C (5) fringed inside with long white hairs, A 5, G (2) with parietal placentation); **Water Forget-me-not**; **Comfrey**; **Gipsywort**; **Marsh Woundwort**; **Skullcap**; **Brooklime**; **Water** and **Marsh Speedwells**; **Figwort**; **Red Rattle**; **Water Bedstraws** (*Galium palustre* and *G. uliginosum*, allied to Goosegrass, Art. 233, both with square stems and small white flrs., the former species has 4 or 5 "leaves" in a whorl, leaves oblong and blunt, flrs. in large cymes, fruit smooth, while the latter has 6-8 parts in a whorl, stiffer leaves with pointed tip, stem-angles more bristly, flrs. fewer in cyme, fruit rough); **Great Valerian** (*Valeriana officinalis*, stems 2-4 feet high, leaves opp. pinnate-compound with 9-21 lanceolate serrate leaflets, pink flrs. in large cymes, K = feathery pappus, C (5) bulged at base, A 3, G (3) with 1 ovule, fruit a composite-like akene) and **Small Valerian** (*V. dioica*, 6-18 inches high, leaves 5-7 cms. long, lower ovate stalked, upper lobed, cyme much smaller, male flrs. larger than female); **Water Ragwort**; **Butterbur**; **Hemp Agrimony**; **Marsh Cudweed**; **Marsh Plume Thistle**; **Yellow Fleabane.**

403. Moorland Vegetation.—A moor is an elevated tract of country consisting chiefly of peaty soil and inhabited chiefly by Ling, Heaths, Bilberry, Cotton Sedge, and rough or wiry Grasses. Low moors, or heaths, show much the same kind of vegetation.

High moors are widespread in Scotland and along the Pennine range in England, occurring also in Wales and Devonshire (Dartmoor and Exmoor). The underlying rock is generally granite, sandstone, or shale, and between this and the peat-layer at the surface there is usually a more or less impermeable intermediate layer of decaying granite or shale, or of glacial clay. The soil is poor and either deficient in water owing to the subsoil being too porous, or saturated with water owing to an impervious subsoil or to excessive rain and mist, or to both causes. On high moors the strong winds not only increase transpiration but also prevent the growth of trees in exposed places, so that the entire vegetation is dwarfed and stunted, whereas on low moors (heaths) there flourish such trees as Pines and Birches, with Alder, Willows, and Bog Myrtle beside streams and in wet places.

Ling, Heaths, Cotton Sedge, and several of the wiry Grasses—making up the chief elements of the "heather association"—grow at all levels so long as the soil conditions are similar. Moreover, wherever water collects owing to lack of drainage and the soil becomes peaty owing to the accumulation of plant-remains, bogs are formed, so that the difference between moors and heaths, with their bog vegetation, is largely a difference of degree only.

On high moors the rainfall is usually very great—over a hundred inches a year, for instance, on the central plateau or basin of Dartmoor, which I have explored with some thoroughness—and the frequent dense mists help to keep the moor extremely moist. The summit of Dartmoor is a large boggy plateau, or basin, surrounded by the characteristic "tor"-capped hills and riven in all directions by crevasses which form an intricate network of peaty trenches and which gradually give rise to the streams—the chief rivers of Devon arise from this desolate region. The aspect of the vegetation is dreary and monotonous, though livened in early summer by the white tassel-like fruit-tufts of the Cotton Sedge (*Eriophorum*), which often form large snow-like patches.

The chief plants found in the boggy and crevassed parts are Rushes, Sedges, Cotton Sedge, Bell and Cross-leaved Heaths, great cushions of Hair-moss (*Polytrichum*), and Woolly Fringe-moss (*Rhacomitrium*), with Bog-mosses (*Sphagnum*) in the wetter places and tufted narrow-leaved Grasses on the hill-sides. Farther down and on the wind-swept outlying ridges the dominant plant is usually Bilberry in the drier parts, with lichens, and Rushes, Sedges, Bog-mosses, etc., in the swamps and along the streams.

404. Types of Moorland.—In the Vegetation Maps of Yorkshire,[1] several types of moorland are distinguished, each named after the dominant (*i.e.* most abundant or most characteristic) plant, the chief types being (1) Cotton Sedge Moor, (2) Heather Moor, (3) Rough Grass Moor. These types are found on Dartmoor and Exmoor, and are doubtless to be recognised on moors generally.

Fig. 176.—Cotton-Sedge on a Boggy Moor.

The **Cotton Sedge Moor** is, as already stated, monotonous in appearance; in autumn and winter there is little except the reddish-brown leaves of the Cotton Sedge, greyish-green in spring when its dull flowers appear, and flecked with white tufted fruits in summer (Fig. 176). The Cotton Sedge is dominant on the higher plateaux at altitudes of 1500 to 2000 feet, and is characteristic of the wettest type of moorland.

The peat of this moorland is deeper (often 30 feet or even more) and wetter than that of the Heather Moor. The leaves

[1] *Botanical Map of Leeds and Halifax District*, by Dr. Smith and Dr. Moss (Bartholomew and Co., 1s. 6d.).

and stems of the Cotton Sedge contain air-spaces communicating with the rhizomes and roots. In extreme cases the vegetation of the Cotton Sedge Moor is very scanty, only a few mosses, liverworts, lichens, and small fungi occurring on the peat between the Cotton Sedge plants. In wet weather the moor is a soaking mass with pools between the tufts of Cotton Sedge and soft peat-banks fringing the numerous water-courses. The Bog-mosses occur chiefly in patches and their remains are seldom abundant in the peat itself, which is chiefly composed of the remains of Cotton Sedge. At the edges of the Cotton Sedge Moor the dominance of the characteristic plant is shared by Ling and Cross-leaved Heath, the former in drier and the latter in wetter places. Other associated plants are Bilberry, Cowberry, and Crowberry, the Bilberry often covering the more exposed rocky summits and ridges.

The **Heather Moor** is drier than the Cotton Sedge Moor, and therefore has a greater variety of plants, though the Ling itself often grows knee-deep and so thickly as to allow of very few associate-plants. The typical Heather Moor is developed at 1000 to 1500 feet, on the drier or steeper sides of the moors, and is brown in winter and green in summer, but purple in autumn when the Ling itself is in flower. The peat is thin—from three or four to a few inches. The most important of the sub-dominant plants are Bilberry, Cowberry, Cross-leaved and Bell Heaths, Dwarf Gorse, Rushes, Mat-grass (*Nardus*), Wavy Hair-grass (*Aira flexuosa*), and Bracken, and almost any of these may become dominant over a considerable area—Bilberry on dry edges and summits, Bracken on steep stream-banks, and so on.

Other plants often present are Tormentil, Heath Bedstraw, Sorrel Dock, Field Woodrush, Sedges, Bent-grass (*Agrostis*), Purple Bent-grass (*Molinia*), and other plants, mostly small and wiry with creeping stems. The taller rushes (*Juncus*) form distinct associations in the swampy basin and beside springs—the larger Juncus marshes are indicated on the six-inch Ordnance map (Art. 420). Along with the Rushes grow such plants as Ivy-leaved Crowfoot, Bog Stitchwort, Blinks, Marsh Cinquefoil, Marsh Pennywort (*Hydrocotyle*), Sundew, Marsh Bedstraw, Lousewort, Butterwort, Bog Asphodel, Pondweeds (*Potamogeton*), etc. Cotton Sedge also occurs here and there on the Heather Moor.

The **Rough Grass Moor** or **Grass Heath** usually replaces the Ling at the edges of the Heather Moor, and may be divided into two types. One (Wet Grass Heath) is flat or nearly so, wet, peaty, and dominated by the Purple Bent-grass (*Molinia*), with the following among its associate plants: Bog Violet, Blinks, Marsh Pennywort, Bell and Cross-leaved Heaths, Bilberry, Bog Asphodel, Rushes, Sedges. The other (Dry Grass Heath) occurs on the steep hill-sides, which are well drained and therefore not peaty, and has plants adapted to a dry habitat, the dominant plant being usually either Sheep's Fescue-grass (*Festuca ovina*) or Mat-grass, with Wavy Hair-grass and Bent-grass often abundant, and such associate plants as Dwarf Gorse, Needle Whin, Heath Bedstraw, Tormentil, Sorrel Dock, Milkwort, Bracken, etc.

On **low moors** we find chiefly Ling, Heaths, Gorse, Bracken, and low (usually creeping) plants which shelter under these, *e.g.* Tormentil, Heath Bedstraw, Milkwort, Red Rattle, and in the boggy places various bog and marsh plants. One naturally associates Ling and the Ericas with hills, but extensive heaths are found, for example, along the coast only a few feet above sea-level. Ling and the Ericas occur at all elevations up to about 2000 feet; above that height they are often replaced by Bilberry. In the south of England, at any rate, Bilberry often occurs extensively in dry woods; altitude in itself has little direct influence on the distribution of this and of various other moorland plants, and one finds in practice every transition from typical heather moors or heaths to woodlands.

Heaths may be very dry or very moist, often passing into marshy land. Dry heaths overlie sand or chalk, from which water drains rapidly; the average summer temperature is usually low, the soil thin and poor in plant food, being often only a few inches thick and forming the only reservoir from which the plants draw their water in summer.

405. Moorland and Heath Plants.—Ling, Bell Heath, and Cross-leaved Heath are closely allied plants, and are much-branched wiry shrubs bearing crowded small narrow leaves. Each leaf is rolled up so that the lower epidermis (bearing the stomates) forms the inside of a tube which opens to the air only by a narrow slit (seen as a white line along the underside), and the edges of the leaf bear hairs which further hinder the escape of water-vapour.

In the **Ling** or **Common Heather** (*Calluna vulgaris*) the leaves are very short and arranged in crossed pairs, forming four rows; the copious branching, minute size of the leaves (2 or 3 mm. long, 0·5 mm. broad), and the closely set four rows of leaves at once distinguish this plant from the Heaths (*Erica*); the rosy drooping flowers are in dense spikes; both K and C are rosy and 4-lobed, the corolla being shorter than the calyx; each of the 8 anthers has 2 appendages and opens by 2 pores at the tip; a bee entering the flower comes against the anther appendages, shakes the anthers, and brings a shower of pollen down on its head, which had previously touched the stigma; ovary 4-chambered with numerous ovules; capsule enclosed by persistent corolla which fades to brown after fertilisation has occurred; capsule ripens in autumn and

Fig. 177.—Sprig of Cross-leaved Heather (*Erica tetralix*).

Fig. 178.—Vertical Section of Flower of *Erica tetralix*.

opens in spring by 4 slits, the small seeds being scattered by the wind; the flowers are doubtless largely wind-pollinated; the pollen is light and dry and escapes in clouds when the plant is shaken violently.

In **Bell Heath** (*Erica cinerea*) the leaves are larger than in Ling, being about 6 mm. long and 1 mm. broad, and are arranged in threes and not so crowded on the stems; flowers red-purple, larger and less densely arranged than in Ling, sepals green, corolla bell-shaped. The **Cross-leaved Heath** (*E. tetralix*, Figs. 177, 178) is lower and less gregarious than Ling and *E. cinerea*, and is chiefly found in the moister places in small groups; leaves in fours, downy below, with a wide slit, much less rolled up; flowers large, pinkish, in small clusters at ends of branches. The **Bilberry** (*Vaccinium myrtillus*) belongs to the same family as Ling and the Heaths (Ericaceae), but differs in having broad thin deciduous leaves which fall off early, the numerous green angular branches carrying on photosynthesis when leafless;

corolla nearly globular (Fig. 179), calyx small, ovary inferior, fruit a berry. Some other species of *Vaccinium* (Cowberry, Cranberry) occur in Britain, but are local and rare; they have evergreen leaves.

The **Crowberry** (*Empetrum nigrum*) is an evergreen "ericoid" (heather-like) plant with narrow rolled-up leaves, though not related to the Ericaceae. It is rare in the south of England, but in the north, especially on the Yorkshire moors, it is often the dominant plant over large areas. Its leaves are in whorls of 3 and 4 and are rolled up so as to enclose a rather large cavity, and the margins of the narrow slit are covered with hairs, those on the two edges interlocking and thus making the leaf an almost closed tube. The flowers are small, dioecious, axillary, sessile, and wind-pollinated, with 3 sepals, 3 petals, male with 3 long stamens, female with six spreading stigmas on a short style; fruit a black globular drupe with a single stone.

Fig. 179.—Flower and Stamens of Bilberry.

The **Grasses** found on moors and heaths are mostly quite different from those growing in meadows. In some of the dry-heath grasses, *e.g.* **Mat-grass, Sheep's Fescue,** and **Wavy Hair-grass,** the leaves are rolled up so that the upper surface forms the inside of a narrow tube opening by a narrow slit. **Purple Bent** (*Molinia*), the typical grass of wet heaths, has narrow but flat stiff leaves; on high moors it is rarely over a foot high, but in lowland bogs it reaches a height of 2 or 3 feet.

When the same species of flowering plant or fern grows both in low-lying or sheltered places and on bleak exposed hills or moors, there is usually a marked difference in the height of the plant, the exposed plants being stunted and having usually narrower and stiffer leaves with thicker cuticle. This is well shown by the Bracken-fern. Two species of Clubmoss (*Lycopodium*, allied to the ferns) grow commonly on moors and heaths; the **Common Clubmoss** (*L. clavatum*) has its creeping stems densely clad with very small pointed leaves, and sends up erect branches bearing less crowded leaves and ending in the "club" or "cone" which bears the spore-cases (one in the axil of each cone-leaf), while the **Fir Clubmoss** (*L. selago*) has no "club" but sends up numerous erect branches with spreading leaves, the upper leaves having spore-cases in their axils; a third species (*L. inundatum*) grows in bogs and has a more trailing habit and less erect branches than the two species just mentioned.

406. Bog-Plants.—The typical bog occurs on heaths and moors, associated with Heather and other heath-plants, and its vegetation consists of peat-forming and peat-loving plants. The distinctions between a marsh and a bog are fairly clear in most cases, though there are transitions from one to the other. The typical marsh occurs on low ground, its water is rich in mineral substances, especially lime, and its plants grow rapidly, either becoming tall or remaining low, but producing numerous leaves and branches each year. In the typical bog the water is poor in lime and other salts, and the plants are mostly slow-growing and of low stature.

Peat-bogs, like the heaths or moors on which they occur, are found at all heights, from a few feet above sea-level up to three thousand. The peaty soil in which bog-plants grow is not sufficiently aerated for the proper formation of nitrates, so that although such soils (bog, peat, morass) often appear on analysis as though they should be extremely fertile, very little of the materials they contain is directly available to serve as plant-food. Some heath and moorland plants are able to make use of peat by being partial saprophytes (Art. 239); Ling, Heaths, and moor Grasses have a covering of fungus-threads on or in their roots, forming a mycorhiza and enabling them to absorb the decaying vegetable matter.

Most bog-plants have more or less well-developed xerophilous characters, due largely to the excess of peaty acids, which makes water-absorption difficult. Mosses, especially the Bog-mosses (*Sphagnum*), of which many species and varieties have been distinguished, play an important part in the formation of bogs. The Bog-mosses, whose appearance and remarkably spongy character are well known to all who have walked over our moors, are specially adapted for storing water. The leaf of a Bog-moss consists of a single layer of cells, which are of two kinds: (1) large empty cells with pores on the walls, (2) small green cells. The green cells are long and narrow, forming a network, each mesh of which is occupied by one of the empty cells; the green cells carry on the living functions, while the large clear cells store up water. Each plant branches and grows upwards, while the lower parts die and lose their green colour, but are preserved from decay by the absence of oxygen and the presence of the peaty acids.

In this way masses of peat may be formed, but as a rule *Sphagnum* only occurs in comparatively small patches on our moors, and its remains are not abundant in the peat itself, which is chiefly composed of the remains of the Cotton Sedge. Peat is formed wherever there is a high rainfall and an impermeable substratum, resulting in the production of water-logged soil in which oxidation and the action of oxygen-requiring bacteria is checked so that complete decay cannot occur. In some districts extensive *Sphagnum* bogs are formed, and *Sphagnum* plays an important part in filling up pools and converting them into swamps and thus preparing the way for the growth of various bog and marsh plants.

An interesting point in connection with peat is that in some places it contains trunks of trees, chiefly Birches, Pines, Oaks, and Willows. This occurs chiefly in the valleys, but the distribution of these trees under the peat indicates that at some past time the present moors bore woods, except on the exposed summits, which probably had never, since the glacial periods, been anything better than heath or scrub. The peat is post-glacial in age, and a large proportion of it has probably been formed within the historical period.

The flowering plants found in bogs have mostly been mentioned already; they include Ericaceae (Ling, Heather, Bilberry); Sedges, Rushes, and Grasses, mostly different from the kinds found in marshes or wet meadows; Bog Asphodel, Bog Orchids, Bog Myrtle, Grass of Parnassus, Bog Cinquefoil, Sundews, Marsh Gentian (*Gentiana pneumonanthe*), Bog-bean, Bog Pimpernel, Butterwort, Bladderwort.

As already stated, peat is very poor in available plant-food, and this fact largely accounts for (1) the xerophilous character of most bog-plants, (2) the presence of insectivorous plants like Sundew and Butterwort in bogs.

407. Humus Plants.—Some of these simply prefer the humus as a medium on which to grow. Others, however, are saprophytes, and use the humus as a source of food. They are aided in this by the presence of symbiotic fungi (mycorhiza) on their roots, which play the part of root-hairs, and after decomposing the humus hand over all or a portion of it in a suitable form to the plant. Plants of this kind commonly have their foliage-leaves reduced to mere scales, as in the Bird's-nest Orchid. When (as in Ericaceae) the leaves are fully developed, the mycorhiza probably enables the plant to absorb nitrogen from the humus, and not carbon.

Humus collects in most bogs and swamps, but here it is the water which is of primary importance in influencing distribution.

408. Chalk Plants.—Chalk soils are usually dry, and, in dry continental climates, plants which grow in almost all soils in England may be unable to develop on the calcareous regions of the continent. Thus Birch, *Hypericum pulchrum*, *Stellaria holostea*, *Galium saxatile*, and Broom are all absent from the calcareous Jura mountains, but grow freely upon the Vosges, on which the soil is formed of decomposed granite, and also in marl soils in which the presence of some clay renders the soil more retentive of moisture.

In the case of chalk and limestone the same rule appears to hold good as with other soils and subsoils, *i.e.* that the distribution of plants depends much more upon the physical characters of the substratum than on its chemical composition. In our moist climate we get all sorts of plants on chalk downs and limestone hills, but still many of them show more or less decidedly xerophilous characters, and some plants are restricted more or less completely to chalky soils.

On **chalk downs** in the south of England we get several Orchids (Bee, Twayblade, Butterfly, Fly, etc.), Traveller's Joy (in hedges), Pasque Flower, Stinking Hellebore, Columbine, Rock-rose (*Helianthemum*, small and shrubby with opp. entire leaves, large yellow flowers, K 3, C 5, A ∞, $\underline{G}$ (3), ovary 1-chambered), Mouse-ear, Chickweed, Salad Burnet, Dropwort (*Ulmaria filipendula*, Rosaceae), Dyer's Weed (*Reseda*, a tall plant easily recognised by its greenish flowers, similar in structure to those of cultd. Mignonette), Salad Burnet, Lady's Fingers, Bird's-foot, Trefoil, Hoary Plantain (*Plantago media*, distd. from other Plantains by having its broad leaves closely pressed to the ground), Hound's-tongue, Thyme, Clustered Harebell (*Campanula glomerata*), Goat's-beard, etc. The chief trees and shrubs preferring chalky soil are Ash, Beech, Yew, Juniper, Wayfaring Tree, Guelder Rose, Spindle Tree, Privet, Dogwood, Spurge Laurel.

On **limestone mountains** in Yorkshire, Derbyshire, etc., there grow, in addition to most of those just enumerated, such plants as Rock Meadow-rue, Baneberry, Globe Flower, Yellow Violet, Mealy Primrose, Bloody Cranesbill (*Geranium sanguineum*), *Dryas*, etc.

409. Clay-Plants.—Pure clay does not form a soil preferred by any flowering plant, and is highly unsuitable to most. When dry a clay soil bakes hard and is almost impenetrable by the roots of plants, while the very fact that when moist it is highly retentive of water renders it difficult for the plant to absorb sufficient water unless the soil contains a large amount. In this case the soil is very badly aerated, and hence for lack of oxygen the roots are unable to develop to any great extent or to penetrate deeply. If mixed with sand, chalk, or humus, however, the soil is much improved, and many plants will survive periods of drought on such soils, whereas they may perish on more porous ones. Such plants as Lily of the Valley, Lesser Celandine, Wood Sanicle, Colts-foot, Primrose and Cowslip, Bittersweet, Yellow Dead-nettle, Garlic, Early Purple Orchid, Blue-bell, are found, in some districts at least, to prefer soils containing a good deal of clay.

410. Sand-Plants.—These include (*a*) those plants which prefer merely a sandy soil, and (*b*) those of the sea-coast (**strand-plants**) which have adapted themselves to the presence of salt. Many such plants grow equally well in ordinary soil, but lose certain of their characteristics, and probably would not survive if left open to free competition. Practically all such plants have strongly xerophilous characters; for example, reduced leaf-surface, thick fleshy or prickly leaves and stems, stunted habit, thick cuticle, deeply sunk stomata, etc. Sand-plants, pure and simple, are often very prickly, thorny, or hairy, whereas hairs are usually absent or few in number on strand-plants.

The following are a few examples of sand-preferring plants: Mousetail (*Myosurus*, Ranunculaceae), Sand Spurrey, Stork's-bill (*Erodium*, allied to *Geranium*), Broom, Wormwood, Golden-rod, Wood Sage.

411. Strand-Plants.—The plants which grow along our shores, either on sand or in mud-flats (salt-marshes), are sometimes called **Halophytes,** or saline-plants. They either prefer salty soil, or grow here because their competitors are more sensitive to salt and are unable to follow them. All strand-plants are more or less xerophilous in character, and this is also the case with regard to plants growing on salt-marshes or muddy shores. Here the plant strives to reduce its need of absorbing water to a minimum, so that it shall not absorb too much salt. Hence the plants are fleshy or leathery, the cuticle is thick, the stomata often sunken, and the leaf-surface often reduced or spiny. Since high winds often prevail, the flowers are usually small, and the seeds are rarely winged, but there are exceptions to both these rules: the Sea-poppy has large yellow flowers, and the Sea-thrift has a persistent membranous calyx, which forms a funnel-like wing on the fruit.

Coast vegetation varies according to the nature of the soils, and we find that shifting sands, sand-banks or "dunes," rocks and cliffs, shingle or pebble beaches, and muddy salt-marshes have each their own typical plants, though there are of course transitions from one to the other.

It is not easy to say just where the sea-shore begins from the land side. It may be limited by cliffs or hills, so that there is little shore and the high tides come up the face of the cliffs; or it may reach for miles inland among salt-marshes and ditches. Even when the shore is well limited, we find on approaching it that trees become scarce (except in sheltered inlets like those on the Devonshire coast) and are usually gnarled, bent away from the prevailing wind, and often covered with the characteristic rock-lichens found on the coast; the ordinary flowers of meadows are largely replaced by various Grasses, Rushes, Sedges, and the typical maritime plants, though many inland species come close to the sea. The operations of gardening and agriculture have caused many plants to take to the seaside as a refuge (*e.g.* Henbane, Teasel), and have removed plants like Sea-kale and Asparagus inland into cultivation. Chenopodiaceae (the Goosefoot family, including Goosefoot, Beet, Saltwort, Sea-blite, Marsh Samphire, Orache) and Crucifers are especially well represented in the shore-vegetation, but most of the larger families have seaside representatives.

412. On **rocks** and **cliffs** we generally find **Sea Plantain** (*Plantago maritima*, with entire smooth fleshy leaves), **Stag's-horn Plantain** (*P. coronopus*, with lobed hairy leaves), **Scurvy-grass** (*Cochlearia*), **Samphire** (*Crithum*), **Yellow Stonecrop, Sea Wormwood, Sea Thrift** (*Armeria*, with heads of pink flowers), **Sea Bladder Campion** (*Silene maritima*), etc. Several of these (Thrift, Sea Campion, Scurvy-grass, and Sea Plantain) occur also on hills inland, but not in the low-lying parts between the hills and the coast. Their xerophilous adaptations enable them to grow in both kinds of habitat.

Trees are rarely found on cliffs, but in addition to the plants just mentioned we get many plants belonging to dry grassy pastures (Carline Thistle, Rock-rose, Milkwort, Agrimony, Bird's-foot Trefoil, Lady's-fingers, Thyme, etc.); also plants of the shaded stream-sides, which have been carried to the coast and find sheltered and moist places suited to their growth (Red Campion, Hemp Agrimony, *Orchis*, Bluebell, etc.).

According to their position on rocks and cliffs, the plants have to get a footing on almost bare rocks, or in loose soil in crevices, or in sheltered nooks where the falling debris has weathered into soil suited to shade-loving and hygrophilous plants. The air is fairly moist owing to the cool breezes and the frequency of fog and rain, but where there is exposure to high winds and salt spray we get xerophilous plants like the Scurvy-grass and Samphire. As a rule, however, typical halophytes are not common on cliffs, though the beaches and rocks at their bases often present the conditions suitable for such plants, which grow most luxuriantly on sand near the sea and in salt marshes.

413. On **sandy shores** and **sand dunes** we get a fairly large flora, varying greatly in different localities, and frequently including rare (though often locally abundant) species.

On the sandy shore itself close to the sea, where the sand is saturated with sea-water a little below the surface and the latter is liable to become dry and hot in summer, there grow such plants as **Prickly Saltwort** (*Salsola kali*, leaves cylindrical and fleshy with a small sharp spine at the tip), **Orache** (*Atriplex*, several species, often shrubby, with mealy leaves and spikes of small green flowers), **Sea Beet** (*Beta maritima*, with glossy ovate or lanceolate leaves), **Horned Sea Poppy** (*Glaucium*), **Sea Convolvulus** (spreading over the sand instead of climbing like the other Bindweeds), **Sea Holly, Sea Purslane, Sea Kale, Sea Rocket, Sea Spurge** (*Euphorbia paralias*, with narrow fleshy leaves, milky juice as in other Spurges), **Sea Milkwort**, etc. All these plants have fleshy, hairy, or leathery leaves, and are either annuals, or if perennial have long taproots or rhizomes, and are able to grow upwards and thus avoid being buried by the shifting sand.

Sand dunes consist of ridges and hollows above the tide limit, formed partly by water-currents (near the sea) and partly by wind (farther from sea). Near the sea the chief plants found, besides those just mentioned, are certain Grasses and the Sand Sedge, whose creeping stems and tufted roots bind the shifting sand together. The rhizome of **Sand Sedge** (*Carex arenaria*, habit like that of the Sedge shown in Fig. 60) burrows deeply and runs in straight lines, sending up aerial shoots, which are therefore arranged in lines along the surface of the sand. The chief Grasses which bind the sand and can withstand being buried by it occasionally are the **Marram-grass** (*Psamma arenaria*) and the **Lyme-grass** (*Elymus*). Other sand-binding grasses are **Sea Couch-grass** (*Agropyron junceum*), and the rather local maritime species of *Phleum, Poa, Bromus, Festuca*, etc.; Sea Barley is very common on our coasts, but it has no creeping rhizome, and is an annual plant.

The **dune hollows**, where not liable to inundation at high tides, often collect rain water and become pools, covered at first by slimy green algae, which make the substratum impervious enough to retain water through winter and spring at any rate, and prepare the way for mosses and liverworts, which in turn produce a fairly retentive bottom. If these hollows collect enough water, Sedges, Rushes, and various other freshwater marsh plants appear—Creeping Willow, Cross-leaved Heath, Marsh Stitchwort, Water Purslane, Bog Pimpernal, Stinking Iris, etc. If the pools are too well drained, various Grasses (*Agrostis, Nardus, Festuca*, etc.) may become dominant, along with such plants as Stork's-bill, White Clover, Stonecrop, Silverweed, Ragwort, Ling, Bell Heath, etc.

Further back from the sea the dunes become more fixed and also levelled by wind, rain, and rabbits, producing in many places fine golfing turf. Here we get a vegetation of the dry-pasture type, including various Grasses (Cock's-foot, Rye-grass, Yorkshire Fog, Fescues, etc.), with Field Woodrush, Bird's-foot Trefoil, Bird's-foot, Gorse, Brambles, Petty Whin, Medicks, Clovers, Burnet Rose, Silverweed, Red Centaury (*Erythraea*, a Gentian with pink flowers in cymes), Thyme, Ling, Milkwort, Heath Bedstraw, Stork's-bill, Sorrel Dock, Milfoil, Ragwort, Cat's-ear, Autumn Hawkbit, Scentless Mayweed, Speedwells, Stonecrop, Dog Violet, Hound's-tongue, Viper's Bugloss, and many herbaceous and low-growing plants.

414. On **shingle and pebble beaches** there is usually a rather limited vegetation, and most of the plants have long roots which can reach the moist soil below the pebbles. Near the sea we usually find various Oraches, Sea Beet, Saltwort, Sea Rocket, Sea Spurge, Sea Holly, Sea Convolvulus, etc., and further back come various plants which are not confined to the seaside, but grow on stony places inland as well, *e.g.* Rest-harrow, Gorse, Broom, Dyer's Greenweed, Silverweed, Burnet Rose, Carline Thistle. The Sea Bladder Campion is a characteristic plant on most pebble beeches.

415. Salt Marshes or mud-flats occur chiefly near the mouths of rivers and along estuaries and creeks. Their vegetation is, on the whole, distinct from that of sand dunes, though a few plants occur in both sand and salt mud, *e.g.* Sea Milkwort, Sea Plantain, Thrift, Scurvy-grass, Saltwort. **Grass-wrack** (*Zostera*) grows not only between the high and low tide-marks, but often to a depth of thirty feet, forming a green submarine meadow among the brown seaweeds (Bladder-wrack, etc.), its matted rhizomes binding the silt while its long leaves float in the water. The typical salt marsh plants, however, grow where submerged only by high tides, or a little above the high tide-mark.

One of the most characteristic salt marsh plants, growing just above high tides or partially submerged, then, is the **Marsh Samphire** (*Salicornia*, with green or reddish cylindrical fleshy jointed stems, the leaves being reduced to small opposite lobes at the joints where also the minute flowers are produced). A little higher we usually find **Sea Sweet-grass** (*Glyceria maritima*), **Sea Arrowgrass** (*Triglochin maritimum*, with long narrow fleshy leaves in a rosette and a long flowering-stem ending in a raceme of yellow-green flowers), **Sea Blite** (*Suaeda*, allied to Saltwort but leaves soft and fleshy and not spiny at the tip), **Scurvy-grass, Thrift, Sea Lavender** (*Statice*, with creeping woody rhizome, lanceolate leaves in a rosette, purple flowers in a curved corymb), **Salt Spurrey** (*Spergularia marina*), **Michaelmas Daisy, Golden Samphire, Sea Plantain, Beet, Sea Wormwood,** etc.

Some of the salt marsh plants extend a long way up an estuary, often forming extensive reed-beds, the dominant plant in which is frequently a variety of Bulrush (*Scirpus lacustris*), and mingle with various marsh plants which can stand a certain amount of brackish water, but are finally replaced by the ordinary freshwater marsh plants.

416. Woodland Vegetation.—The vegetation of a wood consists of (1) the "canopy" or foliage surface of the dominant and sub-dominant trees themselves, (2) the "underwood" of shrubs and small trees, (3) the undergrowth of herbaceous flowering plants, (4) the carpet of mosses, liverworts, and fungi, (5) the shrubby and herbaceous plants at the edges of the wood, and finally the very important but often overlooked teeming population (vegetable and animal) of the soil itself.

A wood is a very complex plant community, showing much greater division of labour and specialisation among the constituent plants than is seen, for instance, in a moor or a marsh. There is a keen struggle for existence, yet each plant has its own special work, which one might almost say benefits the wood as a whole as well as itself. The formation of a wood can only take place if the conditions are favourable with regard to light, moisture, shelter, and soil, while the climatic conditions in a wood differ markedly from those obtaining in open country.

The more decidedly xerophilous trees, such as Pines, can grow in poor shallow soil, but most deciduous trees require rich and fairly deep soils, which have to be prepared beforehand by the growth and decay of successive generations of smaller plants, whose dead and decayed remains form the beginning of the humus essential for the enriching of the soil. In high places fully exposed to wind, trees are either absent or stunted or grow in a distorted manner, which shows clearly the direction of the prevailing wind.

Light is one of the most important factors in the biology of a wood. It has been stated that the light intensity in a Birch wood in summer is about one-fifth that of full daylight on a sunny day, that in an Oak wood about one-twentieth, and that in a Beech wood one-eightieth, but the results obtained with photographic paper (Art. 124) of course vary greatly, owing to differences in habit of the trees, their closeness of growth, etc. However, woods consisting of Beech, Sycamore, Ash, and Elm may be called shade areas, while those consisting of Oak and Birch are light areas.

In the former cases the trees, especially the Beech, by their dense branching and close leaf arrangement, cast a deep shade in which few other trees or shrubs or even herbs can grow, the seedlings of all except shade-enduring plants being killed off.

In the latter case the trees have a less perfect leaf-mosaic, and while affording protection to the undergrowth admit a larger amount of light. The difference in the amount and variety of undergrowth in a dense Beech wood and in a well-lighted Oak or Birch wood is very striking (Figs. 180, 181); even

Fig. 180.—A light mixed wood (chiefly Birch), showing dense undergrowth of Bramble, etc.

under a small clump of Beeches, or a single large Beech, there are very few plants. The struggle for existence in a wood is largely a struggle for light.

In woods the air temperature is slightly below that of the open country, and the daily temperature changes are less pronounced. Owing largely to the shelter from wind, the air is moister, so that woods retard evaporation of rain water. The denser the vegetation the greater do these climatic differences become; the older the trees, the closer their growth, and the greater the proportion of shade-casting trees (*e.g.* Beech) in the wood, the moister is the woodland atmosphere and soil.

Fig. 181.—Beech wood with scanty undergrowth.
(*From a photograph by W. B. Crump, Esq., M.A.*)

There is evidence, historical and geological, that at one time Britain was much more extensively covered with trees than at the present day. In prehistoric times the British forests consisted chiefly of Oak and Scots Pine, but there are now very few primitive or "indigenous" Pine woods, this tree having been planted by man in nearly every case. To-day, as in the past, the influence of man and of animals is gradually changing the character of our woodlands.

Woods are usually distinguished by naming the **dominant tree**, which largely or entirely makes up the tall vegetation, and to a large extent the character of the trees depends upon the soil. In wet soils we get chiefly Alder and Willow thickets, while in poor soils (either dry and rocky or moist and peaty) the Birch flourishes. In soils not too moist and poor we get Oak woods and woods of mixed deciduous trees. Beech woods are chiefly found in the southern half of England on chalk; elsewhere the tree has usually been planted by man. Ash woods also occur chiefly on limestone. Hazel copses are largely found in places where taller trees have been cleared away, as well as on the edges of Oak and other woods. In boggy places and along streams we get patches of Bog Myrtle; on gravelly and sandy soils, especially on heaths, extensive "scrubs" of such xerophilous shrubs as Gorse, Broom, etc.; and so on.

The **underwood** varies greatly according to the shade cast by the dominant tree or trees. In open woods there is abundant undergrowth composed largely of Rosaceous plants like Brambles, Raspberry, Roses, Sloe, Rowan, Hawthorn, Crab Apple, Wild Cherry, Gean, Bird Cherry, also Dogwood, Alder, Buckthorn, Spindle Tree, Guelder Rose, Wayfaring Tree, Elder, Holly, Privet, etc., besides climbers (chiefly Honeysuckle and Ivy), and sometimes introduced plants like Maples, Lilac, Laburnum, Rhododendrons. The underwood becomes more and more scanty the closer the trees are together or the greater the proportion of shade-casting trees like Beech, until in a pure Beech wood it disappears altogether or is represented by Honeysuckle and a few Brambles, besides seedlings of the Beech itself.

The **herbaceous undergrowth** of "wood floor" plants varies in abundance and variety with (1) the amount of shade cast by the trees, (2) the nature of the soil, especially as to moisture and depth of humus. The amount of shade in itself has a great effect on the production of humus, and humus increases the water-holding capacity of the soil.

The chief floor-plants found in fairly well-lighted woods (*e.g.* Oak woods) include various Grasses (*Bromus asper*, *Melica*, *Milium*, *Poa*, *Festuca*, *Brachypodium*, *Aira*, *Holcus mollis*, etc.), Large Woodrush, Bluebell, Twayblade, Arum, Garlic, Daffodil, Bistort Polygonum, Wood Anemone, Goldilocks, Red Campion, Milk Vetch, Bitter Vetch, Wood Pea, Tuberous Pea, Pignut, Trailing St. John's-wort, Sweet Violet, Enchanter's Nightshade, Dog's Mercury, Wood Spurge, Wood Sorrel, Sanicle, Angelica, Primrose, Yellow Pimpernel, Ivy-leaved Harebell, Wood Woundwort, Yellow Archangel, Goldenrod, Wood Hawkweed, Saw-wort, Wood Hawkweed, etc. More local in distribution but abundant in many districts are such plants as Solomon's Seal, Star of Bethlehem, Helleborine (*Epipactis latifolia*), White Helleborine (*Cephalanthera*), Military Orchids, and other Orchids.

Of the Ferns, Bracken occurs chiefly in dry woods, often accompanied by Ling, Bell Heath, Bilberry, Tormentil, Heath Bedstraw, and xerophilous Grasses (*Aira*, etc.); while moist woods have a great variety of Ferns (Lady, Beech, and Oak Ferns, etc.) often with Polypody growing on the tree branches along with the epiphytic lichens and mosses; in deeply shaded woods the Bracken disappears.

As the shade increases the number of floor-plants falls off, until in a dense Beech wood we get, besides Beech seedlings, only a few shade-enduring plants like Sanicle, Woodrush, Wood Sorrel, etc., and in the deep rich humus the Bird's-nest Orchids and the Bird's-nest—both totally saprophytic plants (Art. 238).

It will be noted that most of the wood-floor plants have long creeping rhizomes which burrow in the humus, or short thick rhizomes giving off numerous slender roots, or bulbs which grow deeply (being pulled down by the contractile roots). The humus, permeated with the roots of the more shallow-rooting trees, creeping Ivy stems and roots, and fungus threads (in shaded woods the thick humus resembles mushroom "spawn"), is occupied at different depths by these rhizomes and bulbs. For instance, Yorkshire Fog, Bracken, and Bluebell often grow together, but the rhizomes of the grass are just below the surface, those of the Bracken creep at a lower level, while the Bluebell bulbs are dragged down deeper still by the contractile roots (Fig. 182); the same arrangement holds for various other groups of plants occupying the same soil. In this particular case the Bluebell and the Yorkshire Fog grass send up their aerial shoots in spring, before the Bracken has spread out its large leaves.

It is interesting to watch, at frequent intervals, the **succession of flowers** in a wood throughout the year, especially in spring and early summer, paying special attention to the orderly march of the spring flowerers and to the underground life of the various plants in the crowded soil. The succession of spring-flowers, before the trees and underwood shrubs have expanded their leaves, is roughly as follows: Snowdrop, Dog's Mercury, Wood Anemone, Wood Spurge, Toothwort, Sweet Violet, Bluebell, Primrose, Wood Sorrel, Garlic, Yellow Archangel, Goldilocks, and so on.

Do not remain satisfied with merely observing the order of appearance of these plants; examine their underground parts and try to find out *why* each appears at the time it does, how it is enabled to flower early, how it competes with other plants occupying the same soil, and what advantages it gains by its appearance before or after its competitors. Light, moisture, temperature, habit of growth, and the time of appearance of insects in the case of insect-pollinated flowers, are among the many factors to be considered. For instance, plants which can endure dense shade, *e.g.* Sanicle, can afford to come up later in the year; Bluebell, Daffodil, and some other early flowerers have almost unfreezable sap; the Bracken can rapidly overgrow and overshadow low-growing plants with its large spreading leaves; and so on.

On **wood-edges** we get many small trees, besides shrubs and herbs, which thrive better there than under the shade of the tall trees. Note the convex rounded outline of the foliage canopy at abrupt edges, *e.g.* where the wood is traversed by a wide river or abuts on open country; the overhanging branches over a road or a stream; the more profuse branching of the trees at the edge of a wood or clump, as compared with the less-branched stems and umbrella-like canopy of the trees further in. Plants like Foxglove, Agrimony, Avens, etc., grow commonly at the edges of woods. The vegetation of wood edges shows much the same succession of plants as in the wood itself when trees are blown or cut down and more light is thus admitted; we get first herbaceous plants (Bluebell, Red Campion, Wood Anemone, Wood

Sorrel, etc.), then taller herbs like Foxglove and Angelica, then shrubs (Brambles, Roses, Hawthorn, Rowan, etc.), then Birches and other trees.

417. Spring-flowering Plants.—We have studied many plants which flower in spring. Most of them are perennials, but a few annuals flower in spring and early summer, *e.g.* Shepherd's Purse, Groundsel, Chickweed (these three plants, as well as several species of Speedwell, flower also at other times of year), Hairy Bittercress, Vernal Whitlow, Wall-rue Saxifrage, and a few less common plants. In studying perennial spring-flowerers you will notice that they store up food in rhizomes, bulbs, corms, or root-tnbers; that many of them grow in woods or in hedgerows, which later in the year are often densely shaded by the foliage of the trees or shrubs; that their flowers usually either droop or perform closing movements at night and in bad weather.

Many of the early flowers of spring in this country are garden flowers only, *e.g.* Crocus and Winter Aconite. Others, *e.g.* Snowdrop, Daffodil, Sweet Violet, are grown in gardens, but also occur in habitats which make their garden origin much more questionable. Among wild herbaceous perennials that flower in spring are Cuckoo-pint, Bluebell, Early Purple Orchis, Field Woodrush, Broad-leaved Woodrush, Garlic, Lesser Celandine, Goldilocks, Marsh Marigold, Wood Anemone, Pasque Flower, Red Campion, Stitchwort, Cuckoo-flower, Violets, several Speedwells, Dog's Mercury, Wood Spurge, Wood Sorrel, Wild Beaked Parsley, Golden Saxifrage, Moschatel, Herb Robert (*Geranium robertianum*), Ground Ivy, Red and White Deadnettles, Yellow Archangel, Coltsfoot, Butterbur, Daisy, Dandelion, and many more.

Many of these grow in woods, protected from cold, wind, and snow to some extent, and flower early before the shade of the leaf-canopy overhead cuts off their share of light. Insects, too, forsake the woods to a large extent when they become densely shaded in summer. Flowering so early in the year, the plants must draw upon supplies of food made during the previous growing season by their foliage-leaves and stored up underground in rhizomes, bulbs, tubers, etc.

Among trees and shrubs which have spring flowers the Hazel and Alder are usually first. Other spring-flowering British trees and shrubs are Spurge Laurel, Butcher's Broom, Aspen and other Poplars, Willows, Gorse, Sloe, Wild Cherry, Box, Elm, etc. Among cultivated spring-flowerers are Almond, Jasmine, *Forsythia*, Flowering Currant, Laurustinus, Japanese Quince, Magnolia, etc.

418. Hedges.—Many shade-plants grow in hedgerows, the flora of which presents several interesting features. At the top of a hedge-bank the light is very feeble and the soil dry. Now all plants which grow in dry soil require plenty of light, so that the only plants which can develop at the top of the hedge-bank are either plants with long erect stems, such as the Hedge-mustard, Nettle or Thistle, or climbing plants such as Convolvulus, Hop, Clematis, Goose-grass. Lower down the hedge-bank, where there is more moisture and light, a great variety of plants may develop, while in the shady ditch beneath we find various aquatic, amphibious, and marsh plants.

The hedge itself most commonly consists of Hawthorn, but often of Gorse, Bramble, Sloe, or of small trees like Willow or Hazel. These have usually been planted, as have, of course, the hedges consisting of shrubs like Laurels, Privets, Rhododendron, etc., around parks and plantations. Why do hedges need to be pruned or "cut back," and what is the effect of this operation? Notice that plants like Dead-nettles, Yellow Toadflax, Campions, Stitchwort, when growing close to the hawthorn (or other shrub forming the hedge) push up between the branches and have long weak stems, although the same species, when growing some distance from the hedge, has short erect stems with closely arranged leaves. Cases like these suggest the way in which plants, originally erect and self-supporting, may have become climbers through lack of light and the presence of a suitable support.

It is very interesting to compare the nature and general appearance or "habit" of the plants growing along the north and south sides of a hedge which runs east and west. The south side is, of course, warmer, drier, and receives more light, and various plants grow on this side that either do not grow at all on the north side, or are found there in smaller numbers, and showing less luxuriant growth. In the same way the trunk of a tree which is growing in an open situation (*i.e.* not among others in a damp wood) generally has its moister northern side covered with a green powdery Alga (*Pleurococcus*, which is so common on trunks and palings) and with various Mosses, Liverworts, and Lichens, while the drier south side is usually quite bare. In a damp wood the trunks and branches of the trees are often thickly covered with these "epiphytic" plants, often also bearing Ferns (especially Polypody).

In highly cultivated countries the hedgerows form one of the most important refuges of the original wild plants which covered the country before the advent of the plough. The other chief refuges are by the sides of streams, in stony waste places, and in permanent pastures.

419. Field Observations.—It cannot be too strongly insisted upon that outdoor observations are absolutely essential in studying the distribution of plants and their adaptations to environment. To study this branch of Botany, *i.e.* Plant Ecology, with success it is necessary to have a good general knowledge of British flowering-plants, which can only be acquired by collecting and identifying, as far as possible, all the plants met with. At first attention may be confined to the commoner plants and to those which show well-marked adaptations to their environment, and which occur chiefly in sharply defined "plant associations," *e.g.* water-plants, heath-plants, coast-plants.

The student cannot do better than begin field observations on some definite and fairly uniform area (*e.g.* a sea-shore; pond, marsh, river-bank; heath, common, moor; meadow, cultivated field or garden with its weeds; hedgerow, wood or plantation with its trees and undergrowth, etc.). Study this area at all times of the year, identify as many of the plants as possible, and keep a careful record, with sketches, of your observations. The following hints will suggest the main lines on which the inquiry should be conducted; others will occur as your field-work progresses.

1. Physical and climatic features of the area under observation (*e.g.* chemical and physical nature of the soil; whether retentive and ill drained or porous and well drained; height above sea-level; exposure to, or shelter from, light and wind, etc.).

2. List of the most abundant plants in the area, with notes (and sketches) on the following points in each case: General habit and mode of life (whether annual, perennial, erect, creeping, climbing, xerophytic, aquatic, saprophytic, parasitic, etc.); size, form, texture, etc., of leaves; structure of flowers, with special reference to mode of pollination; structure of fruits, with special reference to mode of seed-dispersal, quantity of seed produced, etc.

3. Reasons why certain species are present in the area

under consideration and absent from neighbouring areas, and *vice versâ*. To determine these, compare the physical features of the different areas, and try to map out the whole district into regions characterised by definite plant associations, which will, of course, be found to merge into one another at their edges.

It need hardly be added that the subject of Plant Distribution cannot be mastered by merely committing to memory lists of plant-names. It must be approached in the spirit of observation and inquiry, and the problems it presents answered with reference to the student's knowledge of the Structure and Physiology of Plants.

420. Vegetation Survey Work, which has been carried out in various parts of Britain,[1] should be attempted by the student on a small scale at any rate.

Get the Geological Survey Map of your immediate neighbourhood, to learn the characters of the underlying rock, and the sheets of the "six-inch" Ordnance Survey for the district, giving the heights, etc.

Visit the area at intervals throughout the year and make lists of the plants found. The various Plant-Formations and Plant-Associations can be shown on the "six-inch" map by means of letters, numbers, signs, or lines, or by colouring with pencils or water-colours.

The smaller plant-communities are called **associations,** while **formations** are larger units each consisting of a group of associations.

While these terms cannot always be sharply defined, Dr. W. G. Smith[2] gives the following illustration:—

"A natural wood consisting entirely of oak-trees has one dominant form—the oak—whose presence is determined by the prevalent climatic, soil, and other conditions, while its size and gregarious nature give it dominance; in this wood there may be other sub-dominant trees or shrubs (*e.g.* birch or hazel), more or less isolated, but which, given the opportunity by removal of the oak, will become dominant forms;

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[1] See papers by Smith, Moss, Rankin, Lewis, and others, in various periodicals (*Geographical Journal*, *New Phytologist*, *Naturalist*, etc.).
[2] *New Phytologist*, 1905.

the motley carpet of the oak-wood is made up of many species dependent on the larger forms for shelter and shade, or living as epiphytes, parasites, and humus saprophytes, and including not only flowering plants, but ferns, mosses, lichens, and fungi. The vegetation of the oak-wood is thus

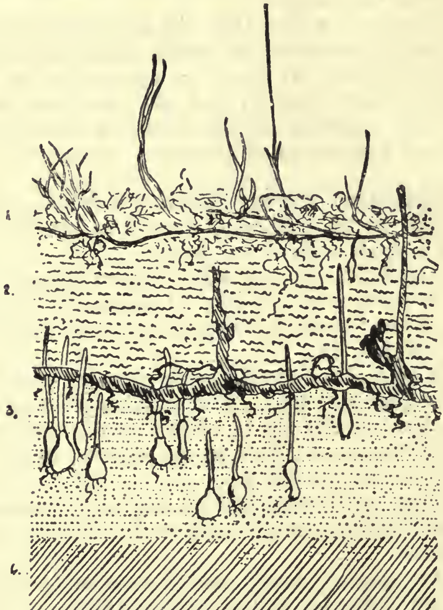

Fig. 182.—Section of Soil, showing how Yorkshire Fog Grass, Bracken, and Bluebell live together, their underground parts being at different depths.

a mixed community with complex relationships, its members struggling for existence and dominance, but it is a coherent whole and may be studied as a unit or *Formation*.

"Within the limits of a formation, there exist smaller societies, each one with dominant, subdominant, and dependent species of its own. Thus the undergrowth of an oak-wood may consist of a *Pteris-Scilla-Holcus* Association, in which Bracken, Bluebell, and Yorkshire Fog together cover a large area (Fig. 182); again it may be a *Calluna-Vaccinium* [Heather and Bilberry] Association, or one of several others."

Dr. Smith gives the following specimen list of plants in a survey:—

"Larch-wood, with a few Spruces, trees about 70 feet high and from 6 to 10 feet apart; two distinct associations found —*Calluna* and Bracken, the latter in hollows, the former occupying the larger, more level floor of the wood. Soil—thin peaty humus, overlying Liassic Limestone, 650 feet alt., Clevelands, W. Yorks.

Calluna Association:

Social species:

Dominant,	*Calluna vulgaris*	40-50%	about 70%[1]
	Erica cinerea	20-30%	
Sub-dominant,	*Vaccinium myrtillus*	5-10%	
	Festuca ovina		about 30%[1]
	Aira flexuosa		
	Agrostis vulgaris		
	Anthoxanthum		

Isolated species:

Characteristic:—*Potentilla tormentilla*, *Galium saxatile*, *Oxalis acetosella*, etc., in decreasing abundance.

Sporadic: *Carduus arvensis* (from farm-land)."

Other well-marked formations are (1) deciduous woods, *e.g.* Beech, Oak, Birch; (2) coniferous woods, *e.g.* Scots Pine; (3) xerophilous, herbaceous, and undershrub vegetation, *e.g.* heather moor, cotton-sedge moor or moss, grassland (on chalk downs, etc.), grass-heath (grasses like *hardus* mixed with such heath-plants as Ling, Heaths, Bilberry, etc.); (4) maritime vegetation, including sand-dunes, salt marshes, shingle beaches, sea-cliffs.

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[1] These percentages are estimated by eye according to the proportion of ground in a small sample area covered by the different forms of vegetation.

421. Zones of Vegetation in Ponds.—In studying the vegetation in ponds and streams, note how the different species tend to be arranged in zones. The arrangement differs considerably in different ponds and streams, each having peculiar features of its own in many cases, so that here (as with other plant societies) I can only indicate the kind of thing to be looked for by the student.

On the margins we get the **Reed Swamp Association,** consisting of plants rooted in the mud (usually with creeping rhizomes), with their leaves and flowers above the water. The most characteristic and successful "social" or gregarious species are those with long erect leaves, e.g. *Iris, Typha, Sparganium, Triglochin, Glyceria aquatica, Digraphis, Phragmites,* Rushes (*Juncus*), and Sedges. The Water Plantain and the Arrowhead have broad leaves, but these are longer than broad and assume a more or less erect position; however, these two plants are not very successful social species. In this association are also included such plants as the marsh Horsetails, Marestail, Water Dropwort, Water Docks, Purple Loosestrife, etc.

The **Floating-Leaf Association,** further from the bank, includes free-floating plants like Duckweed and Frog's-bit, also various rooted plants like Pondweed, Water Crowfoot, Water-lilies, etc. The **Submerged-Leaf Association** is best developed in fairly deep water, especially when the erect-leaved reed-swamp plants are not so abundant as to prevent enough light from entering the water. The **Marsh Association** has already been dealt with (Art. 402).

The following is a description by Dr. Smith of a series of ponds at Filey, Yorkshire:—

"This pond (Fig. 183) was filled with vegetation. At the southern end an inflow is shown, which was bringing in water when we saw it. From the appearance of the channel, it does not always contain water, and only acts as an overflow to some other pond in the same trough. At the northern end there is an outflow depression, which acts as an overflow channel to this pond. The water is probably derived from surface drainage, except in rainy seasons, when there will be some inflow at the southern end, and the pond will attain its maximum depth when the water begins to pass through the overflow

The plants are arranged in four well-marked zones: (*a*) a marginal zone of taller species of Rushes (*Juncus*); (*b*) a zone of Water Dropwort (*Oeanthe fistulosa*), mixed with Water Plantain (*Alisma Plantago*) at the southern end; (*c*) a zone of Bur-reed (*Sparganium*) also mixed with Water Plantain; (*d*) a central patch of Pondweed (*Potamogeton natans*).

The Pondweed lies in the centre towards the northern end; its leaves were large, and with long leaf-stalks, such as occur in deep

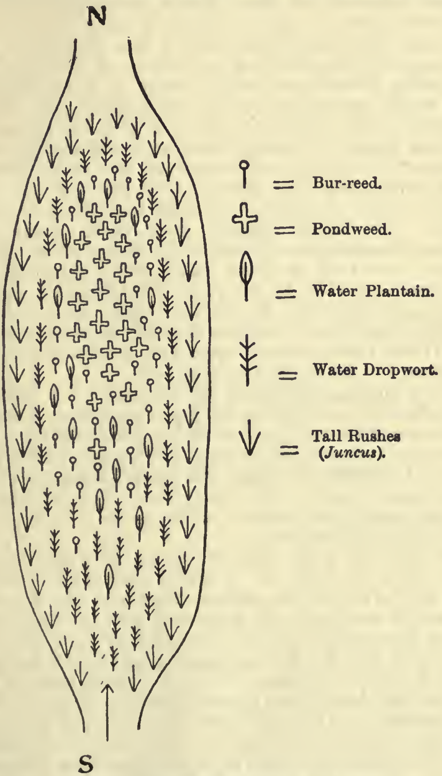

Fig. 183.—Zones of Vegetation in a Pond.

water. From this we suspect that the Pondweed occupies the deepest part of the pond. In consequence of the excentric position of the Pondweed, the zones of Bur-reed and Dropwort are narrow at the northern end, but they are sharply defined. Towards the southern end both plants lose their zonal arrangement, and form masses extending across the pond. The Dropwort, however, is always nearer the shore than the Bur-reed. It may, therefore, be inferred that the Bur-reed prefers deeper water than the Dropwort.

The Water Plantain does not form masses like the other plants, but occurs singly amongst the Dropwort and the Bur-reed ; it is not a social species, whereas the other plants shown are social. It is a feature of social species of plants that they can grow closely together as a mass, and hold their own more or less completely against all comers. One can appreciate this in the case of the Pondweed, with its broad floating leaves lying edge to edge, or overlapping, so as to occupy the whole surface and shade the bottom, thus checking the growth of other plants which may try to grow below them. Amongst trees, the Beech is one of the best examples of this kind of social plant.

The Dropwort, Bur-reed, and Rushes are also social plants, and it is noteworthy that their long, slender, erect leaves are similar in form to the Grasses which on land are amongst the most successful of our social plants. Just as the Grasses, with their closely interwoven roots and stems underground, and their close, erect, leafy shoots above ground, can keep in check the growth of other plants and maintain a close sward, so in our pond the Dropwort, Bur-reed, and Rushes maintain themselves in distinct zones with little mixture. The Dropwort is not quite so successful as the other two, and amongst it plants of Water Plantain have found a place and have also succeeded in gaining ground in the closer Bur-reed zone.

Turning now to the Rushes on the margin. The Rushes form a close well-marked zone, which at the time of our visit was standing in water and therefore formed part of the pond-vegetation. Out of the water there was, however, no scarcity of Rushes, and from general experience most of us would regard the Rushes as plants of the marsh rather than water-plants. The Rush zone of this pond therefore indicates that part of the margin which is only occasionally under water, and is generally marsh.

From this one may infer that this pond, as a rule, contains less water than when we saw it. It has a maximum depth which is determined by the sill of the outflow channel. The ebb extends at least to the lower margin of the Rush zone, but the Dropwort, Water Plantain, and Bur-reed are all plants which may grow in a wet marsh, and it is probable that this is the drought condition of that part of the pond occupied by these plants. From the appearance of the Pondweed we should say that its area is never quite free from standing water.

Fig. 184 represents what has been a pond, but is now so dry that it might be described as a dry marsh. The shape of the hollow is like that of the true ponds, and there is a distinct outflow channel. There is also an inflow channel of the kind seen in Fig. 183, namely, an occasional channel which drains the overflow from some adjacent hollow.

Near the centre are patches of two water-plants—Pondweed and Bur-reed—restricted to what are now the wettest spots. The Pondweed has small reddish leaves with short stalks, the Bur-reed has short narrow leaves ; both are land-adaptations and are probably remains of the original aquatic vegetation which has been displaced.

The other conspicuous plants of the pond-hollow are: (*a*) Water Sweet-grass (*Glyceria aquatica*), occupying the centre except the parts utilised by the Pondweed and Bur-reed; (*b*) *Iris pseudacorus* at the southern or inflow end; (*c*) Marsh Horsetail (*Equisetum palustre*) at the

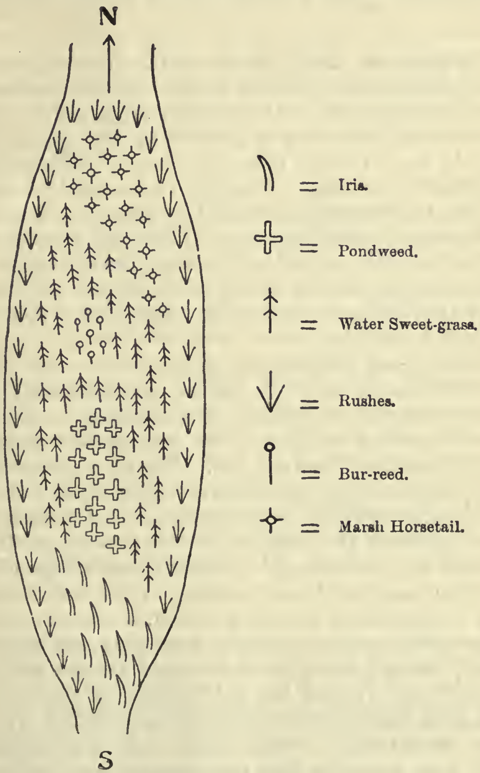

Fig. 184.—"Dry" Pond.

northern or outflow end; (*d*) a broad marginal zone of Rushes. The large patch of Water-grass indicates the part of the hollow which is occasionally under water. It is a feature of this grass that it grows well in a moist place liable to inundation. The Iris and Marsh Horsetail occupy well-defined areas, and both are typical marsh plants. Altogether the vegetation of this hollow indicates that it is moist, and even marshy at times, but is never long under water.

The ponds at Filey are thus instructive examples of aquatic and marsh vegetation. The ponds themselves show every stage of transition from ponds of open water to marshy hollows, and even dry hollows."

422. Weeds of Cultivated Soil.—The vegetation of barren and economically useless lands—moors, heaths, shores, etc.—has undergone but little change during all the centuries that have passed since our country was first inhabited and cultivated by man, though mountain vegetation has doubtless been modified by grazing. Except in such localities as these, the land has been largely disturbed by the operations of agriculture, forestry, drainage, etc. What has become of the plants that once occupied what is now cultivated land? They have been driven from the fields, but with probably very few exceptions they all grow now in the hedgerows, river-banks, thickets, and wood-edges.

There are many interesting points connected with the weeds of cultivated soil. A garden or cultivated field is usually surrounded by hedges, pastures, or woods, but its weeds comprise few or none of the plants belonging to the "natural" vegetation close at hand. The weeds have not come from the neighbouring vegetation, and they could not in most cases survive among the crowded hedgerow and meadow plants.

This brings us to the next point—that most of the weeds of cultivated soil are *annuals*. Annual weeds depend almost entirely upon man and his cultivation of the soil. They have doubtless evolved from ancestors which, to escape competition with perennials, grew on rocks, poor soil, sea-shores, etc., and which, owing largely to their rapid growth and profuse seed-production, invaded the fields tilled by primitive man, and will now never leave until the cultivated ground is allowed to return to its natural state. It is unnecessary to point out how annual weeds can flourish, and be free from competition with perennials, in cultivated fields bearing annual crops such as wheat. The origin of many of these annual weeds is very uncertain; for instance, the common Groundsel is never found wild, though the fleshiness of its leaves suggests that its ancestor was a seaside plant (we know this to be the case with several annual weeds).

About one-fourth (about 70 species out of 300) of native British annuals are cornfield weeds; many of them extend over the whole of the temperate regions, but they probably all emigrated from central Europe or central Asia. Most of our remaining wild annuals grow on rocks or hills, at the seaside, and in other places where there is little competition with perennials. That the annual weeds must have rich soil and that they cannot compete on equal terms with perennials is clearly seen in the succession of the vegetation which springs up on a field allowed to remain fallow or on a piece of cleared ground.

During the first year after the clearing we get chiefly annuals (*e.g.* Poppies, Charlock, Chickweeds, Goosefoots, Red Dead-nettle, Spurges, Scentless Mayweed, several Speedwells, Scarlet Pimpernel, Sow-thistle, Shepherd's Purse, Groundsel, Knotgrass, Fumitory). Next year the perennials, some of which may have already got a footing among the quicker-growing annuals, grow steadily and to a large extent crush out the annuals; perennials which do this effectually include Nettles, Docks, White Dead-nettle, Plantains, Milfoil, Thistles, Daisy, Dandelion, Hawkweeds, etc., also such shrubs as Brambles, and various Grasses like Couch-grass, Cock's-foot, etc. By the third or fourth year many of the annuals have disappeared and the ground is largely occupied by the perennials and a few strong biennials (*e.g.* Burdock). The vegetation which settles in fallow or cleared land varies, of course, with the factors of the habitat—exposure, soil-texture, moisture, etc.

In studying **cornfield weeds** (in fields where cereals or other tall-growing crops are cultivated) note (1) the weeds which grow low down, often forming a thicket sheltered by the forest of tall corn stems, *e.g.* Field Pansy, Chickweed, Speedwells, Corn Salads (*Valerianella*, with minute clustered blue flowers), Stork's-bill, Hop Medick, Hop Trefoil, Black Medick, and many others, some climbing up the corn stems (Fumitory, *Polygonum convolvulus*), some appearing early before the corn has grown up (Corn Pansy, Speedwells, etc.); (2) the tall weeds which grow up with the corn and usually flower and fruit at the same time with it, *e.g.* Corn Buttercup, Corn Cockle, Bladder Campion, Evening Campion, Charlock, Poppy, Hemp Nettle, Corn Mint, and many others, mostly having erect main stems, few branches, and narrow entire or divided leaves more or less upwardly directed; (3) the weeds at the edges and corners of the field, *e.g.* Nettles, Goosefoots, Mallow, White Dead-nettle, Black Solanum, Hedge Mustard, Cow Parsnip, etc.

Also make observations, at different times of year, on the vegetation of **rubbish-heaps, pastures, roadsides, railway-banks** (note the differences between **cuttings** and **embankments** with regard to the conditions of life and the plants found), **garden borders, lawns, ballast-hills** beside seaports, **pit-heaps** beside collieries, **waste ground** near mills, etc. On rubbish-heaps and ballast-hills we often find alien plants (brought from foreign countries) along with such plants as Annual Dog's Mercury, Teasel, Docks, Ragwort, Knotgrass (*Polygonum aviculare*), Henbane (2-4 ft., leaves lobed sticky and clammy, flrs. with 5-lobed corolla yellow with purple streaks). Teasel and Henbane often grow in waste places by the sea, and several plants are rarely found except on rubbish-heaps or on rich waste ground beside houses or farm-buildings, *e.g.* Greater Celandine (*Chelidonium*, Poppy family), White Dead-nettle.

The vegetation of a **lawn** is often very interesting. The lawn itself consists of various grasses (species of *Poa*, *Alopecurus*, *Cynosurus*, *Festuca*, *Phleum*, etc.), often mixed with White Clover, but it usually has various weeds which are well adapted to resist the lawn-mower, *e.g.* Daisy, Dandelion, Plantain, Hawkweeds, Thistles, Cat's-ear, Autumn Hawkbit, which have "radical" leaves in a rosette growing close to the soil and kept there by the contractile roots, also coarse rampant Grasses, like Couch-grass which spreads by long underground runners. A damp or ill-kept lawn has a covering of feathery Mosses on the soil, and is often invaded by various weeds which can compete with the Grasses, *e.g.* Buttercups and even Horsetails.

QUESTIONS ON CHAPTER XVI.

1. For what different purposes do you consider that a plant requires to be supplied with water? How are some plants able to withstand long-continued drought uninjured? Give instances of such plants.

2. How does the climate inside a greenhouse differ from that without? Name plants whose natural habitats are in climates (*a*) drier, (*b*) wetter, (*c*) hotter, (*d*) colder than that of an English garden. What arrangements would you make if you had to try to grow these various plants in England?

3. The island of Singapore produces more than 2,000 native species of flowering plants; the Isle of Wight (about equal in area) some 800; an equal area in the Egyptian Desert less than 200. To what causes would you attribute these striking differences?

4. How far do characters of the soil, other than its chemical nature, determine the flora growing upon it?

5. Describe the chief modes of perennation in herbaceous plants.

6. Describe the different localities in which plants store up nutriment in one year for their own rapid growth in the next year, and state the nature of the stored substance in the case of each plant that you cite.

7. What wild flowers have you found growing along the margins of lakes, ponds, and rivers? Distinguish those which grow with their stems (*a*) wholly in the air, (*b*) partly in air and partly in water, (*c*) wholly submerged. Show by sketches what you mean by the zones of vegetation along the water margin.

8. Name any plants growing with their leaves wholly submerged. How do such leaves differ from leaves surrounded by air?

9. Give the names of four water plants and four marsh plants. Mention all the points you can think of in which water plants differ from land plants. Can you give any explanation of the facts described?

10. Write a list of any plants which you have found growing with their leaves submerged in water. How do such plants obtain the gases which they require for respiration and photosynthesis? Describe the surface structure of a leaf (*a*) in a land-plant, (*b*) in a water-plant.

11. What special anatomical peculiarities would you expect to find in water-plants? Explain how the structure you describe is connected with their conditions of life.

12. Enumerate the more common plants which you have found growing in a marsh.

13. Write a list of plants which you have found on moorland walks. What peculiarities of leaf-structure have you observed in any six of these? How does the possession of such peculiarities profit the plant? What was the nature of the soil on which the moorland plants grew?

14. Name all the plants you have found either on a heath or on a moor, distinguishing carefully those which you have *only* found on heaths or moors. Point out any features which you think fit the plants to live in such situations.

15. Mention twelve plants you have found growing in company with the Ling (*Calluna*). Describe the plants on which such plant-associations occur, and any general features of heath or moorland vegetation you have observed.

16. Write an account of the vegetation you might expect to find growing on a swampy moor, and indicate any points in which the plants appear to be structurally adapted to such an environment.

17. Discuss the ecological conditions that may determine the formation of the "Heather-moor," and give some account of the composition of the flora of each moor.

18. How could you distinguish between Ling, Bell Heath, Cross-leaved Heath, and Crowberry, merely from leaf-bearing branches without flowers? Describe the structure of the leaf in each of these four plants, and explain how the structure is adapted to the habitat.

19. Describe the flowers of Ling, Bell Heath, and Cross-leaved Heath, pointing out their differences and explaining the pollination mechanism.

20. Describe the flowers and fruits of Crowberry. Compare this plant with the Ericaceous moorland plants.

21. How can you explain the fact that most moorland plants, *e.g.* Ling, Heaths, Crowberry, are protected against free transpiration, although moors get so much moisture in the form of rain and mist?

22. Why is the vegetation of a high moor dwarfed, with no trees, while low moors (heaths) are often dotted with tall trees?

23. In what respects do many moorland plants agree with plants growing on sandy coasts and in salt marshes? How may these resemblances be explained?

24. What is the difference between a marsh and a bog?

25. Name several different species of plants that you have found at the seaside and not inland. State exactly where and how each was growing, and mention any characters possessed by each that you think fitted it to its particular circumstances.

26. Give an account of the vegetation of sand-dunes in any region you may select, and point out the special adaptations exhibited by the plants to their surroundings.

27. Mention six plants you have found growing (*a*) on shingle-beaches, (*b*) in salt marshes. Distinguish between those occurring only in these habitats and those you have also found inland.

28. Mention eight plants that you have found growing in each of any three of the following situations:—Cornfields, Freshwater Bogs, Shingle Beaches, Sandy Heaths.

29. What plants would you expect to find in *any three* of the following places:—(*a*) an open heath, (*b*) a salt marsh, (*c*) a Freshwater pond, (*d*) chalk downs?

30. What would you infer as to the characters of the soils in which the following plants were severally to be found growing?—Spurrey (*Spergula arvensis*), Coltsfoot, Rush (*Juncus communis*), Cotton Sedge, Wood Sage (*Teucrium*), Bee Orchid.

31. Give several examples of groups of plants which grow together in the same habitat or locality and flower at about the same season. Why do these plants grow side by side, what causes bind them to special localities, and why do they flower simultaneously?

32. Mention eight plants that you have found growing on open roadsides (not much shaded by hedges), and eight that you have found growing under the trees of a wood. Have you noticed any characters of these two groups which seem to you to have anything to do with the difference of habitat?

33. Show, by reference to alpine plants, to the carpet of spring flowers in woodlands, to flowers of foreign origin in English gardens, to the lack of flowers in hayfields after July, and by other illustrations, that the competition of neighbouring plants is one important condition of plant-life.

34. Name the month or months of flowering of each of the following plants: Alder, Ash, Beech, Bluebell (Wild Hyacinth), Coltsfoot, Elder, Gorse, Hazel, Honeysuckle, Horse Chestnut, Ivy, Laurustinus, Lesser Celandine, Ling, Oak, Pine, Ragwort, Red Campion, Snowdrop, Sweet Chestnut, Tormentil, Water-buttercup, Water-mint, Wood-anemone, Wood-sorrel.

35. Give an account of any observations you may have made on the colonisation by plants of land bare of vegetation. What characters enable plants to colonise such land?

36. What other plants have you found growing among the grass of a garden lawn? Explain why these plants are able to grow there, and show how the garden-mowing machine or scythe and other causes select or influence the flora of the lawn.

37. Mention the six most troublesome weeds in any garden with which you are well acquainted. Explain carefully, so far as you can, the reasons why each is specially troublesome.

38. Describe the vegetation of an Oak *or* Sycamore wood, naming the plants observed and the dates of flowering. Compare the vegetation with that of a Beech wood. How do you account for the difference?

39. Suppose you were asked to write a report on the vegetation of some particular acre of ground (heath, common, meadow, marsh, woodland, moor, or hillside), how would you set about the task? What would you try particularly to find out? What observations and notes would you make? How much time would you wish to be allowed for the inquiry?

APPENDIX I.

THE LIFE HISTORY OF A FERN.

The Fern Family.—The life history of a Fern differs considerably from that of a Flowering Plant. The highest order of plants, including what are usually called Phanerogams, or Flowering Plants, is divided into two groups, the Gymnosperms and the Angiosperms (see Art. 295). We have in the body of this book dealt almost exclusively with the Angiosperms, though the Pine, which is a Gymnosperm, has been partly described; further details of the Pine and its life history are given further on.

The Ferns belong to the group often called the Cryptogams, or Flowerless Plants. But the Ferns differ from all other Cryptogams—seaweeds, fungi, lichens, mosses—in having vascular tissue (wood vessels and sieve-tubes), hence they are placed in a higher group than these plants, the group known as Vascular Cryptogams and including the horsetails and clubmosses as well as the ferns.

Most ferns grow in moist and shaded places, but several kinds are adapted for life in dry and exposed habitats. Two of the most familiar British ferns are the Male Fern of the woods and hedgerows, and the Bracken of the open hills and commons. Since one or other of these ferns can be obtained for study very readily, we shall take them as types of the Fern Family.

The **Male Fern** is easily distinguished from other woodland ferns by its sturdy and robust growth, its massive rhizome, its rosette of large compound leaves, and the kidney-shaped scales dotted about on the lower surface of the leaf.

Pull up a plant in summer, wash its roots free from the soil, and study its external characters. The Male Fern is very readily transplanted into a garden, and observations should be made upon it at different times of the year.

The stout and hard stem, or rhizome, is almost erect, its growing end reaching the surface of the soil. Its surface is covered with the crowded stumpy remains of the leaves of previous years (Fig. 1 A). The leaves die down in autumn, but their withered bases are left on the stem, densely covered with brown scales. The stem itself very rarely branches, but buds are sometimes formed on the bases of the leaves—a bud on each leaf—and these buds may become detached and give

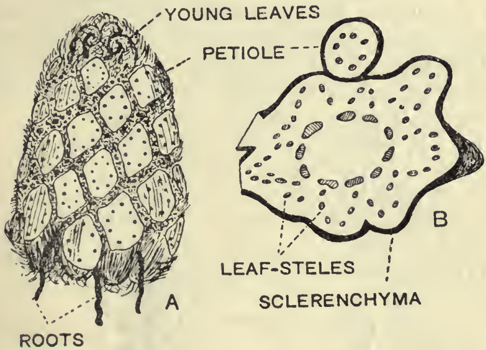

Fig. 1.—Rhizome of Male Fern.
A, Upper part, from which the older leaves have been cut off at the base and most of the roots removed; B, diagrammatic transverse section.

rise to young plants, hence the fern has a method of vegetative propagation. The wiry roots are given off from the bases of the leaves.

At the front of the stem, within the expanded leaves, are seen the young leaves which will unfold next spring and the next again. A rosette of leaves is formed each year, but each leaf takes two years to develop. All the young leaves, as well as the stalks of the expanded ones, are densely clad with the small brown scales, which protect them from cold and drought. The large expanded "fronds," or leaves, are pinnately compound. Note, in each leaf, the long cylindrical main leaf-stalk, showing two ridges along its sides; the pinnae, or leaflets, given off by this main stalk, in two rows corresponding to the ridges; and the lobes into which each leaflet is again divided, also arranged in two opposite rows. We shall return later to the mature leaf.

Note that the young leaves are curiously coiled, each being rolled up on itself like a watch-spring, from tip to base; the expansion, or unrolling, of the leaf should be watched in early summer. Not only is the main leaf-stalk rolled up in this way, but the leaflets are also rolled up on themselves. On picking off the scales which cover the growing tip of the stem, the youngest leaves can be seen; in their first year the developing leaves consist chiefly of the stalk, the

Fig. 2.—Part of the Vascular System of Male Fern dissected out.

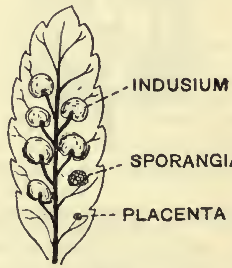

Fig. 3.—Pinnule of Male Fern bearing Sori. The indusium has been removed from one sorus, the indusium and sporangia from another.

rest of the leaf being very little developed. At the very tip, or growing-point, itself still younger leaves can be seen, as minute projections from the soft and delicate tissue of the stem apex.

On cutting across the stem, we find that a large part of its thickness is made up by the old leaf-bases. The whitish ground tissue contains starch and gum, and in this tissue are embedded numerous brownish strands—the vascular bundles. The central ring of thicker bundles belongs to the stem itself, while the thinner bundles towards the outside belong to the leaves (Fig. 1 B). At the outside of the stem there is a layer of hard tissue (sclerenchyma), consisting of fibres. If the older part of the stem is cut off and steeped in water or dilute hydrochloric acid for some days, the soft ground tissue can easily be removed by using a hard brush, the bundles remaining behind as a skeleton. This skeleton resembles a piece of wire netting rolled up into a tube; the meshes of the network correspond to the insertions of the

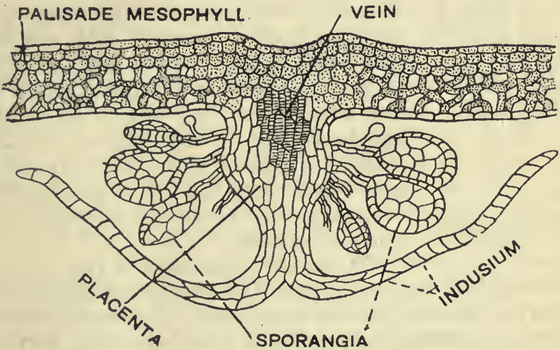

Fig. 4.—Sporangia of Male Fern.
Transverse section through a pinnule and sorus.

leaves, and are called the foliar gaps, while the bundles passing out to the leaves are given off as branches from the edges of these gaps (Fig. 2).

On examining a leaf in summer, one sees a number of small kidney-shaped projections on its lower surface, arranged in two rows on each of the divisions of the leaflets. These projections are at first of a light green colour, but when older they become brown. These are the sori (Fig. 3). Each sorus consists of a collection of small stalked bodies, the sporangia or spore-cases, and on removing the kidney-shaped structure (which covers the group of spore-cases and is called the indusium), it is fairly easy to make out that the spore-cases are all attached to a little projection of the leaflet, called the placenta, and that this placenta is seated on one of the veins (Fig. 4). The veins of a fern leaf end in a very characteristic manner; they undergo repeated forking, the ends of the final forkings being free from each other and not united to form a network.

The fully developed sporangium is oval in outline and biconvex, or lens-like, and has a slender stalk (Fig. 5). Its wall consists of a single layer of cells, and the cells round the edge, starting from the stalk and going over the top of the sporangium halfway down the other side, are large and thick-walled. This row of cells is called the annulus, or ring, though it is not a complete ring but is replaced on the lower half of one edge of the sporangium by thin-walled cells. Inside the spore-case there is a brown powdery mass consisting of the spores, generally sixty-four in number.

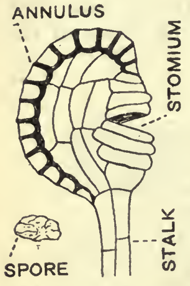

Fig. 5.—Sporangium and spore of Fern.

When the spore-case is ripe, the cells of the ring lose water, contract, and thus put a strain on the thin part of the wall of the spore-case. Eventually the ring springs back, straightening itself and becoming curved in the opposite direction; this takes place suddenly, and the spores are flung out; the place where the ring is incomplete is called the stomium, or mouth, but as a matter of fact it is merely the place where the tearing open of the spore-case occurs, for the spores are jerked out in all directions when the ring bends back, and the spore-case is soon emptied of the spores.

If mature but still intact spore-cases are mounted in water on a slide, the explosion may be watched if glycerine is placed at one edge of the cover-glass and drawn through by means of a piece of filter-paper placed at the opposite edge. The explosion can also be seen if a number of ripe spore-cases are mounted on a dry slide, which is then gently warmed and quickly placed again under the microscope. If now you select for observation a spore-case which has burst open and is lying upon the dry slide, and breathe on the slide, you will see the ring returning to its original curved position; then as it dries again it again becomes straightened out.

From these observations it is clear that the ripe spore-cases burst open in dry weather and scatter the spores, which are very light and easily carried about by the wind. The indusium protects the young growing spore-cases, and becomes shrivelled up and withered when they are ripe. The spore-cases are also protected by being produced on the *lower* side of the leaf.

The spores are very small, and are one-celled bodies, with a thick outer coat and a thin inner coat. The spores of ferns and other flowerless plants are sometimes called seeds; but it is clear that a spore is very different from, and almost infinitely simpler than, a seed. A seed contains a young plant, with cotyledons, root, and shoot, and often a store of food outside of the embryo as well; a spore is a single cell.

What becomes of the spores when they are set free? Instead of searching the neighbourhood of the plant itself, sow the spores and keep them under observation indoors. Dry a leaf on a sheet of paper, which will soon be covered with the dust-like brown spores, and sow them on soil or bits of brick or tile. The soil (lumps of peat or leaf-mould are perhaps best), or the bits of brick or tile, should be either baked in a hot oven for some hours, or else steeped in boiling water, to destroy the germs of fungi that are apt to damage or destroy the germinating spores. Shallow dishes should be used, with some water in them, for the spores should not be watered from above; this would wash them away. The cultures should be shielded from direct sunlight, that the spores may germinate more rapidly.

On germination, for which the same things are essential as in the case of a seed—oxygen, water, and warmth—the outer coat of the spore breaks open, and the contents escape, covered by the thin inner coat, as a green thread, from which a colourless thread (root-hair, or rhizoid) is given off into the soil. The green thread grows along the surface and soon its end broadens out (Fig. 6). Eventually a heart-shaped green plate, the prothallus, is formed; it is about one-third of an inch across.

The prothallus consists of angular cells, containing abundant chloroplasts. Towards the margins it is only one cell in thickness, but the central part, or cushion, consists of several layers of cells. Long root-hairs grow from the lower surface. The prothallus is an independent plant. By means of its chlorophyll it can assimilate the carbon dioxide of the atmosphere, and by the aid of its root-hairs it absorbs water and salts from the soil. Owing to its thinness, gases can penetrate to all parts, hence no stomates are required. The upper surface of the prothallus is quite smooth, but on the lower surface there are, besides the root-hairs, two kinds of projecting bodies, in which are formed the germ-cells. These bodies can be seen with a lens, or with a low power of the microscope.

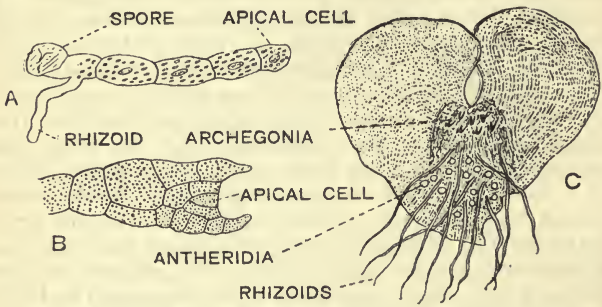

Fig. 6.—Germination of Spore and Development of Prothallus of Fern.

At the front of a well-grown prothallus, just behind the notch, there are several little finger-like projections, situated on the cushion; these can be seen on washing the soil from the underside and holding the prothallus up to the light. These are the archegonia, or egg-producing organs. Each archegonium is a minute flask of which only the neck projects from the surface, pointing backwards—towards the pointed hinder part of the prothallus. The base of the flask is embedded in the tissue of the cushion, and contains the egg-cell. Behind the archegonia there are numerous smaller bodies, scattered over the whole underside of the prothallus; these are spherical bodies, called antheridia, in which the male germ-cells, called antherozoids, are produced.

In examining with the microscope a prothallus mounted in water—the underside being placed upwards—one may see an antheridium burst and set free the male cells. These are coiled bodies, with a number of fine threads at one end and a little bladder at the other. The threads are for swimming, lashing about and propelling the male cell, which rotates as it advances through the water; the little bladder contains starch—a store of food for the journey to be taken by the male cell in its search for an archegonium. In this search, it is helped by an attractive substance given out into the water by the ripe archegonium. The cells in the neck of the archegonium become gummy when ripe, and when the gum absorbs water it swells and causes these neck cells to force open the tip of the neck, leaving a clear passage down to the egg-cell.

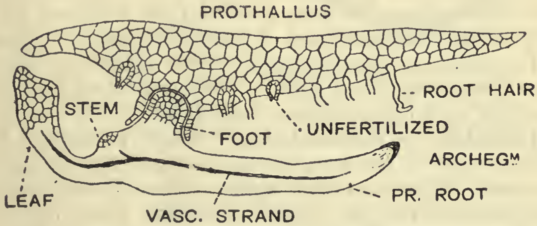

Fig. 7.—Embryo of Fern attached to Prothallus. (Longitudinal section.)

The gummy liquid that exudes from the open neck of the ripe archegonium contains malic acid, and as this diffuses through the surrounding water it attracts the antherozoids, one or several of which may enter the neck and swim down to the egg-cell. Eventually one male cell enters the egg and blends with it, fertilising the egg-cell, and the fertilised egg then grows into a young fern plant with stem root, and first leaf (cotyledon). We know that malic acid (which is present in apples, and so gets its name) occurs in the fern prothallus; and if a fine capillary tube is filled with a solution of this acid and pushed under a cover-glass into water which contains male cells, the latter swim towards the opening of the tube and crowd into it as if it were an archegonium.

Returning to our prothallus cultures, after a month or two we notice a few small leaves growing out from the notch, and on turning the prothallus over we can trace these leaves to the underside at a point where the young roots also arise and grow into the soil. The young plants, with the attached prothallus, should be thinned out if they are crowded, and they can be transplanted to a pot of soil, when they will gradually grow into adult ferns. Before long the prothallus itself withers and disappears.

While the young fern plant was attached to the prothallus it had a special absorbing organ, called the foot, which drew food from the tissue of the cushion; hence the embryo fern consisted originally of four parts—cotyledon, stem growing-point, first root, and foot (Fig. 7). The stem grows very slowly at first, as compared with the cotyledon and the succeeding leaves; the first root is soon replaced by other roots growing from the base of the young stem. The young fern is rather exceptional among green plants in being able to turn green even when kept in darkness, though it does not thrive, but soon dies, unless it gets light.

Alternation of Generations.—It will be noticed that in the life-history of the fern there are really two plants to be considered. These are often spoken of as the two stages, or generations, of the life cycle. The fern plant, by far the larger and more conspicuous of the two, is called the sporophyte, or spore-producing plant. The prothallus is called the gametophyte, because it produces the gametes or germs.

The life cycle of the fern, therefore, is a regular alternation of sporophyte and gametophyte, and this is called the alternation of generations. It will be noticed that both generations begin their development from a single cell, the young sporophyte (fern plant) from a fertilised egg-cell, the gametophyte (prothallus) from a spore. The vegetative propagation of the fern plant, in our type by the breaking off of buds from the bases of the leaves, has no share in the alternation of generations, except that it merely lengthens out the life cycle.

The **Bracken**, which agrees with the Male Fern in all essential respects, differs a good deal from it in details. It covers large areas, especially on heaths and commons, though it sometimes grows in woods, where it may reach a height of five feet, whilst in exposed places it is often stunted and hardly over a foot high. The "frond," or leaf, the portion of the plant which comes above ground, is often mistaken for the whole shoot, or leafy stem. The real stem, or rhizome, creeps underground, often more than a foot deep, and is very different from that of the Male Fern. It burrows along horizontally in the soil, giving off roots all over its surface and only sending up the large compound leaves here and there.

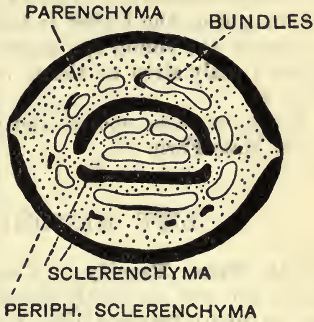

Fig. 8.—Rhizome of Bracken.
(Diagrammatic transverse section.)

Dig up a whole plant and examine the stem. Note the withered bases of the leaves of former years, and the young leaves for next year. The latter are small knobs, covered with brown scales. The stem usually branches once a year, and the growing tips of the branches are covered with scales like those on the young leaves. Each branch, as a rule, produces only one leaf each year, and the leaves are spaced out on the stem and arranged in two rows, right and left. The stem is black in the older parts, except for two lighter lines which run along each flank.

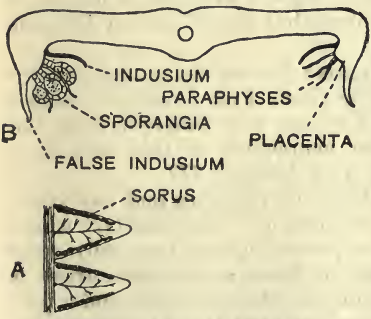

Fig. 9.—Sporangia of Bracken.
A, Two fertile pinnules; B, Transverse section of pinnule.

On cutting across the stem, note the hard blackish band of fibrous tissue which surrounds it except at the light lines just mentioned; these light lines, where the soft whitish ground tissue is exposed at the surface, probably serve for exchanges of gases and may be compared with the lenticels on woody stems. The ground tissue is traversed by dark-coloured bands, consisting of fibres, and by lighter coloured strands which are the vascular bundles (Fig. 8).

The spore-cases are in sori at the edges of the leaflets, and the margin of the leaflet is turned in towards the underside to protect the young spore-cases. A section across a leaflet shows a scaly strip of tissue on the inner side of the sorus (Fig. 9).

The spore-cases, spores, and prothallus are similar to those of the Male Fern.

LIFE HISTORY OF A PINE.

The Pine Family.—The Gymnospermous Flowering Plants are not so highly differentiated as the Angiosperms, and in many respects they resemble the Vascular Cryptogams, forming an intermediate group between these two. They are large plants, usually trees. In the Angiosperms, the ovules, or "young seeds," are enclosed in a cavity, the ovary, but in the Gymnosperms the ovules are freely exposed, since the carpels if present are not closed up to form ovary, style, and stigma. The flowers are always unisexual and generally on the same plant, but sometimes on different plants (Yew, Juniper, etc.).

Scots Pine.—The only native British Gymnosperms are the Yew, the Juniper, and the Scots Pine (sometimes called the Scots *Fir*, though the Firs are very different from the Pines). The main external characters of this tree have already been described; see Arts. 180 and 377.

The plant produces two kinds of branches and two kinds of leaves. The ordinary branches, or "long-shoots," which are produced annually in apparent circles, bear only scale leaves. In the axil of each of these scales there arises a dwarf shoot, which bears a number of scale leaves and a pair of foliage leaves, or "needles" (Fig. 10). In some Pines "needles" are produced in threes or fives instead of pairs.

In the general arrangement of the tissues the stem of the Pine resembles that of a Dicotyledon. A young twig, in its first year of growth, shows a ring of bundles in cross section. Between the bundles there are narrow medullary rays which connect the pith with the cortex; in the cortex there are conspicuous resin passages, lined by a layer of epithelium cells which secrete the resin; and the wavy surface of the section (the ridges being the leaf-bases) is covered by a very distinct epidermis and cuticle. Narrow resin ducts are present in the wood of the bundles.

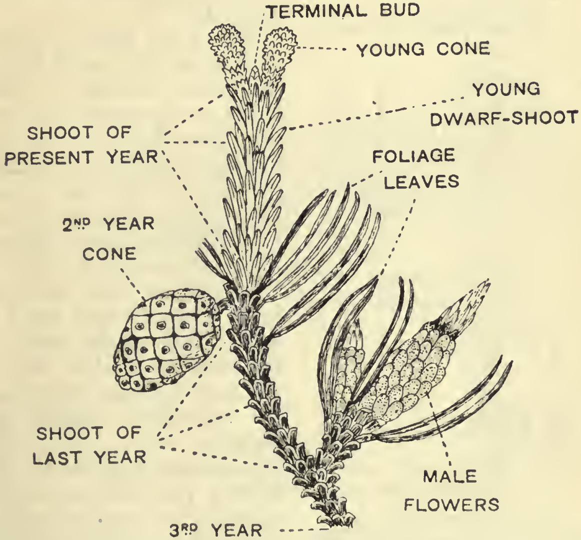

Fig. 10.—Branch of Pine cut in May.
Most of the older dwarf-shoots and foliage leaves removed.

The conducting tissues of the Pine stem are simpler in structure than in the case of a Dicotyledon, and presents some characteristic features. The wood contains no true vessels, or continuous tubes formed by fusion of rows of cells, but consists of long tapering cells resembling fibres in form, but showing various forms of thickening. In the innermost part of the wood, these structures, called tracheids, bear spiral and ring-shaped thickenings, but in the secondary wood each tracheid bears on its two radial faces (the tracheids are square in cross section, Fig. 11) a row of curious pits. Each of these "bordered pits" appears in surface view (that is, in a radial longitudinal section—a longitudinal section taken through the centre of the stem) as two concentric circles (Fig. 12).

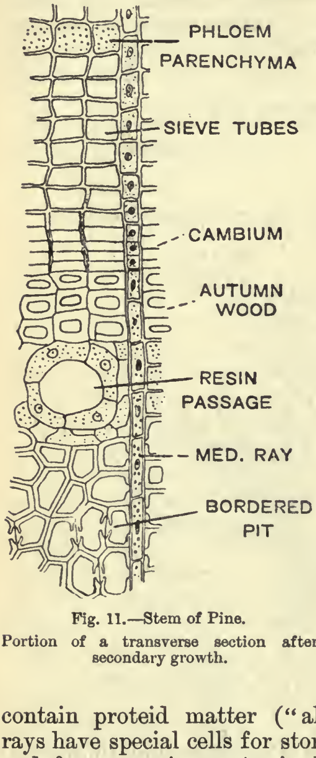

Fig. 11.—Stem of Pine.
Portion of a transverse section after secondary growth.

The bast, which is separated from the wood by the cambium, consists of sieve tubes and parenchyma cells, the sieve tubes being long narrow cells with the sieve plates on the side walls (Fig. 12). The medullary rays, however, are more complex in structure than in Dicotyledons, and are made up of three distinct kinds of cells. Both in the wood and the bast, the middle cells of the rays contain starch, and are therefore called the "starch cells" (Fig. 12). The upper and lower cells of the ray are empty and pitted ("tracheidal cells") in the wood portion of the ray, but where the ray traverses the bast these cells contain proteid matter ("albuminous cells"). Thus the rays have special cells for storing starch, for storing proteids, and for conveying water in different directions, in addition to their important function of binding together the successive shells of wood which are formed each year.

Figs. 11–13 show transverse, and radial and tangential longitudinal sections of the wood. A radial, longitudinal section is one which passes through the middle of the stem; a tangential longitudinal section, one taken peripherally. Thus a radial section runs parallel to the medullary rays in the region in which it is taken, while a tangential section cuts *across* them. This will explain the difference in the appearance of the medullary rays in the two sections. The differences in the appearance of the bordered pits are due to the fact that the tracheides are four-sided, two of the sides being approximately radial and two tangential, and that the bordered pits are confined to the radial walls. Thus, in radial section, the radial walls are not cut

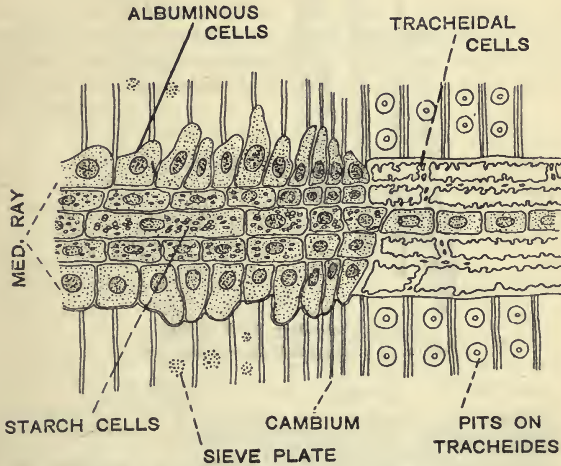

Fig. 12.—Radial Longitudinal Section of Stem of Pine.
The section is taken at the junction of secondary wood and phloem.

through and the pits are seen in surface view; while in tangential section, the radial walls are cut through and the pits are seen in section (Fig. 13).

Fig. 14 shows a transverse section of the foliage-leaf. The **epidermis** consists of extremely thick-walled cells with a strong cuticle. Owing to the erect position of the leaf stomata are developed all over its surface. The guard-cells are sunk beneath the level of the epidermis, so that there is an outer cavity leading down to the stoma. Beneath the epidermis there is a fibrous sclerenchymatous **hypodermis** interrupted beneath the stomata.

The parenchymatous **mesophyll** consists of thin-walled cells, whose walls show numerous peg-like infoldings of cellulose projecting into their cavities. The presence of these is probably connected with the feeble development of air spaces

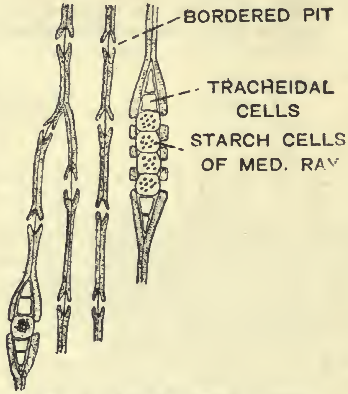

Fig. 13.—Secondary Wood of Pine. Portion of a tangential longitudinal section

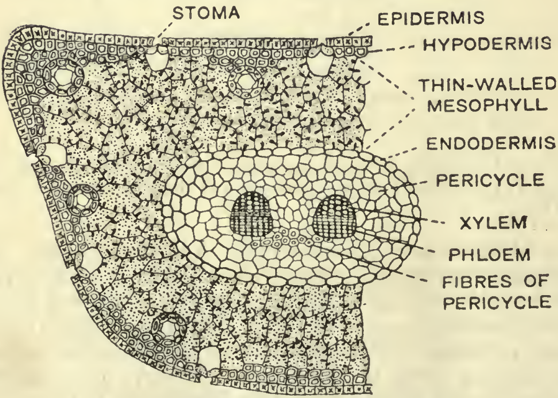

Fig. 14.—Transverse section of Leaf of Pine.

in the leaf, for they increase the internal surface of the cell-wall, and hence also the excreting and absorbing surface of the protoplasm. The cells contain numerous chloroplasts and starch-grains. The mesophyll is not differentiated into palisade and spongy layers. In the mesophyll, immediately under the hypodermis, are a number of *resin-passages*, each with a thin-walled epithelial layer and an investing strengthening layer of sclerenchyma.

In the middle of the leaf there is a conspicuous **endodermis** surrounding a many-layered **pericycle**, in which two **vascular bundles** are imbedded. The bundles are collateral, the xylem facing towards the flat upper surface; there is a rudimentary cambium.

The pericycle contains cells of two kinds :—(*a*) parenchymatous cells containing protoplasm, proteid, and starch; (*b*) similar cells with bordered pits and no contents, resembling tracheides and called tracheidal cells. This peculiar tissue is called **transfusion-tissue**. It is characteristic of the leaves of Gymnosperms. It helps in the transference of nutritive solutions, and thus makes up for the poor development of vascular tissue. The tracheidal cells serve for the passage of inorganic solutions from the vascular bundles to the mesophyll; the other cells for the diffusion of elaborated compounds from the mesophyll to the phloem. In addition to the transfusion-tissue, a number of fibres are developed in the pericycle near the bundles.

The general characters of the male and female flowers have already been described (Art. 377). The male flowers differ from those of most Angiosperms in that the axis (corresponding to the receptacle) is elongated, there are two pollen-sacs instead of four, and there is no perianth. The female flower or cone, when young, shows a stout axis, which bears scales of two kinds:—(*a*) small scales arising directly from the axis—the bracts or cover scales; (*b*) stouter scales developed one on the upper surface of each bract—these are the ovuliferous scales, each bearing two ovules on its upper side. In comparing the female flower of the Pine to an Angiosperm flower, the bract or cover scale is regarded as representing the carpel, and the ovule-bearing scale as corresponding to the placenta from which arise the ovules in the ovary of an Angiosperm.

When ready for pollination, the Pine ovule consists of a mass of tissue called the nucellus, covered by a single integument

(Fig. 15). The pollen-grains, carried by the wind, are brought directly to the micropyle, which contains a gummy fluid, and as this fluid dries up and contracts the grains are drawn down to the surface of the nucellus. Then the cone closes up and grows much larger—owing to increase in thickness of the axis and of the ovule-bearing scales. Pollination occurs in May or June, and during the ensuing winter the cones are green and closed up—not to open again until the seeds are ripe.

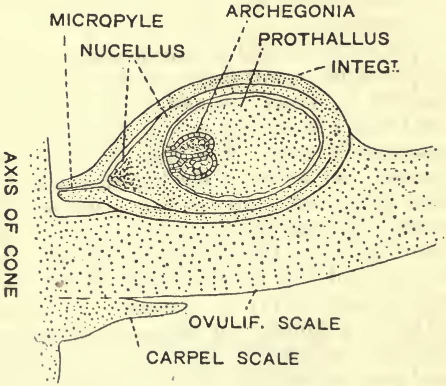

Fig. 15.—Ovule of Pine.
(Longitudinal section—about the time of fertilisation.)

About a year after pollination has been effected, the actual process of fertilisation occurs. In the meantime changes have been going on inside the ovule. A cell at the upper end of the nucellus (the end nearest the micropyle) grows large and then divides up and forms a mass of tissue—often called the "primary endosperm"—in which several archegonia are formed at the end nearest the micropyle. These archegonia differ from those of the Fern in having very short necks and in being buried below the nucellus, instead of projecting freely from the surface of the plant. Then the hitherto dormant pollen germinates, sending pollen-tubes (Fig. 16) down through the nucellus, and carrying the male fertilising nuclei, which enter the necks of the archegonia and fuse with the egg cell.

The fertilised egg grows and divides in such a manner as to form four rows of cells at the lower end of the "primary endosperm." Then these rows separate from each other, and each grows to form an embryo (Fig. 17). Since there are often four or five archegonia, and each fertilised egg gives

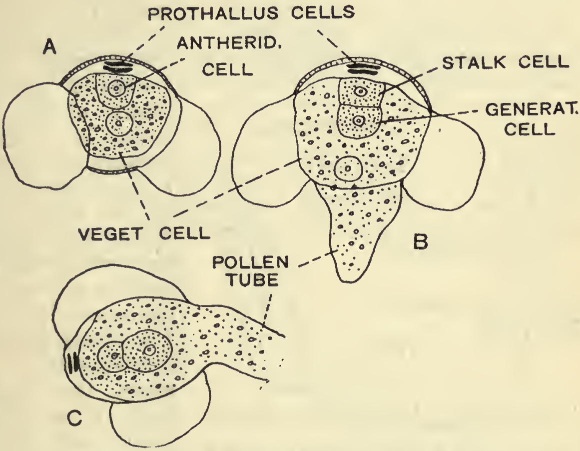

Fig. 16.—Stages in the Germination of the Pollen-Grain.

A, B, early stages in *Picea*, the Spruce, where the antheridial cell divides shortly after pollination ; C, late stage in Pinus.

rise to four young embryos, a single ovule may contain about a score of embryos, which are pushed down into the "primary endosperm" by elongation of their suspensors. Eventually, however, only one of these competing embryos survives in the ripe seed.

In the meantime the tissue we have called "primary endosperm" grows actively and forms the endosperm of the ripe seed, and the successful embryo which lies in its midst consists of root, shoot, and a circle of about a dozen cotyledons. The ripe seed is therefore endospermic. It is furnished with a thin wing, which is formed from the surface tissue of the ovule-bearing (or seed-bearing) scale, and which aids in its dispersal by the wind when the ripe cone opens by lengthening its axis and so separating the seed-bearing scales from each other.

Now, if we compare the structure of the ovule and the mode of fertilisation in the Pine with the life history of the Fern, we can see that the tissue we have called the "primary endosperm" in the Pine ovule corresponds to the prothallus of the Fern, since it produces archegonia essentially similar to those of the Fern. The cell in the nucellus from which the prothallus, or "primary endosperm," of the Pine arises therefore corresponds to a spore, the nucellus itself to a sporangium, and the integument to an indusium.

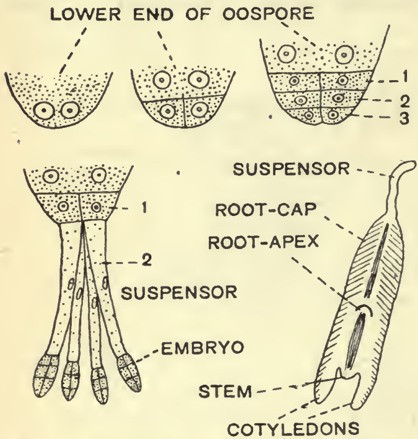

Fig. 17.—Segmentation of Oospore and Development of Embryo of Pine.

Only half the number of nuceli, cells, and rows of cells, is, of course, shown in the early stages.

The "female spore" of the Pine, however, is never set free from its spore-case, but germinates inside it; the prothallus it produces remains enclosed in the spore-case, within which also the embryo is formed; while the whole of these structures remain attached to the Pine plant. This chain of processes leads up to the sharpest distinction between the Gymnosperms and the Vascular Cryptogams, namely, to the production of the seed.

In order to understand clearly the correspondences and differences between the life histories of the Fern and the Pine, however, we should have to study a Vascular Cryptogam in which two kinds of spores are produced—such a type as Selaginella, for instance.

In Selaginella the small spores correspond to the pollen-grains of the Pine (and those of the Angiosperm), while the large spores correspond to the nucellus cell which in the Pine produces the "primary endosperm" or female prothallus, and in the Angiosperm produces the embryo-sac. The small spores of Selaginella, on being set free, germinate by cutting off a small cell (representing the male prothallus) from the rest of the spore, which forms an antheridium similar to that of a Fern, and like it producing active swimming male cells. The small spores (pollen-grains) of the Pine, when they germinate, cut off several prothallus cells, and from the rest of the grain two male cells are formed, but these are not set free to swim about: they are carried to the archegonium by means of the pollen-tube.

In some Gymnosperms, however, a cavity filled with liquid is formed in the nucellus just above the prothallus, the pollen-grain bursts open, and the male cells swim in the liquid of this "pollen-chamber" by means of numerous fine protoplasmic threads.

APPENDIX II.

NOTES ON THE SOIL.

The Soil is the medium in which land-plants may place their roots in such a manner as to enable them to stand erect in the light and air, and it is a storehouse of moisture for the use of plants. The productiveness of a soil depends largely on the amount of water it can hold, and on the readiness and completeness with which plants growing in it can withdraw the water for their use as required. The soil is also a storehouse from which plants get the necessary ash ingredients of their food, the lime, potash, phosphoric acid, etc., which are formed by the breaking-down and solution of the soil-grains. The soil is also a laboratory in which various lowly plants (fungi and bacteria) are at work breaking down dead organic matter, and converting it into nitric acid and other forms in which it becomes available for the use of higher plants.

The Earth's Crust.—By this term we understand the portion of the earth's exterior which comes within our observation. Its thickness is about 10 miles, so that it represents only a relatively thin layer. Since the average density of the crust (2·8) is just about half that of the earth as a whole, it is clear that the interior must have a very high density, and cannot have either the same chemical composition or physical characters as the outer layer.

Rocks.—A rock may be defined as any mass of naturally occurring solid substance forming part of the earth's crust. Rocks may be divided into two main groups: (1) those formed by cooling, at or near the earth's surface, of masses of molten material, and termed *igneous* rocks; (2) those formed by the accumulation of material derived from pre-existing rocks, and termed *aqueous*, *stratified*, or *sedimentary* rocks. To the former group belong granites and basalts, and most of this group are crystalline rocks. To the latter group belong sandstones, clays, limestones; most of these have been laid down under water, and they are not usually crystalline.

Elements of the Earth's Crust.—Comparatively few elements enter into the composition of the common rock-forming minerals (quartz, felspars, micas, hornblende, augite, olivine, calcite, gypsum, kaolin, iron ores, etc.), and about eight out of the eighty elements now known to chemists form about 97 per cent. of the earth's crust. The percentages of these elements are: oxygen 50, silicon 25, aluminium 7, iron 5, calcium 3, magnesium 2, sodium 2, potassium 2. Other elements which, though present in relatively small quantities, are widely diffused and of considerable importance, are hydrogen, carbon, nitrogen, phosphorus, sulphur, chlorine. Only six of all the elements mentioned occur in the free state—namely, carbon, oxygen, nitrogen, sulphur, hydrogen, and iron, the last two only in very small quantity.

Origin of Soil.—There are many agencies at work in the formation of soils, and the processes of soil-growth are in continuous operation. All soil-material is formed by the breaking down of rocks, and soils may be divided into two classes: (1) sedentary soils, formed from the underlying rock; (2) transported soils, which after their formation have been carried into their present position by water, ice, or wind. A sedentary soil has many of the characters of the rock below it, but is usually darker in colour, owing to the presence of organic matter or to exposure to the air, or to both causes. Between soil and rock there is an intermediate layer, the subsoil, consisting of partly broken-down rock and differing from the soil in texture, composition, and colour.

Most rocks consist of fragments or crystals held together by cementing material or by interlocking. The texture is seldom so close as to make the rock impervious to water; even the most close-grained granite or the finest marble will absorb water. The chief agents that cause the "weathering" or breaking-up of rocks and the formation of soil are rain, changes of temperature, frost, the air, earthworms, and the roots of plants.

Rain-water in falling through the air dissolves a certain amount of oxygen and carbon dioxide, which help it in dissolving minerals in rocks. The oxygen oxidises some of the rock substances—*e.g.* rocks containing iron have a red colour due to iron oxide. The carbon dioxide gives the water an acid action so that it can dissolve carbonates and some other substances insoluble in water alone. The mechanical effect of water in wearing down rocks is well known; soft rocks like clays and sandstones are often broken up merely by the beating of rain on their surface, and even the hardest rocks may be worn down by running water, especially when it carries sand or mud in suspension. Besides the direct action of water, there is the action of water under the influence of frost. If water is in the crevices of a rock when freezing occurs, its expansion pushes asunder masses of rock, and the same action breaks up rock-fragments and further pulverises the soil itself.

Apart from freezing, mere change in temperature tends to break up rocks, especially when the change is large and rapid. The sun's heat during the day expands rocks, and the rapid radiation of heat after sunset causes them to cool and contract. The effect of these alternate expansions and contractions is to crack the rock and loosen the particles on the surface, and the effect is increased by the fact that the different minerals in rocks do not expand and contract equally. Even in this country one often notices a difference of about 30° C., and sometimes more, between the temperature during the day and the minimum temperature at night.

The air helps in breaking up rocks in two ways: (1) chemically, by its oxygen uniting with other substances and producing softer materials; (2) mechanically, by the wind carrying dust and wearing down rocks, and also causing rain to beat on rock surfaces.

Sedentary and Transported Soils.—As a rule the rocks from which a soil is derived are found on digging down, but sometimes the soil-materials have been derived from distant rocks by the action of running water, wind, and ice-sheets.

(1) Sedentary soils, in which the products of weathering remain where they are formed, only occur where the surface is fairly horizontal or where plants are growing. The latter prevent the broken-up material from being quickly carried away by rain, and also by their growth assist in the further breaking-up of the rock. Sedentary soils are chalky, sandy, or clayey, according as the underlying rock was limestone, sandstone, or clay. These form the three chief types of soil, but there are of course gradations from one to the other. In the case of limestone, water containing carbon dioxide often dissolves away the lime and magnesia, leaving the less soluble portions of the rock to form the soil. These portions are usually clay and fine sand, so that a soil formed in this way is often clayey, and may contain less lime than other soils not derived from limestone.

(2) The mud carried by every stream after rain is an example of soil in the process of transportation. Another is seen in the way rain washes soil from hill-sides, or from sloping fields (the cultivation of soil helps the action of water in this case, since the surface is repeatedly disturbed by ploughing, etc.). Notice the difference in level of the soil surface when a hedge runs across a slope; the soil carried down the slope is stopped by the hedge or fence, and is gradually piled up against its upper side, while at the lower side the soil is usually carried away, leaving the hedge or fence higher above the surface. In books on Physical Geography you will find accounts of the formation of deltas, alluvial plains, etc., by rivers, also of the action of glaciers and ice-sheets.

The Nature of Soil.—Dry soil consists chiefly of small fragments of rock of various kinds, usually with varying amounts of organic matter derived from the breaking down of plant and animal tissue. This organic matter, or *humus*, can be removed from the soil by burning it. The soil-grains are coated with substances which have been dissolved in the soil-water, and have been deposited when the water evaporated.

Mechanical Analysis of Soil.—The amount of humus in soil is easily ascertained by drying the soil, weighing, then burning the soil thoroughly on a clean shovel or in a porcelain crucible and weighing again. The *texture* of soil is ascertained most readily by the use of sieves. The finest particles (silt-clay) pass through a sieve with 0·05 mm. mesh, and by means of a second sieve with 1 mm. mesh we can separate the residue into sand (passing through) and gravel (remaining on sieve). The structure of the soil is then expressed in percentages, *e.g.* gravel 10 per cent., sand 20 per cent., silt-clay 70 per cent.

Dry some soil by spreading it out on paper and exposing it to the sun in a dry place; weigh out 100 grammes of the dried soil, stir it up in a dish with hot water, transfer to a fine sieve (0·5 mm. mesh), and wash the finer particles through with the help of a camel-hair brush and then with a stream of water. The residue, or "soil skeleton," is then dried and weighed.

By using a series of sieves we can divide the "skeleton" into (1) coarse gravel, left on sieve with 4 mm. mesh, (2) medium gravel, left on 2·5 mm. sieve, (3) fine gravel, left on 1 mm. sieve, (4) coarse sand, the residue which passes through the 1 mm. sieve.

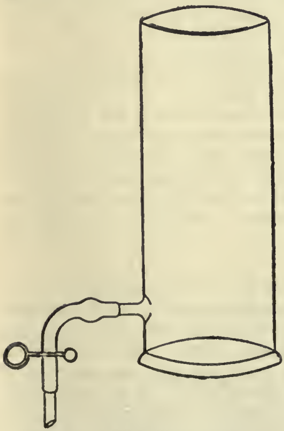

Fig. 18.—Washing Cylinder.

The fine soil, which passed through the 0·5 mm. sieve, is now separated, by washing, into clay-particles and fine sand; we know the weight of this fine soil, so we need not dry it. Pour it into a washing-cylinder (Fig. 18), a glass vessel 30 cms. high and 9 cms. in diameter, with a hole near the bottom into which a bent tube is fitted, passing through a cork and having a piece of rubber-tubing attached with a clip. The liquid is stirred up, the turbid water run off after about ten minutes, and the vessel filled again with water. These operations are repeated until all the **clay** seems to have been run off, and the residue of **fine sand** left in the vessel is dried and weighed.

The following simple methods do not involve the use of a special washing-cylinder, or of a series of sieves.

(*a*) Get about a pound of garden soil, stir it up in water to form a paste; place this in a jar, fill the jar with water, cork it, shake well for a few minutes, then allow to stand till the soil settles to the bottom.

Examine the soil after it has settled; the coarser material at the bottom is *sand*, above this is finer material consisting chiefly of *clay* (the finer grains remain suspended in the water, making it cloudy), and on top of the water floats a little decomposed vegetable matter (*humus*).

(*b*) Place a pailful of water on a table and dip into it a piece of rubber tubing, to act as a siphon. Get a number of tumblers; into one place a handful of garden soil, and stir it up with water to form a thick paste. Suck water through the tube to start the siphon-action, then direct a weak current (by pinching the tube) into the tumbler containing the soil, having a tumbler below to catch the overflow. The weak current will carry over the finest grains When the water runs clear, have another tumbler ready, and let a stronger current come through the tube. Notice the time which the grains of different sizes take to settle and leave the water in each tumbler clear.

Sand consists of grains of various sizes. Sandy soils are called "light" because they are easy to work, though a cubic foot of dry sand weighs about 110 lbs., while a cubic foot of dry clay weighs only 70 or 80 lbs.; sandy soils are more open, more porous, warmer, and drier than clay soils. A pure sand contains little but insoluble silica in the form of quartz-grains, hence it acts practically as a sterile medium, though when watered with dilute nutrient solutions plants are able to grow in it. Sandy soils formed from crumbling rocks which have not been much washed by rain-water will, however, contain most of the elements necessary for the food of plants.

Sandy soils, which are too porous and have not sufficient cohesion for plants to get a good grip of them, are improved by any additions tending to greater consistency and retentiveness, such as the ploughing in of green crops, large quantities of farmyard manure, vegetable refuse of all kinds, powdered clay, black mud from the bottom of ponds, the cleanings of ditches, etc. Evaporation from sandy land during hot weather is largely checked by regular cultivation and the maintenance of a surface-mulch of loose soil an inch or two in depth, or by mulching with two or three inches of manure.

Clay.—In clay the grains are smaller than most of those in sand, but they have a tendency to cling together and become cemented into composite grains. In drying, clay tends to form a hard compact mass, impenetrable by the roots of plants; when wet it tends to become sticky and waterlogged. Clay soils are said to be "cold" because they contain more water than sandy soils, but all good soils contain more or less clay, which is richer in plant-food than any other part of the soil. The presence of clay not only increases the power of retaining water, which is very deficient in pure sand, but also increases the percentage of phosphoric acid, potash, and magnesia.

Clay is also of great service to plants in "fixing" various substances essential for plant-food, that is, in combining with these substances and preventing them from being too readily washed out of the soil by rain-water. The presence of clay increases the power of retaining water, which is very deficient in sand, but this makes it difficult for a plant growing in a clayey soil to absorb enough water unless the soil contains a large amount. In the latter case the soil is badly aerated, and hence for lack of oxygen the roots are unable to develop to any great extent or to penetrate deeply.

Pure clay consists of kaolin (silicate of alumina), but in ordinary clays the minute particles cemented together consist of quartz, felspar, or even carbonate of lime (in marls), as well as kaolin. The cementing material is a jelly-like (colloidal) form of kaolin, which swells up on being wetted, making the clay sticky and impervious. When pure clay is mixed with water, the muddy liquid produced shows practically no sign of depositing its suspended matter. On adding mineral acids, or salts, or lime-water, the jelly-like clay is clotted (coagulated), and falls to the bottom. Salts of lime are nearly as good as lime-water in causing this coagulation, while alkaline solutions—*e.g.* soda or potash—favour the diffusion of the colloidal clay. Lime is added to clay soils to improve their texture; clay-particles quickly settle when a river flows into the sea.

Clay soils are very retentive of moisture and the useful products of manures, but are generally too firm, cold, and damp. Such soils are improved by (1) good drainage, (2) additions of gritty sand, lime, ashes, burnt earth, long straw-containing manure and similar substances tending to increase the porosity of the soil, and (3) deep autumn trenching or tillage, involving the land being left in as rough and cloddy a state as possible for the winter, to secure the disintegration of its particles by the action of alternate freezing and thawing of the water with which its interstices are charged.

(*a*) Take two similar lamp-glasses, and to one end of each fasten with sealing-wax a piece of perforated zinc, to form a sieve; in each case place a piece of blotting-paper in the bottom, covering the zinc. Take two equal quantities of dry clay; place one lot in one vessel as a coarse powder, moisten the other lot, and make it into a paste before pouring it into the other vessel. Fill up each vessel with water, and measure the volume of water which drains through in each case. Another method is to use two funnels, each with a piece of perforated zinc covered with blotting-paper or filter paper.

(*b*) Powder dry clay, then stir it up in hot water and pour it into two vessels (or test-tubes). To one vessel add lime-water, let both vessels stand, and note the result.

(*c*) Using the same apparatus as in (*a*), make a thin paste by working up clay or clayey soil with water, and pour an equal quantity of the paste into each vessel. Fill one vessel up with water (distilled or rain-water if possible), the other with lime-water. Note the time required for 50 c.cs. of liquid to percolate through the clay in each case.

(*d*) Repeat (*c*), using (1) hydrochloric acid, (2) common salt, (3) caustic potash, in solution instead of lime-water.

(*e*) Pack clay or garden soil into a glass funnel, then pour in some ammonia-water, and place the funnel over a tumbler. The water will, if the clay is packed tightly enough, come out at the bottom without any smell of ammonia. The ammonia has been absorbed by the silicate of alumina present in the soil.

(*f*) Repeat (*e*) with (1) dilute solution of caustic potash, (2) dilute solution of phosphoric acid. In each case test the solution with litmus before adding it, and also test the water that comes out at the bottom.

Limestone (carbonate of lime) may be present as soil-grains or merely as a cementing material to quartz-grains. It supplies plant-food in the form of lime, magnesia, and phosphoric acid. Its action on clay has been mentioned. It also acts as a base with which acids, formed by decay of organic matter in the soil, can unite and thus be made harmless. If such basic material is absent, the soil becomes "sour," through the accumulation of organic acids. Even more important is the part played by carbonate of lime in the process by which certain Bacteria convert into nitric acid the nitrogen existing in organic matter or ammonia compounds; this process only occurs in a weakly alkaline solution, and the nitric acid unites with the lime.

Calcareous soils, in which limestone or chalk predominates, are usually greyish in colour. They readily harden and crack when warmed. They are greatly improved by heavy dressings of decayed organic matter, nitrogenous substances, decomposed turf, and dark coloured soil rich in humus.

Humus, the decaying organic matter of the soil, is of great importance both from its physical and chemical properties. It is a light, bulky substance, with high specific heat, great capacity for holding water, and dark colour. The presence of humus gives the soil a loose, open texture, and makes it able to absorb and retain water. In woods, humus often accumulates to a considerable depth, but in ordinary soils it is only present to a depth of about a yard (below which the roots of few plants penetrate), and this part of the soil has a looser texture and darker colour than the underlying subsoil, which contains no humus. Humus contains from 4 to 9 per cent. of nitrogen, far more than is present in the vegetable matter from which the humus is produced. The conversion of vegetable matter into humus is largely caused by Bacteria and Moulds.

Microscopic Examination of Soils.—Examine some sand, mounted in water, (*a*) in transmitted light with the mirror, (*b*) in reflected light without the mirror; sketch some of the grains. Examine in the same way some clay, and try to distinguish between the grains of quartz (clear), felspar (cloudy), mica (brown), hornblende (black). Examine some leaf-mould, teased out in water, and make out the remains of leaves, twigs, roots, etc., and the fungus-threads which branch through the decaying vegetable matter.

Classification of Soils.—The different kinds of soils may be grouped under certain generalised headings according to the amounts of chalk, sand, clay, and humus they contain. **Loams** contain 40 to 70 per cent. of clay mixed mainly with sand. If only from 10 to 40 per cent. of clay is present a *sandy loam* results, and below 10 per cent. of clay the soil is merely *sandy*. A loam containing 70 to 85 per cent. of clay is a *clayey loam*, and above this is a *strong clay soil*. The latter when containing up to 20 per cent. of chalk are termed **marl**, and if more than this they are termed *calcareous marls*. Similarly we have *calcareous sand*, *gravelly loam*, *chalk loam*, etc., while any soil containing over 20 per cent. of organic matter may be termed a humus soil independently of its other ingredients.

Soil-Air.—The spaces left between the soil-grains form capillary tubes extending in all directions. These capillary spaces are occupied largely by air, if the soil is in good physical condition and not water-logged. Great harm is done to plants by over-watering; house-plants are more often killed by this than by anything else, and plants in pots should be watered from below (why?). In general, the soil should not contain more than half its total water-holding capacity, *i.e.* about half of the capillary spaces in the soil should be occupied by air.

The presence of air, containing oxygen, in the soil is obviously essential if healthy growth of seedlings and roots is to take place; moreover, the air in the soil must be kept in circulation. Good ventilation is as necessary for germinating seeds, and for the roots of plants, as it is for the life and health of human beings. Not only is free oxygen in the soil required by germinating seeds and for roots, which must breathe, but many processes occur in the soil that depend on the presence of oxygen. Nitrogen is required for the use of Bacteria, which fix free nitrogen gas and make nitrates, and these Bacteria, as well as others which convert the nitrogen of humus, manure, and other decaying organic matter into nitric acid, require large amounts of oxygen in order to do this work.

The exchanges of gases between soil and atmosphere are brought about in several ways—*e.g.* the slow process of diffusion; expansion and contraction of soil-air due to changes in temperature and in barometric pressure.

The air contained in the soil is not enclosed, but is constantly being renewed by diffusion from the air above. Since the processes going on in soil consist largely of oxidation, or are accompanied by oxidation, the soil-air is poorer in oxygen than the air above. In general, the percentages of oxygen and carbon dioxide together equal 21, but that of oxygen varies from 10 to 20 per cent., that of carbon dioxide from 1 to 10 per cent.

(*a*) To find out the best percentage of water and of air in the soil for any plant, take five tumblers filled with soil. Add to A 16 c.cs. of water each day; to B, 8 c.cs.; to C, 4 c.cs.; to D, 2 c.cs.; to E, 1 c.c. Plant the same number of seeds (small seeds like Wheat or Cress are best) in each tumbler. After a few weeks notice that those receiving too much water do not grow well because of lack of air in the soil; those receiving too little water will suffer from drought. Select the tumbler which gives the best result, and find out how much *water* the soil contains by weighing a sample of the soil (after stirring it up), then drying it and weighing it again. To find out how much *air* this soil contains, put the tube of a thistle-headed funnel to the bottom of the soil in the tumbler, and from a graduated vessel pour in water till it stands level with the surface of the soil. Since the water displaces the air in the soil, we may consider the volume of water poured into the soil as representing roughly the volume of air it contained; compare this with the volume of the soil.

(*b*) Get two glass jars of the same inside diameter. Pour water into one jar until it is rather less than half full, and mark its level. Mark a corresponding level on the other jar, which is to be kept quite dry inside, and put dry soil into this jar until it reaches the mark. We have now equal volumes of water and of soil: Pour the soil slowly into the water; if the soil contains *no* air, it will make the level of the water rise to twice its original height, hence the amount by which it fails to do this measures the volume of air in the soil. Try this simple experiment with different soils (sand, chalk, clay, loam), and find the percentage volume of air in each soil.

(*c*) Tie a piece of muslin over one end of a lamp-chimney, fill the chimney with soil, and set it in a basin. Pour water into the basin, and notice its rise in the soil. Are the spaces between the soil-grains filled with air or with water at the beginning of the experiment? Try different soils, comparing the rise of water in them.

(*d*) Spread out some moist soil or fine gravel in a thin layer on a sheet of paper; notice the glistening appearance of the grains. As the soil dries the grains become dull in appearance; why? In moist soil the water is in the form of films around the soil-grains, and the spaces between the grains are filled with air; only in quite wet soil are these spaces filled with water.

Soil-Water.—Water occurs in soil under three conditions: (1) *free water*, filling the spaces between the soil-grains and free to move under gravity and to trickle through the soil; (2) *capillary water*, adhering to the surfaces of the soil-grains and to plant-roots in films thick enough to allow surface tension to move it slowly from place to place, in any direction where the soil is becoming drier; (3) *hygroscopic water*, which is held around the soil-grains so firmly that it does not move about like the capillary water, and can only be removed by heating to 100° C., when it passes off as steam. Even an "air-dry" soil retains a good deal of hygroscopic water. The free water of the soil is injurious to plants (except those specially adapted—*e.g.* bog- or water-plants), because it interferes with the proper respiration of the root. It is the object of drainage to remove it.

Water-Content of Soils.—The amount of water present in the soil occupied by the roots is called the water-content of the habitat, or home, of the plant or plant-association. The water-content of a habitat depends on the thickness of the water-films around the soil particles. In saturated soils the films run together to form drops and masses of water, while in air-dry soil there is still a thin film around even the smallest soil particles. Hardly any water is present in impervious rocks until cracks are formed by weathering; sandy fields or hills and other dry habitats have from 3 to 15 per cent.; moist meadows, cultivated fields, and woods have from 15 to 30 per cent.; wet habitats, like stream-banks, are more or less saturated, their water-percentage varying from 30 to 80 per cent. according to the texture of the soil.

As we shall see later, the most important differences between the various habitats of plants are chiefly due to differences of water-content.

Available and Non-available Soil-Water.—If a rooted plant is kept without water until it wilts and dies, we find that the soil still contains some water. This non-available water, which the plant cannot use, is retained by the soil because the attraction of the soil-particles increases as the water-films get thinner, until it is greater than the attraction exerted by the root-hairs. The amount of water thus held by the soil varies inversely as the size of the soil-particles, being largest in fine-grained soils like clay and smallest in coarse soils like sand and gravel. The *greater* part of the total water-content is in any case available to plants, but it differs for different kinds of plants and is diminished by excessive amounts of salts in the soil and by low temperatures.

The percentages of total water-content, available water, and non-available water per 100 grammes of dry soil are given approximately in the following table :—

	Sand.	Loam.	Clay.
Total Water-Content	18·5	52	68
Available Water	18	43	55
Non-available Water	0·5	9	13

How Water-Content is Influenced.—The most important factors which influence the water-content of a soil are (1) the nature of the soil; (2) the rainfall; (3) the humidity of the air; (4) the physiography of the habitat.

(1) The amount of the water-content of a soil depends directly on its texture, which determines how much of the water falling on the surface shall run off, and how much of the entering water shall be held by the soil-particles, or drain away under the action of gravity, or rise again from the lower layers by capillarity and thus become available even for roots growing just below the surface.

The finer the texture of the soil—*i.e.* the smaller the grains and the narrower the spaces between them—the greater the depth from which water can be raised; the capillary rise of water is probably as much as 30 ft. in a fine-grained soil—*e.g.* clay loam. The amount of water evaporated from the surface and of that raised by capillarity is greatly increased by winds; capillary action is stronger in moist than in thoroughly dry soil, just as a cloth or sponge absorbs water more slowly when dry than when wetted. The falling of rain on a dry soil will therefore cause the lower parts to become *drier*, while the surface layers will gain more water than that represented by the rainfall. The capillary rise of soil moisture is increased by rolling, which brings the upper soil into closer contact with that below.

The porosity of a soil is measured by the rate at which water passes *downwards* through it. Since the capillarity of soil varies inversely as its porosity, it is sufficient to measure the porosity. Sand is very porous, but has very little capillarity. Clay shows strong capillary action, but is very slightly porous. Porosity and capillarity are determined simply by using a cylinder of soil, and noting the rate of the downward or upward flow of water through it. By similar experiments we can compare the water-absorbing capacity of different soils and the rate of evaporation from them.

(2) Water-content depends absolutely upon rainfall, except, of course, in habitats with a constant water-supply owing to the presence of springs, streams, ponds, or other bodies of water. The soil becomes saturated after heavy rain, and its water-content gradually decreases through a dry period. Snow is often of importance, since it acts as a cover, preventing evaporation, and enters the soil on melting.

(3) Humidity is of great importance as the chief stimulus which controls the loss of water by transpiration. It is influenced by temperature, wind, air-pressure, altitude, and exposure, as well as by the water-content of the soil and the presence or absence of a covering of dead or living vegetation. Heat increases the capacity of the air for moisture and therefore lowers the relative humidity. Dry winds and high winds remove the humid air around plants, and keep the humidity low. Air-pressure affects humidity by varying the density of the air, and therefore its power of holding moisture.

The relatively small daily barometric changes, which constitute "weather," are of little importance except in their relation to rainfall, but the permanently low pressure at high altitudes increases evaporation owing to the rarefaction of the air. Exposure to sun and to prevailing winds, as seen on slopes, has a great influence on humidity; slopes with a southern exposure receive most light, heat, and wind, and are therefore drier than slopes facing northwards.

A dense covering of vegetation on a slope prevents rain-water from running off before it can be absorbed, besides hindering the washing away of soil; the cover also increases humidity by reducing the influence of temperature and wind on evaporation, and a cover of living plants keeps the air moist by the evaporation of water from the plants.

(4) The chief physiographic factors of a habitat are altitude, exposure, and slope. The two former act indirectly on the water-content, by their influence on humidity, which has just been discussed. The chief direct effect of slope is in controlling the amount of water which runs off and that which enters the soil, the amount of rainfall lost by run-off increasing with the angle of the slope.

To compare the **absorption of water by different kinds of soil,** take 100 grammes of gravel, sand, rich loam (good garden or field soil), leaf-mould, and dry, powdered leaves, and put each sample into a wide tube—*e.g.* a lamp-chimney—closed at the lower end by a bored cork ; a glass funnel will do instead. Hold each tube or funnel in turn over a tumbler, and pour into it a litre of water ; then measure the water that runs out at the bottom in each case. Which sample absorbs and retains most water, and therefore allows least water to run through ? In an experiment like this, the weight in grammes of the water absorbed by 100 grammes of each dry sample was : gravel, 5 ; coarse sand, 10 ; fine sand, 30 ; barren sandy soil, 35 ; clay, 55 ; rich loam, 70 ; leaf-mould, 220 ; leaves, 500. These results show clearly that the water-absorbing capacity of soils is greatly increased by the presence of vegetable matter.

To compare the **evaporation of water from different kinds of soil,** take 10 tumblers and fill them to within an inch of the top with the following materials : 1, gravel ; 2, sand ; 3, sandy soil ; 4, 5, 6, loam (garden soil) ; 7, gravel, covered by an inch of sand, with an inch of loam on top ; 8, loam covered by an inch of powdered leaf-mould ; 9, powdered leaf-mould ; 10, water. The materials in tumblers 1 to 9 should be well dried, then an equal amount of water poured into each. Keep the loam in 5 loose at the top by stirring it to a depth of about an inch, and, after adding the water to it, place on the surface an inch of dry, sifted soil. Stir the loam in 6 thoroughly after adding water, and notice that the loam dries in hard lumps after this treatment. Weigh each of the tumblers, and place them together in a position out of direct sunlight. Weigh each day, and record the loss of weight of each due to evaporation of water.

Composition of Soil-Water.—Soil-water contains various dissolved substances—*e.g.* carbonate of lime ; phosphate of lime ; sodium chloride (common salt) ; magnesium sulphate (Epsom salt) ; sulphate of lime (gypsum) ; silicates of lime, etc. ; nitrate of potash (saltpetre) ; compounds of iron, etc.

It has been calculated that no less than 100 tons of mineral matter is annually removed in solution from every square mile of English country. About half of this amount is limestone.

Since there is much diversity in the character and solubility of the rock into which rain-water penetrates, varying as it does from granite and gneiss to limestone and clay, it follows that the material dissolved must also differ considerably in kind and quantity. Scotland, north of a line joining the mouths of the Clyde and Tay, consists chiefly of hard crystalline rock, and the river water of this region contains less dissolved material than any other in the British Isles. Much of the water of North Wales too is almost as free, for similar reasons. England affords a great contrast. Its rounded limestone hills are easily worn away by water, which is rendered acid by the carbon dioxide it has previously dissolved. The gas expelled in bubbles when ordinary water is heated consists partly of carbon dioxide, which was dissolved out of the atmosphere.

How Soil Temperature is Influenced. — The specific heats of different kinds of soil differ considerably. The following list gives the approximate number of heat-units required to raise 100 lbs. of dry soil from 0° C. to 1° C.: Peat, 30; humus, 25; chalk, 20; sandy humus, loam, pure clay and sand, each about 15. It is clear that much more heat is required to raise the temperature of water through 1° than that of the same weight of dry soil; hence a dry soil will warm in the sunshine more rapidly than a moist soil.

A dark-coloured soil is warmer than a light soil, and shows a greater daily variation in temperature. The degree of inclination of the surface and the direction of the slope often exert a marked influence on the temperature of the soil, and especially on its daily range. The effect of a south exposure is to make a difference of 2° or 3° C. in the first foot or more at the surface. When the surface of the soil is very uneven, its heat is lost more rapidly in warming the air above it. If the soil is loose and open in texture, the drier surface layer loses heat to the air, while the poor conducting capacity of the open soil prevents the heat from being conveyed deeply below the surface, and a lower temperature results. If the air is warmer than the soil, as often happens in spring, a large amount of heat may be conveyed rapidly into the soil with rain-water.

Except direct sunshine on the one hand, and direct radiation of heat away from the earth on the other, there is no factor which exerts so strong an influence on the temperature of the soil as the evaporation of water from its surface. When a pint of water evaporates from a cubic foot of soil, it carries with it heat enough to lower the temperature of the soil considerably—if sandy soil about 20° C., if clay-loam about 15° C. To dry saturated sandy soil till it contains half its maximum amount of water requires the evaporation of about 9 lbs. to the square foot when the drying extends to the depth of a foot; the similar drying of clay-loam requires the evaporation of about 12 lbs. of water. It is largely owing to the latent heat of vaporisation of water and to the low specific heat of soil that a wet soil is cooler than the same soil when dry.

When soil is rolled, its texture is made firmer, and it conducts heat better, so that the surface layers become warmer; the temperature at a depth of 2 ins. may be about 5° C., at 4 ins. about 3° C., higher than in entirely similar and adjacent but not rolled soil.

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(*For Appendix see also p.* 495.)

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